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1 Changing Paradigms in Logistics – Understanding the Shift from Conventional Control to Autonomous Cooperation and Control

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1.1 Introduction

The understanding of logistics as the integrated planning, control, realization and monitoring of all internal and network-wide material-, part- and product flows including the necessary information flow along the complete value-added chain is still valid: but the logistic performance is becoming more and more dependent on technological innovations. One reason for this is increasing complexity in combination with a high incidence of potentially disruptive factors. The increasing number of part variants and their combination during the production process of automobiles, for instance, leads to a tremendous number of possible combinations. The resultant complexity can no longer be managed feasibly by means of centralized planning and control systems. In addition, today's customers expect a better accomplishment of the logistical targets, especially a higher due date reliability, and shorter delivery times. In order to cope with these requirements the integration of new technologies and control methods has become necessary. This is what characterizes the ongoing paradigm shift from a centralised control of “non-intelligent” items in hierarchical structures towards a decentralised control of “intelligent” items in heterarchical structures in logistic processes. Such intelligent items could include both raw materials, components or products, as well as transit equipment (e.g. pallets, packages) and transportation systems (e.g. conveyors, trucks).

The recent revolutionary developments within Information and Communication Technologies were marked by miniaturization, ubiquitous communications and digital convergence. The trend is towards embedded systems which are moving beyond local interfacing to globally connected systems and allow increased levels of “collective intelligence”. These systems are based on recent IC technologies such as RFID and wireless communication networks, and intelligent items which can coordinate and communicate with each other. These new technological developments call for novel concepts and strategies designed to implement autonomy in logistic processes (Scholz-Reiter et al. 2004).

This anthology presents first approaches and results on autonomous cooperation and control methods for logistic processes. It is based on the research work within the Cooperative Research Center 637 “Autonomous Cooperating Logistic Processes – A Paradigm Shift and its Limitations” at the University of Bremen and it is supported by the German Research Foundation. The need for a better understanding of this new control paradigm in logistics will be explained in the second chapter of this introduction. Of equal importance is the analysis of the main drivers and the definition of autonomous cooperation and control, as well as the description of the major enablers which follows in the next chapter.

1.2 Drivers and enablers of autonomous cooperation and control in logistic processes

The drivers supporting the paradigm shift within logistics are categorised in fig. 1.1 as market, product, technologies and process drivers. The main change, which applies especially to logistic processes, is the significant reduction of time for the change of states, i.e. the time in between two different states of a system. The dynamics within logistic processes are increasing. This may be observed in the categories listed in fig. 1.1 A heterogeneous market with high demand fluctuations, products which incorpoprate a high number of variations and have short product lifecycles, new and fast developing information and communication technologies, as well as production on demand, characterise this situation. In parallel, the demands on logistic performance and logistic costs are increasing, too. This is indicated for instance by shorter delivery times, higher schedule reliability delivery flexibility and the use of reconfigurable technologies. As shown in the middle of fig. 1.1, besides the demands on shorter delivery time, higher schedule reliability, lower price and high quality, the complexity of all the internal and external influencing parameters of logistic systems is also increasing. Among other things, this increased complexity is due to production in global networks, an exponential increase in the amount of data with the use of new ICT, product structures with a high number of variations. In summary, logistic systems are confronted with increasing complexity in combination with many potentially disruptive factors. These impact factors are the drivers of change for a new control paradigm within logistic processes.

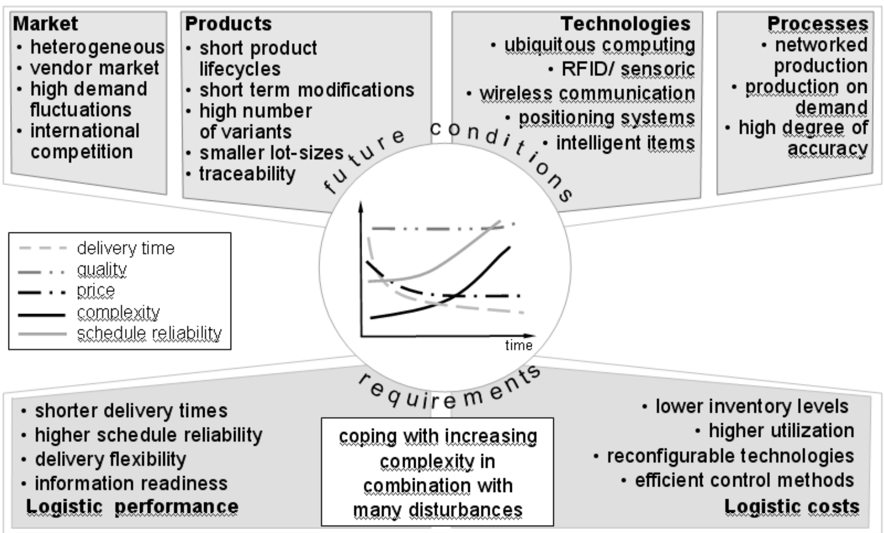

Fig. 1.1 Future conditions and requirements on logistic processes

The paradigm shift is based on the following hypothesis: The implementation of autonomous logistic processes provides a better accomplishment of logistic objectives in comparison to conventionally managed processes despite increasing complexity. In order to verify this thesis, it is necessary to characterize production systems with regard to their level of complexity during the development of an evaluation system.

Autonomous cooperation and control is one factor to guarantee the necessary changeability of logistic processes. Wiendahl et al. defines changeability as characteristics to accomplish early and foresighted adjustments of the factory´s structures and processes on all levels to change impulses with small expenditure (Wiendahl et al. 2007).

Several similar terms exist besides autonomous cooperation and control e.g. self-organisation, self-management or self-regulation. The term autonomous control was initially used in the year 1930 by Pohl and Lüders (Pohl and Lüders 1930). The described example referred to the functionality of a door-bell. The clapper of the bell obtains quasi autonomously the energy for its oscillation by connecting the current to an electro-magnet via the use of a spring. Due to self-induction, the pendulum represented by the clapper is accelerated and consequently the electric circuit is disconnected. The task of the spring is to reconnect the electrical contact. Clearly, if there were a constant energy supply the ring tone would sound continuously. In the proper meaning of the aforementioned definition of autonomous cooperation and control, it is obvious that the clapper does not act autonomously. Actually, nothing else remains for the clapper to do. No decision alternatives exist. But nevertheless, Pohl and Lüders were the first to use the term autonomous cooperation and control in the meaning of "supplying itself with energy". With this interpretation they are quite close to the present understanding of autonomous cooperation and control (Windt 2006).

In order to get a better understanding of autonomous cooperation and control it is necessary to identify the enablers of autonomous cooperation and control which are shown in fig. 1.2 and explained in the following.

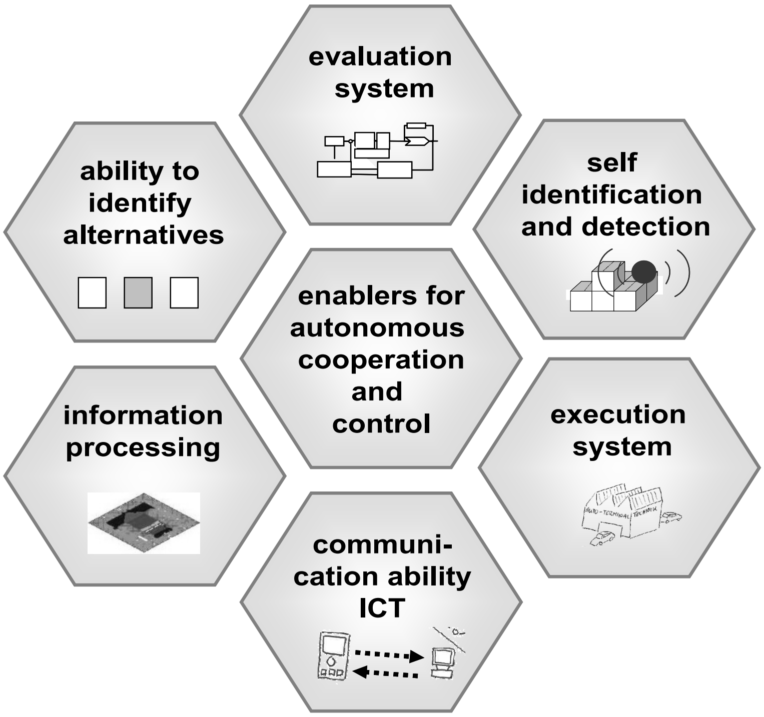

Fig. 1.2 Enablers of autonomous cooperation and control

In order to enable logistic objects (e.g. machine, transportation system, order, product, pallet) to act in an autonomous way the use of ICT is necessary. RFID technology plays a major role in autonomous logistic processes. While the current way of handling data in traditional logistic processes is by means of barcode, the information involved in autonomous processes is handled via RFID tag. Applications in logistics go from automatic stock control and pallet localisation, through automatic registration of goods inbound and outbound, to the saving of detailed information e.g. contents, destination or delivery date (Westkämper and Jendoubi 2003), (Finkenzeller 2002). Future systems will integrate sensors and processing units in embedded systems which will allow the use of a higher level of autonomous cooperation and control.

Positioning systems like the American GPS, the European Galileo or the Russian GLONASS, enable a complete localization of vehicles using a combination of satellite assisted positioning and mobile radio (Gebresenbet and Ljungberg 2001).

Network security systems are being continually enhanced and improved. Safe communication through public networks is an important pre-condition between logistics partners (Cheung and Misic 2002).

The ability to process information and to communicate by using new ICT with other logistic objects represents a second enabler of autonomous cooperation and control. Logistic objects are enabled to detect their situation by processing data from sensors and these objects are also able to assert rendered decisions e.g. to inform a transportation system on a production floor for the transport to another machine. Mobile data transfer systems like Bluetooth and WLAN allow wireless data transmission. Bluetooth can safely synchronize logistic information like addresses, dates and capacities between different terminals. WLAN allows an inexpensive transfer of permanent data streams without the need for elaborate wiring harnesses (Zahariadis 2003).

In December 2004 a new development for the specification of a new communication technology was presented: ZigBee is a new approach addressing wireless sensor networks. Its characteristics are a high density of nodes per network, low power and costs: it represents an optimized short-range wireless solution with lower data rates (ZigBee 2006).

If a logistic object is able to detect its situation on its own by the use of such new ICT, then one key characteristic of autonomous cooperation and control (in fig.1.2 self identification and detection) is attained. In order to acquire the other consecutive characteristics of autonomous cooperation and control it is necessary that the logistic object has the ability to identify alternatives in order to reach its target in a better way. This ability to identify alternatives is another enabler of logistic objects acting autonomously. Nevertheless, there is the need to decide between the identified and given alternatives. Consequently, an evaluation system has to provide methods to evaluate all alternatives. An evaluation system represents another of the enablers necessary for autonomous cooperation and control.

The typical job-shop-scheduling problem, which is characteristic for production logistics, leads to non-polynomial problems. One characteristic of such problems is that the solution space, meaning the range of possible alternative solutions, increases faster than the speed with which decision making takes place.

Without heuristic methods, central control methods are not able find an optimal solution, while nevertheless involving time-consuming arithmetic operations. These time-consuming arithmetic operations often have the effect that during this planning, processes are altered: this causes the elaborately made plan to be invalid even before the beginning of its implementation. Due to this, control systems need to cope with constantly changing plans and simultaneously occurring changes (which are neither visible nor can be influenced) during the process sequence. In addition to that, according to Wiesenthal the control system, has to "imagine" itself and its environment as different in the future. Due to the lack of reliable data and therefore an adequately accurate determination of the future system, the control system has to navigate into an undetermined future (Wiesenthal 2006). As a result of these circumstances, it is not purposeful to implement a complete planning for a longer period in a non-deterministic system. In fact, it appears that decentralized approaches cope in a better way with the previously described problems. Those decentralized control approaches reduce the number of necessary arithmetic operations, and in addition fewer parameters have to be taken into consideration. So decentralized or autonomous control approaches enable the use of conventional decision making methods, which need fewer computational efforts and are therefore time saving, thus reducing the chance of simultaneously occurring changes during processes or simultaneously appearing events. Autonomous cooperation and control hence is able to open new logistic potentials in interaction with complex and dynamically changing process structures. To utilise those potentials, first it is necessary to understand what the term of autonomous cooperation and control describes and what are the major characteristics of this phenomenon – which is the overarching aim of this anthology.

1.3 Autonomous cooperation and control – a general understanding

The basic foundations of autonomous co-operation and control reflect on the idea of self-organization, an interdisciplinary study which has been developing for about 35 years under the labels such as self-organization, autopoiesis, dissipative structures, emergency and complexity theory. The core of the self-organization concept is the formation and development of order in complex dynamic systems (Paslack 1999). In natural sciences, important representatives are Prigogine (Glansdorf and Priogine 1971), in chemistry (theory of dissipative structures), Peitgen and Richter (Peitgen and Richter 1986) in mathematics (chaos theory), Haken (Haken and Graham 1971; Haken 1973) and Foerster (Foerster 1960), in physics (synergetics and cybernetics), and Maturana and Varela (Maturana and Varela 1980), in Biology (autopoiesis). The last concept "autopoiesis" is also applied to other fields such as sociology (Luhman's (Luhman 1973) system theory), psychology concerning family therapy (Hoffmann 1984), jurisprudence regarding the theory of state (Tebner and Willke 1984), marketing (Schüppenhauer 1998) and management (Kirsch 1992). Such transference of research results to various scientific fields might be an indication of high relevance of self-organization for different sciences and its wide recognition. But it is still necessary to adopt the general idea of self-organisation to a capable understanding for logistics. That is why this anthology tries to develop such a definition, in which autonomous cooperation and control is regarded as the answer of a logistic system to complexity and dynamics. Therefore, autonomous cooperation and control is defined as:

> *Autonomous Control describes processes of decentralized decision-making in heterarchical structures. It presumes interacting elements in non-deterministic systems, which possess the capability and possibility to render decisions.*
>
> *The objective of Autonomous Control is the achievement of increased robustness and positive emergence of the total system due to distributed and flexible coping with dynamics and complexity.*

The given definition has been developed within the interdisciplinary working group autonomous cooperation and control of the Cooperative Research Centre (CRC) 637 "Autonomous Cooperating Logistic Processes – A paradigm Shift and its Limitations". Based on this global definition of the term autonomous cooperation and control, further developed definitions related to the relevant science fields will be presented within the articles included in this anthology.

What are the major general and constitutional characteristics of the definition of autonomous cooperation and control given before?

Decentralized Decision-making

Decision concerns the adoption of an action so that an object can reach a state (end state) from another state (starting state). Normally there are some alternative actions and the selection of one specific action has to be preceded by obtaining and processing of necessary information.

The goal-oriented selection between action alternatives is termed as decision-making. (Frese 1993; Laux 1998) Here actions could be either active (self-induced) or reactive (external-induced). Decentralization means the shift from the central point (Frese 1993). For the definition of autonomous cooperation, decentralization means the delegation of decision power, that is, individual system elements are allowed to make independent decisions and are capable of making such decisions by gaining access to necessary resources (e.g. relevant information)

Autonomy

An element of a larger system is autonomous when it is responsible for its own system design, direction and development. In other words, it can make decisions independent from the external entities (Probst 1987). The autonomy of a system or an individual is always measured according to certain criteria and the contextual conditions of the system (Varela 1979; Probst 1987). Criteria could be the scope and extent of decision power. Consequently, autonomy could be seen as the result of the processes of decentralization and delegation (Kappler 1992). In the context of autonomous cooperation, the concept of autonomy is understood as autonomous decision-making.

Interaction

Interaction describes the successful contact between elements (or systems, subsystems etc). "Being successful" means in this context that communication takes place. In other words, the intended contact is able to induce reactions (i.e. reciprocity)(Staehle 1999). Such interactions are central to the autonomous cooperating logistic systems and are realized through communication between system elements such as goods in transportation, vehicles and warehouses. During the interaction processes, information is exchanged in the form of specific data, which could assist in decision-making by the involved elements. With the use of advanced technology like RFID, elements of a logistic system could communicate with elements both inside and outside the system.

Heterarchy

Heterarchy describes the parataxis of system elements (Goldammer 2002). A Heterarchical system is featured by the absence of a permanently dominant entity (Probst 1992). In a heterarchical logistic system such as a production network, there are fewer superordinate and subordinate relationships between logistic elements. This means an increasing level of independence between single elements and a central logistic coordination entity.

Non-determinism

A system is non-deterministic if its behaviour cannot be predicted over a relatively long period despite precise measurement of system states and knowledge about all system laws (Flämmig 1998). For example, the exact output of the system cannot be predetermined based on the input in a non-deterministic system. With such observations, Prigogine brings forward the concept of bifurcation, which means that at this point there are various paths possible for system development. Neither the time point nor the development path to be selected could be predicted, as they follow no causal patterns (Prigogine 1996). With the characteristic of non-determinism, autonomous cooperation strives for higher efficiency in dealing with complexity and uncertainty within processes. The aim is to optimize production and improve order fulfilment. An example could be that components (meeting technological prerequisites such as with imbedded chips) seek the optimal processing path and thus control the production line by themselves. Disruption of the whole or a large part of the process could be prevented, as components could react to disturbance flexibly with alternative actions in hand.

To understand autonomous co-operation and control in logistics on has to delimitate the concept of “Autogenous Processes” vs. the concept of “Autonomous Processes”. Generally speaking, autonomous cooperation could be divided into autogenous processes and autonomous processes (Bea and Göbel 1999). **Autogenous processes** refer to formation of spontaneous order as a result of dynamics and complexity of systems. Such an order is the result of human actions but not human designs (Hayek 1967). In **autonomous processes**, all system members could influence the system order, which could in turn better adapt to system needs and environmental challenges and consequently become more efficient (Bea and Göbel 1999). Here autonomous cooperation is understood as autonomous processes with decentralized intelligence and decision-making. System elements will be given tasks, meta-structures and methods in a general way by external entities, which embody a certain degree of external control. However, the situational concretization of processes within the established framework will be left to the knowledge and capability of elements.

A second delimitation is necessary, which gives an ordered understanding of “Autonomous Cooperation” vs. “Self-organization” vs. Self-management“. The three concepts all describe a system’s ability of creating order with its own resources. Nevertheless there exist differences concerning the form and degree of such an ability. Therefore, a differentiation between these three concepts will be carried out here. **Self-management** is a broad concept, describing the fully autonomous development of a system, which means that the system can formulate its own objectives and plans as well as deciding its own organization forms and necessary resources (Manz and Sims 1980). As a component of management, **self-organization** depicts the way how a system arranges its own structure and processes through its own abilities (Probst 1992). **Autonomous cooperation** has a narrow meaning and refers to only the selection freedom of system members. Regarding the actual situations, system elements could choose among alternatives, which are principally predefined by external entities (i.e. management) (Bea and Göbel 1999).

1.4 Aims of the edited volume

In the preface, the major objectives of this anthology were mentioned:

- To collect **various understandings of self-organization**, which had a comprehensive and differentiable description of the basic ideas about the concept;
- To identify and compare **the scope and depth of autonomous cooperation and control** resulting from various understandings of self-organization, and to summarize the commonness and differences for the terminological purpose;
- To establish **a common conception of autonomous cooperation and control**, which stimulated the cooperation in the research through reflecting various perspectives from different disciplines;
- To develop **a concept system for autonomous cooperation and control** but without concretization, which allowed discipline-specific interpretations in the context of logistic systems.

Concretely, those overarching aims of the anthology set up its focus, which consists of tasks like:

- To define and characterize autonomous cooperation and control;
- To outline the history of autonomous cooperation and control;
- To model autonomous cooperation and control;
- To show the impacts and necessary changes for the management;
- To sketch concepts of autonomous cooperation and control methods;
- To present the use of ICT for autonomous cooperation and control;
- To give first examples of the implementation of autonomous cooperation and control.

1.5 Structure of the edited volume

To answer those questions lying behind the tasks described above, the starting point for this anthology was a now more than three years lasting research within the working group "Autonomous cooperation" of Collaborative Research Center 637 (CRC 637) "Autonomous Cooperating Logistic Processes – A Paradigm Shift and its limitations". As explained before, the overarching aim of CRC637 is to lay foundations for theory building concerning the concept of autonomous cooperation and control (including technologies and instruments) in logistics and to gain extensive knowledge about the involved causal relations so as to apply the concept in practice. In order to achieve these objectives, the research of the CRC 637 tries to identify rules of the paradigm of "autonomous cooperation and control" and to find the means to influence the degree of autonomous cooperation and control on all levels of logistic systems (decision level, information and communication level, and material flow level). The research expects that a higher degree of autonomous cooperation in logistic processes could be one approach to handling complexity and dynamics in logistic systems by increasing flexibility, which could further lead to positive emergence and robustness (i.e. improvement in process quality and achievement of logistical targets). Meanwhile, autonomous cooperation and control could also have negative effects on productivity, which might be attributed to the immanent redundancy in resources as well as structures and the delegation of decision power. Thus, CRC 637 is striving for the solution to the problem of finding the optimal degree of autonomous cooperation and control. Therefore, it was the aim of the working group to set up a common understanding of autonomous cooperation and control, which can be adapted to the individual research aims, contexts, and terminological frameworks of the single subprojects of the CRC 637.

In order to fulfil its objective, the working group "Autonomous Cooperation and Control" first tried to get an **overview of existing ideas about autonomous cooperation and control**. Subprojects each introduced their own understandings of autonomous cooperation and elaborated those characteristics they considered as constitutive. The commonness and differences of the understandings were then discussed.

Next all subprojects of the working group "Autonomous Cooperation and Control" worked out a **catalogue of criteria**, which were used to develop an overarching definition shared by the whole CRC637. Such a catalogue ensured that the conception process conformed to the academic quality criteria regarding definition formulation. Besides, this catalogue also included those criteria that ensure the connectivity between the common definition to be developed and the specific research requirements of the four individual disciplines working together in the CRC637 (production engineering, communication and electrical engineering, computer science and mathematics, economics and business administration). In addition, criteria in this catalogue allowed the global definition to be adapted to the research questions specific to the subprojects, to the application scenarios and to the theory conception for analysis within individual tasks.

Based on this catalogue of criteria and the existing ideas of autonomous cooperation in the subprojects, the subprojects first **redefined their individual understandings** according to those criteria. The new definitions specific to respective subprojects were then again compared so that an oriented and systematic canalization of various understandings could be achieved and the scope of constitutive characteristics could be narrowed down.

In this way the working group "Autonomous Cooperation and Control" deduced **a global definition of autonomous cooperation and control**. On the one hand, this definition reflected the essential understandings of individual subprojects through the procedure outlined above. On the other hand, it satisfied the main terminological interests (in a common understanding) as well as the rules for a transdisciplinary language, and requirements for theory development and practical application.

Next, the necessary **transformation and adaptation of the global definition** was carried out in individual subprojects to better satisfy the individual interests in research without undermining the whole terminological system and the agreed language rules. Consequently, in-depth ideas about autonomous cooperation could be obtained for specific problems, which complement a collectively developed as well as shared and consistent terminology of CRC637.

In order to get a profound understanding of autonomous cooperation and control it is necessary to distinguish between the three main layers referring to Ropohl management, information and communication and the material flow layer (Ropohl 1979). Therefore, the anthology is structured in three main categories.

The **second chapter "**Fundamental Basics and Concepts of Autonomous Control and Cooperation**"** following this introduction focus on the fundamental basics and the description of autonomous cooperation and control concepts. The historical development of autonomous cooperation and control as well as the main criteria are presented. Furthermore, the modelling problem of autonomous cooperation and control is addressed in several articles.

The **third chapter** "Autonomous Control Methods for the Managment, Information and Communication Layer" picks up the ICT developments and how the management processes have to be changed if autonomous cooperation and control is to be integrated in logistic processes. Besides the management view, also knowledge management and knowledge-based risk-management plays an important role and is addressed in this chapter.

The **fourth chapter** "Autonomous Control Methods and Examples for the Material Flow Layer" concentrates on the material flow layer where the developed autonomous cooperation and control methods need to be implemented and executed. Therefore, one enabler of autonomous cooperation and control – an evaluation system for autonomous logistic processes – is presented. Other articles describe scenarios, the implementation and first results of autonomous cooperation and control in practice or on the basis of simulation studies.

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