Chapter 1
Contributions and Limitations of Autonomous Cooperation and Control in Logistics

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1.1 In Search of the Optimal Degree of Autonomous Cooperation and Control in Logistics

The realization of autonomous cooperation and control in logistics is not a question of either external control or autonomous control. Rather, it implies the intention to increase the *degree* of autonomous cooperation and control [9]. This means that at least one of the constitutive characteristics – autonomy, decentralized decision-making, interaction, heterarchy and non-determinism [24] – is ceteris paribus intensified. Technologies (e.g. the intelligent container [15, 16]) or methodologies (e.g. collaborative transportation planning [17]), whose implementation or usage does augment these characteristics in logistics processes can therefore be regarded as enablers for autonomous cooperation and control. In contrast, organizational approaches, technological solutions or planning and controlling routines, which lead to a diminution of the constitutive characteristics, can be appraised as impediments for autonomous cooperation and control in logistics.

Consequently, two main questions arise: Firstly, which degree of autonomous cooperation and control is *feasible*? Secondly, which degree of autonomous cooperation and control is *reasonable*? In other words: which technologies and methodologies are able to increase the degree of autonomous cooperation, how effective are these measures and what is the adequate implementation level in logistics systems?

The underlying purpose is to find the "optimal degree" of autonomous cooperation and control of logistics processes. This leads to the necessity to know the

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drivers for the optimal degree and therefore to know the enablers and barriers for autonomous cooperation and control in logistics systems – on the level of organization and management, information and communication as well as material flow [22].

Hitherto conducted research shows first promising findings: On the *organization and management level*, for example, autonomous cooperation and control can contribute to the flexibility [10, 25] and the robustness [12] of a company's structures and processes and to a transportation system's efficiency [2, 7]. Furthermore, share prices of logistics companies indicates that the implementation of autonomous cooperation-enabling technologies has a positive influence on the company value [4]. On the *information and communication level*, increasing the degree of autonomous cooperation and control of logistics processes can decrease communication costs and energy consumption [14]. Also, the quality of transported food, for example, can be improved by observing the conditions of the transport process and adjusting the transport routes [6]. On the *material flow level*, implementing autonomous cooperation and control in logistics can improve a production system's performance by increasing the ability to cope with complexity [21] and can lead to a higher achievement of logistic objectives (e.g. lead times, due-date reliability) [3].

However, recent research shows also barriers and limitations, which prevents the realization of a higher degree of autonomous cooperation and control of logistics processes: On the *organization and management level*, research indicates that implementing autonomous cooperation-enabling technologies bears higher risks than the implementation of other technologies [4], for example strategic risks, legal risks or operational risks [11]. On the *information and communication level*, technical limitations can be observed, such as the problem of radio propagation, which describes an attenuation of radio waves during the transmission from the sender to the receiver [1]. On the *material flow level* limitations result for instance from the risk that autonomous control methods might cause sudden and unexpected changes of the respective logistics system's behavior. Under certain conditions an intrinsic dynamic behavior and even chaos can occur [20].

In consequence, both questions – to which degree it is possible and to which degree it makes sense to increase the degree of autonomous cooperation and control of logistics processes – have been addressed in former research. However, it is not clear whether the contributions or the limitations overweigh. Additionally, these results cannot be generalized because they focus on individual problems based on individual applications and theoretical foundations [25]. Hence, there is still a gap in research regarding the general contributions and limitations of autonomous cooperation and control of logistics processes. This would substantially contribute to the answer of the central ideal question regarding a general, optimal and feasible degree of autonomous cooperation and control in logistics.

Correspondingly, the underlying aim is to improve the capability to cope better with complexity and dynamics of logistics systems. Therefore, it is essential to gain insights into the benefits und feasibility of autonomous cooperation and control in logistics. This edited volume approaches this question from four different

perspectives on contributions and limitations: organizational, methodical, technical, and practical.

The *organizational perspective* comprises four views: institutional, functional, instrumental, and process-related [8]. Each of these views concentrates on different aspects of organization such as the system itself, the system's structure, measures or processes of organizational design. Therefore, scientific research investigating organizational contributions and limitations of autonomous cooperation and control in logistics needs to consider these views in order to be able to discuss the effects on the system's goal achievement.

The *methodical perspective* implies in a broader view mainly three aspects: selecting agents, defining their goals [18], and modeling a strategy. In a closer view, Windt et al. (2010) define autonomous control methods as "*generic algorithms that describe how logistics objects render and execute decisions by their own*" [23]. For the purpose to investigate contributions and limitations of autonomous cooperation and control in logistics, the broader view should be considered in order to include all of influencing aspects.

The *technical perspective* mainly focuses on developing and improving features of information and communication technologies such as RFID, GPS, sensor networks, etc., and therefore, on physically realizing autonomous control methods. This includes issues such as data integration or multi agent systems. Therefore, the technical perspective provides physical results, which enable logistics objects to decide decentralized.

The *practical perspective*, finally, refers to the actual application of autonomous cooperation and control methods and technologies in logistics practice. Implementing autonomous cooperation and control into industrial routines might produce non-intended results. Therefore, the validity of theoretical scientific findings needs to be tested in the "real-world" in order to be able to give recommendations for logistics management concerning the implementation of autonomous cooperation and control.

All in all, the major research question of this edited volume is the following: What are the major driving forces – fostering as well as hindering determinants – for the feasible and reasonable utilization of the idea of autonomy in the decentralized decision-making of logistics objects in complex and dynamic supply networks – on the level of organization and management, information and communication and material flow?

1.2 Aims

In order to provide a comprehensive and profound knowledgebase for the raised question, the edited volume aims for *the identification, description, analysis, and evaluation of contributions & limitations of autonomous cooperation and control from organizational, methodical, technical, and practical perspectives*. Therefore, it is intended to develop fundamental contributions to the achievement of the

following research aims, which are connected with the overall objective of the research related to autonomous cooperation and control in logistics.
From an *organizational* perspective:

(a) Describing possible organizational determinants, which enable the implementation of the concept of autonomous cooperation and control in logistics.
(b) Analyzing causal relationships between implementing autonomous cooperation and control and organizational structures, processes, activities, and tasks in logistics companies and networks in both directions.
(c) Deducing recommendations concerning the design of organizational structures and processes in order to implement autonomous cooperation and control technologies.

From a *methodical* perspective:

(a) Developing a general setting of methodologies for modeling autonomous cooperation and control in logistics, which is compatible to existing approaches.
(b) Finding a systematic approach for deciding, which autonomous cooperation and control method is best suitable for a certain logistics scenario.
(c) Determining analytically the boundaries of computational capabilities depending on the autonomous cooperation and control method used.

From a *technical* perspective:

(a) Depicting today's technical possibilities to apply the concept of autonomous cooperation and control on logistics processes.
(b) Investigating technical pre-conditions, which need to be fulfilled in order to enable the implementation of autonomous cooperation and control in logistics.
(c) Examining systematically technical restrictions, which limit the possible and feasible degree of autonomous cooperation and control in logistics.

From a *practical* perspective:

(a) Documenting experiences from first applications of autonomous cooperation and control in example production and distribution logistics scenarios.
(b) Deriving from these experience, on the one hand, the potential of autonomous cooperation and control to improve logistics performance.
(c) Investigating, on the other hand, impediments of autonomous cooperation and control technologies and methods after implementation into daily industrial routines.

1.3 Structure and Results

In order to contribute to the research aims addressed above, the edited volume is divided into four corresponding sections:

- Organizational contributions and limitations
- Methodical contributions and limitations

- Technological contributions and limitations
- Practical contributions and limitations

The second chapter *"Organizational Contributions and Limitations"* investigates the impact of autonomous cooperation and control on the organization of logistics systems. Considering four different perspectives of organization (institutional, functional, instrumental, and process-related [8]), this chapter analyzes how the design of structures and processes is affected by an increased autonomy, interaction, and decentralized decision-making in order to determine effects on the achievement of logistics companies' and systems' goals. This is a fundamental perspective on autonomous cooperation and control since this concept is rooted in the principle of self-organization [13], which analyzes how ordered structures emerge in complex and dynamic systems [5, 19].

The chapter's findings show, for example, that logistics companies can use autonomous cooperation-based technologies in order to differentiate from competitors by creating additional customer value. Therefore, autonomous cooperation and control can have a positive impact on the strategic positioning of logistics companies. Furthermore, the effects of different design options of transport chain organization and transportation planning on efficiency and expected revenues are presented. In addition, this chapter shows that autonomous control positively affects a logistics system's (exemplarily a production network) effectiveness, if information about the goods flows is not available. This allows to investigate, how an increase of the degree of autonomous cooperation and control affects the organization of logistics systems.

The third chapter *"Methodical Contributions and Limitations"* discusses aspects of autonomous control methods in logistics. This implies a modeling methodology and preconditions and implications of different methods, but also computability in order to assess the causal relationships between different logistics parameters, autonomous control methods and the resulting performance. The methodical perspective is an essential component for applying the concept of autonomous cooperation and control in logistics [22], since methods describe, for example, how autonomous logistics objects decide and act.

The findings for instance, analyze the performance of different methods depending on dynamics and complexity of the logistics system. Generally, autonomous control methods are superior to conventional methods, if dynamics and complexity increases. However, it is shown that multiple methods within one system can reduce the performance although single methods perform well. This contributes, on the one hand, to the aim to systematically map suitable methods depending, for example, on scenario parameters, and, on the other hand, to the aim to determine the optimal degree of autonomous cooperation and control. In addition, a framework is developed for computational modeling in order to handle the computational complexity of autonomous control methods. This contributes to the aim to develop a general setting of methodologies.

The fourth chapter *"Technological Contributions and Limitations"* considers technological requirements, which are necessary to realize autonomous control methods in logistics. The technological perspective is another essential component for applying the concept of autonomous cooperation and control in logistics since the use of information and communication technologies enables logistics objects to interact, to obtain necessary information, and to decide autonomously [24].

Findings are presented, for example, regarding reliability, range of communication, and the required energy resource of semi-passive RFID tags in order to realize an "intelligent" container. Furthermore, effects of different data integration approaches on the performance (e.g. timeliness, robustness) are discussed, which limit the possible and feasible degree of autonomous cooperation and control. These results contribute to the three beforehand mentioned aims as, first, technical possibilities are considered, second, technical requirements are analyzed, and third, technical limitations are investigated by comparing possibilities and requirements.

The fifth chapter *"Practical Contributions and Limitations"* investigates the realizability of autonomous cooperation and control-based technologies and methods in logistics practice in order to consider aspects that appear if the respective technologies and methods are implemented into daily industrial routines and if "real" data are used. Since autonomous cooperation and control is a relatively new concept, applications in the field are rare. Therefore, there is a need to investigate the usability and feasibility of implementing the concept of autonomous cooperation and control into logistics systems and processes.

The results show that the concept of autonomous cooperation and control is, basically, applicable to logistics and can improve logistics performance. Furthermore, the assumption is validated that autonomous control methods need to be customized for a certain logistics scenario and cannot be recommended generally. For example, the technological infrastructure has to fit the requirements of the chosen methods. Also, the findings of chapter five show the necessity that relevant information is made available. Therefore, this chapter documents implementation experiences and contributes to the aims to derive the potential but also boundaries of autonomous cooperation and control in logistics practice.

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