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Predictive quality-aware control for scheduling of potato starch production

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ABSTRACT

Modern technologies have enabled approaches to estimate freshness of perishable products during production and distribution. This allows supply chains to apply more advanced decision support systems in order to further reduce the loss of perishable products. In this paper we focus on the postharvest scheduling of starch potatoes. In particular we propose a quality-aware scheduling method that can be used in a decision support system for starch potato postharvest operations. Considering the quality of stored potatoes in real-time, the method determines when and how many potatoes should be harvested, sent for starch production, or stored. A centralized and a distributed control strategy are developed, with the aim of minimizing total starch loss in dynamic environments. Simulation experiments illustrate how the proposed approaches deal with disturbances, and that the total starch loss can be reduced when real-time quality information of potatoes is taken into account.

1. Introduction

An increasing number of perishable goods, including food, flowers, and medicine, are produced, transported, and consumed worldwide. Meanwhile, there is a considerable amount of perishables going wasted before being consumed. Particularly, one third of food is lost throughout different supply chains (i.e., production, postharvest, distribution, retail, and consumption) (Food and Agriculture Organization of the United Nations, 2013). Research has shown that the wastage could be reduced via better supply chain coordination with real-time information on the freshness of products (Lin et al., 2015; Amorim et al., 2013).

Potato starch is a widely used ingredient in food and other industrial applications. In the year 2014, 6.9 million tonnes of starch potatoes were harvested and processed for starch in Europe (Starch Europe, 2016). The harvest period of starch potatoes in Europe is between August and April, which is referred to as the starch campaign (Grommers and van der Krogt, 2009). During this campaign, a starch production factory receives potatoes grown by farms in neighboring areas. The largest factory today can process about 250 ton potatoes per hour (Grommers and van der Krogt, 2009). Nevertheless, not all potatoes can be processed immediately due to the large volume of harvested potatoes. As shown in Fig. 1, growers of each farm move harvested potatoes to the starch factory or store them at storages in barns or in pits. The stored potatoes awaits to be transported to the factory for processing (Godard et al., 2012).

According to Wustman and Struik (2007), weight and quality loss happens over time in stored potatoes, because they have an active metabolism. The loss is caused by several factors: evaporation, respiration, sprouting, changes in the chemical composition, damage by extreme temperature, and spread of diseases. Uncertainties in storage conditions can affect the weight and quality loss. For instance, a too low storage temperature can cause more conversion of starch into reducing sugars (Wustman and Struik, 2007). Therefore, managing stored potatoes in uncertain environments is important for reducing loss of quality during the starch campaign.

With the developments of information and communication technology (ICT) and automation in industry, the application of decision support systems (DSS) in supply chain management is gaining increasing attention. A DSS can help decision makers solve complex problems with data and models (Fanti et al., 2017). Particularly, in perishable goods supply chains, sensing technology and weather forecasts can provide awareness of quality information at present and in the near future. With this information, DSS can operate in a manner that freshness of products is also taken into account. In a starch potato supply chain, a DSS could help operations of growers and starch production factories, indicating variety of potatoes being grown by each field, timing, and moment of harvest or storage (Haverkort and MacKerron, 2004). Managed with a DSS that would also consider potatoes' real-time and predicted quality, a supply chain could further reduce its waste, cost, and have a more competitive edge in uncertain environments. The readiness of technologies is discussed in more detail in Section 2.

This paper investigates how information of potato quality could be

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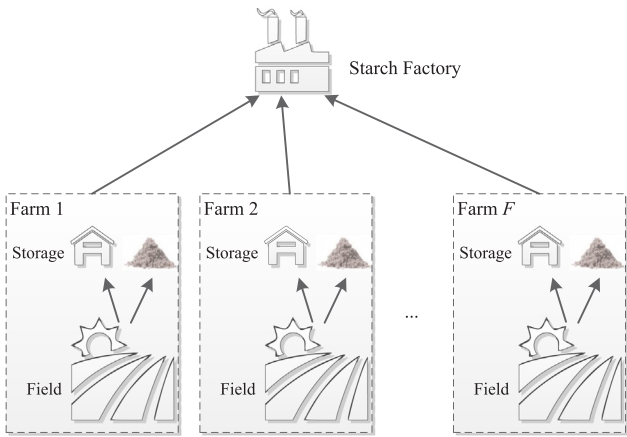

Fig. 1. Movements of potatoes during a starch campaign. Growers of each farm move harvested starch potatoes to the on-farm storages and the starch factory.

considered in designing a DSS for better starch production scheduling during harvest campaigns. Decisions made by a processing plant and growers of potato fields are considered in a fully cooperative setting and a partially cooperative setting. To include quality information, we focus on the influence that historical and predicted temperature has on potatoes' starch content at present and in the upcoming days of storage. A quality-aware modeling method and predictive control strategies are proposed for inclusion in a DSS to optimize the total starch yield from a processing plant. Simulation experiments are carried out for assessing the potential of the developed strategy under changing environments.

The remainder of the paper is organized as follows. In Section 2 we carry out a literature review on postharvest and supply chain scheduling for fresh agricultural products. We also discuss the readiness of technologies to implement DSS in scheduling of a starch campaign. Section 3 proposes models for the components of the starch production system. The design of the predictive control strategies is proposed in Section 4. Section 5 carries out several simulation experiments and discusses the results. In Section 6 we conclude this paper and provide directions for future research.

2. Literature review

Good decision support systems can be beneficial for perishable goods supply chain players: it can reduce operation costs, and improve the effectiveness of the supply chain and freshness of the products. This section firstly reviews research of scheduling methods that can be used in DSS for postharvest handling and supply chains of fresh agricultural products. Subsequently, we focus on the models that use real-time quality information to benefit supply chain players models. Then, we discuss technological foundations for DSS with real-time quality information in potato starch production operations.

2.1. Raw agricultural products postharvest handling

Research has investigated postharvest operations of some agricultural products taking into account information on product quality. López-Milán and Plà-Aragonés (2015) develop a DSS for sugarcane harvesting operations. Freshness of sugarcanes is only inexplicitly considered in their model. Ferrer et al. (2008) investigate a grape harvesting problem. A mixed-integer linear programing model is proposed to support decision making on harvest scheduling, labor allocation, and routing, with the aim of minimizing the handling cost and loss of quality due to delays in harvesting. Similarly, González-Araya et al. (2015) develop an optimization model for apple orchards with the goal of minimizing handling costs and loss of quality. The model considers different categories of apples, which should be harvested in different time windows of the year to achieve the overall maximum quality. Caixeta-Filho (2006) investigates an orange harvest scheduling problem. A model is built to maximize the total soluble solids produced from oranges by selecting when and which grove to be harvested.

These models (López-Milán and Plà-Aragonés, 2015; Ferrer et al., 2008; González-Araya et al., 2015; Caixeta-Filho, 2006) do not consider product quality in real-time, and thus cannot respond to disturbances in changing environment over time. As pointed out by Ahumada and Villalobos (2009), planning models for perishable goods often fail to consider realistic, stochastic shelf-life features present in supply chains, and thus these models cannot respond disturbances during operations.

2.2. Implementation of real-time quality information

Emerging technologies on sensors and communication have enhanced the traceability of supply chains and can provide real-time information about goods and their status (Aung and Chang, 2014). An example is shown in Abad et al. (2009), where smart tags are used to measure light, temperature, and humidity during transportation of fresh products, and can transmit this information to examiners by radio frequency identification (RFID). Such technologies applied in supply chains could provide insights by which better decisions can be made in order to increase the effectiveness of supply chain activities (Van der Vorst et al., 2007; Lin et al., 2015). Some examples can be seen in the literature. Rong et al. (2011) discuss a perishable good supply chain in which a network flow model is used to describe the logistic system and to determine the movements of the flows and the temperature of the facilities. In their method, goods in a flow are distinguished by using multiple nodes representing one location, according to their quality levels. Similarly, De Keizer et al. (2017) use fractions of a flow to represent goods of different quality. Using a different approach, Dabbene et al. (2008) describe supply chains using a hybrid flow-shop model (Dabbene et al., 2008). The model considers both physical parameters (including quality of goods) and logistic parameters.

These studies (Rong et al., 2011; De Keizer et al., 2017; Dabbene et al., 2008) take quality of products into consideration and show that a perishable goods supply chain can benefit from making use of quality information. Nevertheless, their approaches limit the representations of quality features and logistics features in the same model. On one hand, in Rong et al. (2011) and De Keizer et al. (2017), quality features are attached to logistics features, which prevents these models from considering more realistic quality models (Ahumada and Villalobos, 2009). On the other hand, the approach proposed in Dabbene et al. (2008) limits the logistics features to a single supply chain rather than a network with route choices.

In our earlier research (Lin et al., 2016a), a preliminary quality-aware model is developed to resolve the aforementioned problems. The proposed method uses a state-space representation to capture both quality and logistics features of perishable goods in supply chains. In such models, quality features and logistics features do not depend on, but can influence each other. Next, we discuss the technical foundation for this model to be applied in a DSS for a starch potato production problem.

2.3. Toward a quality-aware DSS for potato starch production

On-line quality monitoring methods have shown promising applicability in acquiring quality information of potatoes (Rady and Guyer, 2015). This real-time information has previously been used for quality control in potato storage. Verdijck et al. (2005) develop a model predictive control strategy to optimize the temperature settings in a potato storage.

We propose to further benefit from the real-time quality information in operational decision makings in a potato supply chain, in this case, postharvest operation in potato starch production. In our previous research (Lin et al., 2016b), we made the first step to discuss the potato