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Reducing food losses and carbon emission by using autonomous control – A simulation study of the intelligent container

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ABSTRACT

During the past decades bananas were imported to Europe in reefer vessels. Often, these vessels returned to Central America empty. This resulted in high carbon emissions and high costs. Therefore, importers switched to reefer containers which are shipped to Europe by liner cargo services. However, the amount of spoiled bananas increased with that change. Now a research project has developed the so called "Intelligent Container". This Intelligent Container is able to calculate the green life of its cargo and this leads to the feasibility of quality driven distribution. Thus, the losses of bananas should be decreased and both transport costs and carbon emissions be reduced even further.

In this article we focus on the reduction of the food losses and the carbon emissions. To find the level of the reduction we conducted a computational simulation study. We used an existing distribution network and assumed that all shipped containers were "intelligent". Following the idea of the "Internet of Things" and "Autonomous Logistics" we developed an algorithm which enabled each container to make its own decisions, e.g. which route to take and to which customer it should be transported. The article describes this approach and the results of the simulation study.

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1. Introduction

In the introduction we describe the state of the art and the latest research results of sustainability in food supply chains and then describe logistics processes in general and distribution processes for perishable goods in particular. This chapter closes with the presentation of the Intelligent Container and the considered use case of transportation of bananas from Central America to Europe.

1.1. Sustainability in food logistics

Sustainability in food logistics depends on several factors: efficiency of logistics networks, wasted produce during transport, efficiency of refrigeration equipment, etc. Globalized logistics networks using container ships are in general organized in a sustainable way. Taking into account that worldwide material flows are not evenly spread, empty containers have to be transported. Bretzke (2011) states that strategic decisions are typical examples of a company's responsibility, e.g. configuration of a distribution network. In contrast, companies neglect responsibility aspects of operational processes such as transportation of goods. The transport sector was responsible for 22% of global CO_2 emissions in 2011 (IEA, 2013).

Nearly one third of all the food produced in the world is wasted. There are several reasons why food is wasted, and one reason can be found in the distribution of goods (Gustavsson et al., 2011). The world's population is still growing, and so sustainable systems for producing food are necessary. The European Commission defined sustainability as economic growth, social cohesion and environmental protection (Commissions of the European Communities, 2001). In the past companies concentrated on economic growth, but today social cohesion and environmental protection are becoming more and more important. Furthermore, in the European Union a law has been passed mandating food traceability from the producer to the customer (European Parliament and the Council of the European Union, 2002). Wognum et al. (2011) state that food chains need to become more transparent to regain consumers trust. RFID technology can make a contribution to achieve this aim. These systems can be used to enhance not only quality but also social aspects of sustainability in food supply chains.

Another aspect in improving sustainability in food supply chains is the optimization of transport of refrigerated food. Refrigeration stops or reduces microbiological, physiological, and physical changes of food in postharvest processes. James and James (2010) analyzed the food cold-chain and the effects on climate change. On the one hand carbon emissions of food are extremely high if produced and transported food is not utilized (James and James, 2010). Quite apart from the disposal of food by the customer, failures in the distribution processes such as transportation or

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storage can lead to wasted food. On the other hand, emission reductions can be easily achieved by correctly using and maintaining energy-efficient refrigeration (International Institute of Refrigeration (IIR), 2003).

1.2. Distribution of perishable goods

In a globalized world logistics processes play a major role since goods are transported around the world. In a supply chain four different types of logistics processes take place from the producer to the customer: procurement (inbound) logistics, production logistics, distribution (outbound) logistics and reverse logistics. Summarized, all these processes include transportation, storage and handling of goods. Fig. 1 illustrates these logistics processes in a supply chain.

Production logistics include all transport and storage processes within a company that add value in production. Typical goods are raw materials, auxiliary materials, operating materials, purchased items, semi-finished and finished products or spare parts. All inbound logistics processes are combined to procurement logistics. Procurement logistics typically comprises all materials transported in production logistics. Semi-finished and finished products, merchandise and spare parts are goods that are transported and stored in distribution logistics. Reverse logistics comprises residues (secondary raw materials and waste) such as used and worn products, rebuilt units, returns, empties and packaging (Pfohl, 2010).

Hub and spoke networks have been established for transporting containerized perishable goods (Vahrenkamp, 2007). In these hub and spoke networks there are three stages of transportation: preliminary leg, main leg, and subsequent leg. In the case of the transportation of bananas from Central America to Europe, the main leg is carried out on huge container ships that can transport thousands of containers. On the preliminary leg the containers and goods are transported to the port of loading. The containers are stored at the port of loading for a short time before they are loaded on the container ship. On arrival at the port of destination, the containers are transported to the customers on the subsequent leg. In the same way as on the preliminary leg, these transports can be carried out by road, rail, or feeder ships. The supply chain in a hub and spoke network is shown in Fig. 2.

The analysis of managing food supply chains is divided into distribution network design (long-term), distribution network planning (mid-term), and transportation planning (short-term) (Akkerman et al., 2010). Quality driven modeling and simulation approaches for optimizing the food supply chain have been described for mid-term (Rong et al., 2011; Dabbene et al., 2008; Rijgersberg et al., 2010) and short-term optimization (Chen et al., 2009; Osvald and Stirn, 2008; Hsu et al., 2007). Rong et al. (2011) investigated in a simulation study a generic modeling approach for food production and distribution planning by modeling the quality change of products along the supply chain. Dabbene et al. (2008) presented a novel approach for the optimization of fresh food supply chains combining logistics costs and indices measuring the quality of the food. Another quality modeling approach was conducted by Rijgersberg et al. (2010). By using quantitative microbial risk assessment (QMRA), the food safety in the food chain is modeled and simulated and the impacts on logistics processes were determined. For short-term optimization Chen et al. (2009) developed a simulation framework combining production scheduling, vehicle routing and time windows for perishable foods focusing on the maximum profit for the supplier. Osvald and Stirn (2008) developed an algorithm to calculate the quality of perishable foods using a linear relationship between quality and transportation time. Hsu et al. (2007) explored vehicle routing problems using a stochastic approach to enhance effective delivery decisions under time-varying temperatures and time-dependent travel. In summary, all these approaches use offline information to optimize the distribution processes of food supply chains. To provide online information and thus quality driven distribution of perishable goods, a new approach is necessary.

The distribution of perishable goods is effected by temperature controlling for storage and transportation. Within this temperature controlled network reefer container and reefer trailers can be used for transportation. Inside these reefer containers, a product specific temperature is set so the transported perishables will reach a maximum shelf life based on a defined quality. For distribution several warehouse management methods are used. Common methods are FIFO (First In First Out), LIFO (Last In First Out) and SIRO (Sequence In Random Out). Specialized warehouse management methods have been developed for distribution of perishables: FEFO (First Expires First Out), LQFO (Lowest Quality First Out), LEFO (Latest Expiry First Out) and, HQFO (Highest Quality First Out). Dada and Thiesse (2008) analyzed these methods in respect of selling perishable goods by the use of a simulation study. In this study LQFO achieved the highest rate of sold products and thus the minimum rate of wasted products. To use LQFO the quality has to be determined in quality checks. FEFO achieved the second best selling rate (Dada and Thiesse, 2008). The Intelligent Container can calculate the actual quality of the transported goods and provide this information online in order to match the goods to a customer order while the container is still being shipped. To supplement FEFO and the use of information from the Intelligent Container a new warehouse management method called “dynamic FEFO” has been developed (Jedermann, 2009). Additionally, Lütjen et al. (2013) developed a new scheduling method for quality driven distribution of Intelligent Containers based on a central optimization approach. In summary it can be stated that no approach of decentralized control for Intelligent Containers or food supply chains exists which can be used for the

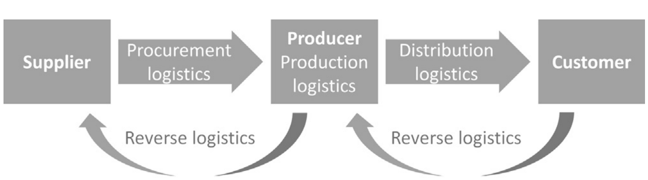

Fig. 1. General supply chain.
(Source: own figure)

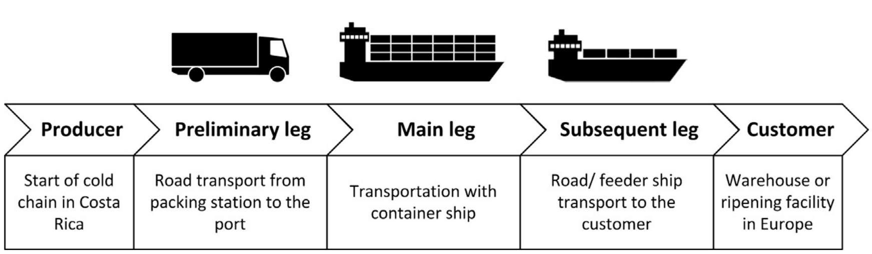

Fig. 2. Distribution of perishable goods.
(Source: own figure)

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