ECOLOGICAL IMPACTS OF AUTONOMOUSLY CO-OPERATING TECHNOLOGIES IN INTERNATIONAL SUPPLY NETWORKS

– A MODEL FOR ANALYZING CO2-EFFECTS BY IMPLEMENTING INTELLIGENT CONTAINERS IN FRUIT LOGISTICS

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Acknowledgement

This research was supported by the German Research Foundation (DFG) as part of the Collaborative Research Centre 637 "Autonomous Cooperating Logistic Processes - A Paradigm Shift and its Limitations".

INTRODUCTION

Corresponding to an increasing awareness of global warming the concept of Green Logistics gains more and more relevance for Logistics Service Providers (LSP) (New 2004). Furthermore, cool chain logistics, especially for fresh fruit needs careful planning in order to avoid unnecessary CO_2 emissions. These accelerating environmental requirements add to the existing wide spectrum of "traditional" challenges (e.g. due time reliability, demanded decrease of total production time and costs) in International Supply Networks (ISN) (Klaus & Kille 2006) that confronts LSP with a highly complex and diversified set of requirements also concerning the field of fruit logistics.

Modern smart technologies (e.g. RFID) might promise an approach to deal with this additional complexity. Those technologies enable a decentralized information acquisition, processing, and decision-making, which is based on the idea of Autonomous Cooperation (AC) (Hülsmann & Windt 2007). One example for applying the idea of AC to logistics is the prospective implementation of a so-called "Intelligent Container" (IC) in fruit logistics (Jedermann & Lang 2009). Due to the smart features of an IC a respective ISN consisting of a large amount of heterogeneous and interacting ICs might exhibit the same characteristics and outcomes as a Complex Adaptive System. Therefore, from a complexity science-based perspective, such an ISN can be regarded as a "Complex Adaptive Logistics System" (CALS). CALS comprise heterogeneous agents that are autonomous, interactive, and able to learn, which leads to self-organization co-evolution and emergence of the whole system (Wycisk, McKelvey & Hülsmann 2008). According to Hülsmann & Windt (2007) the smart features (e.g. self-controlling sensor networks) produce and process more goal-oriented information in a shorter time directly at the place of action than in a centralized logistics system (Hülsmann & Windt 2007). Hence, it is assumable that such-like characteristics and the resulting outcomes might have impacts on the ecological footprint of logistics systems. Consequently, the following question arises: How can the assumable effects, in terms of contributions and limitations of smart, autonomously co-operating technologies, on the ecological footprint of an ISN be verified?

Therefore, using the example of implementing the IC in fruit logistics networks, the paper's goal is to develop a structural equation model that reflects hypotheses about the existence of causal relationships between the visionary implementation of the IC in fruit logistics and its effects on the emission of CO_2. Therefore, the paper aims to provide a characterisation of ISN in fruit logistics as CALS in order to establish a theoretical framework for the model development. Furthermore, the paper intends to develop hypotheses about the existence of causal interrelations between a CALS, based on the smart features of an IC (e.g. the self-controlling sensor network), and the network's CO_2-emissions. These causal assumptions shall be integrated in a conceptual structural equation model that shall serve as a basis for further research and which will be discussed critically regarding its contributions and limitations.

The paper will be structured as followed: The second section will provide a description of the characteristics of the given case in fruit logistics. Additionally, the autonomously controlling and co-operating features of an IC will be presented. This also comprises a classification of IC using logistics systems as CALS. The third section is dedicated to identify variables and causal interrelations between the smart characteristics of an IC and CO_2-emissions as a theoretically profound basis for a further measurement of environmental effects. In the fourth section possible contributions and limitations of the developed model to verify assumed environmental impacts of the ICs-network will be discussed. In the fifth, the paper will conclude with the results and implications for future research.

REALISING THE VISION OF COMPLEX ADAPTIVE LOGISTICS SYSTEMS VIA INTELLIGENT CONTAINERS IN FRUIT LOGISTICS

The planning of the transportation of fresh fruit in the field of cool chain logistics tries to avoid unnecessary CO_2 emissions that are not only due to the length of the transport routes and the required energy for cooling but mainly due to the amount of waste. Depending on the type of fruit, up to 30% of the transported food products do not arrive at the final customer in proper quality state (Scheer 2006). Besides the direct financial loss, this is also an environmental problem. Moreover, all energy that has been spent for growing, cooling and transport is lost. In case of a fixed commitment, a replacement delivery has to be organised with a poor CO_2 footprint caused by low utilization of capacity or necessary air- instead of road- or sea transport. Hence, fresh fruits have a natural loss of quality or shelf life over time. The main causes for reduced shelf life or complete decay are temperature deviations from the recommended transport conditions. In order to deal with these challenges several models have been developed by food researchers, which calculate the amount of lost days of shelf life as a function of temperature deviations (e.g. Tisjkens & Polderdijk 1996). Therefore, the intelligent container (IC) (Jedermann & Lang 2007) was developed in order to implement these developed models by capturing temperature deviations as soon and as accurate as possible. Hereby, the IC provides a processing platform for software agents. These agents evaluate shelf life losses and recommend actions. Standard refrigerated containers only measure the temperature in two points, but the temperature of the supply or return air does not represent the core temperature of the loaded pallets. However, a single container cannot carry out the necessary actions. Compensation for reduced quality as a part of the cargo is only possible within the logistic network. The planning process has to involve external factors, as the state of other ICs and a prediction of demand. Therefore, the IC applies a network of wireless sensors to capture a spatial temperature profile. Thus, the temperature of each pallet is either directly measured or mathematically evaluated (Jedermann & Lang 2009).

By way of illustration: Bananas are shipped from overseas to Europe. The total loss during transportation is in the order of few percent, but because bananas make up the highest share of refrigerated sea transports (Wild 2005), it can be assumed that these losses have a large ecological impact. Bananas are transported in a green unripe state by ship with typical transport duration of two weeks. During the subsequent artificial ripening the Bananas gain their yellow colour. The fruits are exposed to a high ethylene concentration in special ripening chambers. Each ripening room can typically hold the capacity of a 40 feet container. This ripening takes between 4 and 8 days. Afterwards, the bananas are transported to distribution centres and retail stores and sold within maximum of 10 days.

Small deviations of the quality state at arrival in Europe can be compensated by modifying the artificial ripening. Furthermore, controlled ripening is only possible if the chamber is loaded with bananas of equal initial quality. A mixed load of “light” and “dark” green bananas will create a poor result. Typically the temperature has a deviation of 1 °C or 2 °C over the length of the container during sea transport, which is caused by an uneven distribution of the cooling air. In order to compensate the resulting quality deviations the content of different containers can be mixed. The big banana import companies have the necessary infrastructure at their disposal, as high bay warehouses with access to single pallets. However, the required information base is currently incomplete. The quality is only evaluated by random samples by manual temperature measurement at arrival. The link of temperature and quality information per pallet to the infrastructure could provide a means for further reduction of product losses due to inaccurate ripening. Furthermore, an anticipatory planning of warehouse and ripening processes is enabled by real-time access to temperature and quality data during the transport. Consequently, the internal sensor focuses on the internal physical status of the container by measuring the temperature, atmospheric humidity or pressure. These physical variables enable a prediction of the lasting-times of the carried fruits and a ranking of the Container that mirrors the priority of being transported (e.g. "first expires, first out"; cf. Jedermann & Lang 2009).

Consequently, the IC comprises the technical features for the measurement of its internal status. However, the communication with other ICs is still a vision and a goal-oriented implementation of an external sensor network has not been implemented yet. The introduction of such an external perspective could make it possible to realize the complexity science-oriented vision of Complex Adaptive Logistics Systems (CALS) as introduced by Wycisk, Mckelvey & Hülsmann (2008). CALS consist of autonomous adaptive and heterogeneous agents (e.g. the IC) with the ability to learn that lead to co-evolutionary, emerging, evolving and self-organizing systems (Wycisk, McKelvey & Hülsmann 2008).

Therefore, the vision of the IC is to communicate via modern technologies, such as wireless networks with other ICs and with warehouses receiving information about the demand of required goods. By sending and receiving information about its own and the status of the other ICs, the ICs are able to make a priority of their transported goods (First expires, first served). Furthermore, the communication with transportation companies provides the IC with all available transportation routes including e.g. the price or duration of the transportation and destinations that have to be delivered. By computing the information from the internal and external sensors the ICs become so-called 'Smart Parts' that are defined by McKelvey, Wycisk & Hülsmann (2009) as *"[…] logistics entities, which possess the capabilities of interaction and autonomous decision-making through the usage of modern communication and information technologies, such as RFID, GPS, sensor networks and electronic markets (Ems)."* Consequently, the communication within such a logistics network would take external factors such as the state of other ICs and a prediction of demand into account and would try to find a best way or most efficient solution through autonomous cooperation and a decentralized decision making process. It can be assumed that suchlike technologies (e.g. self-controlling sensor networks) produce and process more goal-oriented information directly at the place of action very shortly (Hülsmann & Windt 2007) and that the logistic system then becomes a Complex Adaptive Logistic System (CALS) (McKelvey, Wycisk & Hülsmann 2009).

Wycisk, McKelvey & Hülsmann (2008) identified the following typical characteristics and outcomes of a CALS on the basis of Kauffman (1993), Holland (2005) and Mainzer (1994) listed in Table 1 and fitted to the introduced vision of implementing the IC in a fruit logistics network.

CALS-characteristics		CALS-outcomes	
Heterogeneity	The ICs as Smart Parts can be distinguished by their different priority due to their different internal status.	Emergence	The behaviour of the whole network of the ICs is greater than the sum of its Smart Parts.
Ability to learn	The ICs as Smart Parts can modify their rules of action in order to improve their performance.	Adaptation	The behaviour of the whole network of the ICs adapts to changing conditions.
Interactivity	The ICs as Smart Parts can communicate with other Smart Parts that induces an adaptive reaction.	Non-linearity	The behaviour of the whole ICs-network is nonlinear due to unpredictable long-run effects.
Autonomy	The ICs as Smart Parts are responsible for their own direction and development.	Butterfly-effect	The behaviour of the whole ICs-network can depend on insignificant initial events.
Self-organization	The system arranges its own structure through its own capabilities and new patterns emerge that could not be predicted.	Scalability	The behaviour of the whole network of the ICs has a fractal structure.

Co-evolution	The system autonomously adapts to new environmental requirements to assure the systems´ survival that influences directly or indirectly the rest of the whole network.	Multi-levels	The behaviour of the whole network of the ICs results in structures in which an emergent whole at one level is a component of an emergent system at the next higher level.
Melting-zone	The system comprises a region between the edge of order and chaos.		

Table 1: Typical features of CALS fitted to the visionary scenario of implementing the IC into a fruit logistics network.

With recourse to the increasing relevance of environmental issues in logistics in general and in fruit logistics in special, the overarching question arises, if the implementation of such a technology can optimize or at least improve the environmental performance of a logistics network. Hence, on the basis of this complexity-theoretical framework, the question arises of how do these Smart Parts- and CALS-characteristics of a network consisting of ICs affect its emission of CO_2. Therefore, a model should be developed that reflects hypotheses about the existence of causal relationships between the visionary application of the IC and the ecological footprint in order establish a basis for getting first insights into the overarching question during further research. In order that an empirical analysis or simulation about these effects can be executed, causal relationship between these effects have to be assumed at first. For this reason, the following solution proposal will introduce a model approach that depicts the variables and outlines the existence of causal relationships in order to provide a basis on which these causal assumptions can be verified during further research.

A HYPOTHESIS-BASED STRUCTURAL EQUATION MODEL OF CO_2 EFFECTS OF CALS

The conceptual development of the hypotheses-based model comprises three steps: Firstly, causal relationships between the characteristics and the outcomes of CALS; secondly, causal relationships between the outcomes of CALS and their transportation effects and rate of rejection; finally, causal relationships between the transportation effects and/or rate of rejection and ecological effects.

It can be assumed that the expected CALS-characteristics of such autonomously cooperating ICs could take effects on the outcomes of CALS as Wycisk, McKelvey & Hülsmann (2008) imply. A possible explanation could refer e.g. to the heterogeneity of the agents within a system. The ICs can be distinguished by their different priority due to their different internal status (cf. Table 1). Furthermore, a different priority of an IC would lead to a different selection of possible warehouses and transportation routes. Therefore, due to all the differing priorities of the ICs (a CALS-characteristic) new structures (selection of transportation routes) would emerge and the structure of the system (CALS-outcome) would adapt to the – both internal and external – constraints. Therefore, it seems appropriate to hypothesize that characteristics of CALS listed in Table 1 would be connected with the outcomes of CALS in a causal manner. Furthermore, these emerging structures (e.g. the structures of the selected transportation routes) would be the same in the very rare cases. That is the reason why the accumulation of all the lengths of the routes would also not be the same. This leads to the possibility of assuming a causal relationship between the effects on the transportation efficiency and rejections rates and the ecological effects. Finally, CO_2 emissions are relatively straightforward to estimate, since they depend mainly on two factors (Wright 2008): The type and quantity of fuel burned, whereas the quantity basically depends on the length of the route and on the efficiency factor of the driving mechanism. At this juncture, the velocity, acceleration and transaction costs of sensor-networks could be neglected systematically (Wright 2008) but it can be hypothesized that the transportation effects (e.g. via a differing length of the routes) or rate of rejection (e.g. via a differing quantity of defective goods) have an impact on the emission of CO_2 because these effects would automatically have an impact on the type and quantity of the consumed fossil fuel. Due to the fact that the above-assumed causal effects make no claim to be complete the following Table 2 makes no claim to be complete either, by specifying the latent variables that cannot be directly observed and possible constitutive, indicating (measurable) variables as a first conceptual framework.

Latent variables	Exemplary constitutive, indicating variables
CALS-characteristics: 1. Heterogeneity 2. Autonomy …	- Number of heterogeneous ICs - Rate of external instructions - Number of interactions in one time-step - …
CALS-outcomes: 1. Emergence 2. Adaptation …	- Combinatorial transport routes - Duration of adaptation processes - Growth factor - …
Effects on transportation efficiency	- Length of the route - Cost of transport - Duration of transport - …
Effects on rejections rates	- Quantity of defective goods - Due date reliability - Transport capacity utilization - …
Ecological effects	- Emission of CO2

Table 2: Latent variables and their constitutive, indicating variables for the solution approach of the structural model

Based on Table 2, the following hypothesis for the causal relationships can be derived.

H_1: The characteristics of CALS are correlated through their indicating variables, e.g. a higher degree of heterogeneity, autonomy, etc. with the outcomes of CALS.

H_2: The outcomes of CALS are correlated through their indicating variables, e.g. an emergent structure with the effects on transportation efficiency and/or effects on rejection rates.

H_3: Effects on rejection rates are correlated through their indicating variables, e.g. the quantity of defected goods with the effects on transportation efficiency.

H_4: Effects on transportation efficiency are correlated through their indicating variables, e.g. the accumulated lengths of the routes with the ecological effects.

H_5: Effects on rejection rates are correlated through their indicating variables, e.g. quantity of defective goods with the ecological effects.

Up to now, a model that sets up and checks these assumed relationships between a network of autonomous cooperating ICs leading to the characteristics of CALS and the ecological footprint does not exist. Therefore, it is the idea to use the structural equation modelling as the methodology for the solution proposal, because it intends to test and estimate causal relationships by using a combination of statistical data and qualitative causal assumptions (Pearl 2000). Hereby, the structural model indicates potential causal relationships between latent variables and their indicators. Latent variables cannot be directly observed and measured. Furthermore, it is possible to observe several causal relationships between different variables simultaneously. In this case, latent variables are e.g. the above-mentioned characteristics and outcomes of CALS that are constitutively defined through their indicating variables, e.g. heterogeneity, self-organization, interactivity or emergence, non-linearity and scalability (cf. Table 1).

In this connection, two types of variables have to be distinguished: an independent and a dependent variable. Hereby, a dependent variable regresses on - or is being predicted by

- the independent variable. The terminology of structural equation modelling states that a variable, which is regressing on another variable, is always an endogenous variable and it can also be used as an exogenous variable to be regressed on. While endogenous variables are graphically represented as the receivers of an arrowhead, exogenous variables are graphically represented as a sender of an arrowhead, indicating which variable it is explaining or predicting (Schumacker & Lomax 2004). According to Backhaus (2005) the structural equation modelling approach for analyzing CO_2-effects by implementing the IC in fruit logistics is shown schematically in Figure 1 that reflects the assumed causal relationships of the hypotheses H_1 – H_5.

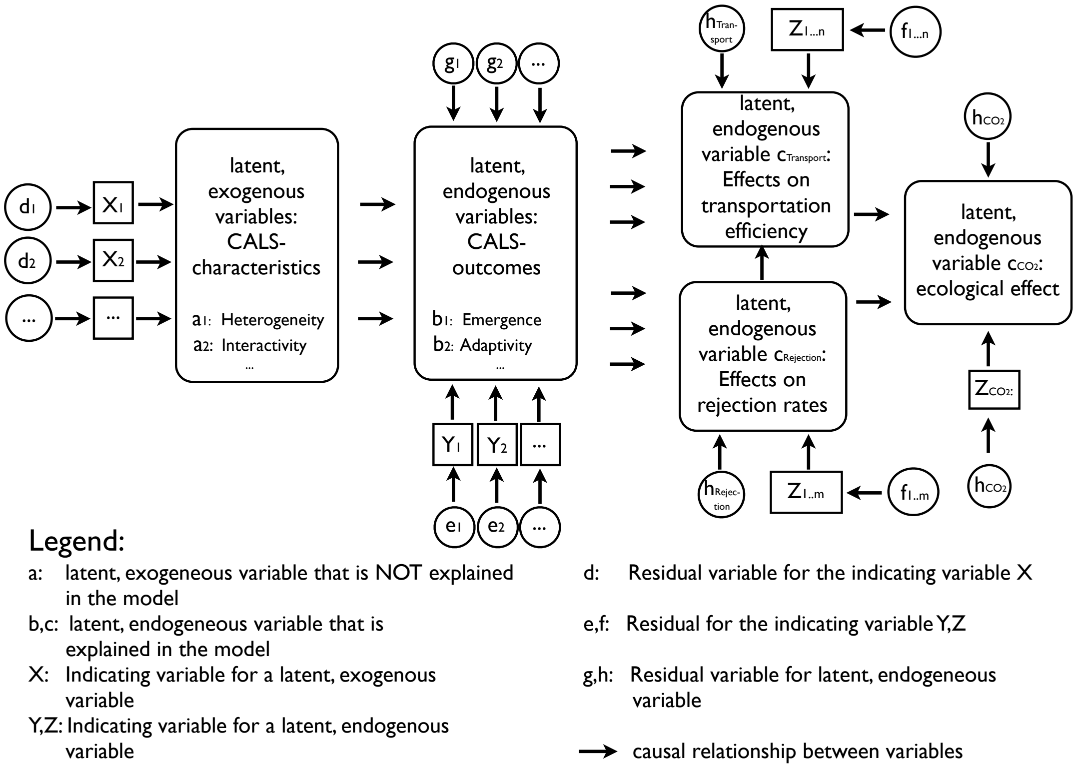

Fig. 1: Schematically representation of the Structural equation modelling approach for analyzing CO_2-effects by implementing the IC in fruit logistics

Therefore, the structural equation model contains the qualitative causal hypotheses between the smart characteristics of the network of the IC and CO_2-emissions at the end. The latent (independent), exogenous variables of the CALS-characteristics are not explained within the model and just indicated by their constituting variables (e.g. X_1 = number of heterogeneous ICs, cf. Table 1). Considering Figure 1 the constitutive indicating variables *Y* and *Z* for the latent (dependent), endogenous variables (CALS-outcomes, effects on transportation efficiency, effects on rejection rate and ecological effects) are the ones from Table 1. Finally, all the indicating variables *X, Y* and *Z* have to be operationalised and measured in further research for testing the assumed statistical correlations. At this point, Figure 1 also shows the residual variables *d*, *e*, *f*, *g* and *h* that represents other affecting influences due to noise, inaccuracies during the measurement and so on. In summary, the proposed hypotheses-based structural equation model comprises the assumed causal relationships and its structural model functions as the basis for measuring statistical data in further research. Conclusively, a structural equation model enables the verification of assumed interdependencies between several latent variables but the question arises about the contributions and limitations of this approach.

CONTRIBUTIONS AND LIMITATIONS OF THE PROPOSED HYPOTHESES-BASED STRUCTURAL EQUATION MODEL

On the one hand, some critical reflections on the weaknesses of the structural equation modelling approach in general shall be given. Herrmann, Huber & Kressmann (2006) mention the tendency to cursorily consider the relationship between the construct and its indicator. Furthermore, the use of reflective instead of formative variables could lead to a false conceptualisation or operationalisation. Additionally, the model needs a modification in order to improve the fit, though estimating the most likely causal dependencies between the variables. Hence, it is important that these modifications also make theoretical sense. Therefore, the term "causal model" must be understood carefully in the meaning of a model, which conveys "causal assumptions" (Hermann, Huber & Kressmann 2006).

On the other side, specific aspects of the given case have also to be considered. Because of the fact that the CALS-characteristics and outcomes depend on each other and that they can hardly be considered separately, current research on Complex Adaptive Systems lacks the quantified analysis of these phenomena (McKelvey, Wycisk & Hülsmann 2009). Furthermore, it has to be carefully deliberated, if all of the outcomes or only a selection (e.g. adaptivity and emergence) shall be directly implemented into the model because the most influential causal driver on the emission of CO_2 are not known at this point. Therefore, further research has to elaborate the characteristics and outcomes of these variables, e.g. the accuracy of the measured physical entities through internal sensors, the type, quality and quantity of information exchanged by the external sensor with the total or with parts of the sensor network, the mathematically evaluated priority of the transported goods and other programs for computing the other status and predicted demands and their degree of smartness or selfishness. Additionally, the characteristics and outcomes of CALS (e.g. self-organization) clearly lack a theoretical explanation in the sense of predicting the outcomes by knowing all underlying variables. Because of the high interconnectedness and its resulting complexity, it is nearly impossible to measure and calculate all information. Consequently, the model could only verify the assumed causal relations without giving a specific explanation about the underlying causal interconnectedness between the variables of Table 2. Finally, a fundamental collection of data and an empirical validation through the analysis of covariance in the measurement model is missing. Consequently, a verification and validation of the structural equation modeling for analyzing the CO2 effects by implementing the IC in fruit logistics is missing and the stability of the concept has not been proofed.

Nevertheless, the main contributions towards the proposed hypothesis-based structural equation model are manifold: Firstly, the structural model assumes the existence of potential causal relationships between latent variables and their indicators; secondly, the structural equation model would make it inherently possible to verify the existence and to identify directions of action of these causal assumptions between the visionary implementation of the IC and the emission of CO_2; thirdly, it could imply possible actions for realising positive ecological impacts; fourthly, these assumed causal relationships could enable a more detailed empirical analysis or simulation in further research; finally, the model could be extended or adjusted at any time by adding more causal relationships.

CONCLUSIONS

This paper intended to conceptually develop a model that is able to reflect variables and the existence of causal relations between the network of ICs as a CALS and the CO_2-emissions. The main contributions towards the described solution approach are the verifiable compilation of causal assumptions by considering the complexity of today's International Supply Networks in order to realise positive ecological impacts. Further research should focus on the remaining limitations to understand the underlying dependencies and improve the model regarding the desired goals by quantifying the characteristics of CALS. In contrast, the measurement of transportation and stocking effects in Table 1 are much easier to detect. However, since the exact relations of implementing the IC into a large fruit logistics network are currently unknown (strategic benefits e.g. in form of system flexibility and adaptivity), the information processing calculation within the IC has to be thoughtful constructed and implemented, since different target functions are possible, e.g. the efficiency or the robustness that all indirectly influence the ecological impacts.

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