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Transportation versus perishability in life cycle energy consumption: A case study of the temperature-controlled food product supply chain

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ABSTRACT

Moving goods from the point of production to markets involves energy use and can have adverse environmental effects. But from the supply chain management perspective, the control of the supply chain, with short time cycles between production and sale to customer, can benefit the environment by closely tailoring production to consumption, and by minimizing the amount of "perishability" in the chain. An energy consumption model is used to explore potential tradeoffs between these two competing tendencies and applied to temperature-controlled food products produced in agricultural regions in the US with mild climates and then distributed around the country using surface transportation. Although the use of rail can reduce life cycle energy consumption compared to truck, the increase in perishability of food products can undercut the energy savings, and in some circumstances, the use of inter-modal rail can be environmentally superior to carload freight for delivery.

1. Introduction

There is a growing interest in the "greening" of freight, logistics, and supply chain management. This involves looking for ways to reduce pollution and greenhouse gas (GHG) emissions, and conserve finite resources, especially petroleum and petroleum-derived products such as gasoline and diesel fuel. Freight and logistical activities have seen recent rapid growths in energy consumption and GHG emissions. Schipper et al. (1997) and Mintz and Vyas (1993) observed this relatively rapid growth in the 1990s, and Davis and Diegel (2006) confirm that freight energy use has continued to outpace other sectors of the US economy through 2003.

One of the contributing factors to this growth in energy use is the shifting of increasing amounts of high-value freight (finished products as opposed to bulk raw materials) to higher-cost, higher level-of-service modes such as truck and air-freight – high-value modes. For example, the share of rail ton-miles of food products in the US declined from 45% to 22% between 1977 and 2002, while that for truck climbed from 49% to 63% (US Department of Commerce 1981, 2004). One response has been a growing interest in reversing this trend and moving more finished products by rail or truck-rail inter-modal systems to reduce energy consumption as well as addressing other concerns such as road congestion.

One aspect of modal shifting that been less explored is the effect of modal choice decisions on energy consumption due to perishability of the product. The implicit assumption of changing mode is that modal choices can be made without affecting energy consumption at other stages of the supply chain, so that savings made by using rail translate into overall savings for the life cycle of the product. Here, we explore the effect of perishability on overall energy consumption using a multimodal model that tracks perishability as well as modal choice.

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Perishability affects energy consumption in a number of ways. Energy waste occurs when the "embodied energy" of the product is consumed in its production, but the product does not deliver value to the final customer because it is rendered unusable before it can be consumed. We hypothesize that high-value modes, while consuming more energy to move products, are less likely to incur product loss due to perishability and hence incur lower loss of embodied energy. A product that moves more quickly and reliably through the supply chain may also be less subject to damage, again reducing loss of embodied energy. For other time-sensitive items such as garments or footwear, if the item remains in the supply chain too long, it may not "perish" *per se*, but it may become obsolete so that it is no longer attractive to the final customer. Products that move more quickly through the supply chain may also consume less energy in storage, for example as with food products requiring refrigeration.

Consideration of energy consumption in this more holistic way that includes both vehicular and embodied energy emulates the supply chain management approach to optimizing the financial returns from logistical supply chains. The goal of modern supply chain management is to optimize materials sourcing, production costs, transportation choices, inventory costs, and expenditures on retailing and marketing, so as to maximize the profit of the enterprise. In a similar way, with sufficient data and analytical effort, the energy consumption and air pollutant/greenhouse gas emissions of the entire supply chain could be optimized in a single comprehensive process that might include local impacts such as the nuisance effects of heavy vehicles as well.

2. Network model development

2.1. Conceptual basis for the model

The core of the product model deployed here is a life cycle energy consumption model that tracks both the time required and energy consumed from the growing of crops to be used as ingredients in products to sale of the product. Products that reach their sell-by date prior to being sold are assumed to be discarded without being purchased and consumed by the individual customer. Therefore, these products incur an energy consumption cost on the system, but do not contribute to meeting consumer demand for the product. To investigate the effect of different mixtures of modal shifting on perishability, we create scenarios in which the modal split among truck, carload rail, and inter-modal is chosen *a priori*, and then volumes of products are either assigned to the shortest path in the case of truck, or distributed among multiple paths in the case of the other two modes. In the latter case, we use either probit- or logit-based stochastic assignment to distribute the volume of shipment among alternative paths.

The stages of the product life cycle are shown in Fig. 1. Agricultural input for a product are grown in an appropriate region, and then transported in the form of raw material (e.g., grain, fruit, vegetable in this case) to a food processing plant where they are transformed into a finished food product. Downstream from the processing plant, the product is transported through the US surface freight transportation network, by truck or rails, to a retail outlet where it is made available for sale to customers. The model tracks the number of days elapsed from time of packaging through time spent in transit to the destination and time spent available for sale in the retail outlet. If a customer purchases the product prior to the sell-by date, it is

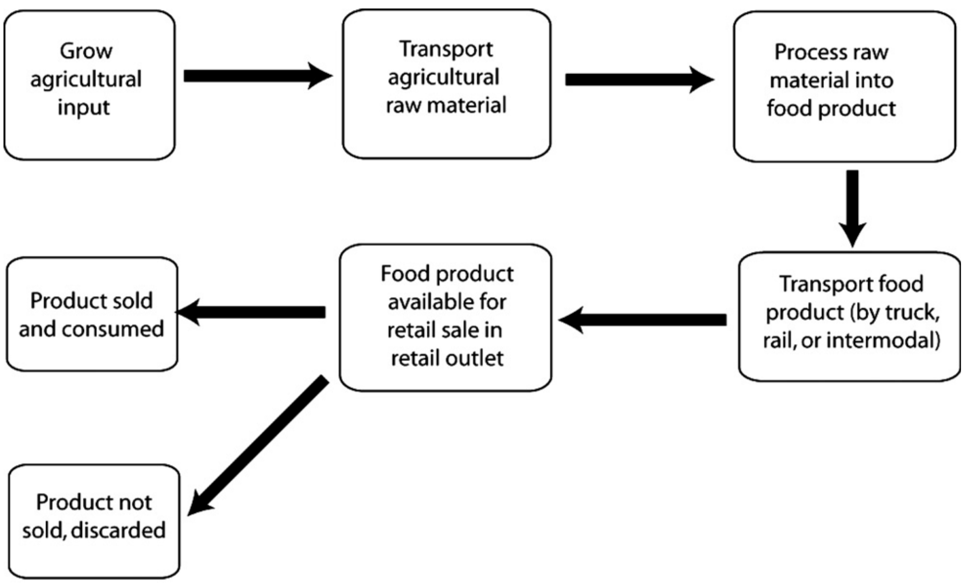

Fig. 1. Flowchart of food product movements.