OPTIMIZING RAW MATERIAL PURCHASES AND SALES ALLOCATION IN THE JUICE AND CONCENTRATE EXTRACTION AGRIBUSINESS: THE CASE OF A SMALL COMPANY IN COSTA RICA°

OTIMIZAÇÃO DA COMPRA DE MATÉRIA-PRIMA E ALOCAÇÃO DE VENDAS NO AGRONEGÓCIO DE EXTRAÇÃO DE SUCOS E CONCENTRADOS: O CASO DE UMA PEQUENA EMPRESA NA COSTA RICA

Johanna Solorzano Thompson[*]
Javier Molina Paniagua[**]
Nicole Valeria Víquez Ramírez[***]

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Abstract

This article presents an optimization model for raw material purchase and sales allocation, developed using linear programming techniques to enhance the performance of a company in the agro-industrial sector. The study focuses on the production of concentrated fruit juices, which is carried out using two daily-operated production and packaging lines with different capacities. By analysing monthly machinery capacity and efficiency requirements, fruit supply availability, and customer demand, the proposed model significantly improved operational efficiency and positively impacted the company's profitability.

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[*] Universidad de Costa Rica, Costa Rica. ORCID: https://orcid.org/0000-0002-0276-6849. E-mail: johanna.solorzano@ucr.ac.cr

[**] Universidad de Costa Rica, Costa Rica. ORCID: https://orcid.org/0000-0003-2815-5437. E-mail: javier.paniagua@ucr.ac.cr

[***] Universidad de Costa Rica, Costa Rica. ORCID: https://orcid.org/0000-0001-6101-3540. E-mail: nicole.viquez@ucr.ac.cr

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JEL Codes: B23, C44, C61, L23

Resumo

Este artigo tem como objetivo desenvolver um modelo de otimização de compra de matéria-prima e alocação de vendas desenvolvido a partir de modelos de programação linear para o fortalecimento de uma empresa do setor agroindustrial. A área fabril, na qual este estudo foi desenvolvido, é a produção de sucos de frutas concentrados, utilizando duas linhas de produção e envase para uso diário, mas com capacidades diferentes. O modelo proposto aumentou significativamente a eficiência da operação atual e impactou positivamente a lucratividade da empresa com a análise dos requisitos mensais de capacidade e eficiência do maquinário, fornecimento de fornecedores de frutas e demandas de clientes atuais.

Palavras-chave: programação linear, sucos de frutas, distribuição, compra de materiais, custos
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INTRODUCTION

Suppliers play a crucial role in an organization's value chain, as they contribute to optimization, efficiency, and overall performance. Therefore, it is essential to implement effective methods for selecting, evaluating, and reassessing suppliers to ensure they meet the required capabilities and standards. This approach is grounded in the integration of suppliers into the product development process, which enhances collaboration and helps generate a competitive advantage (Jiménez Tang-Chang, & Rosas Martínez, 2015). However, while outsourcing enables firms to concentrate on their core activities, reliance on suppliers also introduces certain risks, such as non-compliance, delays, or supply disruptions (Ruiz Torres, Ablanedo Rosas, & Ayala Cruz, 2012).

Operations management is another key determinant of an organization's competitiveness, particularly in relation to factors such as price, quality, delivery reliability, and flexibility. These four elements are directly linked to the company's operational efficiency, which in turn depends on accurately determining competitive prices and market demand (Sáenz, 2005). Therefore, operations must be optimized to match customer expectations while ensuring the efficient use of resources, including machinery, labour, tools, and facilities (Sotero Trujillo, 2020).

As previously noted, in the production sector, the quantities to be manufactured must align with scheduling constraints, market demand, and plant capacity, while also meeting the requested specifications. Planning supported by mathematical techniques enables defining objectives, selecting and allocating resources, and developing strategic plans. Linear programming is one of the most effective quantitative tools for decision-making and resource optimization (Fernández, 2011). By applying such methods, organizations can identify the best option among a set of alternatives, determining the most efficient way to allocate raw materials or other resources in order to maximize profits or minimize costs (Alvarado Boirivant, 2009).

Transportation is another factor that influences an organization's competitiveness, as it constitutes a significant component of logistics costs and, consequently, affects the final marketing price of a product or service. Effective transportation management enables companies to meet delivery deadlines at competitive prices, thereby enhancing their own operational efficiency as well as that of downstream actors in the supply chain. However, transportation requires a high degree of coordination and precision to respond to unforeseen changes and both external and internal factors. Poor management of these elements can result in significant inefficiencies. Accordingly, implementing transportation optimization models supports more efficient operational processes (Flores Torres et al., 2019).

The purpose of this article is to develop a linear programming model for optimising raw material purchase and sales allocation, aimed at enhancing the performance of a company in the agro-industrial sector.

I. LITERATURE REVIEW

Juice production is a widely accepted and practical method of fruit consumption, driven by its ease of processing, the demand for liquid food products, and its content of functional ingredients, such as vitamins. By enabling the dissolution of these components, juice processing extends the shelf life and availability of fruits while also allowing for the use of surpluses from other production lines (Gamboa et al., 2016).

The agro-industrial sector generates significant amounts of waste from the processing of natural products, including peels, skins, stems, residual pulp, and other plant materials. Due to their high content of polysaccharides and fibre, these by products are increasingly being used as functional food ingredients (Fraguela et al., 2023). In addition, the selection process of certain foods produces substantial waste, contributing to agro-industrial losses during the transformation of raw materials. Although such losses could serve as valuable sources of protein, strict quality control standards often result in their classification as rejected materials unfit for export (Acosta Fernández, 2020).

Costs refer to the resources required to produce a good or service with the aim of generating income. In this context, production costs consist of direct materials, direct labour, and indirect manufacturing costs. Indirect costs include expenditures related to indirect materials, indirect labour, and other supporting activities. To enhance productivity and reduce labour and material inputs, organizations rely on equipment such as tools and machinery, which are associated with depreciation, energy consumption, and fuel usage—components typically classified as indirect production costs (Cabrera De Palacio, 2018).

According to the study by Echeverría Ríos et al. (2021), on various conceptualizations of the term *price*, it refers to the sum of values exchanged by the consumer to obtain the benefits associated with a product or service, typically through the payment of a specific amount of money. However, beyond monetary value, other elements that provide utility to the consumer are also considered in the purchasing decision. This broader view of price establishes a conceptual link between the economy, consumers, and organizations.

A distribution channel refers to the pathway through which an organization obtains goods—often directly from the producer—for subsequent distribution or resale. It encompasses the entire process by which products move from the manufacturer to the end user. In the agricultural and agro-industrial sectors, the distribution channel spans the product's journey from cultivation to final consumption, which may include delivery to hotels, restaurants, or other end points. This process typically involves multiple intermediaries responsible for distribution logistics. However, such intermediation can reduce producers' profit margins while increasing profits at each stage of the distribution (Rosas, 2020).

In organizations, suppliers play a crucial role in meeting customer needs by providing products and services in accordance with specified requirements. Effective supplier management contributes to the optimal functioning of a company and involves a negotiation process between the buyer and the supplier aimed at securing the highest possible quality at a competitive price (Torres Avila et al., 2021). The supplier selection process must consider both the supplier's ability and willingness to deliver the requested products and services under pre-established conditions, such as quality, price, service, and payment terms. In addition, organizations must account for the variability in market behaviour, which can affect the qualitative and quantitative characteristics required (Sarache Castro et al., 2009).

In a successful supplier-customer relationship, the supplier must meet the established specifications and requirements, which are typically formalized through a binding contract or agreement. Consequently, companies must evaluate and select suppliers based on their capacity to deliver the requested products or services. This process involves ongoing assessment and periodic re-evaluation to ensure that the selected suppliers remain the most appropriate for the organization (Yacuzzi, 2012).

Operations research addresses decision-making and resource management problems through a quantitative approach. By analysing problematic situations, it identifies key variables and their interrelationships within mathematical models, which offer multiple potential solutions and help determine the optimal one to improve the given conditions. In essence, operations research provides a mathematical framework for efficiently solving complex problems (Velásquez Restrepo et al., 2013). The process begins with observing and formulating the problem through data collection. Next, a mathematical model is constructed that captures the problem's core aspects, thereby ensuring the validity and effectiveness of the resulting solutions (Jiménez Tang-Chang & Rosas Martínez, 2015).

Linear programming is a planning tool that aims to identify the optimal solution to a specific problem using an optimization procedure. Through constrained optimization models, organizations can make administrative decisions that optimize a set of feasible values for decision variables, subject to defined restrictions and an objective function. In other words, decision variable values must be selected according to the constraints and guided by either maximization or minimization goals (Epen el al., 2000).

According to León, Díaz, and Orendain (2007), linear programming enables the optimal allocation of machinery within an organization's production system, identifying which products each machine should process according to its capacity and customer requirements. Additionally, the transportation model facilitates the optimal distribution of goods by determining the most cost-effective routes and shipment quantities, taking into account the origin, destination, and transportation costs of the supplies. One of the most commonly used methods for solving linear programming problems is the Simplex method, which can be implemented using tools such as Excel Solver. This approach is particularly useful in the fields of business, finance, and administration. Supporting this, Eppen et al., (2000) described the Simplex method as an efficient optimization algorithm that fits a model to identify the optimal solution under a set of linear constraints.

II. METHODOLOGY

II.1. Data

The study was carried out in 2022 at a small-sized company[1] located in San José, Costa Rica, dedicated to the extraction of juices and concentrates. The company offers three products: mixed concentrated fruit juice (pineapple, papaya, and orange), concentrated orange juice, and concentrated cas[2] juice.

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1 According to the OCDE company-size classification, this company is considered small, as it has15 employees.

2 Cas is a tropical fruit (*Psidium friedrichsthalium*), similar to guava.

To meet raw materials needs, eight suppliers were evaluated, and three were ultimately selected, as not all were able to supply the full range of products or the quantities demanded by the industry. Given the presence of two production and packaging lines, and in view of projected production levels for the coming years, a purchasing standardization strategy was implemented. Under this strategy, the selected suppliers agreed to maintain the same proportion of the total demand they have supplied in recent years.

As a result of the strategy described above, the quantities supplied, the unit purchase costs of the fruit, and the transportation costs for each supplier are shown in Table 1.

Table 1. Allocation of fruit purchases by supplier

Supplier A	Supplier B	Supplier C
Pineapple: 35% share of total fruit demand, with a purchase cost 15% above the market price, and a transport cost of USD 0.012 unit/km.	Pineapple: 40% share of total fruit demand, with a purchase cost 12% above the market price, and a transport cost of USD 0.02 unit/km.	Pineapple: 45% share of total fruit demand, with a purchase cost 15.5% above the market price, and a transport cost of USD 0.013 unit/km.
Orange: 45% share of total fruit demand, with a purchase cost 10% above the market price, and a transport cost of USD 0.013 unit/km.	Orange: 45% share of total fruit demand, with a purchase cost 11% above the market price, and a transport cost of USD 0.012 unit/km.	Cas: 65% share of total fruit demand, with a purchase cost 12% above the market price, and a transport cost of USD 0.011 kg/km.
Papaya: 65% share of total fruit demand, with a purchase cost 12% above the market price, and a transport cost of USD 0.03 kg/km.	Cas: 65% share of total fruit demand, with a purchase cost 13% above the market price, and a transport cost of USD 0.010 kg/km.	Papaya: 65% share of total fruit demand, with a purchase cost 12% above the market price, and a transport cost of USD 0.035 kg/km.
Cas is not transported.	Papaya is not transported.	Orange: 40% share of total fruit demand, with a purchase cost 12% above the market price, and a transport cost of USD 0.0135 unit/km.

Note: The distance from each supplier's facility to the processing and extraction plant is measured in kilometres: Supplier A, 8 km; Supplier B, 7 km; Supplier C, 7.5 km. Source: Own elaboration.

Throughout the study period, data were collected on fruit reception at the plant, including quality assessments and waste percentages. Table 2 shows the rejection rates by supplier and by fruit, primarily due to non-compliance with quality and safety standards, among other factors.

Table 2. Rejection rates due to quality issues at the plant, by product and supplier

Supplier	Pineapple	Papaya	Orange	Cas
A	5%	5%	7%	NA
B	4%	NA	8%	5%
C	6%	5%	6%	4%

Source: Own elaboration.

In addition to fruit selection, data were collected from the peeling process, which involves removing the peel and other non-usable parts prior to initiating the juice production cycle. On average, the usable proportion of each fruit was 90% for papaya, 80% for pineapple, 75% for orange, and 80% for cas.

To produce fruit juices, each batch required 250 g of papaya, 6 oranges, 1 125 g of pineapple, and 0.6 L of water. For cas pulp, 14 units per litre and 0.65 L of water were used; for orange juice, 10 oranges per litre and 0.25 L of water were used. The company does not maintain initial or final inventories of raw materials or finished products. The fruit purchasing analysis was conducted using kilograms for papaya and pineapple, and units for orange and cas. Subsequently, all data were converted to litres of juice.

Two production lines were used (L1 and L2), with daily production capacities of 4 000 and 5 600 litres of juice, respectively. The production was distributed as follows: 34% fruit juice, 45% orange juice, and 21% cas juice. The efficiency of each line by product type is shown below (Table 3).

Table 3. Production line efficiency for fruit juice processing

Production Line	Pineapple	Papaya	Orange	Cas
L1	95%	95%	95%	95%
L2	85%	90%	95%	87%

Source: Own elaboration.

Monthly direct and indirect costs were calculated based on the industry's cost model, including labour, materials, depreciation, and administrative and financial expenses associated with the operation (Table 4).

Table 4. Direct and indirect manufacturing costs per litre of juice (in USD).

Production Line	Fruit	Orange	Cas
L1	4.06	3.77	3.54
L2	3.62	3.45	3.00

Source: Own elaboration.

At the commercial level, the company sells its products through several distribution channels: supermarkets (C1), brick-and-mortar stores (C2), fast food restaurants (C3), and vegan food restaurants (C4). Table 5 presents the sales prices for each type of juice by distribution channel.

Table 5. Unit sales prices per litre of juice (in USD)

Company	Fruit	Orange	Cas
C1	4.11	3.80	3.54
C2	4.49	3.77	3.63
C3	4.19	3.80	3.64
C4	4.21	3.81	3.59

Source: Own elaboration.

Maximum demand is determined by the available supply, as customers are willing to purchase as much as possible. Customer 1 has a minimum demand of 6 000 litres of fruit pulp, 10 000 litres of orange pulp, and 20 000 litres of cas. Customer 2 requires at least 5 000 litres of fruit pulp, 8 000 litres of orange pulp, and 12 000 litres of cas. Customer 3 demands a minimum of 9 000 litres of fruit pulp, 8 500 litres of orange pulp, and 6 500 litres of cas. Customer 4 has a minimum demand of 1 000 litres of fruit pulp and 14 000 litres of orange pulp, with no minimum demand for cas, but would purchase as much of it as possible.

II.2 Model

Based on the information collected, two linear programming models were applied. The first aimed to identify the optimal quantity of fruit from each supplier to assign to each production line, considering both the capabilities of each supplier and the processing capacity of each machine. The analysis was conducted on a monthly basis, following the production requirements determined by market demand and the seasonality of the different fruit harvests. The proposed approach was solved using a transportation and resource allocation model to minimize costs for the company.

The transportation model was formulated as follows through the objective function:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} L_{ij}X_{ij} \tag{1}$$

Where:
i: each supplier, $i = 1,2,3 \ldots n$
j: each production line, $j = 1,2,3 \ldots m$
L_{ij}: priority level of assignment of supplier i for production line j
X_{ij}: priority level of assignment of each fruit provided by supplier i to production line j

The model includes the following constraint: the processing capacity of each production line must not be exceeded.

$$\sum_{i=1}^{n} Lij \leq QL \tag{2}$$

Where:
QL: production capacity of the machine.

Another constraint ensures that the quantity of fruit assigned to the production lines does not exceed the required amount:

$$\sum_{j=1}^{m} Xij \leq QX \tag{3}$$

Where:
QX: quantity of fruit needed for production.

In addition, the approach included an optimization model for the delivery of the different types of juice to the four types of customers, with the aim of maximizing profits using the data provided in Tables 4 and 5.

The linear programming model presented the following form, using the objective function:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} CijXij \tag{4}$$

Where:
i: delivery rate to each customer, *i* = 1,2,3…n
j: delivery rate per production line, *j* = 1,2,3…m
C*ij*: priority level of allocation of juice produced in line *j* to customer *i.*
X*ij*: priority level of allocation of juice *j* to customer *j*.

The model also incorporated constraints to ensure that the minimum and maximum monthly demand for each type of juice by each customer was met, avoiding shortages or oversupply:

$$\sum_{j=1}^{m} X_{ij} \leq \text{or } \geq QX \tag{5}$$

Where:
QX: quantity of juice (in litres) requested by customers, representing both minimum and maximum demand levels.

III. RESULTS AND DISCUSSION

The Solver complement solution uses an algorithm based on the Simplex method to solve linear programming problems. The optimization model identified the most cost-effective distribution of fruit purchases among the selected suppliers, which is presented in Table 6. This allocation results in a total monthly agro-industrial cost of USD 61 681.36. A total of 38 199 kilograms of pineapple, 19 082 kilograms of papaya, 1 644 300 oranges, and 74 256 cas fruits are used.

Table 6. Optimized fruit purchase allocation for juice production, in kilograms per production line.

L1				
Supplier	Pineapple	Papaya	Orange	Cas
A	7 876	7 449	86 326	0
B	3 333	0	466 159	28 654
C	10 223	3 465	406 690	13 330
L2				
Supplier	Pineapple	Papaya	Orange	Cas
A	6 162	5 574	61 661	0
B	2 607	0	332 971	22 026
C	7 998	2 593	290 493	10 247

Source: Own elaboration.

Optimization model 2 produced the results presented in Table 7, where each production line operates at its maximum fruit processing capacity and converts the input into to respective types of juice.

Table 7. Optimized monthly juice production by production line.

Product Type	Production Line	Assigned Capacity (litres)	Condition	Maximum Capacity (litres)
Fruit Juice	L1	37 800	≤	37 800
Orange Juice	L1	50 400	≤	50 400
Cas Juice	L1	23 800	≤	23 800
Fruit Juice	L2	27 000	≤	27 000
Orange Juice	L2	36 000	≤	36 000
Cas Juice	L2	17 000	≤	17 000

Source: Own elaboration.

The results presented in Table 8 indicate the optimal monthly allocation of each type of juice to meet the minimum requirements of each customer, yielding a maximum monthly profit of USD 73 000.89. This represents a 14.5% increase compared to the profit obtained before applying the model. In addition, the table shows the most efficient distribution of production from each line to the respective customer.

Table 8. Optimal monthly allocation of juice production by customer and production line (in litres)

Customer	Juice Type	Production Line 1	Production Line 2
	Fruit Juice	6 000	0
1	Orange Juice	10 000	0
	Cas Juice	20 000	0
	Fruit Juice	22 800	26 000
2	Orange Juice	0	8 000
	Cas Juice	3 800	8 200
	Fruit Juice	9 000	0
3	Orange Juice	27 400	0
	Cas Juice	0	8 800
	Fruit Juice	0	1 000
4	Orange Juice	13 000	28 000
	Cas Juice	0	0
Condition		=	=
Assignment		112 000	80 000

Source: Own elaboration.

The model was applied over a three-month period to validate its performance, as the company did not have a predefined purchasing strategy. The results demonstrated its adaptability to the company's production conditions and supplier availability.

Compared to other studies, Flores Tapia et al. (2021) showed that shipping quantities and costs significantly influence total company expenses, reporting a 20% cost reduction when the model was periodically analysed and projected for the following year. Similarly, a study in textile industry achieved production optimization without the need for additional machinery, resulting in a 2.78% increase in the capacity of the production centres, nearly doubling their initial output (Arredondo et al., 2017).

Finally, Peña Florez and Rodríguez Rojas (2018) selected three out of seven suppliers to determine the supply quantities based on product size requirements and each supplier's capacity to meet demand. Their findings indicated that a one-unit increase in the capacity of the main supplier would result in a 3% reduction in total costs.

CONCLUSIONS

The model proved to be a flexible and user-friendly tool for industry personnel, who successfully learned to manage its parameters, collect relevant data, and update it as needed. This enabled to establish a data-driven decision-making mechanism based on mathematical functions, providing sufficient information to identify suppliers, coordinate sales, and schedule production efficiently and optimally. Therefore, the model is expected to be integrated into automated purchasing and inventory allocation systems, contributing to greater automation within the industry and a reduction in error rates.

The data generated by the model facilitates the analysis of financial structures and supports the improvement of individual profit margins by strengthening negotiations with customers and suppliers, especially when a customer's profitability is low and vulnerable to fluctuations in raw material costs.

Given that supplier selection is a critical factor in an organization's operations, this study makes it possible to determine the optimal quantity to purchase from each supplier and to assign production volumes to each line, based on quantities, costs, and production capacities using linear programming. This approach aims to enhance the competitiveness of the products offered in response to customer demand. As a result, the company can minimize total costs and maximize profits under the optimal scenario identified.

In addition, a comparison with other studies—most of which apply linear programming and the transportation model—reveals a shared focus on optimizing production volumes, transportation costs, plant capacity based on time efficiency and available labour, and supplier selection and evaluation. Collectively, these studies contribute to the growing body of scientific research dedicated to improving the use of resources in companies within the agribusiness sector.

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