Autonomous Co-operation of "Smart-Parts" – Contributions and Limitations to the Robustness of Complex Adaptive Logistics Systems

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Abstract

In logistic markets there is an increasing use of new Autonomous Co-operation technologies, like RFID or sensor networks [Rie08]. These elements, which are called "Smart-Parts", are enabled to interact by the appliance of the new technologies (e.g. RFID-chips) in logistic processes, making own decisions without an external control of a superior hierarchic entity. The technologies allow autonomously acting parts getting smaller and the number of logistic systems including "Smart-Parts" is by trend increasing. This higher number of elements consequently results in a higher degree of complexity. Hence, those systems can be described as Complex Adaptive Logistics Systems (CALS). However, the dynamic of these CALS with "Smart-Parts" results in an impossibility to forecast the system's reactions and behavior due to the fact, that "Smart-Parts" render own decisions, based on information they got from other elements and finally based on the behavior of other system's elements. Hence, the unpredictability of the system's future state leads to the problem of achieving its robustness based on the balancing of its required stability and flexibility. Therefore, the question arises how "Smart-Parts" affect a CALS' robustness as there is a link between them in the way that "Smart-Parts" influence Autonomous Co-operation, Autonomous Co-operation influences adaptivity and finally adaptivity influences robustness ("Smart-Parts" -> Autonomous Co-operation -> Adaptivity -> Robustness). Therefore, the paper intends to analyze the possible effects caused by "Smart-Parts" and Autonomous Co-operation in order to identify contributions and limitations to the CALS' robustness. So, the paper proceeds as it follows. Firstly, the need for robustness in CALS as the balance of the system's stability and flexibility is outlined. Secondly, the concept of Autonomous Co-operation in CALS will be described. Thirdly, an evaluation of Autonomous Co-operation regarding the contributions and limitations to robustness will be accomplished.

1. Introduction

In times of globalization, the availability of standardized information technologies enables Logistic Service Providers to act on several worldwide markets leading to an increasing number of competitors, more price competition, and homogeneity of logistic services [Kla06]. Therefore, Logistic Service Providers are confronted with changing settings of requirements, caused by the phenomenon of hyper-competition, describing a fast moving business with a high competition in the fields of price-quality positioning [Dav95]. This demonstrates that the differentiation by offering lower price or higher quality services is one possible solution to gain competitive advantages [Mül05], whereas the standardized and homogenous services are unable to create added values for a customer leading to the possibility of substitution.

Due to the homogeneity of the offered services, the recognition of differences in logistic services quality is a challenging task (e.g. the transportation of goods). So, the need for another capable way for differentiation and gaining competitive advantages emerges. In this term a significant increase of service quality might result from "Value Added Services" [Pfe08]. Every added service (e.g. packing of goods, mounting, and quality control) allows the Logistic Service Providers' customer to improve his own services and thereby constitutes a higher value to the customer. Moreover, if no competitor is able to imitate or substitute this special service, a "unique selling proposition" and thereby a competitive advantage for the Logistic Service Provider is created [Hül08]. Since the Logistic Service Provider's long-term survivability essentially depends on their ability of creating competitive advantages by offering unique services [Dew05], companies should focus on that.

One way to create competitive advantages by offering these special services is the appliance of new Autonomous Co-operation technologies, like RFID or sensor-networks [Sch04]. These autonomous logistic processes are based on the use of interacting system elements, called "Smart-Parts". They can be described as intelligent machines or goods enabling a system to carry out a non-human based decision-making and problem solving [Wyc08]. Thus, enhanced using and the further development of these new information and communication technologies leads by trend to smaller autonomously acting parts and therefore to an increasing number of logistic systems including "Smart-Parts". Hence, an increasing number of interrelations in logistic processes occur [Hül07], leading to a higher degree of complexity and dynamics, because of the increasing number of possible interactions and the increase in different possibilities of behavior. Due to the complexity observed and the ability of "Smart Parts" to act autonomously, such systems can be described as Complex Adaptive Logistics Systems (CALS) [Wyc08]. They have to have a high adaptivity to cope with the increasing complexity and the resulting higher amount of information, due to the fact that they have to be flexible to get sufficient information as well as to be stable to avoid the incoming of too much information. In this context, the term "adaptivity" as the simultaneous requirement for system's stability and flexibility can be described as the system's ability to find the balance between absorbing the increasing amount of information from the environment (flexibility) and the necessity to keep the amount of needed information on a manageable level (stability) [Hül08a]. In other words, to assure an adequate information supply as well as to avoid an information overflow the system's success and survivability depends on its robustness. Robustness means on the one hand the ability to resist against a number of endangering environmental influences and on the other hand the ability to restore its operational reliability after being damaged [Mck08]. However, the autonomous interaction of the system's "Smart-Parts" leads to a higher degree of dynamic and thereby nearly to an impossibility to predict the system's behavior and future system states [Bös07], due to the fact that the "Smart-Parts" decision-making process depends on further behavior and decisions of other elements. Hence, the process of absorbing, selecting, and handling information depends on the behavior of the system's "Smart-Parts" and cannot be controlled by a higher institution.

Due to the direct interconnections between the "Smart-Parts", their behavior and the resulting dynamic and complexity of CALS, the system's robustness is not given per se. But to understand the effects and interdependencies on robustness, resulting from autonomous interacting "Smart-Parts" in CALS, and to show possibilities for achieving a high degree of robustness and assuring the system's long-term success the following question has to be answered: How does the robustness of CALS depend on the dynamics of autonomous cooperating "Smart-Parts"?

Hence, the aims of this paper are threefold: First, it intends to give a description of CALS as well as of the concept of Autonomous Co-operation. Second, it aims to analyze possible effects for CALS' robustness emerging from the using of Autonomous Co-operation. Third, implications to handle robustness as flexibility and stability in CALS will be outlined.

The paper includes three main parts plus an introduction and final conclusions. The first main section deals with the problem of robustness in "Smart-Parts" CALS. Therefore, a literature research is used to describe the future developments of logistic systems to the point of CALS and the resulting need for robustness. The second part is also based on research of current literature and technological developments to describe the implementation of the concept of Autonomous Co-operation in CALS. Thereby, the characteristics of Autonomous Co-operation are linked to the "Smart-Parts" to show the influences resulting from an implementation. The last section outlines the contributions and limitations for robustness resulting from the Autonomous Co-operation in CALS by discussing the possible effects on increasing or decreasing the system's flexibility and stability, resulting from the Autonomous Co-operation's characteristics in connection with the systems including "Smart-Parts". This allows a link between the CALS and the Autonomous Co-operation to show the possible effects of their robustness.

2. Problems of Robustness in "Smart-Parts" Complex Adaptive Logistics Systems

2.1 "Smart-Parts" in Complex Adaptive Logistics Systems

According to McKelvey et al. [Mck08], a paradigm shift in logistic research occurs in terms of an ongoing change from centralized control of non-intelligent elements in hierarchical structures to decentralized control of intelligent elements in heterarchical structures. Due to the parallels between logistic systems and Complex Adaptive Systems (CAS) concerning their properties, a further change regarding the understanding of logistic systems is rising, evolving from linear structures to complex systems and newly to CALS [Wyc08]. The CAS concept comes from biology where it is mostly linked to living entities [Gel02]. According to the CAS definition, it is a system that emerges into an adequate form by autonomously acting and co-evolving agents without being controlled or managed by a higher entity [Wyc08]. The co-evolving and interacting agents, trying to reach own goals over time, enable the CAS to adapt to changing environments [Hol95].

Logistic Systems also consist of a high number of entities, the so-called "Smart-Parts", differing by their dimension (e.g. whole organization, departments, teams, machines, containers) [Wyc08]. Thereby, the whole organization (e.g. company) can be a "Smart-Part" in logistic systems like worldwide Supply Chains, whereas the whole organization consists of own "Smart-Parts" like containers. These parts interact by exchanging resources like finances, products, services or information [Sur05]. Furthermore, for sustaining their willingness to interact, the entities have to be heterogeneous in their characteristics and goals. Otherwise, there are no incentives, which motivate the individual element to participate in a co-operation. The heterogeneity is a pre-condition for the existence and functionality of CALS [Wyc08]. These incentives are maintained through the essential information sharing caused by the different goals the entities are aiming for. Additionally, organizations and departments have to be able to learn to adapt their entities to changing environment requirements. But this ability is decreasing by looking to "Smart-Parts" like ships, containers or single goods [Wyc08]. This leads to the point that all parts in logistic systems shall be able to interact autonomously and to make own decisions to cope with the mentioned problems. A solution is given by progress and recent developments in communication and information technologies (e.g. RFID and sensor networks). These new technologies can be used to enable non-living-items to change their decision-rules and therefore to learn [Spe06]. Based on the learning ability they can act autonomously to a certain degree and render own decisions without the need to consult another entity on a superior level

[Kap92]. Therewith, the “Smart-Parts” can be seen as co-evolving and interacting agents, rendering own decisions, and the system can be described as CALS.

2.2 The need for Robustness in ”Smart-Parts” CALS

Due to an increasing amount of inter-relations between the systems’ elements, described as “Smart-Parts”, as well as between the system and its environment [Pat82], this intensification of interaction leads to an increase of the systems complexity. Furthermore, more elements (“Smart-Parts”) in logistic systems can change the systems’ states, causing an increase of dynamics [Con98]. In this term, dynamics describes the rate of modification of a system over a specific time [Coy77] with a dependency of the system’s state from its elements [Kri98]. Higher dynamics leads to an increasing amount of information about the system’s environment as well as to an increasing change rate within the information the logistic management is confronted with [Hül04]. According to Ansoff [Ans84], the success and survivability of a system depends on its ability to reach and maintain a strategic fit between on the one hand the organization’s positioning and competence-profiles and on the other hand its environmental requirements. This strategic fit is necessary for the efficient usage of resources, in terms of avoiding frictions in the internal processes [Sch87]. Hence, organizations have to absorb and process information from and about their environments to avoid a so called “information overload” [Hül07]. Based on this lack of information or lack of information processing capacity, an inability to fulfill the organization’s functions can occur [Sch03], because important information about logistic tasks is missing or cannot be processed adequately. Therefore it is essential for an organization to find the balance between absorbing the increasing amount of information and keeping the amount of information that has to be processed at a manageable level [Hül08a]. The absorption of relevant and important information leads to the possibility of reacting to environmental changes and therefore to the organization’s flexibility, whereas the second part assures the organization’s stability by avoiding the information overflow [Luh94]. This ability to balance the flexibility and stability of an organization is called adaptivity [Hül08a], which is on the one hand needed to absorb enough information to avoid an undersupply and on the other hand important to impede the inflow of too much information. In addition, a system can be called robust, if the system itself and its including “Smart-Parts” are able to adapt to complexity and dynamics [Mee07] by balancing the systems’ flexibility and stability itself without any intervention. Moreover the system’s robustness is a requirement to resist against influences (e.g. information overload), which endanger the fulfillment of logistic tasks (e.g. ensuring the material flow with regard to the time, quality and place). Furthermore, the robustness of CALS can be seen as the ability to restore itself after being damaged [Wyc08].

3. Implementation of Complex Adaptive Logistics Systems

3.1 The Concept of Autonomous Co-operation

As shown above, CALS including their processes are more and more characterized by an increasing complexity due to lots of part variants and a tremendous number of possible combinations and variations [HÜL07a]. That is caused by today's customers who expect shorter delivery times with a higher reliability, a global availability of desired goods and a broader variety of products and services [HÜL07a]. A high robustness of logistic systems as the balance between system's stability and flexibility [Mck08] is desirable to cope with the complexity, to offer a feasible management of logistic systems and to assure the system's ability to fulfil its logistic tasks [Sch03, Hül08a]. Therefore, a concept is needed to create higher robustness for handling the tensions of an increasing complexity [Wyc08]. One possible approach is using of the concept of Autonomous Co-operation for managing CALS' "Smart-Parts" in an appropriate and successful manner [HÜL07a]. Windt and Hülsmann defined Autonomous Co-operation 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 [and Co-operation] is the achievement of increased robustness and positive emergence of the total system due to distributed and flexible coping with dynamics and complexity."* [Hül07a].

According to this definition the main characteristics of Autonomous Co-operation are decentralized decision-making, autonomy, interaction, heterarchy, and non-determinism.

Decentralized decision-making means that the entities ("Smart-Parts") of a system are capable to make their own decisions about their actions based on the available information to them [Hül08a]. They are also able to reflect the reactions of other entities regarding their decisions and to adapt their own behaviour [Kap92]. Accordingly, these entities act **autonomously** and moreover, they establish **interaction** with other entities ("Smart-Parts") to receive relevant information [Sur05]. But the autonomous behaviour and the interaction presume a suitable information supply to guarantee an efficient decision-making [Hül07a]. Information supply and coordination in common logistic systems (e.g. central planning) is usually done by a superior entity, which initiates communication, coordination etc. whereas entities in CALS act autonomously. In autonomously controlled systems the need for a **heterarchical structure** arises [Gol02] to enable entities to share information and interaction [Bös07]. Then if the system structure is homogeneous, all entities would be aiming for the same goals and the information flow would be constrained after achievement of objectives. As a result, the elements are on the one hand independent from any kind of control entity [Hül07a], but on the other hand the interdependencies within the systems are significantly higher. In conjunction with the autonomy of the system's entities, the predictability of the over-

all system's behaviour is nearly impossible [Bös07]. And even if all relevant data is available to measure the current system state (which is unlikely due to the common size of logistic systems), the behaviour would still remain unpredictable because the combination of the relevant data with all decision alternatives makes the problem unmanageable again [Fla98]. This aspect is known as **non-determinism** [Bös07].
All the mentioned characteristics can be transferred either to a single "Smart-Part" or to a system of "Smart-Parts" whereas each "Smart-Part" or system of "Smart-Parts" have to have these characteristics as a requirement to apply the concept of Autonomous Co-operation. Therewith, the appliance of "Smart-Parts" is one vehicle to realize the concept of Autonomous Co-operation and they can be seen as a pre-condition. The more "Smart-Parts" are implemented, the more the characteristics of Autonomous Co-operation can be achieved and vice versa.

3.2 Achieving Autonomous Co-operation by "Smart-Parts"

An implementation of Autonomous Co-operation in logistic systems can be realized through the appliance of new information and communication technologies. RFID-chips or sensor networks are some examples, which enable entities in a logistic system ("Smart-Parts") not only to communicate with each other, but as well with their environment [Hül07a]. Such entities may decide autonomously based on available information. Implementing these technologies also represents the other characteristics. Beside the decentralized and autonomous decision-making, entities can interact, a heterarchical structure is created and finally, the system's behaviour becomes unpredictable [Hül08a].
However, even if all of the mentioned characteristics seem to apply, there will be no logistic systems which meet all of them to 100 percent, yet. The appliance of the concept of Autonomous Co-operation and the degree of Autonomous Co-operation always has to be regarded as a continuum between total external controls on the one hand and total Autonomous Co-operation on the other hand. To which extent the specific characteristics are matched has to be evaluated case by case. Therewith, the measuring problem of Autonomous Co-operation emerges [Hül06]. The more complex and dynamic the system is, the more difficult is the measurement of the degree of Autonomous Co-operation. It has to reflect the interactions on the level of sub-systems, like manufacturers, suppliers and distributive trades, as well as interactions on the level of single elements within those sub-systems, like trucks, ships, planes, containers and single goods. The next section evaluates the effects of autonomous cooperating "Smart-Parts" on the robustness of CALS.

4. Contributions and Limitations of Autonomous Co-operation to the Robustness of Complex Adaptive Logistics Systems

According to the explanations above, it can be summarized, that a system's adaptivity, resulting from its stability as well as from its flexibility, leads to the robustness, which is a requirement for the system's success and its ability to handle logistic tasks. Moreover it can be assumed that the characteristics of Autonomous Co-operation influence the robustness of CALS because the flexibility as well as the stability depend on the "Smart-Parts" behavior and decision-making process. To prove this assumption and detect the specific effects, the characteristics of the Autonomous Co-operation have to be analyzed regarding to their contributions and limitations to the flexibility and stability of a logistic system. Since the characteristics of autonomously cooperating systems depend from each other, every specific characteristic with its own effects should be analyzed regarding the others. The following figure illustrates the interdependencies between the characteristics and a system's adaptivity:

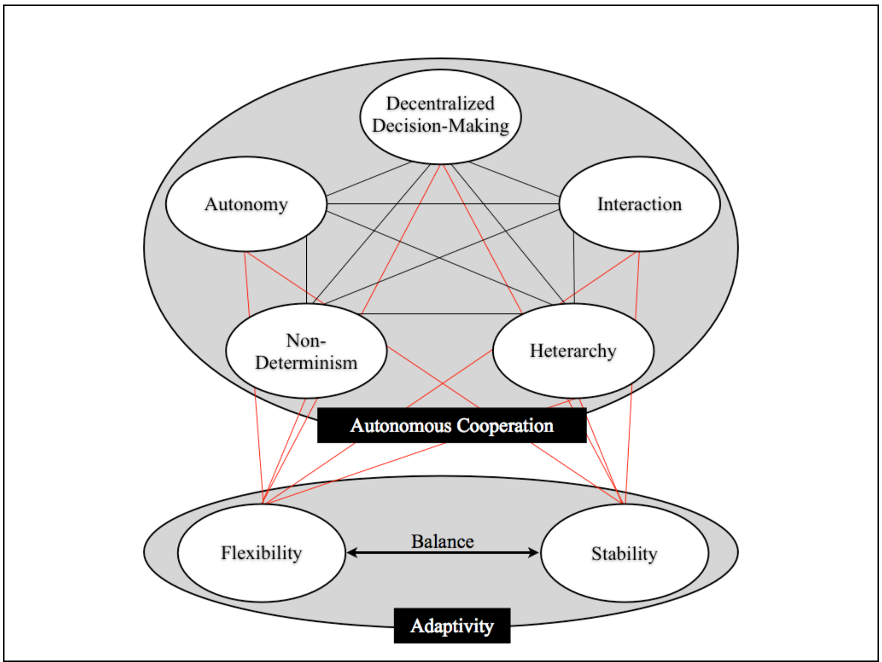

Figure 1: Characteristics of Autonomous Co-operation and their Interdependencies and Effects on Adaptivity

Figure 1 shows the characteristics of Autonomous Co-operation (Decentralized Decision-Making, Autonomy, Interaction, Non-Determinism, Heterarchy) as well as the adaptivity and the interrelations between on the one hand the several characteristics (connections illustrated by black lines) and on the other hand the Autonomous Co-operation and adaptivity (connections illustrated by red lines). Thereby, it points out the requirement of balancing the system's flexibility as well as its stability to achieve the adaptivity which is illustrated as equilibrium between them. By striving for the optimal balance between flexibility and stability higher system adaptivity and therewith a higher robustness might be provided. Moreover, it is shown that there is a high number of interrelations between the characteristics of Autonomous Co-operation and the stability and flexibility. This emphasizes the high amount of possible effects on robustness, resulting from the implementation of Autonomous Co-operation in CALS. Nevertheless logistic systems will never meet the characteristics of living systems to 100 percent because of the existence of human elements managing parts of it. Hence, a "Smart-Part" element of the system usually does not interact with the others to a degree of 100 percent [Wyc08]. Therewith, the degree of the system to act autonomously depends on the degree of interaction. If a single "Smart-Part" changes its behavior, the change of other elements' behavior is caused automatically. Thus, the existing problem of measuring individual degrees of Autonomous Co-operation of the "Smart-Parts" [Hül06] leads to the related problem of measuring the number of relations, which means that the adaptivity of a system is not easy to identify without knowing the exact relations between the characteristics. For the following research the effects are differentiated by their influence to increase or decrease the system's stability and to increase or decrease the system's flexibility. Between those two extremes, a negative trade-off can be assumed: less flexibility induces more stability and vice versa. That means an optimization of both stability and flexibility is always an optimization of the balance between them and not an isolated optimization of both, which is impossible, because of their **contradictionary** characteristics.

Influence of Autonomous Co-operation on increasing System's Stability

Since "Smart-Parts" in CALS act autonomously without be controlled by a higher entity, the complexity the whole system is confronted with is distributed to its several elements, because it has to be absorbed by every single element. In consequence, that leads to a release of the supervising entity [Hül08a], by **the distribution of complexity**. Moreover, the whole system's capacity to process information increases by the ability of the "Smart-Parts" to render their own decisions [Hül07]. That means that the threat of an information-overload decreases by the **increase of the system's information processing capacity**. Because of the direct interaction of the "Smart-Parts", they are able to provide each other with relevant and target-oriented information [Hül07], reducing the **amount of information-flow** to get the same information standard. In addition, these effects might be able to stabilize the system by supporting the handling of incoming information, and thereby leading to an increase of the system's robustness.

Influence of Autonomous Co-operation on decreasing System's Stability

For a high degree of interaction between the "Smart-Parts", an intensification of the interrelations is needed to create a more standardized and robust communication basis and enable the "Smart-Parts" to interact more efficient. Therewith, more complexity has to be absorbed, since a higher amount of information has to be processed. This leads in fact to an increase of the system's inherent complexity by the **additional complexity**. Moreover, an increase of the system's inherent dynamics can occur by the increase of its complexity [Con98], caused by shorter decision-periods whereas the amount of information remains the same. This leads for example to an increasing amount of information about the environment, which is constantly changed by the **additional dynamics**. Furthermore, the interaction between the "Smart-Parts" leads to local bases of information, which are needed to make own decisions and reach the system's global optimum [Sur05]. Therefore, information about the system's optimum must be allocated to the elements by their interaction. Nonetheless, if the elements have the relevant information about the global optimum, it can although differ from the local optimum, if the elements decide not to go for it. This results from the fact, that one element does not know how the others will act, which leads to a significant relevance of expectations about the other elements' actions for the own decision-making process [Pou93]. Therefore, it is possible, that the elements do not try to reach the goals of the whole system, which leads to the **risk of global inconsistencies of decisions**. Another effect results from the non-determinism of the autonomously controlled systems. Due to the **Non-Predictability** of the system's future states and the missing of an external control entity, no one can monitor the "Smart-Parts" and detect critical incidents regarding their behavior or decision-making. Because a control entity is not required, the autonomously adaption of the "Smart-Parts'" behavior to environmental changes causes a decrease of the system's stability. In addition, the first two effects result from an increasing amount of information, while the last two result from a decreased information processing capability. So the Autonomous Co-operation can destabilize the system by decreasing the system's ability to keep information inflow at a manageable level and thereby decreasing the system's robustness.

Influence of Autonomous Co-operation on increasing System's Flexibility

Owing to the system's non-determinism the concept of Autonomous Co-operation enables the system to react flexible to environmental changes as well as to become capable and possess the right to develop its own paths. It is not determined to a certain future system state. The "Smart-Parts" in such a system are flexible in decision-making, since they do not have to consult a higher entity to render a decision, what finally leads to an **increase of the system's flexibility in decision making**. The elements heterogeneity is an important requirement for Autonomous Co-operation, because the individual decision-making process leads to a certain variance of decisions and therewith of their behavior. If too much elements would render the same decision, this could in turn lead to a damage of the system's reliability because of inefficiencies based on redundancies and a worse information flow caused by a decrease of interaction. So the decentralized decision making contributes to the heterogeneity of the system's "Smart-Parts" [Wyc08] and therewith act as **Assurance of sufficient heterogeneity**. In addition these effects increase the system's flexibility and lead in fact to a higher robustness.

Influence of Autonomous Co-operation on decreasing System's Flexibility

Especially in autonomous cooperating systems, where some of the "Smart-Parts" are human beings, the problem of **longer decision making times** can occur. As every single unit has to decide upon its goals and how to reach them, a longer decision-making process is the consequence, compared to the decision-making of a higher entity where the decisions are made at a central planning unit. So it can be outlined that on the one hand the Autonomous Co-operation can lead to a higher information processing capacity, whereas on the other hand this process can be decelerated by the Autonomous Co-operation. In consequence, this might reduce the system's ability to react on environmental changes and thereby decreases its flexibility, what finally leads to a decrease of the system's robustness.

In addition, it can be summarized that several effects, resulting from the concept of Autonomous Co-operation, influence the stability and flexibility and thereby the adaptivity and robustness of CALS. Nevertheless, the specific effect on the adaptivity cannot be described, because it depends on the balance between stability and flexibility in the current case and thereby on the current degree of system's stability and flexibility. Therefore, the adaptivity has to be evaluated in every specific scenario. On the one hand the stability can be increased by a distribution of complexity on several "Smart-Parts", an increase of the system's information processing capacity and a lower amount of information flow. On the other hand the stability can be decreased by additional complexity and dynamics, by a higher amount of elements, the risk of global inconsistencies by different goals and the non-predictability of the system's future states. Moreover, an increase of the system's flexibility is given by the system's flexibility in decision making and the assurance of sufficient heterogeneity. Finally a decrease of the flexibility can occur by a possible deceleration of information capacity. Furthermore the outlined effects show the possible effects of increasing and decreasing the system's stability and flexibility, by the implementation of Autonomous Co-operation. Due to that, it points out possible activities to reach equilibrium between the stability and flexibility as well as keep the stability and flexibility in balance. The effects are summarized in Table 1.

	Stability	Flexibility
+	• Distribution of complexity • Increase of the system's information processing capacity • Lower amount of information flow	• Increase of the system's flexibility in decision making • Assurance of sufficient heterogeneity
-	• Additional complexity • Additional dynamics • Risk of global decision inconsistence • Non-Predictability	• Possible deceleration of information processing (esp. for systems with human beings)

Table 1: Effects of Autonomous Co-operation on a system's adaptivity

5. Conclusion

The overarching intention of this paper is to illustrate that robustness could be increased by using Smart Parts for implementing organization principles of Autonomous co-operation. The robustness provides a logistic system with the essential capability for an optimal and successful handling of its logistic tasks. Hence, an evaluation of several effects of Smart-Parts to Autonomous Co-operation and finally on the robustness of CALS is accomplished by investigating the effects of the specific characteristics of Autonomous Co-operation towards the relation between flexibility and stability. As the main result several possible effects of the characteristics of Autonomous Co-operation on the increase as well as on the decrease of the system's stability and flexibility and therewith on its robustness were outlined. It was illustrated, that an optimization of the balance between stability and flexibility should be aimed for to achieve an optimal degree of Autonomous Co-operation associated with an optimal adaptivity. Furthermore the existence of interrelations and the occurrence of effects caused by the characteristics of Autonomous Co-operation towards the adaptivity of logistic systems were demonstrated. However, the interdependencies of the Autonomous Co-operation characteristics as well as the not measureable degree of "Smart-Parts" interaction and unpredictable future system states lead to the impossibility of deriving an approach for the successful balancing of stability and flexibility in CALS. In addition, the explicit identification and measurement of the characteristics of Autonomous Co-operation as well as of the indicators stability and flexibility in common logistic scenarios is not quite easy, caused by the difficulties of determining an appropriate scaling. Because of these limitations, further research to develop an adequate measurement instrument should be performed. Moreover, relevant indicators should be defined to facilitate the process of identifying the characteristics of Autonomous Co-operation in CALS and the other mentioned values. This specific measurement results and the indicators could then be used to develop an efficient approach and to deviate general strategies for increasing the robustness of autonomous controlled CALS. For logistic systems practice an equilibrium between stability and flexibility should be aimed for, and the main focus should lie on the exploitation of effects that increase the system's flexibility and stability combined with a simultaneously avoidance of effects that decrease its flexibility and stability.

The main result of this research is a theoretical framework to deduce practical recommendations which are applicable to logistic systems, whereas the possible consequences have to be evaluated critically from case to case. In order to further enhance the findings the next step should be the development of a measurement model to investigate and evaluate the interrelations between the relevant characteristics (Autonomous Co-operation, flexibility, stability etc.).

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