Collaborative Transportation Planning in Complex Adaptive Logistics Systems: A Complexity Science-Based Analysis of Decision-Making Problems of "Groupage Systems"

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Abstract. This paper aims to analyze decision-making problems in Groupage Systems from a complexity-science perspective. Therefore, the idea of Complex Adaptive Logistics Systems (CALS) and its inherent organization principle of autonomous co-operation and control will be presented. Furthermore, Groupage systems as a way to implement collaborative transportation planning will be introduced and, in combination with the idea of CALS, resulting decision-making problems for so-called 'smart parts' in logistics systems will be deduced.

Keywords: Complex Adaptive Systems, Logistics, Collaboration, Groupage Systems, Decision-making Problems, Complexity Science, Autonomous Co-operation.

1 Introduction

Modern logistics has become more complex than ever before [e.g. 1,2,3]. Some reasons for this development can be observed on different basic levels of supply network systems. One reason is evident on the level of the system's elements: the management of logistics systems has to face an increasing number of agents which have to be controlled within such a system [2]. Another group of reasons can be found on the level of inter-relations: resulting from the rising number of agents more and more inter-relations between numerous and heterogeneous agents have been established [e.g. 4] – in the managerial dimension (e.g. recursive negotiations between opposing stakeholders) as well as in the informational and communicational dimension (e.g. integrated data exchange and warehousing) and in the dimension of material flow (e.g. atomization of goods and transportation means). Finally, some reasons may

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emerge on the level of characteristics, which may be represented by altering functionalities in logistics (e.g. Hülsmann & Grapp [5] describe the development from isolated basic corporate functions of transportation, storage, and handling up to a comprehensive concept of globally integrated, boundary spanning network processes of value creation). Therefore, one major question of logistics management today is, how to cope with the immanent and increasing complexity of supply systems [6].

An organizational principle that has recently been discussed as a capable approach to cope with complexity in logistics management is based on the idea of self-organization and is called autonomous co-operation and control [6]. It can be understood as *"(…) 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."* [7]. With the implementation of the organizational principle in a large and diversified logistics structure like an international supply network (ISN) [e.g. 5] this structure intensifies its characteristics as so-called complex adaptive logistic systems (CALS) [2,3,4]. One example of such a system that already incorporates elements of autonomous co-operation and control is the concept of collaborative operational transportation planning in so-called "Groupage Systems" [8].

Hence, this paper intends to analyze Groupage Systems from a complexity-science perspective with regards to resulting decision-making problems. The results show that Groupage Systems are CALS and the limitations imposed on the system by its complexity are explained. Therefore, this paper comprises three major steps in its argumentation: First, it briefly outlines the idea of CALS, especially the concept of autonomy-driven co-operation and control; second, it describes the so-called "Groupage Systems" as a way to implement collaborative transportation planning; finally, it discusses under the postulates of complexity sciences-principles the decision-making problems of "Groupage Systems" in CALS.

2 Complex Adaptive Logistics Systems (CALS) – Autonomously Controlled International Supply Networks (ISN)

Recent research works on logistics systems observe a shift from linear supply chains to non-linear and complex networks [2,9]. One example for this are so-called international supply networks (ISN), which can be described as a consortium of companies involved in diverse organizational structures of different supply chains and competing with each other to a certain degree [e.g. 5,10]. In order to consider the developments of ISN to shift by trend towards complex networks, several authors took on the analogy of complex adaptive systems (CAS) as they have been described by e.g. Holland [11,12] or Kauffman [13]. Consequently, the term CALS was introduced to supply chain management [2,4,14].

CALS consist of a large number of elements as well as sub-systems. In order to sustain the logistics system's operational reliability and due to their interdependencies, it is necessary for them, to exchange resources (e.g. products, finances or information). In other words, the logistics system's entities are to a certain degree **interacting** with each other [2]. Their incentives to interact derive from their different endowment with these resources [4]. In consequence, the logistics system's operational reliability depends to a certain degree on its elements' **heterogeneity**. Furthermore, due to the interactions between the system's elements and the mentioned phenomenon of increasing interdependencies between them, they react and have therefore mutual influences on each other. In consequence, a logistics system **co-evolves** on the one hand with the evolution of its elements and on the other hand with its environment [3]. In addition to these different endowments with their resources, the elements have different goals as well as different rules, which, in turn, determine their behaviour, in order to reach these goals. Whereas human elements in logistics systems (e.g. management teams) are able to change these rules over time, and therefore **to learn**, this ability is at least arguable for non-human parts, like containers or single goods. However, recent developments in information and communication technologies (e.g. RFID or smart tags) make it possible, to extend this perspective [15] which leads to the development of the term 'smart parts' [4]. In consequence, this ability to learn enables the respective single entities to act **autonomously** and therefore to plan, decide, and act without any impact of an external entity [16]. Theoretically, this enables the logistics system to develop as well without any impact of an external control entity on a global basis. In other words, the system develops the ability of **self-organization** [2,3]. An essentiality of self-organizing systems is that they are located in so called **melting zones** [13], which means, that they do neither pass over the edge of chaos [17,18] nor the edge of order [19,20]. Within CALS there might be two ways of decision making to establish the ability to adapt the system's performance, strategies, organizational profiles, and resources to changing and diversifying environmental requirements. One is autonomous cooperation and control run by the agents of such a system; the other is centralized delegation, which creates a hierarchical structure among the agents. Because the latter has shown its limitations in coping with the complexity of large scale supply network structures, the organizational principle of self-organization shall here be applied to logistics via the concept of autonomous cooperation and control.

What are the supplementary major characteristics autonomous cooperation and control is described by? The idea of self-organization, *"(…) does not present an 'over aging paradigm', but there is a general overlapping of attributes such as autonomy, interaction and non-determinism (…)"* [21] as they can be found in the contributions of Von Foerster 1979 [22], Glansdorff and Prigogine 1971 [23], Haken 1973 [24], Maturana and Varela 1980 [25], Lorenz 1963 [26], Mandelbrot 1977 [27], and Bick 1973 [28]. In addition to autonomy and interaction as they have been already mentioned for CALS generally, further characteristics of autonomously controlled systems are decentralized decision-making, heterarchy and non-determinism. **Decentralized decision-making** describes the ability of a system's elements, to decide on their own about their next steps, without the need to consult a control entity, which is located on a hierarchically higher level. Consequently, an autonomous controlled system is characterized by **heterarchy**, which means, that all elements are equipped with the same (or respectively a similar level) of decision-making power. The combination of these characteristics leads in logical consequence to the impossibility of predicting future system states and therefore, to the system's **non-determinism** [7].

3 Groupage Systems

One approach to increase the degree of autonomous cooperation in CALS are so called Groupage Systems [8]. In Groupage Systems the options for transportation planning at each freight forwarder are extended by horizontal cooperation between several freight forwarders. Then, an additional mode order execution is the forwarding of some transportation orders to cooperating partners in order to achieve a better leveling of available capacity. This cooperation between several competing freight forwarders in Groupage Systems offers the freight forwarders more possibilities than the option of subcontracting only because the plans of the partners can be harmonized in order to improve capacity utilization. This exchange of orders is part of the collaboration and requires the incorporation of acquired partners' orders into the planning process. The Groupage System may include a mechanism for exchanging the transportation orders automatically and thus, for adjusting transport capacity across the partners [8].

Kopfer and Pankratz [8] discuss the modeling of Groupage Systems as Multi-Agent Systems. Multi-Agent Systems offer the possibility to model the decentralized planning situation, where each autonomous participant pursues individual rational objectives. Autonomous decision making in transport logistics can be modeled at various levels of detail ranging from freight forwarding agents as smallest autonomous units [29] via agents for each vehicle [30,31] to agents representing individual orders which strive for certain transports according to pre-specified rules [32]. However, the more detailed the degree of autonomy is, the more communication links between the individual agents are necessary to find a good solution.

4 Decision-Making Problems

Decision making problems occur whenever there is more than one possibility to achieve a certain goal, whereas decisions within a logistics system vary in their degree of complexity and predictability. Exemplary decision-making problems shall be outlined: In the initiating phase of transport collaboration [33], a decision has to be made on how many partners should participate, which will be guided by considerations on transaction costs and efficiency potential [8]. Following that, every involved decision making unit has to decide, whether to participate or not and to take into account, that participation includes the sharing of information with cooperation partners [34]. Furthermore, smart parts that are able to decide on their own about their next steps [4] render their decision based on local information [2], which can depart from information about the whole system's global optimum.

Additionally, in connection with the complex structures of ISN, problems like hyper-linking occur. Hyper-linking means that single agents are affected by the behavior of other agents – not only within a certain logistics system (e.g. warehouses and logistics service firms in a fruit supply chain), but also from different logistics systems (e.g. a certain fruit supply chain and meat supply chain use the same transportation means like container ships) as well as from non-logistics systems (e.g. financial or societal systems). Therefore, agents are highly interwoven with others [35] they might not even know. Each of these systems and their agents depend on the numerous, heterogeneous and dissimilar agent's activities and system performances (e.g. financial crisis). Therefore, the decision making of each single agent is influenced by the decision making of other agents. This might lead to manifold decision making dilemmas [1] and can lead to a complexity induced lock-in situation that results in suboptimal and dysfunctional decision making with a limited choice of possible decisions [36]. "Dysfunctional" reflects on the limited capability of a rational choice. The evident lack of information for the decision, as it is described by the problem of bounded rationality [37], refers to "suboptimal" [21].

5 Conclusions

Groupage Systems might be an appropriate and capable way to cope with a high degree of complexity in modern supply networks, which can be described as complex adaptive logistics systems (CALS). Groupage Systems are based on the concept of autonomous co-operation and control, which strives for the implementation of the idea of self-organization via the processes of decentralized decision-making in the heterarchical structures of logistics networks with numerous, heterogeneous, but equal agents. However, decision-making within Groupage Systems bears several problems, which limit the contributions of collaborative transportation planning to cope with complexity in large-scale supply systems such as hyper-linking. As an illustrative example the phenomenon of hyper-linking might lead to a higher risk of suboptimal and dysfunctional decision making, which can counterproductively affect the decision of partners to participate in the co-operation of Groupage Systems and to share their information with their partners in such a system. Therewith, future research requirements result on the one hand from the non-existence of a general optimum degree of collaboration regarding a minimized risk that emanates from decision making problems. This leads to the necessity, to analyze this question individual as the case arises. On the other hand the same problem is still unsolved for the optimal degree of its basic concept autonomous co-operation and its single degrees, like interaction or autonomy.

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