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Research Paper

Grain supply chain network design and logistics planning for reducing post-harvest loss

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In this paper we present a mathematical model for reducing post-harvest loss (PHL) in grain supply chain networks. The proposed model determines the optimal logistics for grain transportation and infrastructure investment by identifying the optimal locations for new pre-processing facilities and by optimising roadway/railway capacity expansion. The objective is to minimise the total system cost, including both infrastructure investment and economic cost from PHL. In this paper we incorporated both quality and quantity PHL during the transportation, transhipment, and pre-processing stages in the supply chain and considers different PHL rates for processed and unprocessed grains. Finally, we conducted a numerical analysis on a real-world network in the State of Illinois and a series of sensitivity analyses to provide insights into the optimal system design under different scenarios.

1. Introduction

Post-harvest loss (PHL) occurs when both the quantity and quality of a food product are degraded from harvest to consumption. Quality PHLs occur primarily as PHLs of nutritive or caloric value, as a decline in customer perception of the product's acceptability, or as the edibility of the food (Kader, 2005). Quantity PHLs occur as the decline of the amount of a product, measurable as a difference of weight. Quantity PHLs are easier to determine than quality PHLs; the difference in the weight, for example, of grain that is infested with insects can be easily determined. By contrast, quality PHLs such as deterioration of nutritive quality are more difficult to determine, and are often overlooked (Gorgatti-Netto, 1979). The amount of PHL is substantial. Since "as much as half of all food grown is lost or wasted before and after it reaches the consumer" (Parfitt, Barthel, & Macnaughton, 2010), reducing PHL can significantly increase food availability. A typical grain supply chain includes several post-harvest stages in which quality or quantity PHL may occur. Figure 1 shows the different post-harvest processes and logistics and the potential PHLs in the supply chain from farms to ports, and

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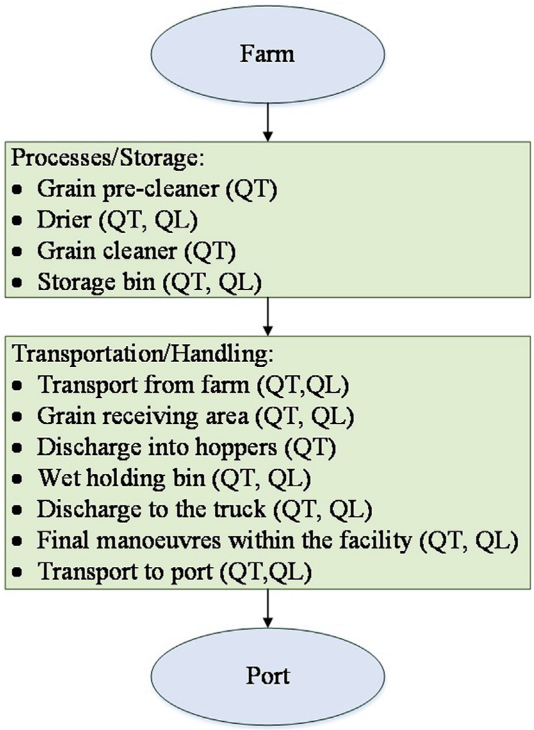

Fig. 1 – Post-harvest logistics from farms to ports (Modified from Silva, 2014): QT = quantity PHL, QL = quality PHL.

illustrates how quality and quantity PHLs occur in most stages of the supply chain (see Fig. 2).

Various factors contribute to quantity and quality losses at multiple crop supply chain stages, including those during the harvesting activities (e.g., edible crops being left in farm fields, ploughed into soil, or eaten by pests), those due to non-optimal harvesting times, or those occurring in post-harvest stages such as processing, storage, handling and transportation. Quantity PHL during transportation is mainly due to poor logistics infrastructure. Studies in Brazil determined that the main causes of grain crop PHLs were inadequate harvest techniques, lack of storage facilities, and poor transportation, handling, and packaging practises (Gorgatti-Netto, 1979; Bartosik, 2010). All of these PHL factors can be classified into three major categories: operational, environmental, and socio-economic. Operational factors include: harvesting methods and timing; field sorting; grading and packing; pre-cooling; transportation; storage; packaging and labelling; and secondary processing. Environmental factors are climatic conditions like wind, rainfall, humidity, and temperature, all of which influence both food quantity and quality during harvest, transportation, and storage. Socio-economic factors include urbanisation, globalisation, and economic conditions.

Studies on PHL have focused on devising estimations of PHL and on PHL prevention technologies. These studies have examined: stage-wise PHL (Rembold, Hodges, Bernard, Knipschild, & Oliver, 2011); PHL caused by fungi, weather, and the cost of capacity overinvestment (Magan & Aldred, 2007; Allen & Schuster, 2004); information processes and supportive technologies (Reiche, Fritz, & Schiefer, 2009); and technology selection (Ekman, 2000). However, literature describing models food PHLs from a more comprehensive supply-chain perspective is very limited. Other studies focused on various aspects of agriculture logistics, including: supply chain optimisation of biomass (Lin, Rodriguez, Shastri, Hansen, & Ting, 2013, 2014); agriculture supply chain modelling from harvest to distribution (Apaiah & Hendrix, 2005); inventory and uncertain customer demand (You & Grossmann, 2010); the product value PHL over time in the supply chain (Blackburn & Scudder, 2009); simulation of technologies and packing procedures on product quality (Tollner, Prussia, & Florkowski, 2006); and global logistics features (Goetschalckx, Vidal, & Dogan, 2002). Ahumada and Villalobos (2009) reviewed the literature related to production and distribution planning for agricultural crops. Of particularly relevance, Hajibabai, Bai, and Ouyang (2014) modelled the complex interactions between transportation infrastructure and freight logistics efficiency and developed a joint optimisation model of freight facility locations and pavement infrastructure rehabilitation under network traffic equilibrium. Another thrust of research in agriculture logistics, such as that done by Kang, Önal, Ouyang, Scheffran, and Tursun (2010), Bai, Hwang, Kang, and Ouyang (2011), Bai, Li, Peng, Wang, and Ouyang (2015), and Wang, Ouyang, Yang, and Bai (2013), focused on biofuel supply chain efficiency and reliability. Bai, Ouyang, and Pang (2012, 2016) studied impacts of biofuel supply chains on agricultural land use and food market equilibria. To the best of our knowledge, there is no systematic study on reducing PHL accounting for PHLs in different stages of a supply chain network, nor any study that develops optimal strategies for system design and management that considers the trade-off between economic cost and PHL.

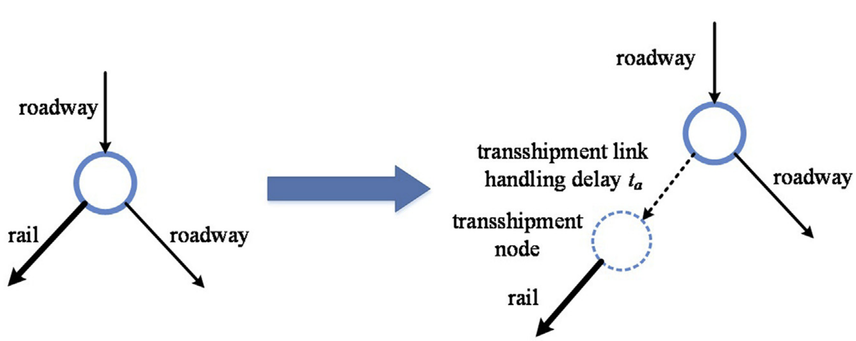

Fig. 2 – Network modification to incorporate transhipment.