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# Production and logistics planning in the tomato processing industry: A conceptual scheme and mathematical model

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ABSTRACT

This paper presents a conceptual scheme of the production and logistics planning problem faced by Brazilian tomato processing industry and proposes a linear programming model that appropriately represents and supports decision making in agricultural and industrial activities. Tactical planning decisions in the tomato processing industry are related to the size of tomato areas, choice of tomato varieties to be cultivated, planting and harvest periods, transporting tomatoes from agricultural fields to processing plants, the production of semi-finished products (concentrated tomato pulps) and final products to consumers, as well as managing inventories and transportation of these products to warehouses in the plants. The model has been tested using real data and the solutions for the production and logistics plans compared to the data have demonstrated the model's potential to be used in practice for planning the whole tomato season and industrial key activities, as well as exploring the sensitivity analysis of the problem data.



## 1. Introduction

Tomato crops for processing are subject to environmental constraints, which impose production seasonality due to climate and land use conditions. The demand of manufactured tomato-based products has experienced fluctuations due to market behaviors, particularly related to different regions worldwide and periods of the year. Data from the Food and Agriculture Organization of the United Nations (FAO) show that the tomato is the second most produced vegetable crop in the world. In Brazil, the tomato sector (fresh and processing) occupies the $12^{th}$ position in quantity among all agricultural products, surpassing the production of potatoes, beans, pork, cotton, and other economically important products (IBGE, 2014).

Tomato crops have a production cycle which lasts from 100 to 120 days, mainly according to the characteristics of variety and climate conditions while the plants are growing. There are several tomato varieties available on the market offered by seed companies, having distinguished agronomic features (yield, disease and weed resistance, maturity curve etc.) and also industrial ones (soluble solids content, pulp color, fruit firmness etc.). All these features make decisions concerning agriculture and industry difficult to be analysed and to be taken, especially regarding the choice of the tomato varieties for the producing regions, as well as planning the cultivation calendar to meet industrial requirements. The soluble solids content, measured in degree brix (symbol °Bx) can be considered the most important industrial feature, which means the sugar content in an aqueous solution. One degree brix is equivalent to 1 gram of sucrose in 100 grams of solution. This unit is often used to express the concentration of soluble solids in tomatoes and concentrated tomato pulp.

In the tomato processing industry, tactical decisions refer to planning the annual crop, i.e., the size of cultivated areas and the planting and harvesting periods, as well as planning the industrial aggregate production and managing the inventories of concentrated tomato pulp and final products for consumers. Analyzing tactical decisions related to the production of concentrated tomato pulps and final products is particularly challenging due to uncertainties in the supply of tomatoes, and consequently in the final products to meet the demand of the markets. In practice, companies in this industry plan the tomato cultivation in producing regions by designing a presumable scenario of the tomato season. During the growing season, agricultural teams hold weekly meetings to monitor field activities.

Weather conditions are the main concern for the tomato processing industry, since the plants can be seriously damaged by rainfall, and it is not possible to carry out farming operations in heavy rainy periods. In good weather conditions (i.e. no rainfall),

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agricultural teams often plant more tomato areas than planned in contrast to few planted areas when the climate is unfavorable. Planting more in some periods and less in others, seriously affects the industry due to an excess or lack of tomatoes at harvesting time. Thus, production and logistics costs increase, either due to physical losses of tomatoes in long unloading queues, as demonstrated by Gameiro et al. (2008), or to idleness of industrial facilities.

The processing tomato season usually extends for four months, whereas the demand of tomato-based products is throughout the year. These features are conflicting between the objectives of the agricultural teams, which aim to maximize the tomato production during the harvest, and the targets of industrial teams, who attempt to adjust their production according to market demands. These conflicts are partially solved by transforming the harvested tomatoes into semi-finished products (concentrated tomato pulps), which are then stored and subsequently consumed throughout the year.

These are examples of management issues that the tomato processing industry faces annually in crop and industrial planning, which could be analysed by using mathematical programming models combined with optimization tools. Some agribusiness sectors in Brazil and worldwide have faced tactical production and logistics planning problems. In some studies, models and decision support tools were reported in the literature, such as in the citrus industry: Caixeta-Filho (2006), Munhoz and Morabito (2014), Ferreira et al. (2016); sugarcane: Higgins et al. (2004), Kawamura et al. (2006), Paiva and Morabito (2009); grains: Junqueira and Morabito (2012), cellulose pulp: Santos and Almada-Lobo (2012); fishery: Albornoz and Canales (2006), among others.

The contribution of this study is to present a conceptual scheme of the production and logistics planning problem for the tomato processing industry and to propose a mathematical model, which appropriately represents and optimizes the key agricultural and industrial tactical planning decisions. We also intend to contribute to developing a decision support tool for this industry. To the best of our knowledge, we are not aware of any other study in this line of research for the tomato processing industry. Furthermore, we took this opportunity to briefly describe the tomato processing industry in Brazil.

Besides this introduction, this paper is organized as follows: in Section 2, we concisely describe the Brazilian tomato processing industry and review the related literature. The conceptual scheme of the production and logistics planning problem is presented in Section 3. The mathematical model is described in detail in Section 4 and its computational results are discussed in Section 5. Finally, in Section 6, we draw some conclusions and offer perspectives of further extensions of this study.

## 2. The tomato processing industry in Brazil and a literature review

Worldwide the annual processing tomato production has fluctuated between 30 and 40 million tons in recent decades. The Northern hemisphere contributes with approximately 85% of the world production, particularly the United States of America, China, Italy, Spain, Turkey, Iran and Portugal. In the Southern hemisphere, Brazil and Chile are the only countries where there are significant productions, participating globally with 4% and 2%, respectively. Over many years, the tomato processing industry has been known for its stability of production capacity, both in increasing and reducing, as it depends on investing in buying equipment, building new facilities or closing down ones that were already working. These events require a significant amount of financial and time resources. Another reason that contributes to the stability is the availability of irrigated areas for growing tomatoes, which hardly ever changes significantly from one year to the next.

In most countries in the Northern hemisphere, the growing season does not usually coincide with other vegetables. In particular, in the United States (~35% of the world production), the extensive areas in California (~95% of the US production) are furrow irrigated and are not allocated to other crops in the same time period. In the Southern hemisphere, the irrigated areas suitable for growing tomatoes are highly competitive with other crops at the same time, particularly for the production of corn seeds.

In Brazil, the average annual production of tomatoes for processing was about 1.3 million tons in recent decades (WPTC, 2015). According to available data from the Brazilian Institute of Geography and Statistics (IBGE), the average area cultivated with tomatoes (fresh for direct consumption and processing purposes) from 2000 to 2010 was approximately 56 thousand hectares (IBGE, 2014). The fieldwork of Rocco (2014), jointly with Brazilian tomato processing companies, estimated that in the last decade (2001–2011), growing tomato areas have been divided into approximately 60% for fresh tomatoes, around 33.5 thousand hectares, and the remaining 40% for processing tomatoes (22.5 thousand hectares). The geographic distribution of fresh and processing tomato productions in Brazil is quite different. Fresh tomatoes are produced in almost every part of the country and near consumption centers, on medium to small size farms, using the staking method for plant fastening, and furrow or drip irrigation. Tomato production for processing is concentrated in specific regions, mainly in the states of Sao Paulo, Minas Gerais and Goias. This is due to the plant climate requirements, particularly for warm and dry locations, and the availability of extensive irrigated areas; mainly by using drip or sprinkler (center pivot) methods.

Cultivation of fresh tomatoes extends throughout the year, while processing tomatoes have a specific crop calendar. Planting processing tomatoes takes place specifically from March to July, and harvesting from June to October. The climate is responsible for determining the specific cultivation periods and farming operations. A cultivation calendar of processing tomatoes in Brazil is illustrated in Fig. 1, where number 1 means the first fortnight of the month and number 2 means the second one. The activities are concentrated in periods of low rainfall in the producing regions.

The agribusiness chain of the tomato processing industry can be exemplified using a flowchart, as shown in Fig. 2. Initially, there are suppliers of production inputs, i.e., agrochemical companies of pesticides and fertilizers, and firms that produce tomato seeds and seedlings. Often the tomato processing companies establish direct relations with these suppliers in order to make aggregate purchases to supply their tomato growers. This relationship is marked by bargaining power between the parties due to the amounts traded. Moreover, discounts in prices of goods and services are normally observed due to the economy of scale. Tomato growers can supply processors, which transform tomatoes into only semi-finished products (concentrated tomato pulps) or may also manufacture final products (ketchup, sauces, soups etc.) for the end consumers.

Some companies operate by buying concentrated tomato pulps from the market, without dealing with farmers, and they only produce final products. Companies in the logistics branch, i.e. those that are responsible for distributing and storing manufactured products, provide services to processors, aligned with wholesalers, food service and retailers. These companies vary in size and scope of operations, and contribute significantly to how the final price of the product is calculated for consumers due to their margins. Final consumers may be grouped into different categories, particularly related to their income; which usually determines preferences and consumption patterns. It is noteworthy that the relations described for the flowchart in Fig. 2 are arbitrary and lend