Towards Quality Driven Distribution of Intelligent Containers in Cold Chain Logistics Networks

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Summary: The 'Intelligent Container' represents a novel transport system with the ability to autonomous decision-making regarding to the condition of its transported goods. For example, fruits in cold chain logistics networks are very sensitive to mould and tend to perish. This can cause huge losses during transport, because the state-of-the-art reefer containers are only able to control the temperature but not in relation to the fruit condition. The 'Intelligent Container' is able to monitor the condition of fruits precisely as well as to track its geographical position. Thereby, the transport losses can be reduced due to better climate control and enhanced distribution strategies. This paper focuses on the development of a new scheduling method for distribution by applying principles of quality-driven customer order decoupling corridors (qCODC). Such corridors allow the dynamical change of container to order's assignments. These raise the flexibility of the decision-making process. Therefore, a simulation model will be developed and used in order to evaluate the potential of the new scheduling method based on the concept of the 'Intelligent Container' and qCODC.

Keywords: Optimization, Scheduling, Monitoring, Cooling.

1. Introduction

The concept of intelligent container bases on equipping normal reefer (refrigerated containers) with additional control units, which give the so-called "intelligence" to the container. The reefer is an intermodal container, which can be used for the transportation of temperature sensitive cargo. By having an integral refrigeration unit, the reefer requires electrical power for cooling. Therefore the container vessels as well as the transhipment places have to be equipped with electrical connections. For road transport, the container can be powered from diesel powered generators (gen sets), which can be installed on trucks. In addition to present technologies of temperature monitoring, which are limited to an offline evaluation after transportation, the intelligent container reacts in real-time to condition changes.

2. **Concept of Intelligent Container**

2.1. Technical equipment

Nowadays, the temperature in a reefer container is measured at two points. It is determined whether the temperature lies within a prescribed optimal range. However, these values are not directly representative, because the air flow inside a container diversifies in every case in a different way. In the Intelligent Container sensors are positioned between the goods to produce multiple and distributed measurements. The system is so designed that when the goods are moved, the sensors will move accordingly. Consequently, the ambient temperature of the goods is measured continuously. The sensors transmit their readings wirelessly to a control unit in the container. On the basis of complex biological models the measured data are interpreted to determine the condition of the goods.

The central control unit is part of a wireless sensor networks (WSN), which consists of various independent low-power wireless sensor-nodes and a central control unit for data transmission and preprocessing (fig. 1).

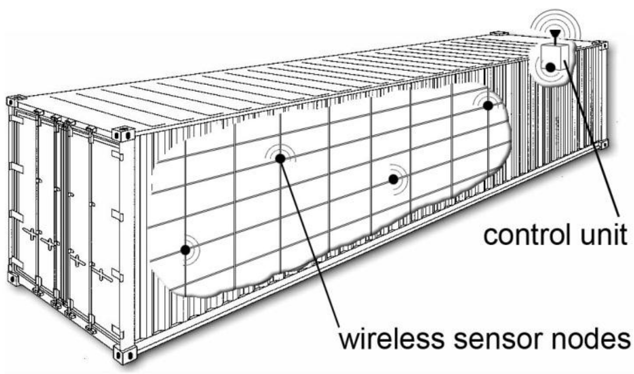

Figure 1. Intelligent container with control unit and sensor nodes.

By using the electrical cooling infrastructure, the control unit of the intelligent container can be charged at the most time of transport. The control unit has a microcontroller, which is used to process the acquired sensor data and transmit these data to a central computation unit for analysis. The sensor nodes can be equipped with various sensors. For the quality monitoring of bananas, several temperature sensor nodes and an ethylene sensor are used. The sensors nodes have to be steadily distributed over the whole container in order to get a good volumetric resolution of the conditions in the container in order to predict the product quality. The wireless sensor network can be flexible enhanced with additional sensor nodes, which can be inserted directly in the food boxes.

Since the information will be communicated via telematics to the logistics control station, the condition of any product is known at any given point. This information is used to control the flow of goods. Consequently, the decision-making process is supported by information about the product quality. Therefore, it is possible to estimate if it is better to sell quickly or to store.

2.2. Approaches of quality driven warehouse management

The general idea of the Intelligent Container is about the use of quality driven planning and control method. In the context of warehouse management a couple of dispatching rules, like e.g. FIFO (First In First Out), LIFO (Last In First Out) and SIRO (Sequence In Random Out) exist. Additionally, some methods with focus on decision-making for perishable goods, like e.g. FEFO (First Expires First Out), LQFO (Lowest Quality First Out), LEFO (Latest Expiry First Out) and HQFO (Highest Quality First Out), were developed. By applying FEFO, products are selected first, which are expiring next. By applying LEFO, products are selected first, which will expire the latest. LQFO is about selecting first the product with the lowest quality. HQFO is about selecting first the product with the highest quality.

Dada and Thiesse made a comprehensive study in the context of perishable goods about these methods [1]. They created a simulation model of a two-stage distribution supply chain with a central warehouse and compared the efficiency of the different dispatching rules to each other. Within this analysis SIRO, LIFO, LEFO and HQFO constantly showed high percentages of spoilage, FIFO, FEFO and LQFO were the best policies concerning spoilage. The highest rate of sold products was achieved by using LQFO. Lang et al. developed the concept of the so-called "dynamic FEFO" due to the application of online monitoring capabilities [2], which should improve the performance of FEFO and promise a minimum of waste of perishable goods. The given approaches of quality driven warehouse management are suitable for linear supply chains but not suitable for supply networks, wherefore the concept of quality driven order decoupling corridors (qCODC) is developed for the Intelligent Container.

2.3. Quality driven order decoupling corridors (qCODC)

The positioning of customer order decoupling points (CODP) is one of the biggest challenges in supply chain design [3]. An efficient position of the CODP helps to save costs and gives a high flexibility to fulfil costumer demands. Thereby, the most important factors are given by the maximum delivery lead time and the volatility of the order volume [4]. In supply chain management it can be differed between three types of buffers: inventory, capacity and extra time [5]. The buffers can be used in order to achieve a delivering of the product in the asked time and needed quantity by having acceptable service levels. As result, the most supply chain use a CODP by having a part of make-to-order (MTO) and a part of make-to-stock (MTS). In pure distribution scenarios also the terms of deliver-to-order (DTO) and deliver-to-stock (DTS) are well-known. The idea of DTO is to deliver a product by having a specific customer order. The concept of DTS means the delivering of goods to a stock by having only predicted demands. Thereby, the complete delivering process bases on forecasts and a push logic. Ingoing customer orders are fulfilled by using the stock. The order processing includes the optimization of preferring urgent orders and long delivering lead times. The idea of quality driven order decoupling corridors (qCODC) are about the combination of DTO and DTS in a scenario of perishable goods (fig. 2).

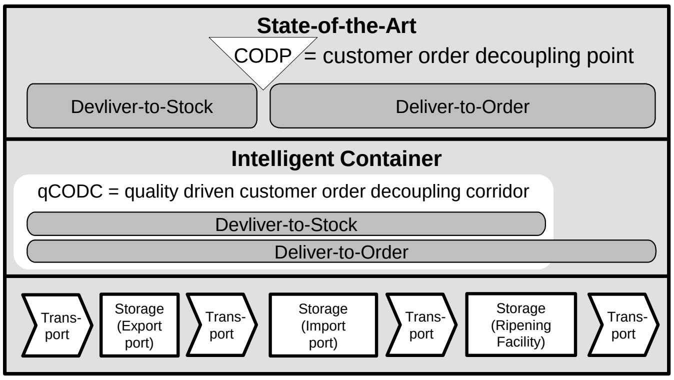

Figure 2. State-of-the-Art vs. Intelligent Container.

In such a scenario, the distribution system has to deal with disturbances due to goods, which have not the demanded quality level. Therefore, a safety stock is required, which can substitute the volume of rejected goods as well as the fulfilment of short time orders. Not all customers can estimate their sales in a good way and need short time replenishment.

The Intelligent Container enables such new concepts by providing the necessary information about the location of itself and the quality conditions of its loaded goods. The concept of qCODC enables a quality-driven distribution of perishable goods. That means, in cases of changes in the product quality a new allocation of goods to customer orders can takes place. For example, goods with lower quality and thus lower shelf-life would be distributed to nearby customers. Such a quality-driven distribution would lead to less waste of foods and more cost efficient processes.

3. Scenario of Banana Distribution

In order to give an example of application areas for the concept of intelligent container, a real-world scenario of banana distribution by using reefer containers is chosen, which includes also the ripening process (fig. 3).

The bananas are harvested at the farms, packed in packing stations and transported in containers to the port. Outgoing from the port of Moín in Costa Rica the bananas are transported by vessel to Europe. In Europe four main ports exist for the transhipment processes, which include short time storage, quality inspection and preperation for land transport. The containers are carried by trucks to the ripening facilities, which are located all over Europe. Additionally, some of the containers are transhipped in Hamburg for further transport to a minor port in Scandinavia. Arriving at the ripening facilities, the quality of bananas is checked again and the ripening process is started. Meanwhile, the containers are brought back to the ports. Depending on the customer orders, the demanded amount of bananas is packed on pallets and is delivered by truck to the different supermarkets.

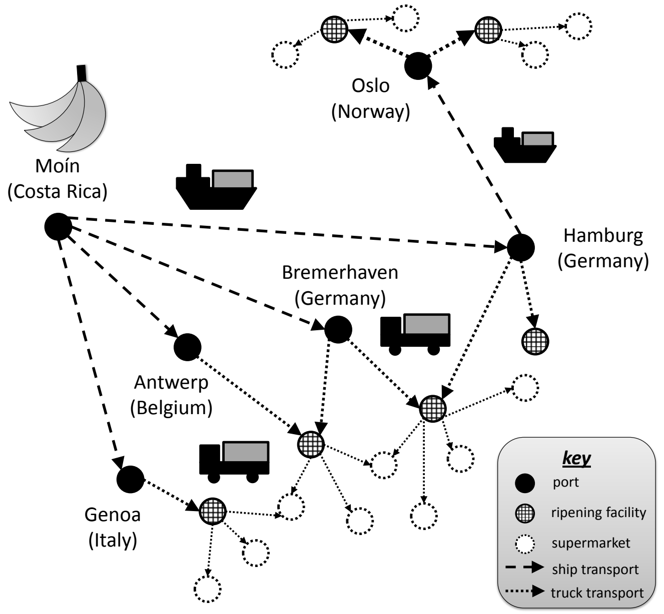

Figure 3. Distribution of bananas in the logistics network.

By applying the state-of-the-art concept, the customer order decoupling point (CODP) is positioned after the quality inspection process, which is run at the port. The concept of the intelligent container will use a permanent quality monitoring by applying the method of quality driven customer order decoupling corridors (qCODC) in order to guarantee a flexible and robust distribution of perishable goods.

4. Simulation Model

4.1. Prediction of product quality and shelf-life

During the transport bananas will be cooled to 13.9 °C. Hence, the natural ripening process is slowed down. The shelf-life can be predicted exactly under these conditions. However, there are several reasons, which cause a spontaneous ripening. For instance, the bananas are stressed by crushing or squeezing during the transport. These bananas produce ethylene, CO_2 as well as warmth and, thus, bananas in the surroundings will be infected and will also ripen spontaneously. The ripeness of bananas can be classified by their colour into seven degrees, but only five degrees of ripeness are relevant for distribution (tab. 1).

Table 1. Banana shelf-life model.

	degree of ripeness				
	1	2	3	4	5
probability of +1 degree per day	1,0%	2,0%	3,0%	4,0%	5,0%
probability of =degree 5 per day	1,0%	1,0%	1,0%	1,0%	1,0%

The bananas start with 1 and will ripe until 5, when they have to be sold to the end-customers. The probability of a spontaneous ripening increases with the duration of transport. We consider this in our banana shelf-life model which is fundamental for our simulation. A biological validation of these probabilities and an enhanced shelf-life model will be carried out.

4.2. Structure of the Simulation Model

The simulation model consists of a couple of nodes and transport relations, which represent the logistics network (fig. 4). The routing of the containers from its origin to its destination considers the travel times as well as the actual processing and waiting time at the nodes. The optimization of the distribution is about the assignment of containers to orders, which is done dynamically during the simulation runs. The objective is to achieve a good service level within the given restrictions. The objective function is multi-criteria and minimize the weighted sum of delay, transport time and perished fruits.

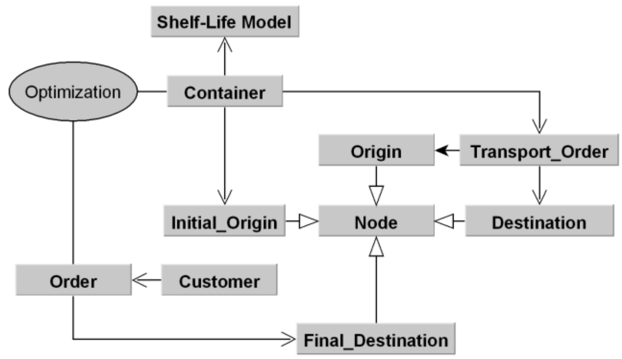

Figure 4. UML-class-diagram of simulation model.

5. Simulation Results

The objective function in the simulation model is designed to achieve just-in-time logistics. Therefore, positive as well as negative deviations of delivery date, transport time and degree of ripeness are evaluated. The following simulation results are calculated for the given logistics network of figure 3 by having a system load of 12 orders á 5 containers within 100 containers available (tab. 2).

Table 2. Simulation results of small scenario.

	Scenario	
Orders	State-of-the-Art	Intelligent Container
in-time	8	10
delayed	2	0
not fulfilled	2	2

6. Conclusion

The intelligent container as starting point for the method of quality driven customer order decoupling corridors (qCODC) shows substantial improvements of process performance in first results. The further research will focus on detailing the shelf-life model as well as on the validation of the simulation model. Additionally, the optimization heuristic will be compared to solutions of linear programming and autonomous control.

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