Reference: Hülsmann, M.; Windt, K.; Wycisk, C.; Philipp, T.; Grapp, J.; Böse, F.: Identification, Evaluation and Measuring of Autonomous Cooperation in Supply Networks and other Logistic Systems. In: Baltacioglu, T. (ed.): Proceedings of the 4th International Logistics and Supply Chain Congress. Izmir, Turkey, 2006, pp. 216-225 *(also subproject: A1)*

IDENTIFICATION, EVALUATION AND MEASURING OF AUTONOMOUS COOPERATION IN SUPPLY NETWORKS AND OTHER LOGISTIC SYSTEMS

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Abstract

The implementation of autonomous cooperation in logistic systems seems to be an appropriate method to cope with the increased requirements on competitive enterprises caused by highly dynamic and complex environments. In order to manage autonomous cooperating logistic processes efficiently, its measurement and evaluation are essential preconditions. The objective of this paper is to introduce the concept of autonomous cooperation in logistic processes and to answer the questions on how autonomous cooperation could be measured and evaluated. To obtain a comprehensive and multi-perspective picture of autonomous cooperation, the several steps of analysis are divided into two sequenced parts. The first sequence of examination contains a general perspective, which is exemplified by supply networks. The second sequence represents a specified engineering perspective of autonomous cooperation in a production logistic system.

Keywords: Autonomous Cooperation, Supply Networks, Production Logistics, Measurement, Evaluation

1. Introduction

Recent changes like short product life cycles as well as a decreasing number of lots with a simultaneously rising number of product variants and higher product complexity lead to an increase of complexity of production systems. Therefore competitive enterprises have to develop new planning and control methods for their supply networks and their production systems in order to cope with these requirements. To achieve an ability to adapt on these new challenges the approach of decentralized planning and control by intelligent logistic objects in autonomously controlled production systems – called autonomous cooperation – seems to be an appropriate method.

In order to prove in which case autonomously cooperating processes are more advantageous than conventionally managed processes it is essential to specify what is exactly meant with autonomous cooperation, how does it differ from conventional control and how achievement of logistic and economic objectives in autonomously cooperating systems can be estimated and compared to achievement of objectives in conventionally controlled systems. The necessity for an operationalization of the idealistic concept of autonomous cooperation will be outlined in this paper, as it is a basic requirement for every single logistics company to decide if and to what extent autonomous cooperation should be implemented. Through the utilization of a measurement tool, logistics management has the opportunity to evaluate potentials of the concept and concretize measures for a shift from a mostly centralized to a more decentralized planning on the decision-making level (e.g. formation of autonomous working groups), information and communication technology level (e.g. use of RFID) as well as for the goods level (e.g. intelligent freight units). Furthermore, it is essential to develop an adequate evaluation system out of general business and engineering perspective in order to prove that the implementation of autonomous cooperation in production systems is of advantage in relation to conventionally managed systems. The evaluation of autonomous cooperation contains relations between a specific degree of autonomous cooperation and targeted objectives, which can be logistic objectives or financial objectives, for example. Therefore both the level of autonomous cooperation and the degree of the achievement of considered objectives (e.g. logistic, financial) must be measurable.

For this purpose, this paper introduces in the second chapter a general definition of autonomous cooperation exemplified by a supply network. Additionally, a specified definition in the context of engineering science and its meaning in the context of production logistics will be given to obtain a common understanding of the term autonomous cooperation. The third chapter deals with the evaluation of autonomous cooperation. Therefore, at first a general measuring concept, which is based on a scoring model, is introduced to give an insight into

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essential conditions of measuring ideas of autonomous cooperation of logistic systems. Later a specified measuring approach based on the engineering understanding of autonomous cooperation will represent an example on how a measuring concept of autonomous cooperation in production logistics system could look like. Based on those measuring methods, two evaluation concepts for autonomous cooperation will be introduced. One represents the general business perspective, which contains an evaluation of real-options resulting from autonomous cooperation. The other one stands for the engineering perspective in order to accomplish a comprehensive evaluation system for a production logistics system. A conclusion and further research tasks can be found in chapter four.

2. Understanding of Autonomous Cooperation

The vision of autonomous cooperating logistics processes emphasizes the transfer of qualified capabilities on logistic objects as explained above. According to the system theory, there is a shift of capabilities from the total system to its system elements (Krallmann 2004). By using new technologies and methods, logistic objects are enabled to render decisions by themselves in a complex and dynamically changing environment.

2.1 General Definition of Autonomous Cooperation

The source of the idea of autonomous cooperation is derived from different concepts of self-organization (e.g. cybernetics (von Foerster 1960), dissipative structures (Prigogine & Glansdorff 1971), synergetics (Haken 1973), autopoiesis (Maturana & Varela 1980), and chaos theory (Peitgen & Richter 1986). The focus of study is the autonomous evolution of ordered structures in complex systems. To specify the term ‘autonomous cooperation’ for the following analysis, a working definition, which was established in the work of the CRC 637, is presented. In this paper, autonomous cooperation describes processes of decentralized decision-making in flat organized structures of logistic processes. It requires that interacting elements in non-deterministic systems possess the capability and the possibility of making decisions independently. The implementation of autonomous cooperation aims at an increased robustness and positive emergence of the complete system through distributed and flexible coping with dynamics as well as complexity (Hülsmann & Windt 2006). Consequently, autonomous cooperation is based on the idea that systems cannot only be regulated by an external force, but also within the system as an internal force.

In supply networks for example, this concept means leaving operative decision-making in its sub-systems, sub-units, and sub-elements which are part of the network, while the individual system components operate independently from centralized decision-making structures. Due to the existence of various sub-systems in a supply network, the surface of the total system expands and allows more complex processing. Through independently operating sub-systems a higher degree of flexibility is assumed, which raises the capability to compensate complexity and dynamics caused by unexpected changes and to fulfill the long-term strategic goals of the major supply network actors (Hülsmann & Grapp 2005).

2.2 Specified Definition in the Context of Engineering Science

The general definition for the term autonomous cooperation provides the basis for the development of a definition in the context of engineering science, which is focused on the main tasks of logistic objects in autonomously controlled logistics systems:

“Autonomous control in logistics systems is characterized by the ability of logistic objects to process information, to render and to execute decisions on their own.” (Philipp et. al 2006)

In the context of engineering science this comprehension of autonomous cooperation is used in the following chapter to present an evaluation system that allows examination of the ability of autonomously controlled systems to cope with increasing complexity through better accomplishment of logistic objectives. In order to identify autonomous cooperating logistic objects, dissociation from conventionally managed logistic objects is necessary. The definition of autonomous cooperation explained earlier, describes the maximum level of imaginable autonomous cooperation. Thus, all system-elements in an absolutely autonomous controlled system are able to interact with other system-elements and to render decisions on the basis of a self decentralized target system in combination with suited evaluation methods. In general, logistics systems probably contain conventionally managed as well as autonomously controlled elements and sub-systems, respectively. Thus it can be declared, that there are different levels of autonomous cooperation which is called level of autonomous control. For example, one part of a production lot could be able to coordinate each production stage of the lot which represents a high level of autonomy; meanwhile other parts only allocate data regarding their processing states. Consequently, the latter mentioned case shows a lower level of autonomy.

3. Multi-perspective Measurement and Evaluation Concepts of Autonomous Cooperation

To apply and manage autonomous cooperation in logistic business processes efficiently, a continuous monitoring system is needed. Before the management can evaluate whether autonomous cooperation helps gaining company’s goals or not, it has to be informed about the current degree of autonomous cooperation within their processes. Consequently, for an adequate establishment of this conceptualization, its contributions will only be manageable if they are measurable (Drucker 1954). On the basis of the measured degree, an evaluation of autonomous cooperation can take place regarding its influences on general objectives like financial and logistic objectives, and if a higher or lower degree of autonomous cooperation in the logistic process is more useful.

This chapter will focus on the measuring and evaluation of autonomous cooperation. Based on two different measurement concepts for autonomous cooperation, two different concepts will be introduced. The general evaluation concept evaluates autonomous cooperation out of an economic perspective, which has a high relevance until the concept of autonomous cooperation will be implemented in logistic processes as its cost-value ratio is transparent and its possible profits are traceable. The second evaluation concept deals with the impact of autonomous cooperation on logistic objectives. Together with the measurement of the level of autonomous cooperation it allows an investigation of the coherence between the level of autonomous cooperation and the performance of production systems.

3.1 Measurement of Autonomous Cooperation

In the following, first a general measurement concept of autonomous cooperation is presented which introduces the measurement problem of autonomous cooperation and that is adaptable to different logistics scenarios, like a supply network. Later a more specified measurement concept of autonomous cooperation shall also be exemplified in the field of production logistics which will give a more detailed insight into a possible measuring approach.

3.1.1 General Measurement Approach and of Autonomous Cooperation

Previous research has focused on abstract contributions of the concept of autonomous cooperation (e.g. Hülsmann & Grapp 2005, Hülsmann & Wycisk 2005a, b). Before introducing a general measurement approach of autonomous cooperation, it is necessary to define its basic requirements that determine its design. Based on measurement theory there is a need for validity or reliability regarding the used indicators and their key operators (Kromrey 2000). On the one hand they shall allow deduction of the degree of autonomous cooperation. On the other hand it is necessary to design a measurement system that integrates economic indicators in order to identify contributions to the objectives of autonomous cooperation (Hülsmann & Grapp 2006). Besides the basic requirement of measuring, an instrument should be able to visualize the results and it should support to interpret them (Bronner 1989). Due to existing dynamics of a logistic system and its processes that are quite evident through phenomena as real-time economy, there is not just a static optimum of autonomous cooperation. It can be assumed, that the degree of autonomous cooperation varies over time. A continuous monitoring system for the degree of autonomous cooperation is needed on all levels of logistic processes (Hülsmann & Grapp 2006).

A first step in developing a measurement concept for autonomous cooperation is defining its scope of application. To capture an entire logistic system while keeping a manageable degree of description, a trichomoty of logistics is used. It consists of the decision system (management), information system (information and communication) and execution system (material and goods flow) (Scholz-Reiter et al. 2004). A second step is to choose an appropriate basic measurement method. The chosen basic method of measuring the degree of autonomous cooperation is a scoring model. The third step of developing a measurement concept contains defining the constitutive objects of measuring. In this scoring model the constitutive characteristics of the general definition of autonomous cooperation (decentralized-decision-making, autonomy, non-determinism, interaction, heterarchy) (Hülsmann & Windt 2006) shall represent autonomous cooperation. They are transferred and specified in each case into indicators and key operators for each level of a logistic system (Hülsmann & Grapp 2006). The selection of characteristics and indicators depends on the field of application. A measurement concept which measures the degree of autonomous cooperation in a supply network could differ from a measurement concept of production logistics.

Figure 1 illustrates a general process of measurement of autonomous cooperation by the characteristic of "decentralized decision-making" at the executive level of a logistic system, which could be specified as local disposition.

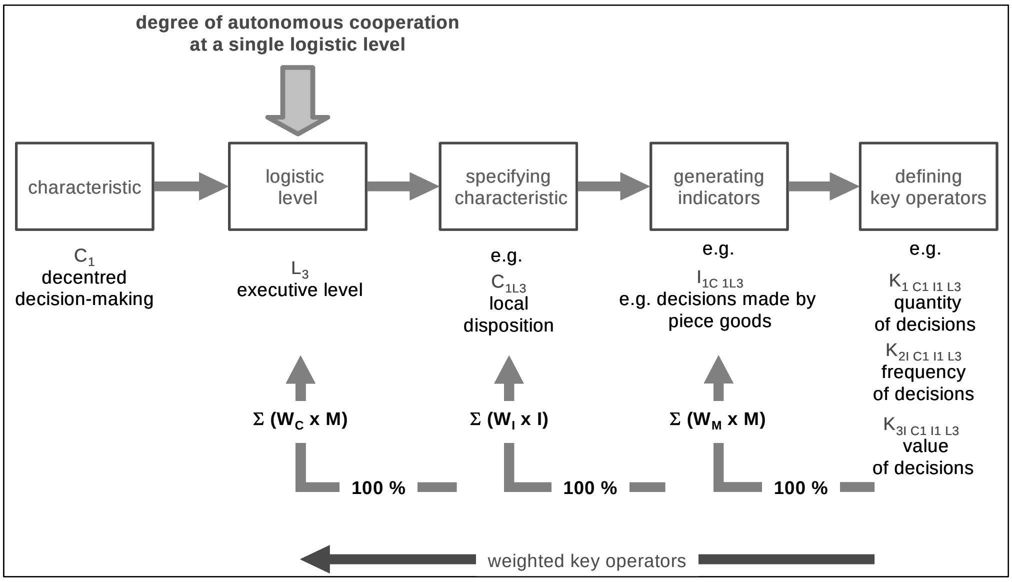

Figure 1. Scoring model to measure the degree of autonomous cooperation (Hülsmann & Grapp 2006)

The specified characteristic local disposition will be transferred into indicators e.g. "decisions made by piece goods". Key operators enable to measure each indicator (Orth 1974) such as in the example: quantity, frequency or value of decisions. The amount of all weighted key figures assigns the value of the particular indicator. Finally, the sum of all weighted indicators composes the weighted score of specific characteristic for a particular level of the production logistic system. To apply the scoring model in practice one possible tool could be a software-based question sheet (Hülsmann & Grapp 2006).

To fulfill the requirement of visualization of the developed measurement instrument, the measured degree of autonomous cooperation can be charted on a polarization graph (Hülsmann & Grapp 2006). The polarization graph represents the measured degree of autonomous cooperation based on its constitutive characteristics, which are in a general understanding decentralized-decision-making, autonomy, non-determinism, interaction and heterarchy (see figure 2). The measured results of each characteristic of autonomous cooperation can be pictured on a scale form from 0 to 100%, while a higher percentage indicates relatively higher degree of autonomous cooperation and a lower percentage indication stands for a relatively higher degree of centralized coordination. Additionally a comparison of the different logistic levels of a logistic system (decision system, information system and executive system) is assumed to be possible regarding their individual degrees of autonomous cooperation (Hülsmann & Grapp 2006).

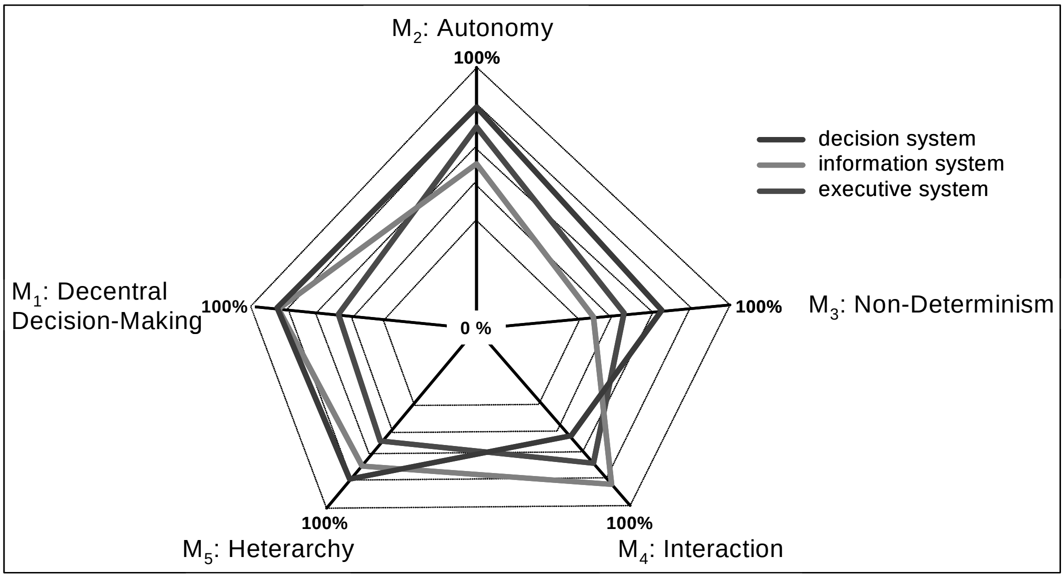

Figure 2. Polarization graph as a possibility to visualize and compare the degree of autonomous cooperation in the different logistics levels (Hülsmann & Grapp 2006)

For a context based interpretation of the gained results not only the measured quantitative degree of autonomous cooperation is significant but its combination with a temporal and spatial analysis (Hülsmann & Grapp 2006). Even if the degree of autonomous cooperation is equal for certain characteristics in different logistic systems, the relevance of the respective value differs with an increasing spatial and temporal validity. The score of the measured degree of autonomous cooperation of the scoring model cannot be used to gain perceptions about the quantity of autonomous cooperating elements. Consequently, it just represents a tendency of more or less autonomous cooperation within a logistic system. Furthermore, due to the logistics systems immanent dynamics it is assumed that the calculated values of the scoring model cannot be considered as absolute. Consequently, the degree of autonomous cooperation should be measured or monitored at different phases in a logistic process (Hülsmann & Grapp 2006).

3.1.2 Specified Measurement Approach of Autonomous Cooperation in the Context of Engineering Science

The main characteristics of the definition of autonomous cooperation in the context of engineering science are the ability of logistic objects to process information and to render and execute decisions. These characteristics can be assigned to different layers of work in an enterprise. In accordance with Ropohl (Ropohl 1979), different layers of work can be classified in organization and management, informatics methods and I&C technologies as well as in flow of material and logistics, each concerning decision and information and execution system.

The decision system is characterized by the decision-making ability. As mentioned before in autonomous controlled production systems decision functions are shifted to logistic objects, which are aligned in a flat organizational structure. These functions contain planning and control tasks and enable logistic objects to assign their progression. The decision-making process includes the identification and evaluation of decision alternatives on the basis of a self, decentralized objective system, the selection, instruction and control of the best rated alternative as well as possible adjustments. The basis for decision-making is the information processing ability on the information system layer. In autonomous controlled production systems logistic objects must be able to interact with each other as well as to store and to process data. The execution system layer is characterized by the decision execution ability of logistic objects. Autonomous logistic objects are able to measure their current state and react flexibly to unforeseeable, dynamic influencing variables. Mobility and high flexibility of the resources are other main criteria of autonomous cooperation in production systems.

In the following a catalogue of criteria is derived, that contains the main criteria of autonomous cooperation described above as well as their properties, which describe the different levels of autonomous cooperation in a logistic production system. The catalogue of criteria is illustrated in form of a morphologic scheme in figure 3.

System layer	Criteria	Properties			
Decision system	Time behaviour of objective system	static	mostly static	mostly dynamic	dynamic
	Organisational structure	hierarchical	mostly hierarchical	mostly heterarchical	heterarchical
	Number of alternative decisions	none	some	many	unlimited
	Type of decision making	static	rule-based		learning
	Location of decision making	system layer	subsystem layer		system-element layer
	System behaviour	elements and system deterministic	elements non-/ system deterministic	system non-/ elements deterministic	elements and system non-deterministic
Information system	Location of data storage	central	mostly central	mostly decentralised	decentralised
	Location of data processing	central	mostly central	mostly decentralised	decentralised
	Interaction ability	none	data allocation	communication	coordination
Execution system	Resource flexibility	inflexible	less flexible	flexible	highly flexible
	Identification ability	no elements identifiable	some elements identifiable	many elements identifiable	all elements identifiable
	Measuring ability	none	others	self	self and others
	Mobility	immobile	less mobile	mobile	highly mobile

increasing level of autonomous control →

Figure 3. Extract of catalogue of criteria for autonomously controlled systems (Windt et al. 2005)

The transferring of qualified capabilities (e.g. decision-making, data processing, measuring) from the total system to the system elements, i.e. autonomous logistic objects is the vision of autonomous cooperation. Therefore the visualized system layers relate both to the total system and the system elements. Each criterion has a series of properties, with an increasing level of autonomous cooperation in their order from left to right. For example, a logistic system rendering centralized decisions has a lower level of autonomous cooperation than a system with decentralized decision-making by its elements.

The grey marked properties in Figure 3 show exemplary, how a considered production system could be represented in the catalogue of criteria. This example is described in the form of an exemplary production logistics scenario with the individual criteria and their marked properties following (figure 4).

Each criterion characterizes the behavior of logistic objects and is assigned to different system layer, i.e. decision-making system, information system and execution system. The first production stage contains the manufacturing of a part on two alternative machines (Mij). The raw materials that are needed for production are provided by the source (So). In the second production stage, the assembly of the parts that were produced in the first stage is done alternatively on two machines (Aij). The manufactured items leave the material flow net at the sink (Si) (Windt et al. 2005).

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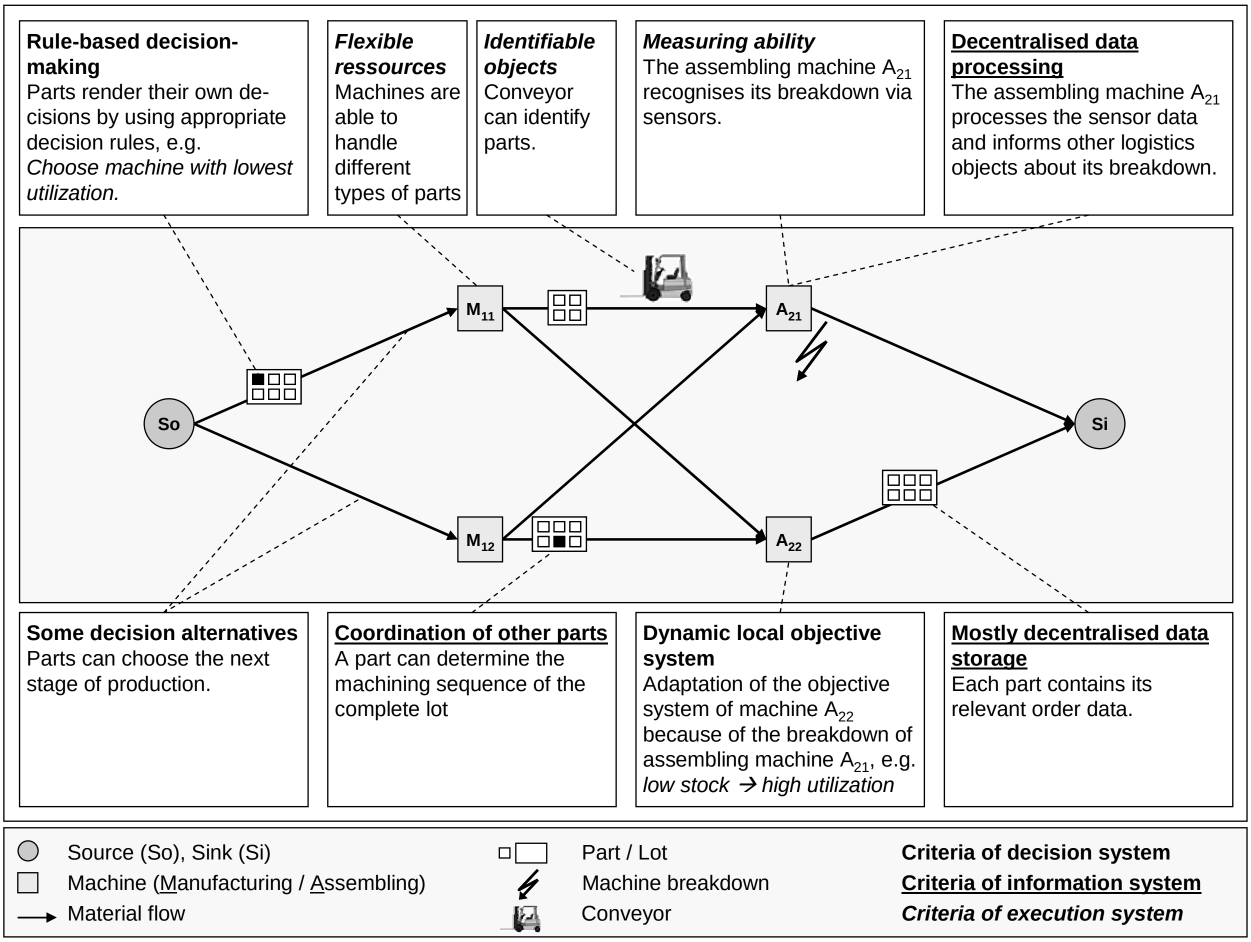

Figure 4. Autonomously controlled production logistic scenario (Windt et al. 2005)

3.2 Evaluation of Autonomous Cooperation

In the following, first a general evaluation concept of autonomous cooperation out of financial perspective is presented which is based on the real-options theory. Secondly out of engineering perspective a more specified evaluation concept in the field of production logistics is introduced which allows a concrete determination of the level of logistic objective achievement.

3.2.1 General Evaluation Approach of Autonomous Cooperation

Through the appliance of autonomous cooperation a higher degree of flexibility in the system structure is assumed (Hülsmann & Windt 2006). More precisely, autonomous cooperation feed the logistic system with more acting alternatives to adapt to changing environmental demands. The question that arises is what values those additional options have for acting out of an economical perspective for the firm? To evaluate autonomous cooperation in this context, the real-options-approach could be an appropriate base. This approach differs from other financial evaluation concepts in considering the value of flexibility (in terms of options of acting) explicitly (Trigeorgis 1996). Objectives of a real-options-based evaluation are to identify and to assess options of acting as a result of autonomous cooperation in logistic processes.

The Real-Options-Approach belongs to the research field of investments and finance. Current methods of dynamic investment analysis are the Net-Present-Value-Approach, the Dynamic Amortization Calculation and the Method of Internal Rate of Return (Hommel & Pritsch 1999), whereas the Real-Options-Approach represents an extension of the Net-Present-Value-Approach. Starting point of evaluation is defining the net present value of the considered system (Nowak 2003). The next step of evaluation is the assessment of the options of acting resulting from autonomous cooperation. Different kinds of real-options resulting from autonomous cooperation could be identified, like options to wait/defer, options to expand, options to innovate and switching options. There are several methods to calculate the value of the different kinds of real-options, but what they all have in common is the analogy to financial options (Hommel & Pritsch 1999).

However, the general applicability of the real-options-approach for evaluating autonomous cooperation is not completely proved yet. At first, the process of calculation of the options-values are said to be complicated. The risk of false calculations and mistakes is not marginal. Furthermore, the value of a real-option is hard to forecast due to uncertain future developments of influencing factors. The calculation of volatility is based on foretime information, whose validity is not guaranteed or on objects of comparison. Using objects of comparison could lead to over- or underestimation and thus lead to mistakes in the calculating process of real-options. In the end the life expectancy of real-options is not scheduled as financial options are. This also could lead to false results in the real-options-analysis (Arnold 2005; Hommel & Pritsch 1999). Overall, the real-options-approach seems to be established in theory and practice due to its ability to evaluate options of acting in their flexibility. If it is the right method to evaluate autonomous cooperation it will be further examined in research.

3.2.2 Specified Evaluation Approach of Autonomous Cooperation in the Context of Engineering Science

In order to prove whether the implementation of autonomous logistic processes is useful, an adequate evaluation system is needed. In production logistic systems an adequate evaluation system reflects the degree of logistic objective achievement related to the level of autonomous cooperation. Consequently the degree of the logistic objective achievement as well as the level of autonomous cooperation must be measurable. The level of autonomous cooperation of logistics systems can be determined with an adequate operationalization based on a catalogue of criteria as described before. Furthermore, the logistic objective achievement can be ascertained through comparison of target and actual logistic performance figures related to the objectives low work in process, high utilization, low throughput time and high due date reliability.

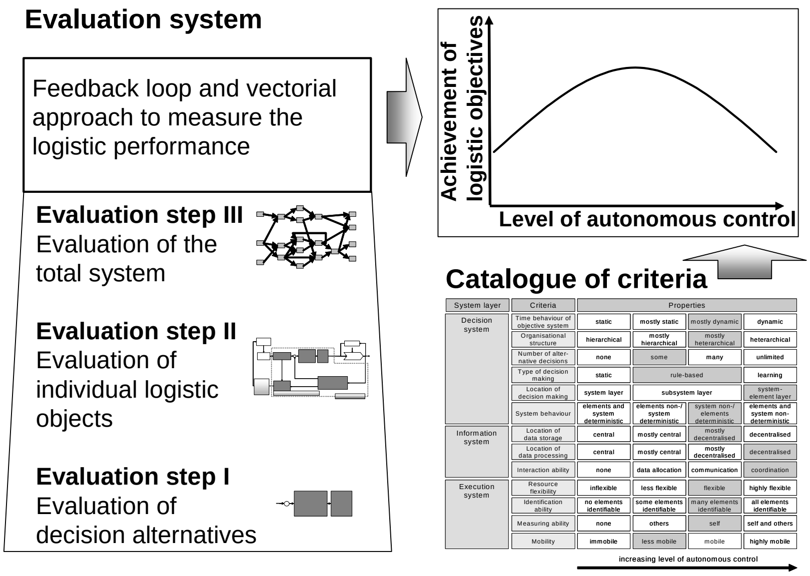

Figure 5. Logistic objective achievement vs. level of autonomous cooperation (engineering science) (Philipp et al. 2006)

Simulation studies showed that a low level of autonomous cooperation in conventional controlled logistics systems leads to a sub-optimal achievement of logistic objectives (Scholz-Reiter et al. 2006). An increase of the level of autonomous cooperation e.g. by decentralization of decision-making functions to the logistic objects causes a rise of the achievement of logistic objectives (comp. upper curve (right) in figure 5). However at a certain level of autonomous cooperation a decrease in the achievement of logistic objectives can probably be noticed caused by chaotic system behavior. By means of simulation studies the limits of autonomous cooperation shall be detected. Therefore it is possible to specify in which cases an increase of autonomous cooperation does lead to higher performance of the system.

The logistic measurement and evaluation from engineering point of view is bases on a feedback control approach for individual logistic objects as shown in figure 6.

The controlled process is a production process with two logistic objects (an order object as well as a resource object) involved. Starting from a global system of objectives, target values for varying object classes are deduced. This enables for example from an order's point of view a differentiation between customer order and storage order with different target weights for delivery reliability and throughput time of an individual order. Local objectives for individual logistic objects arise based on the object classes' objectives. These local objectives act as reference value for the feedback control approach for autonomously controlled processes. Eventual changes during the production process can immediately be realized through a feedback loop by measuring simultaneously the relevant logistic performance figures. Based on this feedback loop suitable solutions to react on process changes can be found by the evaluation of possible alternatives (Scholz-Reiter et al. 2006).

The deviations of production process from locally desired values are analyzed within the controller (figure 6). All possible alternatives to react on the process deviation will be taken into consideration and are evaluated regarding its forecasted logistic performance. This first evaluation step (figure 5) provides the basis for the following operation procedures of a logistic object through the production floor.

The evaluation-based decision will subsequently be executed by the actuator. For example this might be the transport to a different machine if the object decides to change the manufacturing system because of a higher potential of the degree of logistic objective achievement. At the end of a production order the actual logistic performance figures are compared with the target performance figures (normative-actual value comparison). On this basis the degree of logistic objective achievement of an individual object is calculated. This determination represents the second step of the evaluation system. By taking all objects within the entire system into account and in combination with weights of different objects it is possible to determine the degree of logistic objective achievement for the overall system. The weighting of individual objects or object classes allows to emphasize the importance e.g. of bottleneck machines or specific customer orders. This consideration of the overall system represents the third step of the evaluation system. The target values as well as the actual values are expressed in the form of a vector. This enables a mathematical description and a calculation of the different objective achievements. Through the decentralized feedback control of individual objects an opportunity is given to react on eventual changes or disturbances near real time and thus to increase the logistic performance of the overall system while measuring the individual degree of logistic objective achievement (Philipp et al. 2006).

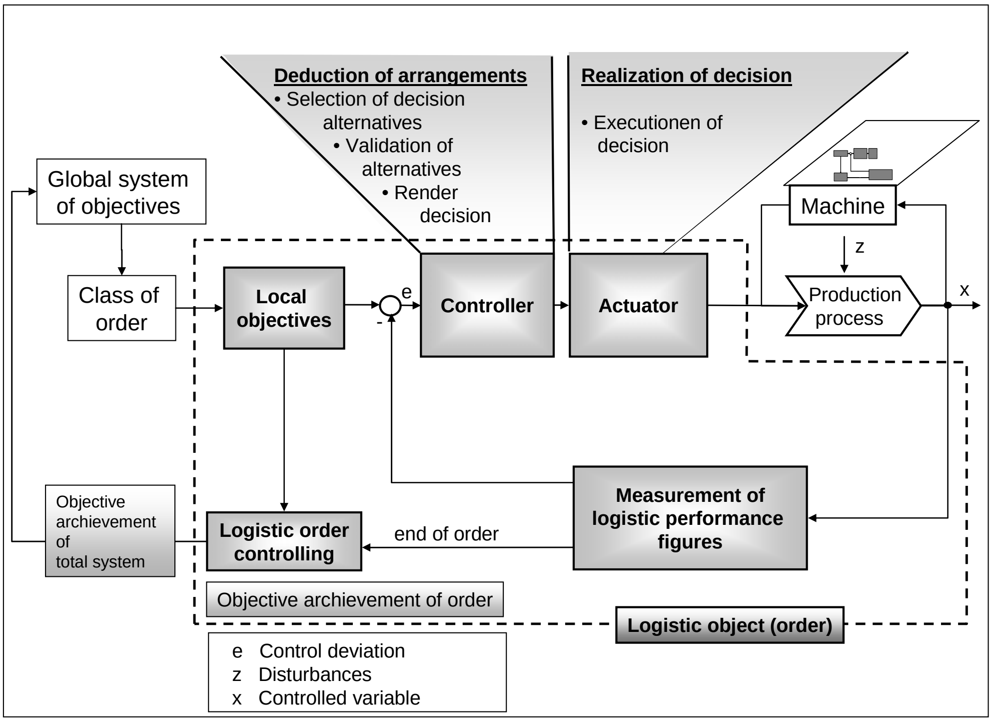

Figure 6. Feedback loop of autonomous cooperation (Philipp et al. 2006)

4. Conclusion

Within this paper autonomous cooperation as a new planning and control approach to cope with challenges caused by increasing complexity and dynamics of today's logistics was introduced. To achieve a common understanding a general definition of autonomous cooperation exemplified by a supply network as well as a definition in the context of engineering science was presented. To manage autonomous cooperation efficiently, it has to be measurable and appraisable concerning its relation to central steering objectives like logistics or financial objectives.

Therefore, at first general requirements for measuring autonomous cooperation as well as a measuring concept, which is based on a scoring model, was introduced. Afterwards a specified measuring approach based on the engineering understanding of autonomous cooperation was presented. To ensure the identification of autonomous cooperating processes in production logistic systems and their distinction to conventionally controlled processes a catalogue of criteria was developed. To demonstrate this catalogue, its criteria, the concerning properties were explained by means of an exemplary shop-floor scenario. For the purpose of evaluation of autonomous cooperating processes two concepts were introduced to consider different perspectives of evaluation. One represents the business perspective and the other one the engineering perspective in order to accomplish a comprehensive evaluation system.

Further research is necessary concerning the development of the presented measurement and evaluation concepts of autonomous cooperation. The general scoring model approach has to be enhanced regarding the spatial and temporal analysis of the level of autonomous cooperation. In order to obtain a concrete number for the level of autonomous cooperation from an engineering point of view the catalogue of criteria needs to be operationalized. Furthermore the development of additional criteria and properties is planned in the near future. The evaluation concepts from business perspective and engineering perspective need further research regarding the definition of specific performance indicators for autonomous processes. By usage of simulation studies these evaluation concepts can be validated as a preparation for the implementation in real logistic systems. These simulation studies will also allow the identification of an optimal level of autonomous cooperation in a specific system. The coherence between the level of autonomous cooperation and the logistic performance is dependent on the system's complexity. For this reason it is necessary to do further research on the characterization of complexity in production system as an additional component of the evaluation system.

Acknowledgement:
This research was supported by the German Research Foundation (DFG) as part of the Collaborative Research Centre 637 »Autonomous Cooperating Logistic Processes – A Paradigm Shift and its Limitations« at the University of Bremen.

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