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A novel facility and equipment selection model for whey utilisation: A Brazilian case study

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ABSTRACT

Whey is a by-product of cheese making that is a potentially important source of nutrients, but which currently goes to disposal in many parts of the world. In this paper, we analyse the efficiency of investment in whey-processing with the aim of releasing the productive potential of currently unexploited whey supply chains. We introduce a decision support model for production and distribution of products derived from whey that extends a globally inclusive facility location problem. The basic tenet of the model is that equipment selection during the initial stages of facility planning is critical, as capital costs in the early stages of supply chain design go into purchases of new machines and site conditioning. The model selects the optimal combination of whey processing equipment, facility locations and transportation routes subject to budget, equipment availability and final product requirements. The results from the model inform the members of a cluster of cheese makers on the infrastructure investments that better release the productive potential of the supply chain of their valuable by-product and, at the same time, avoid environmental damage. We use the model to find the optimal configuration of a whey supply chain for an actual cluster of small cheese makers in Minas Gerais, Brazil, and demonstrate that important savings can be achieved by investing early on in adequate processing facilities.

1. Introduction

Achieving better utilisation of the whey produced by small cheese manufacturers is a common challenge in countries where dairy is an important economic activity. In Brazil, for example, Wissmann et al. (2012) reported on the environmental and economic losses caused by disposing of whey in the environment. They noted that, on average, each tonne of untreated whey is equivalent to the daily effluents of a settlement of 470 people and concluded that treating whey can significantly reduce the environmental cost from 5.59% of the total operational costs to 3.98%, a relative reduction of 29%. A case of particular interest is the state of Minas Gerais, which concentrates 30% of Brazil's dairy industry. From its 12 regions, Triângulo Mineiro/Alto Paranaíba is the most important, with 1.8 million kilolitres per year, followed by Sul/Sudoeste with 1.3 million kilolitres, and by Zona de Mata, with 0.762 million kilolitres. In terms of processing capability, Minas Gerais is the state with the highest number of dairy companies and the highest volume of processed milk, with 31.7% of the total volume produced by the Brazilian dairy industry (Institute for Industrial Development of Minas Gerais, 2003).

Whey is a by-product of cheese making that is also a potentially important source of nutrients. Although the nutritional value of whey has been known for decades, for a long time it was considered by the cheese makers as a by-product of low commercial value. This situation changed after the discovery of functional and bio-active properties of its components, mostly of whey proteins, which have been found to affect physiological responses of

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animals (Gauthier and Pouliot, 2003; Ha and Zemel, 2003). Today, there are profitable markets that transform this by-product into high value-added products with application in dairy, meat, dry foods, bakery, confectionery, food supplements, drinks and pharmaceuticals, among others.

Despite this potential, approximately half of the world's whey production goes to waste or to animal feed without any further treatment, mostly in developing countries (Durham et al., 2004). The disposal of whey in the environment causes considerable damage due to its high biochemical oxygen demand (BOD), resulting from the presence of lactose and proteins (Siso, 1996). To avoid this damage, it is necessary to design and build efficient whey processing facilities using the most viable technical and economical configuration of the whey process chain, taking into account transportation logistics, location of processing facilities and available equipment.

1.1. Existing work on decision support tools for the dairy supply chain

Previous research has partially addressed some aspects of this problem. Regarding milk processing and facility location, Wouda et al. (2002) presented a study to re-design the supply chain of a major Hungarian dairy company after major consolidation. They used a mixed-integer linear programming model to find the optimal number of plants, their locations and the allocation of the product portfolio to these plants, while minimising the sum of production and transportation costs, without considering equipment alternatives. Basnet et al. (1999) reported a scheduling system to allocate runs to milk tankers that collect milk from farms for processing at a central location, and proposed a heuristic to successfully solve problems of practical importance. Baklieva-Bancheva et al. (2007) presented a more ambitious, multi-objective study that aimed at assessing the trade-off between the interests of milk vendors, consumers and retailers. Banaszewska et al. (2013) presented a comprehensive dairy valorisation model that serves as a decision support tool for mid-term allocation of raw milk to end products and production planning. The linear programming model was used to analyse the effect of seasonality in milk valorisation, which proved useful for the company under study. Although this model is very complete and well suited for its purpose, it does not assist the decision maker in selecting equipment at the processing sites, as is the case for the model introduced in the present paper. Recently, Bilgen and Çelebi (2013) presented a multi-period model to optimise the production and distribution schedules of a Turkish dairy producer. The model is a hybrid, simultaneous optimisation and simulation model where simulation is used to adjust operation times.

Regarding the logistics of production, Doganis and Sarimveis (2008) presented a customised mixed integer linear programming model for optimising packaging lines of dairy products that consist of multiple parallel machines. Geary et al. (2010) developed a model that simulates milk collection, standardisation and product manufacture, aimed at determining the best product mix considering market conditions such as prices and demand. Although this model is quite detailed in regards to production and also considers re-utilisation of by-products, it falls short on suggesting the best equipment for producing the optimal product mix.

Regarding the optimisation of the technology used for whey processing, Pinto and Giordano (2009) presented an integrated environment for simulation, monitoring, control and optimisation of a cheese whey refinery. This model was also developed partly to avoid the disposal of whey by small producers, and aimed at validating experimental data; however, it was not concerned with selecting optimal facility locations and equipment. The closest approach to the equipment selection methodology we propose is, to the best of our knowledge, presented in Almutawa et al. (2005). Although not directly concerned with the dairy industry, this paper clearly articulated the idea that equipment selection during the initial stages of facility planning is critical, as most capital costs incurred are related to investment in new machinery. In the present paper, we use this idea to extend a globally inclusive facility hierarchy problem (Daskin, 2013), which to-date has been used only in the services industry.

Most logistics and production models in the dairy industry are deterministic. An exception is the work of Guan and Philpott (2011), who presented a multi-stage stochastic programming model that takes into account uncertain milk supply, price-demand curves and contracting. The model was solved using a decomposition algorithm, and produced approximately optimal policies that outperform deterministic policies in simulations. Although the model we introduce in the present paper does not consider variability explicitly, it represents a first step towards the development of a stochastic model, which remains an objective for further research. The interested reader may refer to Kelly (2007) and Jelen (2009) for details on whey properties, products and processing, which are beyond the scope of the present paper, and to Melo et al. (2009) for a complete review on facility location and supply chain management.

1.2. Objectives

The contribution of the present paper is twofold. The first contribution is to introduce a novel formulation that extends a *globally inclusive facility hierarchy problem* (Daskin, 2013) to allow for whey *equipment selection*. The selection of the right equipment in the early stages of supply chain design is critical, given the large proportion of capital costs that purchases of new machines and site conditioning represent. To the best of our knowledge, this type of models (also known as *successively inclusive service hierarchy*) has been used only in the services sector (e.g., Santibáñez et al., 2009), not needing to account for processing equipment at the facilities. The model we present aims at selecting the optimal combination of whey processing equipment, facilities and transportation routes subject to budget, equipment availability and final product requirements, in order to inform the members of a cluster of cheese makers on the infrastructure investments that better release the productive potential of their valuable by-product and, at the same time, avoid environmental damage. It addresses the following questions: What is the most viable technical and economical configuration of the whey process chain? What routes, facilities and processing equipment should be selected? What configuration alternatives are feasible, and what is the trade-off among them?

The second contribution is to explore optimal configurations of the whey supply chain for an actual cluster of cheese producers in Minas Gerais, Brazil, using data from surveys prepared by the Center for Graduate Studies and Research in Business Administration of the Federal University of Minas Gerais (Martins et al., 2013). We analyse the effect on this system of changing the budget available for construction, the transportation costs and the availability of equipment, and demonstrate that considerable savings can be achieved by investing early on in adequate processing facilities.

The remainder of the present paper is structured as follows: Section 2 introduces the whey supply chain and the case study, including an outline of the methodology for equipment selection. Section 3 presents the linear programming optimisation model and introduces the scenarios, and Section 4 presents and discusses the results. Section 5 rounds up the discussion and identifies future work. Appendix A contains the nomenclature and full formulation, and Appendix B explains the preprocessing stage and provides