Transportation cost and level service a wheat agribusiness industry: modeling the logistics network in a real case study

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Abstract

Today, wheat and its by-products are considered the important food grain source for humans across the world. Accordingly, integrally investigating the wheat supply chain and the service level to consumers is of great importance in strategic decisions in this agribusiness industry. In this respect, this paper addresses a real case study of wheat supply chain in Latin American country using real data. This company is responsible for manufacturing and distributing more than 50 different products in the domestic market. The problem consists to fix distribution centers (DCs) considering a set of the potential locations for establishing a high service level. Therefore, the main goal of the current paper is to determine not only the optimal locations to establish distribution centers but also the provide a service level consider the last mile delivery of products at the minimum possible cost. Materials and methods are based on Operations Research techniques considering sensibility analyses to develop different scenarios. The computational implementation used the AMPL© language with the IBM ILOG CPLEX© Optimization Studio solver using a real large database involving: transport costs, production costs, demand for products by cities, distance between locations, etc. The results propose a set of logistics optimization scenarios to reduce costs considering different service levels for consumers to supports decision-making by managers. Finally, this paper contributes to the agribusiness area by presenting an efficient mathematical model for optimizing the costs of the logistic operation of the wheat industry, which can also be expanded or adapted to reduce costs another agribusiness industries.

Keywords: Logistic Costs of Wheat; Level of Service; Logistical Costs in Agribusiness.

1. Introduction

Cereals, including wheat, rice, barley, maize, rye, oats and millet, make up the majority of the production of the crop sector, being the most important food sources for human consumption (CENDOYA *et al.*, 2018). In this sense, the emergence of logistics and supply chain management as a fully mature business discipline may depend on the development of foundational supply chain management perspectives embracing a focus on responsiveness (RICHEY *et al.* 2021). According Aradiel Abad *et al.* (2022), the transportation represents around 30% of the total cost of a product. Like any other cost, they are computed to determine the price of the good or service, so that the higher it is, the greater its share in the final value of production (SOLIANI, 2022). In this regard, Amin-Chaudhry *et al.* (2022) affirm that many agribusinesses have chosen to automate their production to increase efficiency and reduce costs. However, not all parts of an agribusiness can be automated.

Wheat, after rice, is the most important source of calories as well as source of protein for humans (CENDOYA *et al.*, 2018). Wheat and its by-products are considered the most important food grain source for humans across the world. Accordingly, integrally investigating the wheat supply chain is of great importance in strategic decisions (HOSSEINI-MOTLAGH *et al.*, 2019). In general, a wheat supply chain network design (WSCND) deals with determining the optimal location, number and capacity of silos and four factories (LUCAS; CHHAJED, 2004).

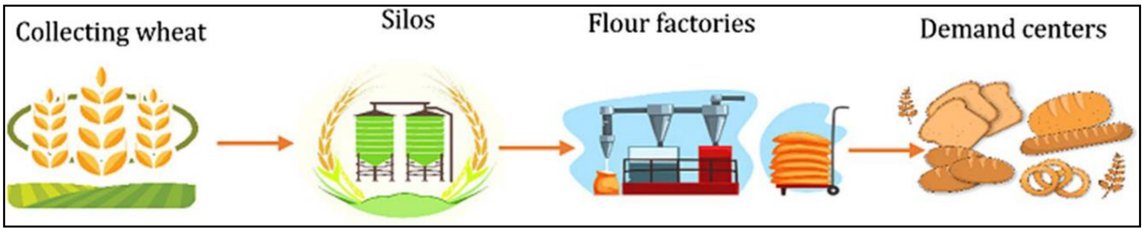

Figure 1: An overview of wheat supply chain
Source: Hosseini Motlagh et al. (2019)

One of the main objectives and as a result of the logistical operations carried out in warehouse environments and distribution centers is to reduce the response time to the fulfillment of the customer's order with a high degree of accuracy. Agility in response can mean opportunities in the market in which the organization operates. The distribution strategy of a company that operates in the retail and product distribution segment plays a critical role in relation to the organization of operations and internal activities that are carried out in the DCs, as well as the physical location of these environments become relevant for maintenance. The level of logistical service is understood to be the fulfillment of the customer's request in a shorter period, with quality at an adequate cost (KEMAHLIOĞLU-ZIYA; BARTHOLDI, 2011; VIEIRA *et al.*, 2017).

Given what has been described, this study proposes a new logistic design applying a mathematical optimization model which considers plants, centers distributions, multiple products of the wheat and its by-products market in the domestic demand of a South America country. In addition to involving cost reduction, the study analyzed the level service (delivery time) to consumers using real data, enabling support for the company's decision-making.

The research gap in this study is represented by the need to associate the reduction of logistical costs with satisfactory service levels (time delivery of products to consumers) in the wheal supply chain network. In this sense, this research is justified by presenting results that support decision-making regarding logistical costs in the context of the production and transportation of products derived from wheat, a relevant agribusiness commodity. Therefore, this study proposes logistics optimization scenarios to reduce costs considering different levels of service to consumers.

In turn, the contributions of the research are outlined as follows: (1) apply an efficient mathematical model considers all layers of the wheat production chain network and seeks to minimize the total cost of the network considering the service level to costumers; (2) to present a model consistent with the wheat production chain network, being possible to adapt it to other types of grains or different agribusiness industries (corn production, feed production, etc). Finally, (3) to apply of the mathematical model using real data from the company's supply chain to supports decision-making by managers.

The remainder of this paper is organized as follows. In the next section, we review the literature about mathematical modeling applying in the supply chain network design relating the seminal and relevant researches in this theme. Section 3 presents the materials e methods describing the formulation problem and the solution methodology. Section 4, there is a detailed results and discussions with our main findings analyzing different scenarios. Section 5 concludes the research and provides the mains contributions the future research.

2. Literature Review

A comprehensive review about Modeling Supply Chain Network Design (SCND) and Wheat Supply Chain Network Design (WSCND) is presented following.

2.1. Modeling supply chain network design

This section presents three important mathematical formulations developed for SCND involving the problem of location, multi-commodity distribution and production flow. Since the mid-1960s, discrete location has evolved into a mature field of research. The vast majority of the literature is dedicated to single-period problems with a static customer demand pattern (MELO; NICKEL; SALDANHA-DA-GAMA, 2009).

A pioneering effort in the use of a simulation model for location decisions by Schyn and Maffei (1960) describes a consulting assignment at the Heinz Company. The approach used in this research has since been applied to many firms with multiple factories and multiple warehouse operations. Geoffrion and Graves (1974) were among the first to solve the version of the multi-commodity location problem. In this model, production capacity at each plant for each product is known and fixed. The product demands for multiple customer zones are known and fixed. The demands are satisfied by shipping products through distribution centers (DC) with each customer zone assigned exclusively to a single DC. The potential site locations are selected to minimize total network costs. The costs consist of fixed costs to use a DC, a variable operating cost (based on the amount of products shipped through a DC), and total transportation cost involving the transport of products from a plant to a DC and a customer zone. The model is computationally complex and authors are able to develop an efficient solution procedure based on Bender’s decomposition. They solved their problem by considering the linear programming sub-problem and decomposing it into as many different independent transportation problems as there are commodities. The formulation and modeling were applied to a real problem of a food industry with a hundred products produced at 14 locations with a national geographic distribution.

Kuehn and Hamburguer (1963) propose a Mixed Integer Linear Program (MILP) and a heuristic solution is produced. This work outlines a heuristic computer program for locating warehouses providing considerable flexibility in modeling the problem to be solved and can be used to study large-scale problems.

Cohen and Lee (1989) presented a deterministic Mixed Integer Problem (MIP) model to maximize the global after-tax profits considering optimal policies for facility network design and material flows. The decision variables for the network design issues included location and the capacities of all production facilities considering sourcing decisions, production, and distribution planning.

Daskin (1995) discusses the problem of multiple products in the flow distribution system presenting a general case involving the transport of products from the factory to the consumer market directly or through distribution centers. Pirkul and Jayaraman (1996) developed an MIP model for a multi-product, tri-echelon, capacitated plant and warehouse location problem. The model objective was to minimize the sum of fixed costs of operating the plants and warehouses as well as the variable costs of transporting multiple products from the factories to the warehouses and finally to the customers.

In the mathematical modeling of Jayaraman and Pirkul (2001) three major cost structures are proposed: production costs that incorporate fixed and variable costs of the plants (factories), fixed and variable costs for the transportation of raw materials from suppliers to plants, and fixed and variable distribution costs of finished products from factories to customers zones through distribution centers. Additionally, the model and solution procedure developed were applied to real world data obtained from a health-care product manufacturer in the US. The authors say that the heuristic was able to find solutions that would have been practically unobtainable with commercial integer programming codes. Further, the enterprise took advantage of economies that could be achieved by such flow of products to a customer zone. Lee and Dong (2008) introduce a Tabu Search (TS) approach for the design of a two-echelon network. The proposed model includes some practical elements of SCND such as the direct shipment of a single commodity from plants to customers and location decisions concerning both plants and warehouses. Computational experiments demonstrate high-quality solutions for end-of-lease computer products with a modest computational overhead.

Lee and Kwon (2010) proposed a Mixed Integer Programming (MIP) model for distribution center operation planning with three multi-stages. The authors presented a hybrid heuristic for a distribution center using tabu search and decomposed optimization. The heuristic is constructed using the decomposition of the networks to gain in the computational efficiency, and tabu search to use the neighbor solutions. The tabu search applied used a priority rule designed by using the so-called Unit Cost Ratio. The performance of the heuristic algorithm is applied using several instances generated for evaluation with respect to the number of plants, distribution centers, customers and products.

Shi, Zhang & Sha (2012) presents a Lagrangian based solution algorithm for the network design problem in a build-to-order (BTO) supply chain. The problem is to determine where to locate the distribution centers and to which distribution center or plant the retailers are assigned. Computational results show that the Lagrangian based algorithm can present very good solutions to all the examples in short CPU time.

Rabbani *et al.* (2020) investigated and presented an efficient solution approach for supply chain network design problem. A heuristic graph theoretic-based algorithm is proposed for solving a multi-echelon responsive supply chain network design problem considering lateral transshipment provides a trade-off between transportation costs and inventory handling costs at the retailers. The results indicate that the proposed algorithm generates high-quality solutions in a reasonable time in comparison with the exact solver.

2.2. Wheat supply chain network design

Koopa & Kiani (2006) formulated a wheat transportation model by considering both domestic and imported wheat. In their model, the wheat was shipped from supply points to storage facilities and demand centers with the aim of minimizing the transportation cost. Farahani and Elahipanah (2008) developed a model for maritime transportation planning in a wheat supply chain in a multi-commodity multi-period context by considering fuzzy random parameters. In this case, Farahani et al. (2009) proposed a mixed integer programming model to determine the amount of wheat moved between provinces in each month. They solved the problem using Genetic Algorithm (GA) and compared the results with lingo software. Li et al. (2013) developed a hybrid evolutionary algorithm for Australian wheat blending case and tested the model using real data from past years.

Ge et al. (2016) presented a simulation model for Canadian wheat supply chain by focusing on wheat quality and minimized the cost of the wheat supply chain. Mogale et al. (2017) presented a multi-period model for Indian food grain supply chain to obtain the optimal transportation, allocation, and capacity of silos. They provided two main contributions to their work.

In a recent study, Hosseini-Motlagh, Samani & Abbasi Saadi (2021) presenting a new mathematical model, the total cost of the wheat supply chain network design is optimized. The proposed model integrates collection, production, inventory, and distribution echelons of the wheat supply chain, simultaneously. It shows the proposed robust model is more effective than deterministic one that can be applied to make robust strategic and tactical decisions for the wheat supply chain. Moreover, the sensitivity analysis of influential parameters is conducted. Finally, according to the obtained results as well as sensitivity analysis, some managerial insights are provided.

3. Materials and Methods

In order to perform this application research, the present paper is based on Operations Research and methods. Johnson and Montgomery (1974) define Operations Research as a scientific method of management decision making. In this method, decision problems are transformed into mathematical models which have to determine the optimal decision for the problem examined. To develop the application of problems solving techniques, the main phases of a typical Operations Research study are adopted (WAGNER, 1986; WINSTON, 1994; HILLIER; LIEBERMAN, 2010). These phases can be briefly described as: problem formulation, mathematical modeling, computational implementation, solution and experimental tests and finally the model application in the real problem.

3.1. Problem description and case study

We consider a supply chain composed of four echelons: suppliers, factories, warehouses and retailers or final customers. These echelons are represented in Figure 2. Here, we propose a supply chain that considers multiple products, single period, and deterministic demand, based on these assumptions.

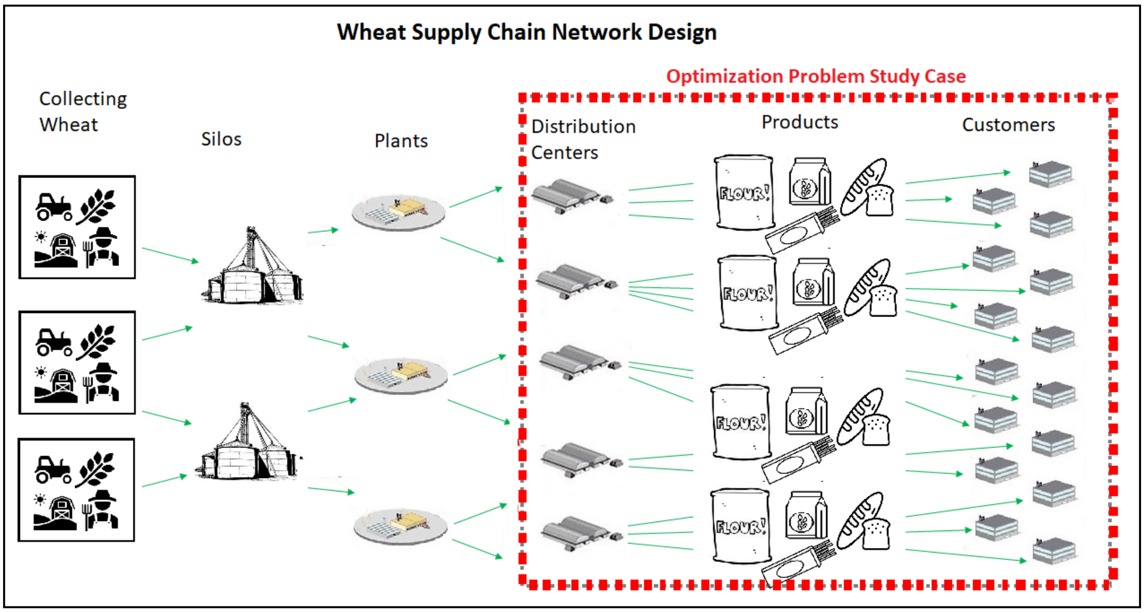

Figure 2: Wheat Supply Chain Network Design

Source: Elaborated by the authors (2023)

The motivation for defining this problem is a real case study of the wheat industry in a South America country. Wheat is one of the most vital commodities across the world, particularly in South America, it is known as a strategic commodity. Hence, the wheat and its by-products market are extremely consuming by de population. The purpose of the case study is to prove the effectiveness of the mathematical model by proposing different logistical scenarios evaluating the level of service to supply the domestic demand of a company. This case study in a Latin American country addresses a wheat supply chain comprised of dozens of distribution centers and hundreds of customers considering more than 50 different product types. In this problem, suppliers and factories are considered only for the flow of raw materials and products, since these facilities are already strategically fixed. Therefore, the solution consists to fix demand centers considering a set of the potential locations for establishing a high service level.

3.2. Mathematical Formulation and Computational Implementation

The mathematical modeling elaborated in this paper is based in Jayaraman & Pirkul (2001), Pirkul & Jayaraman (2010), Lee & Kwon (2010), Farias *et al.* (2017) and Galvez & Borenstein (2022). According to the mathematical notation in Table 1, the formulation of the mathematical model applied in this study was elaborated.

Table 1: Mathematical notation

Symbol	Defintion
Sets	
F	Set of factories, index by *p*
C	Set of costumers, index by *c*
W	Set of warehouses, index by *w*
S	Set of products, index by *s*
Parameters	
d_{sc}	Demand for product $s \in S$ at customers $c \in C$
U_w	Maximum number of warehouses that are opened
U_f	Maximum number of factories are opened
u_s	capacity utilization rate per unit of product $s \in S$;
CAP_W	the annual throughput at warehouse;
CAP_f	the capacity of factory $f \in F$;
CT_w^o	the annual fixed cost of operating warehouse $w \in W$;
CT_f^o	the annual fixed cost of operating factory $f \in F$;
CT_{fs}^p	the unit production cost of products $s \in S$ at factories $f \in F$
CT_w^g	the unit cost of throughput at warehouse $w \in W$;
CT_{fws}^t	the unit transportation cost of product $s \in S$ from factories $f \in F$ to warehouse $w \in W$;
CT_{wcs}^t	the unit transportation cost of product $s \in S$ from warehouse $w \in W$ para a cidade $c \in C$;
Decision Variables	
x_{fws}	the amount of product $s \in S$ shipped from factory $f \in$ to warehouse $w \in W$
z_w	a binary variable, it is 1 if warehouse $w \in W$ is selected, and 0 otherwise
g_{wc}	a binary variable, it is 1 if customer $c \in C$ is assigned to warehouse $w \in W$, and 0 otherwise

Objective Function

$$\min \sum_{w\in W} CT_w^o z_w + \sum_{w\in W}\sum_{c\in C}\sum_{s\in S} CT_w^g d_{sc} g_{wc} + \sum_{f\in F}\sum_{w\in W}\sum_{s\in S} CT_{fs}^p x_{fws} + \sum_{f\in F}\sum_{w\in W}\sum_{s\in S} CT_{fws}^t x_{fws} + \sum_{w\in W}\sum_{c\in C}\sum_{s\in S} CT_{wcs}^t d_{sc} g_{wc} \quad (1a)$$

Subject to

$$\sum_{w \in W} g_{wc} = 1 \qquad \forall c \in C \qquad (1b)$$

$$\sum_{c \in C} \sum_{s \in S} d_{sc} g_{wc} \leq CAP_w z_w \qquad \forall w \in W \qquad (1c)$$

$$\sum_{w \in W} z_w \leq U_w \qquad (1d)$$

$$\sum_{f \in F} s_f \leq U_f \qquad (1e)$$

$$\sum_{c \in C} d_{sc} g_{wc} \leq \sum_{f \in F} x_{fws} \qquad \forall w \in W, \forall c \in C \qquad (1f)$$

$$\sum_{w \in W} \sum_{s \in S} u_s x_{fws} \leq CAP_f \qquad \forall f \in F \qquad (1g)$$

$$z_w = \{0,1\} \qquad \forall w \in W \qquad (1j)$$

$$g_{wc} = \{0,1\} \qquad \forall w \in W, \forall c \in C \qquad (1k)$$

The objective (1a) is to minimize the sum of the annual cost of warehouses, the throughput costs of warehouses, the production costs of factories, and transportation costs of products from factories to customers through the warehouses. Constraints (1b) ensure that each customer zone is assigned to one warehouse. Constraints (1c) guarantee the capacity of each warehouse is not violated. Constraints (1d) and (1e) impose an upper bound on the number of warehouses and factories, respectively. Constraints (1f) force that each warehouse has sufficient products for its associated customers. Constraints (1g) guarantees the capacity of any factory is satisfied.

Computational implementation was developed using the IBM ILOG CPLEX© Optimization Studio version 20.1, with the computational procedures performed with an Intel® Core™ i7-8565U processor with 1.80 GHz and 16 GB of RAM.

To apply Operational Research methods, this study used a large real database involving: transportation costs, production costs, demand for products by cities, distance between locations, number of cities, number of DCs and number of products. The database was organized in Microsoft Excel©. Likewise, the results obtained from Cplex© Solver were organized for the elaboration of different scenarios, and subsequent analysis.”

The next section presents the results of applying the proposed model in reals scenarios.

4. Results and Discussions

For the results accuracy, the sensitivity analyze was carried out of model considering the specifications and, in particular, the precision of the input data sets, the appropriateness of the parameters and the quality of results. In this sense, we accomplished extensive experimental tests to verify the accuracy of the model and computational implementations, as well as to define the best parameter setting. The analysis of the results presented solutions within an acceptable optimality range for case study in reasonable computational time.

The modeling and solution procedure developed in this study were applied in the realistic problem of a company in South America which is one of the biggest producers and distributors of wheal in his country, with a highly influential market-share in domestic context.

The annual domestic demand was basically defined by the company using the historic sales information and the estimated market-share for products manufacturing by the company. Likewise, a preliminary study was conducted to survey the information relating to transport costs, production costs and demands of each product considering in the logistic company network. In addition, the transportation costs from the suppliers to factories, factories to warehouses, and warehouses to consumers were defined using data in the real context. According to the marketing strategy, different logistical scenarios were presented considering costs and service levels to support the company's decisions. In order to determine an efficient logistics network, the company considers ten potential cities at its disposal to allocate the distribution centers (DCs).

The first scenario, call Scenario 1 DC, presented in Figure 3 consider just one distribution center. The Scenario 1 DC presented the higher transportation costs and the lower service levels. Scenario 1 DC had the highest transport costs and the lowest service levels, as only one DC provides a long distance between the DC and the cities served. The service level considers the delivery time from the DC to the customers, with the service level represented by the 24-hour, 48-hour and over 72-hour ranges. The Scenario DC 1 service level presented 14% of the sales demand delivered until 24-hour, 13% of sales demand delivered until 48-hour and 73% of the demand delivered over 72-hour range. The level of service, associated with the cost of transportation, are the main information to drive the firm's decision.

To illustrate the logistical structure of each scenario, considering different numbers of distribution centers, Figure 4 represents the segmentation of customers in the company's domestic demographic region.

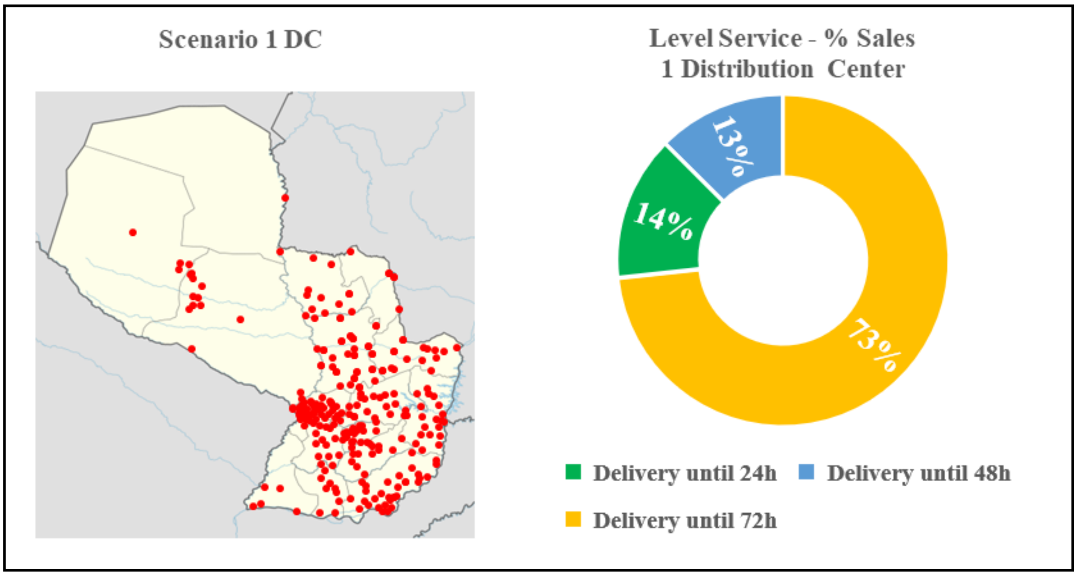

Figure 3: Scenario 1 DC – Distribution Clients and Level Services
Source: Elaborated by the authors (2023)

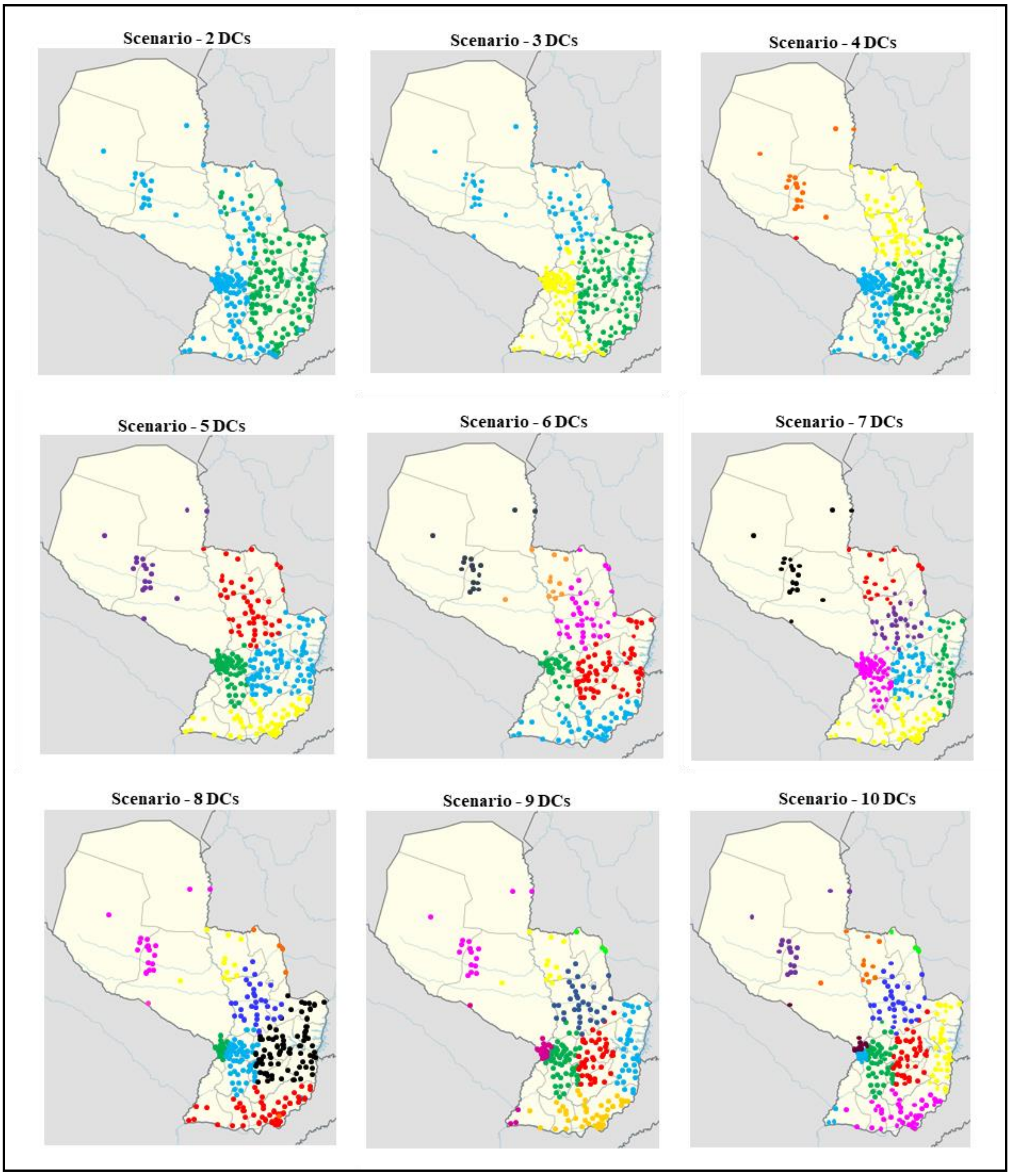

Figure 4: Scenarios - Demographic segmentation
Source: Elaborated by the authors (2023)

In this sense, the Figure 5 presents the different levels of service for each of the scenarios elaborated from the results from the application of the model in the case study.

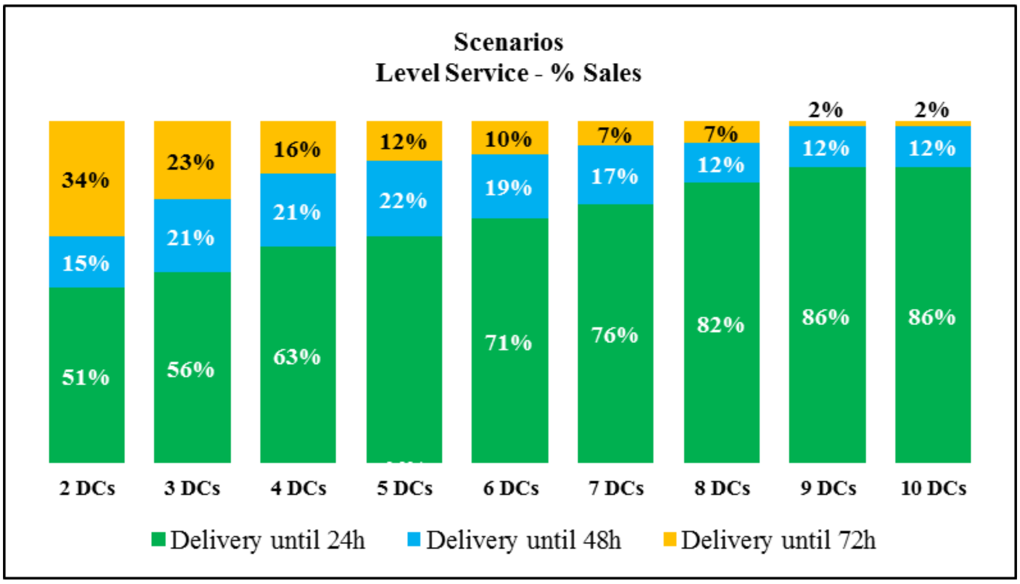

Figure 5: Scenarios and Level Service
Source: Elaborated by the authors (2023)

Considering the service levels represented in **Figure 5,** it is identified that the “Delivery until 24h” service level is the highest (86% of sales are served in until 24 hours) in Scenario DC 9 and Scenario DC 10. However, the cost of implementing and operating nine and ten distribution centers significantly increases investment and operating cost. Likewise, it is observed that the greater the number of DCs, the greater the level of service, because the distance between the DCs and the customers reduces. According to Figure 6 the level of service improves as it increases the number of distribution centers, with reduced transport costs, as the distance between distribution centers and customers also decreases. In this sense, it is fundamental to analyze the different service levels of each of the scenarios together with the respective transport costs.

As the objective of optimization in this context is to reduce costs combined with the quality of the service level, Figure 6 shows the curve of decreasing transport costs as the logistics network incorporates a greater number of distribution centers.

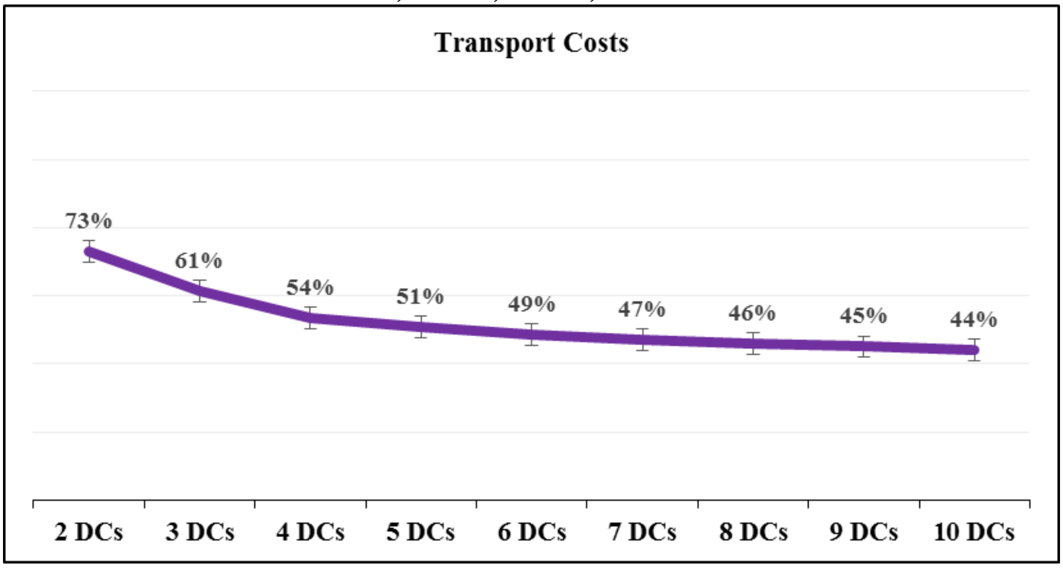

Figure 6: Scenarios and Transport Costs
Source: Elaborated by the authors (2023)

Using Scenario DC 1 as a reference for the transportation cost analysis, Figure 1 demonstrates the representation of transportation costs for each of the scenarios. For example, in Scenario DC 2, the transport cost is equivalent to 73% of the transport cost presented by Scenario DC 1, that is, it reduces the cost by 27% when compared to Scenario 1. In the same sense, analyzing Scenario DC 3, the reduction is 39% when compared equally to the transport cost of Scenario DC 1. Finally, in Scenario DC 10 the transport cost is equivalent to 44% of the transport cost of Scenario DC 1. In this way, according to Figure 6**,** it can be seen that the reduction in transport costs is accentuated up to the scenario that considers five DCs. From the scenarios that consider more than five DCs, the cost of transport reduces slightly.

The Figure 7 shows the comparative analysis of results obtained in the modeling applications considering a level of service according to the transport costs associated with each scenario. We emphasize that Scenarios 4 DC, Scenarios 5 DC and Scenarios 6 DC present service levels compatible with the current business strategy and, concomitantly, present reasonable transport costs when compared to the other scenarios

Analyzing the grouping of the best results obtained in the modeling application, it is possible to identify which scenarios are most adequate to support decision making. The three highlighted (red dotted line) scenarios present **24-hour delivery service levels between 63% and 71%**, with **transport cost representing 54% to 49%** of the estimated cost for Scenario 1 DC.

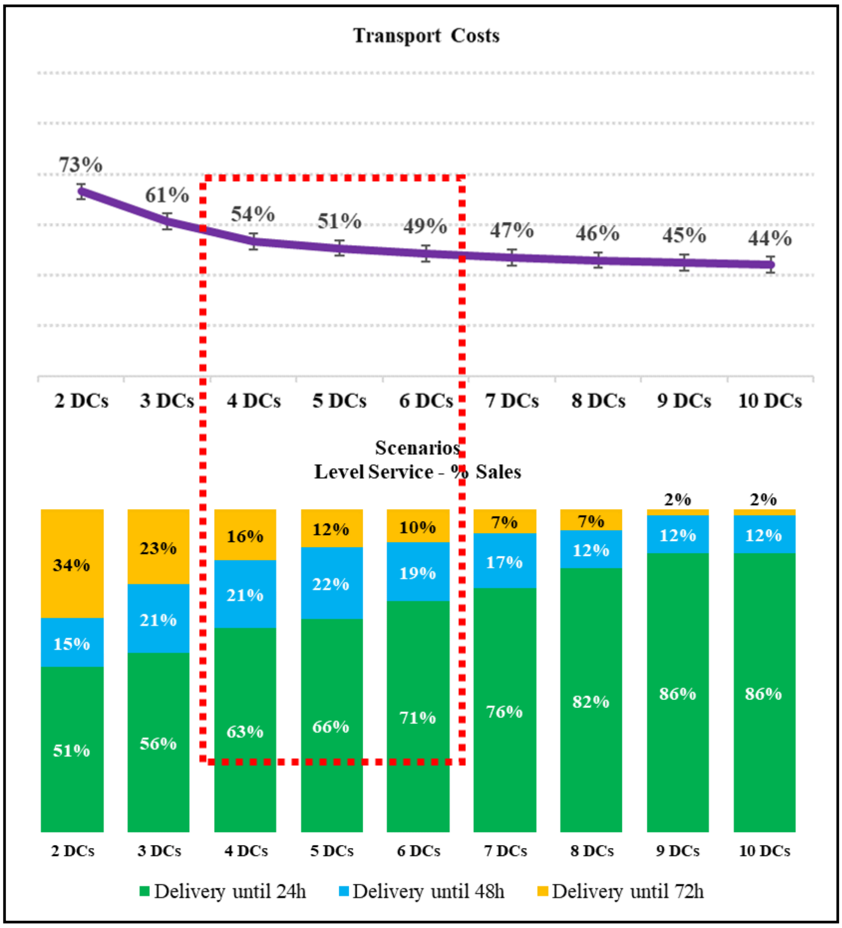

Figure 7: Wheat Supply Chain Network Design
Source: Elaborated by the authors (2023)

In this sense, it is understood that this set of alternatives enables a managerial insight to guide decisions in the company in the search for an efficient logistics network that optimizes costs and provides service levels that are satisfactory to the company's strategy.

This section developed the presentation and analysis of the proposed scenarios from the results obtained by the computational implementations. The results show the best cost-effective alternatives for structuring the company's logistics network are considering: transport costs and customer service levels.

5. Conclusions

In the domain of supply chain network design, various factors influence the decision-making process regarding the location of facilities in wheat supply chain network design. So, identify of the success factors and how they affect the design of supply chain network is an exhaustive and complex process. In this sense, in this work is proposed for design and modeling of the wheal logistic network fixing DCs considering a set of the potential locations for establishing a high level of delivery service for products manufactured by a wheat company with a domestic demand.

The main goal of the current paper was to determine not only the optimal locations to establish Distribution Centers but also the provide a service level consider the last mile delivery of products at the minimum possible cost. Moreover, a real case study of an important South American country is provided to assess the capability of the proposed model.

The application of the model using real data from the company's supply chain allows for different logistic scenarios considering cost reduction and an adequate level of service to support managers' decision-making. In this sense, analyzing the grouping of the best results obtained in different scenarios, managerial insights for operational, tactical and strategic decisions can be adopted. Finally, this article successfully implemented computational implementation using an efficient and robust mathematical formulation to reduce costs in logistics operations considering a real case study involving the agribusiness industry.

This article contributes to the agribusiness area by presenting an efficient mathematical model for optimizing the costs of the logistic operation of the wheat industry, which can also be expanded or adapted to other agribusiness products. Furthermore, the article presents an analysis associating the logistical costs and the levels of customer service, which is an important subsidy for the companies' decision makers. Future works can be focused on including some aspects in the optimization network, such as: costs of human resources in process, fixed costs involving the installation of warehouses, through the cost of the storage process and multiperiod planning.

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