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# Towards Quality-aware Control of Perishable Goods in Synchromodal Transport Networks

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**Abstract:** Innovative technological developments are leading to smart ways for producing food more efficiently and of higher quality. Nevertheless, lots of perishable goods are wasted because of inefficiencies during the subsequent transport process. The amount of wastage could be reduced via better planning and control of transport activities. Perishable goods logistics can be better supported by real-time information of goods and the emerging concept of synchromodality, as sensing and communication technology develops. In this paper a decision making system is proposed for perishable goods logistics service providers to reduce loss of freshness using synchromodal transport. The approach starts from the perspective of individual containers and the different types of equipment/vehicles used to transport these containers. With both the perishing feature and the transport situations of perishable goods considered, the controller decides when and where containers with such goods should be moved to. Simulation experiments illustrate how the approach could improve the quality and reduce the operation time during transport processes.



*Keywords:* Perishable goods, synchromodal transport, transport networks, system and control, integer programming

## 1. INTRODUCTION

Agriculture is the primary source for food worldwide. Technological insights lead to production mechanisms of previously unforeseen performance. Food created in this way is produced at higher quality. Unfortunately, worldwide food spoilage is still severe (Gustavsson et al., 2011): around one third of the food produced for human consumption is wasted. Wasting happens throughout supply chains, including production, post-harvest, distribution, retail, and consumption (FAO, 2013). Transport plays an important role in supply chains: during transport processes, the quality degradation of fresh products can be influenced by the dynamic environment that the goods are exposed to (Hertog et al., 2014). With up-to-date information and proper planning of perishables transport, the loss of goods and their freshness could be reduced (Lin et al., 2015). This will enable maximally benefiting from smarter agricultural farm technology.

Real-time traceability makes supply chains more transparent and efficient. This is even more true for supply chains of agricultural products: deterioration that may happen unexpectedly (van Boekel, 2008) can be identified using sensor and communication technologies (Abad et al., 2009); and fast responses can be made to re-schedule transport plans in order to keep the most freshness of perishable products during transport (Aung and Chang, 2014). Thus, food loss in agricultural supply chains could be reduced with the information on freshness and the flexibility of transport systems.

Synchromodal transport has received much attention in recent years. It refers to "the concept of optimizing all network transportation in an integrally operated network, making use of all transportation options in the most flexible way" (van Riessen et al., 2015). This provides the possibility for transport planning to be updated even when the goods are already on the way. The update may include changes of route or modality, making full use of the transport system with great flexibility and efficiency. Synchromodality has great potential for perishable goods logistics. With the real-time information of changes of freshness, the transport plan can be updated accordingly before or during transport, in order to avoid congestions and to better preserve freshness of goods.

Limited research has focused on the transport of perishable goods considering changes of freshness. Yu and Nagurney developed a food supply chain model based on network (Yu and Nagurney, 2013). The model incorporates the food deterioration by introducing arc multipliers: when flowing through an arc, the products in this flow deteriorate by a certain degree decided by the attribute of that arc. A flow model developed by (Rong et al., 2011) incorporates deterioration in a different way: the model duplicates each location in order to represent different temperature and quality of products. When considering perishable goods, a disadvantage of flow models is that they can only incorporate quality features to transport networks. However, the deterioration of food is not only influenced by transport planning due to uncertainties of environments and variabilities of food products (van Boekel, 2008). A flow shop


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approach developed by Dabbene et al. considers both logistics planning and product quality measuring (Dabbene et al., 2008). As indicators of the performance of perishable supply chains, the logistic costs and total loss of product quality can be reduced using a specific optimization algorithm. Although the approach separates perishing features from logistic features, it does not consider route change in real-time information.

Inspired by the study (Dabbene et al., 2008), we propose in this paper a decision making system for synchromodal transport of perishables. We consider a number of containers that each needs to go through a series of transport stages (e.g., loading, shipping, etc.) before reaching their final destination. The control question is then at what time the containers should move from one transport stage to the next one, in order to keep freshness of the cargo at the destination. We also consider the handling time and the capacity for each stage due to efficiency and availability of handling equipments. Moreover, the quality of perishables can decrease at varying rates during the procedure of transport. A system and control perspective is adopted to structure the proposed approach.

The remainder of this paper is organized as follows. In Section 2, we propose the system model for transporting containers with perishable goods. Section 3 describes the quality-aware control method that minimizes the total quality loss for all containers. Simulation experiments and results are recorded in Section 4. Section 5 concludes the paper and provides directions for future research.

## 2. DESCRIPTION OF TRANSPORT NETWORK

In this section, we describe the system of synchromodal transport network for perishables. Dynamics regarding movements of containers as well as the network are explained.

### 2.1 Object-oriented modeling for transport system

When containers go through a transport process, they are handled by different types of equipments (e.g., trucks, ships, automated guided vehicles (AGVs), quay cranes, etc.). We divide the transport process into a finite set of stages determined by the types of handling equipment, and each container changes its stage as it is being moved for handling by one piece of equipment to the next. The transport is finished when a container reaches its final stage. As a result, containers are considered as dynamic components in the system, rather than part of network flows.

When entering a stage, the container is being handled by certain equipment. The handling time and capacity are limited by the equipment used in each stage. As a result the containers cannot move to the next stage before the handling is finished, and there can only be a maximum amount of containers being handled in a particular stage at the same time. For example, when a container needs to be loaded onto a vessel from a stacking area of a terminal, it is put on an automated guided vehicle (AGV), and then picked up by a quay crane as the AGV stops by the vessel. Afterwards, the container goes with the vessel to its destination. Therefore, the stage of this container is moved from "being stacked in the terminal" to "being loading onto a vessel", and then "being transported by a vessel". During the movements, the handling time and capacity are determined by the equipments involved in the handling of the container.

Information on quality of the goods carried is considered as an intrinsic attribute of each container and can be influenced in different ways when in different stages. For instance, when containers are stacked in a terminal, the temperature inside may increase due to sunshine during daytimes. But when a container is in a warehouse, the influence of sunlight is not obvious. These environmental changes may affect the quality of the products carried by containers, for these products may deteriorate at different rate in different environments. We assume that the quality of fresh products is homogeneous in each container, and that it can be measured accurately.

### 2.2 Container dynamics

The stages each container needs to go through are represented by a directed graph $G = \{N, E\}$, with $N$ the nodes representing possible stages and $E$ the arcs representing possible transitions between stages. The status of container $m$ ($m \in M$, the collection of considered containers) is represented by a binary variable $x_{mi}(k)$, where $i$ is one of the stages ($i \in N$), and $k$ the $k$-th time step (between two time steps is a time duration). So, as an example, $x_{56}(7) = 1$ represents that container 5 is in stage 6 after time step 7. It is logical to have the constraint that at each time step, each container must, and can only be at one of the stages:

$$\sum_{i \in N} x_{mi}(k) = 1, \forall m \in M, \forall k \in \{1, 2, \dots\}. \tag{1}$$

The decision of moving container $m$ from stage $i$ to stage $j$ at time $k$ is denoted by a binary variable $u_{mij}(k)$, where $(i, j) \in E$. Note that this decision is made at time step $k$ but results in the following time period between $k$ and $k+1$. Especially, containers are allowed to stay at a stage over several time steps, with the corresponding decision $u_{mii}(k) = 1$ $(\forall (i, i) \in E|_{i \in N})$.

Containers move from one stage to another according to a particular sequence, following the directed arcs. We define $P(i)$ as the collection of predecessor stages of $i$ (nodes having arcs pointing to $i$), and $S(i)$ as the collection of successor stages of $i$ (nodes having arcs pointed from $i$). The dynamics of container movement can be denoted as follows:

$$\begin{gathered} \sum_{p \in P(i) \cup \{i\}} u_{mpi}(k) = x_{mi}(k), \\ \forall m \in M, \forall i \in N, \forall k \in \{1, 2, \dots\}, \end{gathered} \tag{2}$$

$$\begin{gathered} \sum_{s \in S(i) \cup \{i\}} u_{mis}(k+1) = x_{mi}(k), \\ \forall m \in M, \forall i \in N, \forall k \in \{1, 2, \dots\}. \end{gathered} \tag{3}$$

Equation (2) describes that for all the containers, their states $x_{mi}(k)$ between time step $k$ and $k+1$ are determined by the decision made for time step $k$, that containers can move from any stage $p$ (all predecessor stages of $i$ including $i$ itself) to the stage $i$. Similarly, Equation (3) indicates