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Reducing postharvest losses of apples: Optimal transport routing (while minimizing total costs)

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ABSTRACT

Fresh products may suffer considerable damage during postharvest transportation caused by vibrations and shocks (i.e. transient vibrations that damp out over time). The Belgian apple industry is yearly worth 125–140 M euro (EBITDA to apple growers) and experiences losses between 10 and 25% corresponding to 10–25 M euro. Apple losses can be attributed to fungal diseases that enter the apple through bruised or punctured tissue and contaminate the fruit. Vibrations occurring during transports are a major contributor to bruises or punctures on apples, and, as a consequence, need to be avoided.

An effective method to reduce the apple loss rate is by minimizing the number and intensity of vibrations that occur during the transport route. In this paper, we suggest planning transport routes based on transportation costs as well as costs related to the loss rate of apples. As a consequence, the transport vehicle is able to avoid road segments with poorly maintained road segments or road segments that are more susceptible to induce higher vibration amplitudes. The results of transport simulations illustrate that the Belgian apple growers can gain industry profits of 250–1500 thousand euros. Both from an economical as well as an ecological perspective our findings are substantial and relevant. The methods used in this research can be adopted by other fruit varieties by transforming the input parameters.

1. Introduction

Transport is a crucial phase in the distribution of fresh food products, from the harvesting operation to the consumer. However, during transport and handling, fresh products may suffer considerable damage. A myriad of research papers has been published on this topic for diverse food products like pears (Zhou et al., 2007), strawberries (Fischer et al., 1990), bananas (Wasala et al., 2015), kiwis (Tabatabaekoloor et al., 2013), watermelons (Shahbazi et al., 2010). The problem of damage to apples is most extensively researched due to the high loss rates of apples (Vursavus and Özguven, 2004; Van Zeebroeck, 2007; Dobrzanski et al., 2006; Acıcan et al., 2007). The loss rate can be attributed to the appearance of bruises, the most common type of post-harvest mechanical injury. However, the likeliness that the presence of minor mechanical injuries, which later on lead to fungal diseases, is often overlooked by the market inspectors (Van Zeebroeck, 2007). Postharvest pathogens, such as gray mold (*Botrytis*) or blue mold (*Penicillium*), are able to enter the fruit by the dead or wounded tissue and contaminate the fruit. As a consequence, total product loss levels, depending on customer awareness, between 10 and 25% are typically found (Van Zeebroeck, 2007; Acıcan et al., 2007; Jijakli and Lepoivre, 2004; Sholberg and Conway, 2004; Eissa et al., 2013). Even peak values with a loss rate up to 50% are observed (Van Zeebroeck, 2007). The economic and ecological costs emphasize the importance of reducing mechanical damage to fresh products (Amorim et al., 2013).

Multiple stages can be distinguished for the distribution of Belgian apples beginning with the harvest in the orchard and ending with being sold on the Belgian market (Van Zeebroeck, 2007). After picking the apples in the orchard, the apples are transferred from the picking baskets into the wooden bulk bins (Fig. 1). Afterwards, the apples are transported from the orchard to the storage rooms with a forklift tractor or possibly bulk transport. Then the apples are transported to the auction. At the auction, they are unloaded off the bulk bins, graded, sorted and transferred to other packaging types. Finally, the apples are transported to the seller and in the last step transported by the customer. At the auction apples are sorted over diverse categories, presented in Table 1 – Appendix A. Apples not used for direct consumption by the user are processed in other food products (e.g. juices and compote) (Dobrzanski et al., 2006). However, the price for degraded apples (not suitable for direct consumption) is 1/3 of the normal auction price (Van Zeebroeck et al., 2003).

In the literature on apple losses during postharvest processing, four

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Fig. 1. Transport of apples in wooden bulk bins & bruise damage of apples. ().
Source: Acıcan et al., 2007; Okanagan-Kootenay Sterile Insect Release Program, 2018

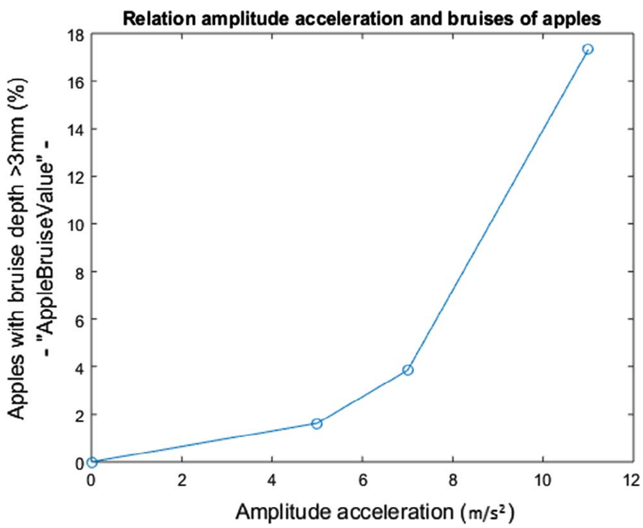

Fig. 2. Relation acceleration – apple bruises. (Duration transformed to 1 s on frequency of 4 Hz) In Fig. 2, the relation between the acceleration amplitude of the imposed vibrations and the percentage bruises of apples is depicted, performed by Van Zeebroeck et al. (2006). The graph is convex, which indicates that vibrations of high acceleration (and transient vibrations of high amplitude that damp out over time) are more harmful for apples than vibrations of lower acceleration. The current relation with respect to vibrations and bruises of apples is incorporated in the constructed model to simulate damage to apples during transport (variable name "AppleBruiseValue"). Source Fig. 2: (Van Zeebroeck et al., 2006).

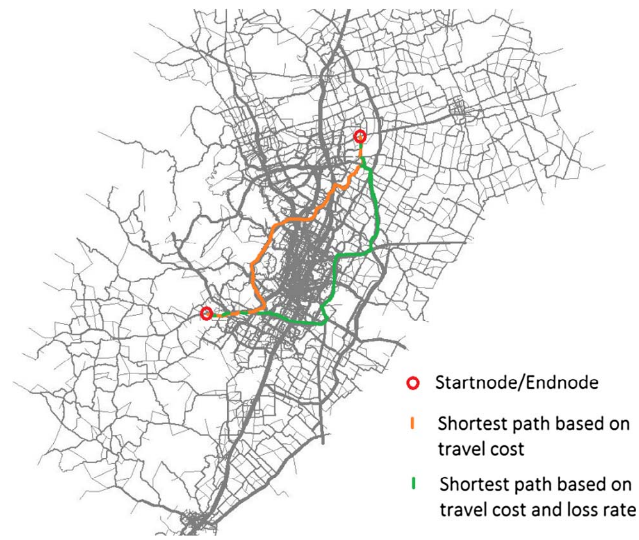

Fig. 3. Austin, Texas network. (With simulation of transport path based on costs) In Fig. 3, a graphical representation of the freely accessible network of Austin, Texas is presented. The figure indicates two possible simulations of apple transport in which the shortest path is calculated based on the travel cost (a) and based on both the travel cost and the loss rate of apples (b). Source Fig. 3: Barge, 2013.

categories of research papers were distinguished by Van Zeebroeck (2007): (1) on the source, magnitude, and nature of the impact and vibration input (e.g. single fruit impacting on single fruit (Pang et al., 1992; Jones et al., 1991; Schoorl and Holt, 1985), a fruit container subjected to vibrations (Acıcan et al., 2007) (2) on the packaging material and the container itself (e.g. damping and cushioning properties (Eissa et al., 2012) (3) on the influence of individual fruit with neighboring fruit in modifying the vibration input (Gołacki et al., 2009) (4) on the susceptibility of fruit to damage as a function of maturity, temperature, size and cultivar (Dobrzanski et al., 2006). While this is important research, a research gap is left to reducing fruit loss rates by minimizing the number of vibrations that occur during the transportation of fruit. On the one hand, the duration or the exposure to vibrations could be diminished by taking the shortest path from origin to destination. On the other hand, the amplitude of the vibrations can be

Table 1
Damage classes of apples according to USDA scale.

Damage class		[Extra information in the attached reference]
I		Grade Standard Reference: Title 7 CFR 51.300
	U.S. Extra Fancy	This category includes apples of the highest quality. Different tolerances and quality requirements (e.g. color, bruise depth) are used for different apple varieties. A combination grade (U.S. Extra Fancy – U.S. Fancy) may be used
II		Grade Standard Reference: Title 7 CFR 51.301
	U.S. Fancy	Apples of higher medium quality can be classified in class II. Different tolerances and quality requirements (e.g. color, bruise depth) are used for different apple varieties. A combination grade (U.S. Extra Fancy – U.S. Fancy and U.S. Fancy – U.S. No.1) may be used
III		Grade Standard Reference: Title 7 CFR 51.302
	U.S. No. 1	Apples of lower medium quality can be classified in class III. Different tolerances and quality requirements (e.g. color, bruise depth) are used for different apple varieties. A combination grade (U.S. Fancy – U.S. No.1 and U.S. No.1 – U.S. Utility) may be used
IV		Grade Standard Reference: Title 7 CFR 51.303
	U.S. Utility	U.S. Utility-apples have the lowest quality. Different tolerances and quality requirements (e.g. color, bruise depth) are used for different apple varieties. A combination grade (U.S. No.1 – U.S. Utility) may be used

Source: United States Standards for Grades of Apples/Legal Information Institute/Cornell University Law School, 2002.