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3.5 Proactive Knowledge-based Risk Management

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3.5.1 Introduction

Globally distributed production networks accompanied by the reduction of the vertical range of manufacturing, customer-driven markets, decreasing product life-cycle times and increasing information flows alter the requirements for the management of logistic systems and processes. The reduction of the size of goods that have to be transported and as a consequence thereof an increasing amount 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. These developments for example are caused through the evolution of virtual organizations and the increasing maturity of new information and communication technologies (ICT) technologies like RFID and ubiquitous computing.

To coordinate all these processes, an increasing demand of required information for just in time deliverables is needed. These requirements exceed the abilities of existing standard logistic processes. Dynamic development of modern ICT—e.g. telematics, mobile data transfer, and transponder technology—open new possibilities for the development and emergence of intelligent logistic systems which can fulfill the requirements of rising utilization and relative shortened logistic infrastructure. 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.

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. Coming along with the autonomy of the logistic objects is a shift from the responsibility for the realization of the decisions from a central deciding system to the single logistic object. This has to be regarded by developing a concept for the management 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.

The complexity of logistic systems depends on the amount of the embedded logistic objects. The amount and the character of the relations within logistic systems affect also the complexity of the logistic system. The third factor, which is an important influencing factor for logistic systems, is the dynamic of the system. This dynamic is displayed by the number of system states and changes in the amount of system elements. However, the complexity of a logistic system allows still no conclusion regarding the sensitivity of the system in relation to the malfunction of individual objects or relations between them. The integration of strategic planning may enable the system to compensate a temporary or unlimited mal-function of an object or a system relevant relation between two or more objects. The increased use of modern 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.

Risk in autonomous logistic processes

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. 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. Traditional literature on risk management (RM) knows six strategies to handle risk: (1) acceptance, (2) avoidance, (3) reduction, (4) transfer, (5) compensation, and (6) diffusion (e.g. [1]). Not all of them are applicable for an autonomous system. The possibilities of avoiding, reducing and partly compensating risks by a proactive risk management system are to identify and analyze risk which could be dangerous for the fulfillment of goals given to the autonomous logistic object in advance. Such a risk management system will be developed in the sub project “Risk Management” of the Collaborative Research Centre 637.

The consequence from the shift of responsibility from a central instance to an autonomous logistic object is a different situation of risk which could endanger the success by reaching of the goals of the logistic process. In classic logistic systems a malfunction of the centralized, deciding instance is a danger for the success of all logistic processes. 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 sys-tem. By contrast to a central deciding instance there are other risks to be considered in logistic system which is based on autonomous logistic objects. 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 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 object level can compromise the goal of the total system. 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 the figure 1.1:

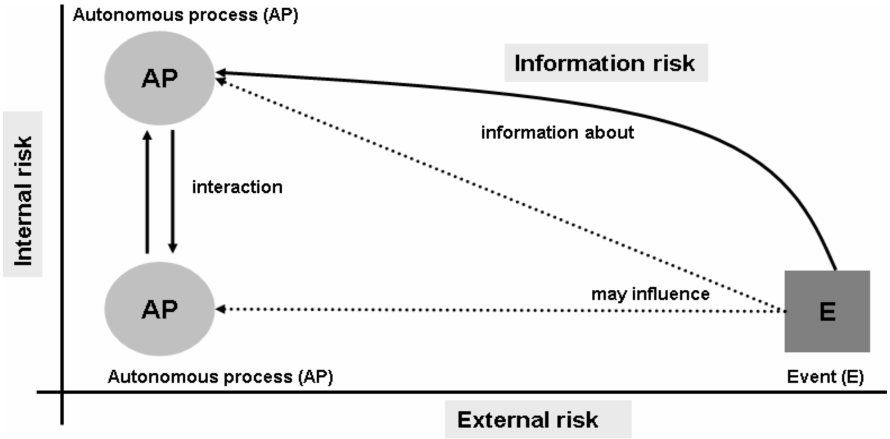

Fig. 1: Risks induced by events.

Managing the types of risk mentioned and shown above 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.

An additional advantage caused by the use of a proactive risk management in comparison to a traditional reacting risk management system is the gain of auxiliary scopes. Avoiding needless hazards and getting the chance of using these scopes can be made available by:

- Evaluation of all available information
- Examination of new Information regarding the validity and relevance for the processes
- Interpretation of new Information in relation to given risk factors
- Analysis of risk factors and
- Evaluation of the overall risk for the whole process

As shown above the existence of a proactive risk management system leads to more opportunities and more calculable risk for the autonomous processes. The question about the gained opportunities and the more calculable risk to answer is: How to manage the risk? A declaration of defining an effective risk management was made by Kenney:

"The principal element involved in managing risks can be boiled down to a single sentence: Good process risk management results in perfect containment and safe handling of the hazard." [2, pp. 12 - 13]

This single sentence has to be enhanced for autonomous cooperating logistic processes: *…in perception of existing and future options for the autonomous objects*. Kenney exemplifies the fundamentals and principles for a functioning risk management system in three predications [2]:

1. The hazards of a process must be capable of being defined at any time.
2. The risks resulting from these hazards must be controllable by equipment, by procedures, or by some combination thereof.
3. Management must uncompromisingly maintain control over the equipment and procedures that are identified to control the risks. [2]

A possible approach about how these tasks can be realized in a risk management system is to develop a suitable comprehension of risk for autonomous logistic processes and objects, examine existing risk concepts and determine the requirements for their realization.

Definition of Risk for autonomous logistic processes

To develop a suitable comprehension of risk, existing definitions of risk and approaches of risk management have been analyzed. As part of this analysis many definitions of risk, hazard and uncertainty have been examined. The first step was the differentiation of the terms risk, chance, uncertainty and hazard because in some cases risk and uncertainty are used in the same context and the terms chance and hazard are not well differentiated.

In established literature nescience of the future and future developments are called uncertainty in wide sense. If an impartial or pseudo-impartial (subjective) occurrence probability can be allocated to a future event or development of events it is called risk. If it cannot be allocated to a future incidence, it is called uncertainty. This differentiation was developed by Frank Knight and is deemed to be the economical standard approach [3, pp.125]. This differentiation is also used by Motsch. Motsch describes that decisions fraught with risk exist if the deciding instance has clear knowledge about the occurrence probability. If this instance knows only the amount of possible and relevant future conditions but can not give full particulars about the occurrence probability the decisions are made under uncertainty [4, pp.1].

The possibility to assess risk during the planning phase and the accomplishment of logistic processes is a necessary feature for a proactive risk management which shall be able to modify the original plan which was developed after a process oriented risk assessment if necessary. All of these differences between the diverse risk definitions and concepts of risk lead to the next part of this chapter which contains the requirements for a risk term to be developed and the development of the risk term itself.

For the development of an adequate definition of risk in autonomous logistic processes additional requirements have to be considered. The requirements for a suitable risk term for an application in a pro active risk management system are:

1. The total risk and the individual risks are connected to the system "autonomous logistic processes". This is important, because the risk assessment will be done by an autonomous object, which is part of this system and not an external element which does not influence the system by its decisions.
2. The risk term includes upside risk and downside risk. The consideration of both characteristics of risk is necessary because there is also the possibility to outperform the given goals of a specific process.
3. Risk is connected to the goals and /or aims of the system (and the process as part of the system). This fact is important for an automated evaluation and assessment of risk accomplished by single agent.
4. Risk has to be regarded in connection with endogenous and exogenous influences or malfunctions. To consider internal and external developments is important because the system "autonomous logistic objects" is not a closed or self-contained.

From these requirements and the examined definitions and approaches of risk the following definition for the CRC 637 was developed:

"Risk is the contingency that the result does not correspond to the goals of the system due to differences."

This definition includes uncertainty about the future and future events by using the terms risk and contingency. Upside and downside risk represented by chance and hazard are contained by using the term "differences" which allows a positive or negative deviation in relation to given goals and does also apply on internal and external risk. This deviation can be of technical and economic origin. It is applicable for the use in autonomous logistic objects because of its simplicity and reduction on terms which may be used in a dynamic system on their own.

The definition of risk is the basis for the development of a pro-active risk management system for robust logistic processes. To develop this risk management system the research on methodical concepts on risk analysis in the context of autonomous objects in a complex and dynamic system is the next step in realization.

To realize the development of a proactive risk management system it is also essential to implement a suitable mechanism of risk identification and risk analysis into the logistic objects. For this reason existing methods of risk management have to be evaluated considering some requirements which are essential for the implementation into an autonomous logistic object. The next step in developing a pro active Risk Management is to choose a risk concept which contains a methodological approach which can be integrated into an autonomous logistic object.

3.5.2 Risk management for autonomous decision-making

The main difference between engineering oriented and other approaches is the declaration of the meaning of the term risk and the understanding in relation to the possible impact(s). Most engineers consider risk as a negative term, where only a possibility of loss or a negative development is included.

Two examples for engineering oriented approaches are:

- Risk is the hazard of the negative deviation between plan and reality [5, pp.256].
- Operational Risk is the risk of loss resulting from inadequate or failed internal processes, people and systems or from external events [6, p.4]

These are the so called asymmetric approaches of risk because the appearance of risk is only expected in a way with consequences which characteristics show only in one direction (positive or negative development). Most of these approaches are used in different forms of safety analysis like FMEA (Failure Method Effect Analysis, developed in the 1960's) or for example HAZOP (HAZard and OPerability Studies, developed in the early 1970's and extended to software development in the 1990's). These kinds of risk oriented safety analysis were originally developed to reduce only the error probability in engineering or chemical research and development. An exception in relation to the other approaches which are mostly focused on engineering tasks is the approach of Haindl. Haindl exemplifies that risk (especially delivery risk) is the hazard of loss caused by external disturbances within the field of the supplier as well as in communication between supplier and customer [7, p.8]. If a definition of risk comprises additional positive possibilities it can be allocated to the symmetric approaches of risk. The differentiation between symmetric and asymmetric can be found in [8, p.11].

Financial and entrepreneurial approaches as well as approaches on project management used in the majority of cases are symmetric approaches and differentiate between downside risk (negative development) and upside risk (positive development). Downside risk is also called hazard while upside risk is referred to as chance. An overview on these differentiations can also be looked up in [8, p.11]. The mathematical approach on risk (Risk = probability * impact) can also be treated as a symmetric approach because the impact can be positive or negative.

Another differentiation of risk concepts in relation to the definition of risk is the differentiation between action risk, which may result from a wrong decision and precondition risk which results from changing conditions of the relevant environment. A determination of these two risk differentiations was made by Haller and can be found in Mikus "Risikomanagement" [9, p.8]. The insufficiency and the problems by using action risk oriented concepts or definitions will be discussed in the paragraph "Risk as a possibility of a wrong decision" [10, pp.7–19].

To integrate a suitable risk term for autonomous logistic processes it is also important to analyze existing concepts of risk and risk management for that the interdependencies between definition of risk and a risk concept can be considered by developing a CRC specific risk term. This consideration is necessary because both are bearing columns of a proactive risk management system and affect each other.

Haerterich [10, pp.7–19] divides risk in three main areas:

1. risk as goal deviation
   a risk as a possibility of a wrong decision
2. risk as a deficit of information and
3. risk as a combination of deficit of information and goal deviation

These concepts have a different orientation and understanding of risk and risk management. They will be shortly introduced and analyzed on their advantages and disadvantages. The first approach is "Risk as goal deviation". Risk comprises the possibility and not the realized goal deviation. This concept has a high fit with respect to complex system structures with different impacts and probabilities. The goal deviation is a neutral factor which contains hazard and chance. Part of the goal deviation approach is "Risk as a possibility of a wrong decision". This concept also includes a correlation to given goals, because a decision can not be assessed as wrong without goal analysis. It is difficult to measure decision oriented risk, because the risk assessment can be conducted after analyzing what really happened and how other decisions would have influenced the result under the existing conditions. This relation between deciding in a situation fraught with risk and examining this decision afterwards is also a problem by using the action risk oriented concept following Haller. The next approach is the "Risk as a deficit of information" concept. Risk is here characterized as a lack of information in situations where a decision has to be made. The disadvantage of this concept is the limitation to situations where decisions have to be made. Risk always exists and it is not limited to selected situations. The last concept is "Risk as a combination of a deficit of information and goal deviation". This concept follows from the combination of the goal deviation approach and the information deficit approach. The risk is divided into two components:

1. description through objective and subjective probability distribution and
2. a goal deviation for symmetric or asymmetric risk

The approach of a risk concept in a logistic environment has to fulfill several requirements. The first requirement is the measurability of the risk and the contained risk factors. In the approach that considers risk as a goal deviation this problem can be solved by splitting the total risk. Chosen examples for risk are:

- time risk (early, in time or delayed delivery or production)
- cost risk (within monetary restrictions, overpriced)
- quality risk (quality related to the input data and related to the object quality; this can also be enhanced by regarding sustainability of the accomplished process steps)

It is possible to measure the relevant risk factor for a sufficient risk assessment with this idea. The "Risk as a deficit of information" approach is not able to fulfill the requirement of measuring risk adequately, because risk is reduced to a probability distribution but the flexible characteristics (additional cost, delay in delivery, damaged object) remain unconsidered.

After consideration of these facts we have the highest fit for autonomous logistic objects by usage of the goal oriented approach or the approach where risk is defined as a combination of a deficit of information and goal deviation. Regarding these facts concerning risk concepts supports the definition of risk developed for the CRC 637 because it fulfils the requirements shown above and fits into the risk concepts chosen above. The subset "risk as a possibility of a wrong decision" of the goal oriented approach is not sufficient for a risk management approach which fulfils the requirements for future oriented logistics; because in this approach risk is limited to the decision points and can not occur during the realization of a decision. Another reason which constricts this concept for an application in a logistic environment is the fact that the real risk can only be assessed after a logistic process has finished and all states and decision that lead to an optimal result are known. Yet, another reason for the refusal of the subset "risk as a possibility of a wrong decision" is the difficulty in allocating unexpected events and certain decisions.

There are different possibilities to assess the risk in complex logistic systems and for autonomous logistic objects. One possibility is to analyze potential nonconformities and malfunctions in relation to their cause and the other possibility is to examine process relevant events in relation to their impact on the logistic system or on the logistic objects. This leads to a classification of methods into forward oriented methods which evaluate occurring events and backward oriented methods which analyze the causes for malfunctions. Another important element for developing a risk management system is the ability to manage nearly all risk afflicted situations without external help. This can only be realized if the method(s) used for the risk management do not need abilities which are used by human (supported) instances like associativity, because autonomous objects do not posses such abilities but shall be able to asses the risk in the logistic processes. For this reason it is obvious that the method of risk management integrated in a in a complex and dynamic logistic system has to consider the potential fuzziness of the information which are essential for the decisions. This can only be realized if the chosen approach of risk management is able to examine the consistency of the information and act in case of need without them if they are not fully available by using a methodological approach which also uses components of plausibility and decomposes complex problems into parts to assess the risk.

To fulfill the requirements for the development of a proactive risk management system in complex logistic systems or for autonomous logistic objects it is required that the method is forward oriented and can be well integrated into an ICT supported system architecture because the application of such environment has many advantages compared to a central, human controlled system and may be realized based on requirements shown above. It is also important that the method which will be used is able to assess risk as a permanent factor during the whole process and has the ability to regard:

- uncertainty
- upside und downside risk and
- internal and external risk

How these abilities of the risk management can be realized and which requirements have to be regarded concerning the realization in an autonomous logistic object will be presented in the next part of this chapter.

3.5.3 Requirements for risk management for autonomous systems

As shown above 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 or with lowest possible fuel consumption. But primary goal fulfillment is only one aspect of risk management within an autonomous system. 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.

Collectives of autonomous systems in the way they are modeled in our work (i.e. all logistic entities in a transportation network are regarded as a collective—in itself subdivided into enterprises, trucks, loads, etc.) have a close relationship to social systems. 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 [11]. Following [12] intelligent entities in a collective must above all be seen as autonomous in that they can't be directly manipulated neither by a "governing authority" nor by other members of the collective. This autonomy of individual agents implies that the collectives' performance highly depends on the individual "willingness" of its members to contribute to the global goal.

In case of a pure technical system one could argue that it is the designer's responsibility to ensure the "willingness" of the autonomous entities. This can be achieved as long as we deal with closed systems. In open systems the benevolence of an entity cannot be a priori assumed. Therefore it is crucial for an autonomous entity in an open system to assume the autonomy and hence the possibility of malevolence of its counterpart be it artificial or human. 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. Most classical methods of risk management employ brainstorming and experts assumptions to assess the possibilities of events that can have an influence on a process [13] prior or during a structured process. In a technical autonomous system one can either employ these methods 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.

Engineering risk aware autonomous processes

Engineering autonomous processes in logistics includes three perspectives: material, information, and management. The challenge for the implementation of autonomous decision behavior is to enable distributed systems, where the different levels gain the ability to interact autonomously and flexibly. For the design and implementation of autonomous entities as autonomous decision-makers this challenge includes high-level decision-behavior which may not be realized by simple reactive architectures. Therefore, we assume that intelligent entities with deliberative decision behavior and explicit knowledge representation and reasoning capabilities are needed to meet these requirements.

We believe 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 also 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 sudden event and thus has only delayed access to the relevant information.

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 as well as 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. Economical management interests therefore require the technical system to be dependable in terms of awareness of hazards, competitor malevolence, malfunctions, etc.

The special challenge in logistics arises from the different interests within the system. On the interaction level, entities should maximize their utility. Each entity is a representative of an enterprise and, therefore, its local decision behavior should improve the performance of the corresponding enterprise. However, on a global level, we hope to achieve a better performance of the overall logistics resp. the optimization of the global system. For practical applications, it still has to be proven, that optimization 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. So dependability of the technical system is of utmost significance to the principal and implies that it behaves as ordered. Thus, the conclusion of straightforward emergence of macroscopic optimality from microscopic autonomy has to be questioned especially in this domain.

The engineering task therefore involves the provision of mechanisms for local autonomous decision capabilities as well as for dependability from a (human) principal's prospect. 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 risks in its decision process.

Knowledge and uncertainty

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 [14, p.77]. The goal of risk management (RM) is to attempt to optimize the entities decisions in the presence of incomplete, imprecise, or debatable information by reducing the uncertainty about future events.

Thus, context-based, situation-aware, and local decision-making, which in turn supports autonomous, self-managing behavior of logistic entities, calls for the integration of knowledge management functions with the entities planning and situation assessment.

Knowledge is and evolves locally in different entities and organizations. Only the ability to represent, organize and communicate knowledge enables the deliberative decision making of an autonomous entity as well as its collaboration with others and thus the emergence of distributed problem solving. It is obvious that knowledge is a core element of an approach to autonomous logistics, as it is constitutive for sophisticated decision-making within an autonomous entity [15].

As uncertainty is the major source of risk in decision-making the autonomous entity will need a mechanism to evaluate the knowledge it has regarding the expected state of the environment that might influence the current goal. To achieve this is a challenging task for a technical system. It involves not only to have knowledge but also to generate hypotheses about future states of the environment and to evaluate the amount of knowledge it has regarding this hypothesis.

A logistic entity's environment is inherently unpredictable. While the degree of uncertainty of well structured environments such as container stowage is relatively low, others especially open world logistics involving multi modal routing and road traveling are highly dynamic and in many ways unpredictable. In this many issues that arise in autonomous robotics are also applicable to autonomous logistics (e.g. [16]).

Internal models of the environment are abstractions of the real world. As such they only partially model the underlying physical processes of the logistic entity and its environment. Furthermore the capability of acting of a logistic entity is limited depending on its kind. On the one hand a self-steering trolley on a shop floor has all actuators it needs to fulfill its task of getting its payload from one place to another. Uncertainty arises only from control noise or mechanical failure. A single parcel on the other hand has no physical actuators at all and will therefore be inherently unsure weather its intended action is going to be carried out.

What Thrun et al. state for robotics is also very true for autonomous logistics: "Managing uncertainty is possibly the most important step towards robust real-world robot systems." [16, p.4]

Planning and predicting

Decisions are subject to changing conditions. 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 fulfill a given goal an autonomous entity will have to use its knowledge of its environment to formulate a plan. Thus planning is a crucial capability for autonomous systems.

The complexity of a planning task increases with the amount of uncertainty in the environment. 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.

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 processes occurring in the environment and extrapolate them 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.

Components of autonomous risk management

Thus for a proactive risk management within an autonomous logistic entity we need 5 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.

3.5.4 Implementation of proactive risk management for autonomous logistic entities

The goal oriented risk concept chosen above is destined to enable a risk management strategy for autonomous entities such that they achieve robust behavior supporting a global goal. We employ the agent metaphor to model autonomous logistic entities and to support autonomous decision-making. Agents seem to be adequate due to their inherent autonomy and flexible interaction which enables them to interact dynamically in open systems.

Software systems implementing autonomous logistic processes (i.e., agents) need to share information on a continuous basis, for example, product specifications, manufacturing capabilities, delivery schedules, etc., and are required to make decisions which are consistent with the policies and overall economical situation of the enterprise they represent. In this context [15] introduce autonomous knowledge management (KM) to support the agent in improving its decisions in the presence of incomplete, imprecise, or debatable information as well as the inherent uncertainty that results from the dynamic of the domain.

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) [17]. 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. In the BDI (belief, desire, intention) approach as introduced by Rao [18], the strategic layer of agents may be modeled within desires, operational aspects within beliefs, and tactical features within intentions or plans. The BDI approach also attempts to closely mimic human decision-making1 and is the currently most widely used approach for modeling intelligent behavior within the agent research community [21].

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 optimization, which may also be based on competing goals. [22] introduces a dynamic conflict resolution scheme for an agents options which in turn are derived from its goals.

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 an abstract sense this could mean to equip the agent with meta knowledge and meta reasoning capabilities, which is considered impossible for an artificial system as it would mean to engineer consciousness—a claim that AI has finally identified as unrealizable. For our approach we don't aim at a universal meta reasoning ability but add one meta layer to an agents reasoning capabilities, which can be realized by modal logics (cf. [23]).

In [17] 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 [15]. It includes explicit risk and knowledge management, 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 risk management to identify and assess the risks associated with one or more options, and knowledge management 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, risk management may be unable to decide on risk. This triggers knowledge management to acquire the missing information or detailed information on the current situation – including alternative actions. Knowledge acquisition may retrieve knowledge from other agents or directly from external sources/sensors.

A central component of our approach is the representation of decision-support parameters which govern the risk management and knowledge management 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).

As stated before risk is related to uncertainty. 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 knowledge management. Risk management 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 risk management is heavily depending on knowledge. Therefore it can only function in close collaboration with a knowledge management infrastructure. A description of the mechanisms of this of this collaboration and the core task of knowledge-based risk assessment will follow.

Pattern matching for risk identification

The initial task and most important prerequisite for successful risk management is its ability to identify risk and evaluate its potential conse-

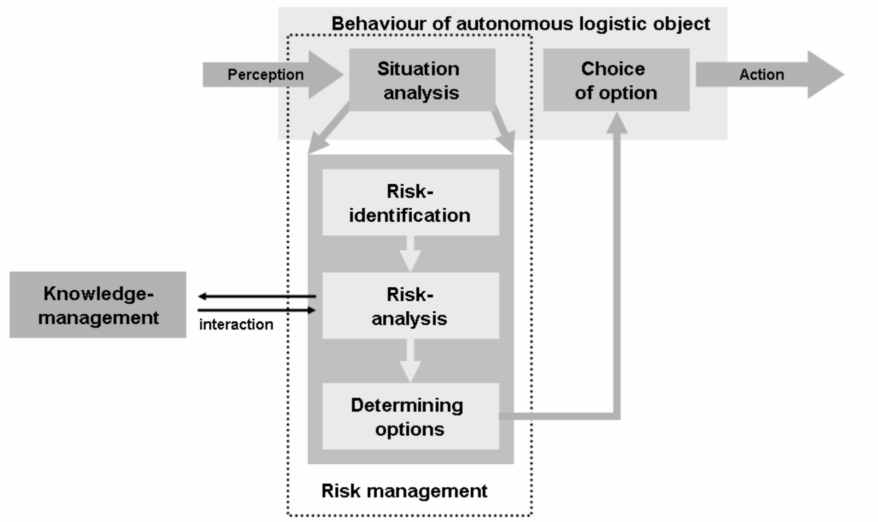

Figure 2: Agent decision process with risk and knowledge magement

quence. 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 Fig. 1.2) 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 [22]). 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 et al. [24] 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.

Risk assessment

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 [25] (see also [26]). This theory provides us not only with one probability measure for a 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.

3.5.5 Conclusion

New possibilities in reducing damage, lateness and other aberrations to given goals for autonomous logistic objects through the usage of a suitable risk management concept are described in this chapter. Risk Management with its containing parts of risk identification and risk assessment can be a solution to reduce risk in transportation or production for the autonomous objects and is also needed to make the autonomous logistic objects robust against suddenly appearing events which were not considered during the planning phase of the logistic processes. The chapter gives an overview about different levels of risk and Risk Management for planning and controlling the logistic processes by agent based autonomous objects. The handling of information from the real world with implemented methods of risk management to realize risk oriented decisions is a challenging task for an agent based autonomous logistic object. In this chapter the basic risk management concept and a technical realization of a local RM system were introduced and discussed regarding the requirements for agent based logistic objects. To complete the risk management system a component of planning has to be integrated. This is still an open task because until now the risk management 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 risk management interacts with the knowledge management. But the complexity in determining the uncertainty and modeling the risk for the complete autonomous process has strong influence on the model (hidden markov or bayes net) to be chosen and on the further development for that it is an important task for the near future.

3.5.6 References

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