SFB 637 Autonomous Logistics

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Risk management for agent based autonomous logistic objects

Abstract

Intelligent logistic entities with the ability of autonomous control are a possibility to face currently arising challenges in logistics. This paper introduces opportunities of using risk management by agent based technology for realizing robustness of autonomous control in the domain of logistics.

Introduction

Mainly Logistics has developed to a key success factor in globally distributed production within the last years because of its cross-sectional function. Changes introduced by product life cycles enhanced by reverse logistics, rapid changes in company structures and information flows lead to more complex logistic systems. Unbounded trade between several enterprises as a consequence of spatial distributed production of components leads also to higher requirements for the management of logistic systems and processes. The higher amount and the reduction of the size of goods that have to be transported and as a consequence thereof an increasing number of transports are main reasons for a relative shortage of logistic infrastructure and lead also to rising utilization of existing logistic processes and to more complex logistic systems. Additionally a specialisation of the ways of transportation and their carriers which are connected to the transported goods can be observed.

But the 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 logistic processes represented by entities which have the ability and capabilities for decentralised coordination.

The complexity of logistic systems is a compound measure of various (depending on the approach) properties—(Bar-Yam, 2003) 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, 2004) 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." We follow Simon (Simon, 1996) in his widely adopted definition of a complex system as one, that consists of a large number of elements which interact not only in trivial manners thus explicitly adding the interactions or relations between elements to Ottinos definition but subsuming Bar-Yams properties under those two. Modern logistic systems qualify for being complex systems in that sense.

The dynamic 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.

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 their relations or the whole system.

To support the system in managing its complexity and the belonging dynamics the development of novel information and communication technology (ICT) offers some opportunities which can be combined to an auxiliary framework.

These circumstances lead to a higher degree of needed information for the successful management and more effective planning and control mechanism for the logistic processes. The development of present-day available systems in telematics and positioning systems allows the handling of the information concerning the position of logistic entities in the system, their origin and their point of destination. Mobile data transfer and transponder technology (i.e. RFID) enable the single logistic entities to communicate with each other. The use of networking and terminal technology allows the management of complex logistic systems on local and on global level. How these technologies encourage the development of a new logistic concepts and their realisation will be shown in the following figure:

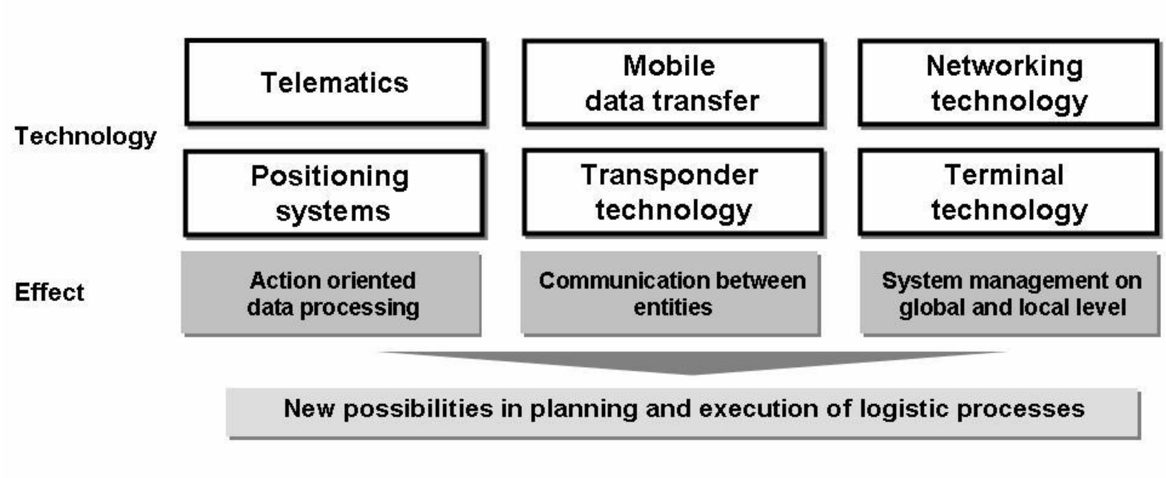

Figure 1: Technologies and their effects

The usage of these novel ICT's allows the development of concepts for autonomy of the logistic entities such as cargo, transit equipment and transportation systems.

Autonomous processes as possible solution

Because the dynamic and structural complexity of logistics networks makes it very difficult to provide all information 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 autonomous in non deterministic systems (Hülsmann, forthcoming).

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 the global 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 system relevant 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 deciding system 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 which is an after-effect of the high number of logistic objects which are needed in such a system.

Global optimisation under the condition of autonomy

Optimisation on a global level given the proposed autonomy of entities in a complex (logistic) system usually requires nothing less than a global utility function (GUF) to which all autonomous entities can commit themselves. In a logistic context we could think of i.e. packages, trucks and warehouses. Such a world utility function provides an objective measure of how well the system performs.

The autonomy of the entities in our approach however implies the existence of local or “private” utility functions in each and every logistic entity. In the application domain these private utility functions may well be determined by the entities affiliation to a company or organisation. In that we face a combined forward and inverse problem of constructing a technical system as a collective (Kagan, 2003) in which the single entities have private utility functions which need not be designed to optimise the GUF but rather a partial utility function defined by a proper subset of the whole collective (i.e. entities belonging to one enterprise or one supply chain, etc.). Deduced from the possibly conflicting goals of those partial utility functions the character of an emerging GUF and the possibilities to optimise it by tuning the risk management on local level still are to be investigated.

Risk in autonomous processes and caused by autonomy

The increased use of novel (ICT) doesn’t necessarily assure the constant availability and high quality of data and information to plan and control the logistic processes. A malfunction or a loss of information- and communication systems can lead to substantial negative consequences. The increased complexity of logistic systems is followed by a more complicated planning and control of logistic systems and of the related processes. The hazard of delayed delivery and reduced adherence to delivery dates are results of complex system structures and increased customer requirements. The numerated hazards 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. Hazard and chance are consolidated in the term risk which includes both characteristics. For complex logistic systems which are composed out of a high number of autonomous entities risk has to be regarded on system level as well as on entity level. On entity level risk is the possibility of failing given logistic goals like time of delivery and cost which are individually composed for each logistic entity. This kind of risk represents the individual risk for the logistic entity. On system level risk exists more on an economical level for the involved enterprises and firms which are part of the logistic system. This kind of risk depends more on the status of the whole system and on long term effects of the amount of the logistic processes.

Coming along with the shift of responsibility from a central instance to an autonomous logistic entity is a different situation of risk which could endanger the success of reaching the goals from the entities. A malfunction for example of the central deciding instance is a danger for the success of all logistic processes which is not more relevant in a system which consist of autonomous entities. 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. By contrast to a central deciding instance there are other risks to be considered in a logistic system which is based on autonomous logistic entities. For an autonomous logistic object it has to be kept in mind that there are additional risks which result from the required communication between the involved entities and that the interaction between them which leads to non calculable states on local and global level. Finally hazards also arise from the autonomy of the entities itself in that it can no longer be guaranteed, that a specific entity acts benevolent to others in face of its own individual goal (Weigand 2004). It is also important to consider that contradictory information generated from different entities is another source of risk for the logistic processes in relation to their specific goals and that an optimisation object level can compromise the goal of the total system. These flexible characteristics of possible disturbances can be categorised in 3 types of risk:

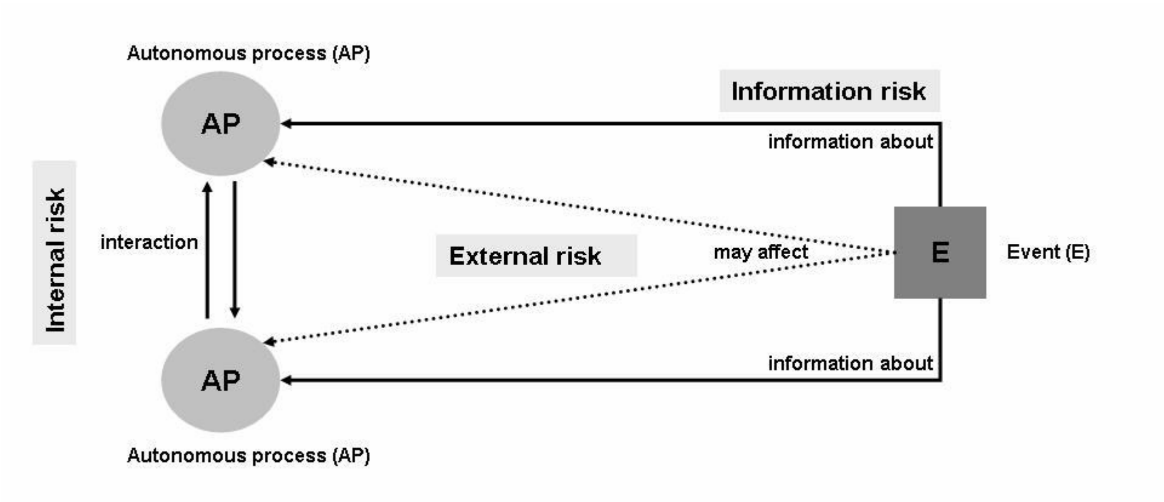

Figure 2: Types of risk in autonomous logistic processes

The task of a risk management (RM) for autonomous logistic entities is to enable them to adjust their behaviour in relation to the existing situation for realizing their logistic goals. To achieve this, the autonomous entities have different possibilities. Traditional literature on RM knows six strategies to handle risk: (1) acceptance, (2) avoidance, (3) reduction, (4) transfer, (5) compensation, and (6) diffusion (e.g. (Finke, 2005). Not all of them are applicable for an autonomous system. The possibilities of avoiding, reducing and partly compensating possible risks by a proactive RM system are to identify and analyse risk which could be dangerous for the fulfilment of goals given to the autonomous logistic object in advance. The proactivity results from the ability of the RM system to assess and evaluate possible risk by getting the information about it and before the realisation of the event which is fraught with risk.

Managing the types of risk mentioned and shown above is essential to understand the meaning of risk for autonomous logistic entities and their environment. To handle existing and new risks for autonomous processes and autonomous entities a proactive RM 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 RM system supports also the autonomous entities in decision taking and realising these decisions considering the risk which is related to the whole logistic processes. For this reason the development of a proactive RM system can be considered as a relevant success factor for autonomous logistic processes.

Developing and implementing a proactive RM system in a complex logistic system with autonomous logistic entities enables the entities to avoid needless hazards and offers the possibility of using auxiliary scopes for fulfilling the logistic goals. To realize this it is essential that all available information can be evaluated by the autonomous entities in respect to their relevance and influence on them. It is also required that new information which where not available from the beginning can be interpreted in relation to given risk factors by each logistic entity locally. In connection with the interpretation of the new information they have to be analysed and evaluated for that the autonomous logistic entities are able to asses the overall risk for the whole process.

The development of such a RM system depends on the abilities given to the logistic entities. A promising approach is the implementation of intelligent agents as representatives of the logistic entities for managing the logistic processes. Agent based logistic entities have the ability to asses available information and realise risk oriented decisions in a complex logistic system while interacting and communicating with each other. How this can be realised will be shown on the next pages.

Applying the autonomous agent metaphor to logistics

Engineering autonomous processes in logistics includes three perspectives: material, information, and management, which can be seen as three conceptional layers of a decision problem (see figure 3).

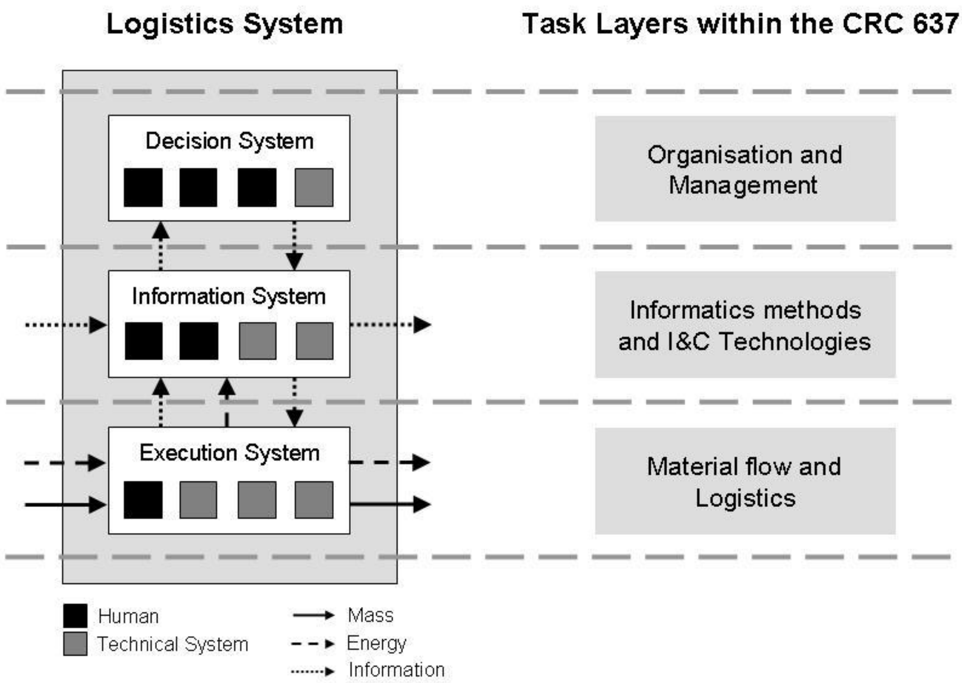

Figure 3: Level in logistics system and task layers within the CRC 637

The challenge for the implementation of autonomous decision behaviour is to enable distributed systems, where those different layers gain the ability to interact autonomously and flexibly on a technical basis. The challenge for the management level that arises from this approach is discussed in (Ehnert, forthcoming and Dembski, 2005). For the design and implementation of autonomous entities as autonomous decision-makers this includes high-level decision-behaviour which may not be realized by simple reactive architectures. Therefore, we assume that intelligent entities with deliberative decision behaviour and explicit knowledge representation and reasoning capabilities are required to meet these needs.

The domain specific challenge in logistics however arises from the different interests within the system. On an individual interaction level, entities should maximize their utility. Each entity is a representative of an enterprise and, therefore, its local decision behaviour should improve the performance of the corresponding enterprise. However, on a global level, we hope to achieve a better performance and sustainable management of the logistic system. For practical applications, it still has to be proven, that optimisation is realized at least on the enterprise level, as the enterprises have to invest into this innovative technology and transfer competence on the entities level. Thus, the conclusion of straightforward emergence of macroscopic optimality from microscopic autonomy has to be investigated especially in this domain.

Local decision-making and planning

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 entities have to consider uncertainty and possible risk to make it robust against suddenly appearing events and gradually 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 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.

We believe and want to show that this kind of autonomous, decentralized decision-making can help make the operational processes more efficient, cost-effective, and allow the participating enterprise to stay competitive. It is a major improvement over traditional centralized approaches in which individual entities are ill-equipped to deal quickly with sudden events since control usually resides with the expeditor who is removed from the scene of the event and thus has only delayed access to the relevant information.

Regarding decision-making based on local knowledge as the core ability for an autonomous entity we have to focus on how it can be enabled to identify, assess and regard possible risks in its decision process. A decision within a computer implemented autonomous entity always is a decision among previously known alternatives. So the decision process will have to calculate and assign some kind of value to all known and accessible alternatives in order to choose for exactly one.

Enabling this type of autonomous decision-making is challenging given the potentially large number of entities that could be involved, the dynamic and sometimes even competitive environment in which the entities operate. In principle, enabling a technical system, to make decisions that are designed to impact real-world entities delegates the assessment of consequences of the decisions to the agent. To the same extent as the future is perceived as decision-dependent, any decision to be made by the technical system must be regarded as risky (Luhmann, 2003). The goal of RM is to attempt to optimise the entities decisions in the presence of incomplete, imprecise, or debatable information by reducing the uncertainty about future events.

Fundamentals of a technically enabled proactive risk management

A pro-active RM system is being implemented to tackle this issue. This RM system incorporates an autonomous identification of possible risk based on the knowledge of the domain. 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.

The major shortcoming of current agent deliberation cycles is the relatively simple discovery and evaluation of alternatives. The standard approach to creating consistent subsets (goals) for action selection is not sufficient for dynamic environments, as the agent must often conduct multi-criteria optimisation, which may also be based on competing goals. Hence 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.

A framework for an enhanced agent deliberation process is sketched in figure 4. This framework is being developed as a common basis for risk and knowledge-management in agent decision-making (Langer, 2006). It includes explicit risk and knowledge management (KM), termed decision-support in the figure, which may work in an inter-leaved fashion to augment the deliberation cycle of the agent. Generally speaking, we use RM to identify and assess the risks associated with one or more options, and KM to acquire missing knowledge, for example, to improve risk assessment or to generate additional options. Our decision-support system can be integrated into any intelligent agent that utilizes some form of deliberation with separate option generation and selection phases.

Agent decision process

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. Due to incomplete or uncertain knowledge, RM may be unable to decide on the presence or amount of risk. In order to overcome this situation it triggers KM to acquire the missing information or details on the current situation including alternative actions. Knowledge acquisition may retrieve knowledge from other agents or directly from external sources/sensors.

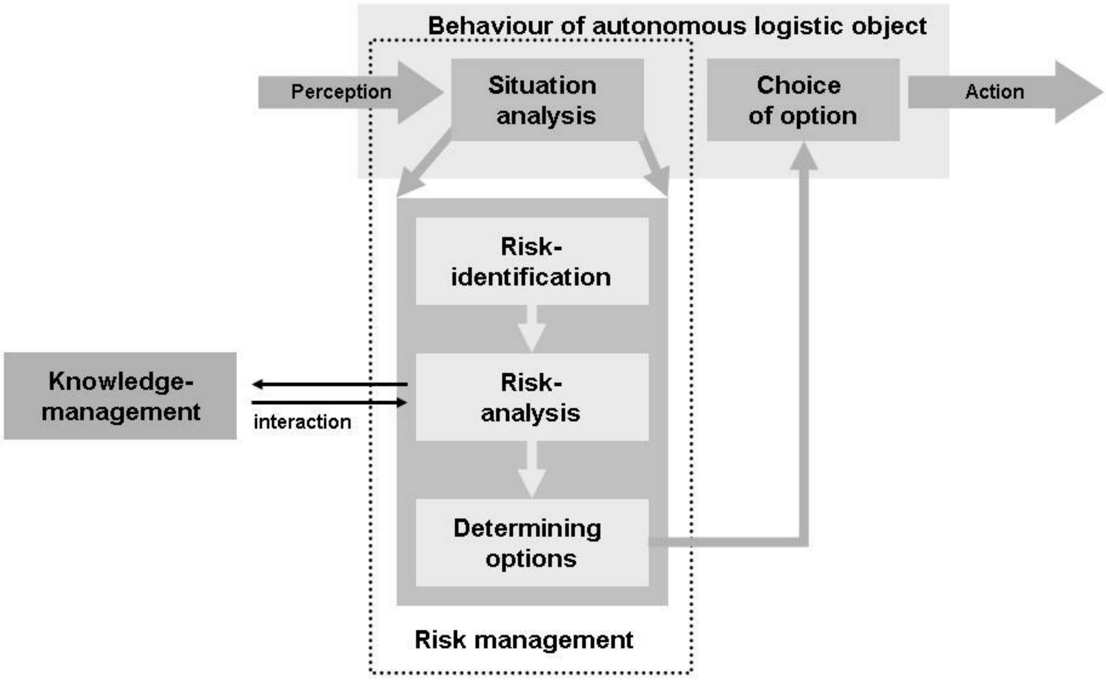

Figure 4: Agent deliberation cycle

A central component of our approach is the representation of decision-support parameters which govern the RM and KM processes as well as the interactions between them. For example, when RM invokes KM to acquire missing knowledge to help assessment of risk, it communicates the importance of obtaining the missing knowledge to KM. This helps KM selecting the proper strategy. Another parameter used by KM is availability which expresses the probability that an item of knowledge is available from any known source at this time. Availability of knowledge is based on prior experiences and used by KM, for example, in deciding which knowledge items should be acquired (in case there are choices).

Uncertainty – or, to be more precise, the lack of certainty – is associated with risk in that on the one hand it is a source of risk and on the other hand risk can only be identified and evaluated given at least a minimum amount of confidence in the current state of knowledge. Thus the acquisition of facts that can reduce uncertainty is one strategy to handle risk. In this section we present an approach to assess the amount of uncertainty and a strategy to reduce it by invoking KM. RM is a continuous process that will trigger further deliberation as soon as a fact is added to the knowledge base, which makes the situation risky. As already mentioned in the introduction, risk arises whenever a subsequent decision must be based on incomplete knowledge and thus might turn out wrong. Our concept of RM is heavily depending on knowledge. Therefore it can only function in close collaboration with a KM infrastructure. In the following we will describe the mechanisms of this collaboration and subsequently describe the core task of knowledge-based risk assessment.

The initial task and most important prerequisite for successful RM 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 beliefs with patterns.

In the situation analysis phase of an agent's deliberation cycle (see figure 4) 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 (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, 2005) we define a risk pattern as a formal description of a situation where certain occurrences may be dangerous for the agent. A risk pattern is defined by a set of predicates with unbound variables which can be unified with the beliefs. Each pattern has a gravity value assigned to it which indicates the possible (i.e., worst case) outcome of the incident described by that pattern. A pattern matching module evaluates the beliefs and substitutes the matching variables in the pattern. It registers all substitutions of variables with matches in a risk pattern. Additionally every substitution is annotated with the gravity value of the pattern.

In the next step of risk assessment the agent evaluates the evidences (i.e., beliefs), which are now tagged as risk relevant according to the degree of uncertainty it has about this evidence. Together with the gravity value high uncertainty can trigger acquisition of additional knowledge. This evaluation follows the idea of reasoning about evidences introduced by (Shafer, 1976 see also Halpern 2003). This theory provides us not only with one probability measure for given evidence but adds a value indicating the degree of belief or certainty in a hypothesis. We interpret this as a measure for the need of additional evidence to support or contradict the hypothesis and such increase the certainty.

A threshold depending on the gravity value assigned to the risk pattern determines when the acquisition of new evidences will be finished, i.e., the certainty is considered high enough to assign a value to the risk emanating from this pattern. The process described above is continuously evaluated against the world model of the agent as well as every anticipated future world state such enabling proactive risk identification.

Concluding remarks

New possibilities in reducing damage, lateness and other aberrations to given goals for autonomous logistic entities through the usage of a suitable RM concept are described in this paper. RM with its containing parts of risk identification and risk assessment can be a solution to reduce risk in transportation or production for the autonomous entities and is also needed to make the autonomous logistic entities robust against suddenly appearing events which were not considered during the planning phase of the logistic processes.

The handling of information from the real world with implemented methods of RM to realise risk oriented decisions is a challenging task for an agent based autonomous logistic entity. To complete the RM system a component of planning has to be integrated. This is still an open task because until now the RM can assess risk only on the actual situation and has the ability to evaluate the current knowledge but is not able to predict future world states.

To reduce the uncertainty for planning the RM interacts with the knowledge management. But the complexity in determining the uncertainty and modelling the risk for the complete autonomous process has strong influence on the model to be chosen and on the further development for that it is an important task for the near future.

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