Research in Transportation Business & Management xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Research in Transportation Business & Management

journal homepage: www.elsevier.com/locate/rtbm

Coupling facility location models in the supply chain of perishable fruits

Javier Arturo Orjuela-Castro[a,*], Lizeth Andrea Sanabria-Coronado[b], Andrés Mauricio Peralta-Lozano[c,d]

[a] Universidad Nacional, Universidad Distrital Bogotá, Colombia
[b] Universidad Distrital Francisco José de Caldas, Bogotá D.C., Colombia
[c] Universidad Distrital, Bogotá D.C., Colombia
[d] Supply Chain, Logistics and Traceability Research Group, GICALyT, Colombia

ARTICLE INFO

Keywords:
Facility location
Mixed linear programming model
Supply chain
Fruits
Perishable food

ABSTRACT

The problem of locating facilities in perishable agricultural food supply chains has not been widely addressed, especially not in urban areas. However, the subject has gotten more attention in recent years due to consumer concerns about food being fresh and healthy. Having reviewed the literature, the authors identified a lack of location models for mountainous urban areas in developing countries. This research proposes a mixed linear programming model for the localization of collection centers and companies processing perishable foods in mountainous regions, based on a multi-product and multi-echelon transport system. The model was evaluated through a case study of fresh fruits being delivered to Bogotá, the capital of Colombia, a developing country with a topography of mountain ranges. As transport and packaging allows the product to be influenced by the variations in altitude, the fruit is exposed to changes in temperature and relative humidity. This is linked to the perishability of the food and its quality at the moment of reaching the final consumer.

1. Introduction

The establishment of new facilities, as well as the expansion, reduction or relocation of existing facilities is usually long-term projects, part of the strategic decision level in the supply chain (Melo, Nickel, & Saldanha da Gama, 2006). Location decisions are a critical aspect of ensuring that a supply chain is efficient. An unsuitable location will lead to an excess of costs that are reflected throughout the operating life of the facilities (Meng, Huang, & Cheu, 2009).

Consumers' concern about the quality of food, health and the environment has increased. In this context, an adequate location of the facilities makes it possible to keep the product fresh by keeping the time of storage and transport between facilities as short as possible (Tong, Ren, & Mack, 2012; Morganti & Gonzalez-Feliu, 2015). Accordingly, in mega-cities the location of facilities is very important to ensure food security and food safety, as well as urban sustainability. For example, Bogotá's metropolitan area, has more than ten million inhabitants and is supplied with perishable food by producers located within a radius of no more than 200 km. This includes collection centers, processing plants and distribution centers as written by Crainic, Ricciardi, and Storchi (2009) and Taniguchi, Thompson, and Yamada (2014).

The location of agricultural facilities is of great importance in developing countries (Morton, Bitto, Oakland, & Sand, 2008), where capitals are mega-cities needing high quantities of food, agricultural production is spread throughout the territory, the average size of farms is small and a large number of farmers often lead to the need for multiple facilities as well as capacity constraints (Lucas & Chhajed, 2004). This type of supply chain must be adapted to environmental needs without neglecting competitiveness (Validi, Bhattacharya, & Byrne, 2014). In these countries, there are few cold supply chains to conserve perishable foods. The products are transported in vehicles that do not isolate from changes in temperature, relative humidity or atmospheric pressure, a critical situation in countries with mountain ranges, such as Colombia (Orjuela-Castro, Casilimas, & Herrera, 2015; Orjuela-Castro, Sepulveda-Garcia, & Ospina-Contreras, 2016). The packaging used also does not favor the conservation of foods (Orjuela-Castro, Herrera-Ramírez, & Adarme-Jaimes, 2016).

This paper aims to propose a model for locating facilities within a topography of mountain ranges, including factors of temperature and relative humidity on the perishability of fresh food, not contemplated by previous research. This is important in mountainous regions, where perishable foods are transported in trucks that do not preserve the organoleptic characteristics of fresh foods, such as fruits and vegetables.

The authors of this paper propose a multi-product and multi-echelon model of mixed linear programming for locating collection centers in

* Corresponding author.
E-mail address: jorjuela@udistrital.edu.co (J.A. Orjuela-Castro).

http://dx.doi.org/10.1016/j.rtbm.2017.08.002
Received 30 November 2016; Received in revised form 10 August 2017; Accepted 21 August 2017

rural areas and processing companies in urban areas, in order to evaluate losses of perishable foods. First, a review of the literature is presented to position this paper in relation to existing works. Then, the research problem and the mathematical model are presented. In order to illustrate the proposed approach, the model is applied in the case study of the fruit supply chain in the Colombian region were Bogotá is located, Cundinamarca. Finally, conclusions are presented and future developments of the presented work are addressed.

1.1. Literature on location models for perishable food distribution

The supply chain of food consists of a network covering production, processing, distribution and even consumption (Calderon & Orjuela Castro, 2004). In the supply chains of perishable foods, for example fruits or meat, a part of the product arrives fresh to the consumer (Orjuela-Castro, Caicedo-Otavo, Ruiz-Moreno, & Adarme-Jaimes, 2016). One of the main issues in freight transport is the location of the distribution centers, important nodes in the logistics systems (Di, Wang, Li, & Wang, 2011). Their location determines network constraints and directly affects the efficiency and effectiveness of supply chain operations (Chen & Zhong, 2013). That is of particular importance in agricultural supply chains for two reasons. Firstly, in comparison to an industrial product an agricultural product has a lower value, higher consumption level, shorter lifespan, a more complex distribution process as well as being more difficult to store. These factors are reflected in higher logistical costs that often lead to an increase in the selling price (Di et al., 2011). Secondly, consumption areas are in general concentrated in cities, whereas production areas are in rural contexts. In developing countries such as Colombia, an important part of the cities' food supply is produced regionally (i.e. about 100–150 km from the city). For these reasons, a suitable location of both processing companies and warehouses in the distribution network is necessary (Khalili-Damghani, Abtahi, & Ghasemi, 2015).

Location problems in the perishable food supply chain (PFSC) have been addressed in various ways such as the P-Median Problems (Tong et al., 2012; Zhi-lin & Dong, 2007; Xiaohui & Wen, 2009; Zhang & Yang, 2007), P-Coverage (Marulanda, Leguizamón, & Niño Mora, 2010), P-Centre (Boudahri et al., 2011), Hubs (Yang, Liu, & Yang, 2012; Etemadnia, Goetz, Canning, & Tavallali, 2015), Multi-product (Zhao & Dou, 2011; Jouzdani, Sadjadi, & Fathian, 2013), Multi-services (Neungmatcha, Sethanan, Gen, & Theerakulpisut, 2013) and trainings. The location and allocation models comprise formulations varying in complexity from a simple linear model to non-linear probabilistic models. Solution algorithms include, among others, local search, genetic algorithms, and approaches based on mathematical programming (Klose & Drexl, 2005).

There are few models that have considered the characteristics of foods and many less those of perishables (Sanabria-Coronado, Peralta-Lozano, & Orjuela-Castro, 2017). Ahumada and Villalobos (2009) conduct a review of the planning and production models applied to agricultural products, classifying models according to the type of product in perishable and non-perishable. Akkerman, Farahani, and Grunow (2010) find that the objective function most treated in the literature is to minimize the total cost of opening facilities in specific places, as well as production and distribution costs for sending products through the distribution network.

The first work done on distribution for perishable products is perhaps that of Federgruen, Prastacos, and Zipkin (1986) where the authors present an allocation model for perishable products. They consider a combined problem of allocation of available inventory and the distribution from a regional center to a given set of locations with random demand.

Gong, Li, Liu, Yue, and Fu (2007) analyze the problem of inventories and location of facilities for agricultural perishable products in China. They propose a model that minimizes the total cost of transportation, level of inventories and quantity of waste in the supply chain. Also in China, Zhi-lin and Dong (2007) develop an optimization model for the location of a logistics distribution center for agricultural products, including an economic analysis of construction and operation.

Huang and Xie (2009) propose a model for the location of food distribution centers. They evaluate efficiency, safety and reliability in order to improve response time, delivery time and operating cost. In the same vein, Xiaohui and Wen (2009) use a model for finding the optimal location of distribution centers for fruits and vegetables in Beijing. They including the space-time relationship to eliminate the discrepancy between the producer and the end user, reduce logistical costs and waste. Hiassat and Diabat (2010) lay out a model for the location of facilities. They determine how many warehouses need to be opened, where to locate them and which customers to allocate to each one. A single supplier distributes a perishable product with a defined lifespan to multiple retailers through a set of distribution centers.

Di et al. (2011) design a distribution network with a model to which they add the distribution centers of perishable agricultural products. Each center has sufficient capacity to serve its area of consumption. It minimizes total cost, including location, inventory, transportation, and damage costs. Boudahri et al. (2011) present a model that seeks to minimize the costs of location and transport and allocates slaughterhouses in the chicken meat distribution chain. It takes into account the capacity of facilities and vehicles. Zhao and Lv (2011) design a model for facility location, including production capacity and mode of transport in an agro-food supply chain, reducing production and transportation costs.

Tong et al. (2012) propose a location model including service schedules for farmers' markets, mobile sales organized directly by farmers to end-customers in the supply chain. It takes into account demand variability, distance and the number of trips the clients make to these places of sale. Yang et al. (2012), on the other hand, present a fuzzy model for travel time and source-destination nodes that minimizes the maximum travel time between each installation. Diatha, Karumanchi, and Garg (2012) propose a model of routing and multi-objective location in the market of mushrooms. The possible locations of distribution centers are known and assigned a distribution channel. It seeks to minimize costs, distances and response times.

Drezner and Scott (2013) propose a model that combines inventory and facility location decisions for perishables. They consider the location of a single distribution center serving a finite number of outlets. They reduce the total cost, consisting of transport and inventory costs, to a minimum. Chen and Zhong (2013) suggest a location model of logistics centers for distribution of perishable products, considering the impact of the perishability on the global distribution cost. It establishes the distribution zones and their respective routes, described with a generic algorithm.

Jouzdani et al. (2013) propose a dynamic model for facility location and supply chain planning for milk. The objective is the optimal location of the facilities and to calculate the right volume of production for minimizing transport costs, considering the traffic on the roads and the uncertainty of demand. Neungmatcha et al. (2013) formulate a model with the objective of finding the optimal location for the installation of sugar cane supply stations, maximizing the use of total capacity and minimizing the total cost.

Firoozi et al. (2014) evaluate the integration between inventory control and facility location. They study how changes in location decisions influence transport costs and affect optimal inventory policy. Govindan, Jafarian, Khodaverdi, and Devika (2014) propose a multi-objective optimization model in a perishable food supply chain that integrates sustainability with the determination of the number and location of facilities, optimizing the quantity of products delivered and the routes through which the distribution is made.

Etemadnia et al. (2015) examine the location of wholesale facilities in a PFSC for fruits and vegetables to facilitate the transfer between production and consumption sites. To minimize the total cost of the network, they include transportation costs and the cost of locating each