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Optimization of the distribution logistics network: a case study of the metalworking industry in Colombia

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Abstract

Logistics management is a key factor for business competitiveness because of the variety of strategies available to improve the distribution of goods through the supply chain, enabling the optimization of the resources assigned to this effect. A key aspect for good logistics management is the distribution network, where the location of the network components plays a key role, especially in the case of distribution centers, which are platforms through which the goods received from factories or suppliers are redistributed to the various points of sale. In the above context, this case study proposes a solution for selecting two locations from among four possible sites for construction of distribution centers for a company in the metalworking industry, aimed at minimizing operating costs through the design of a logistics distribution network, using as a tool the GUSEK software. To this effect, the aspects taken into consideration include vehicle capacity, the costs associated with opening a distribution center, types and volume of the products to be shipped, costs associated with the travel distances, the production capacity of the factories, and customer demand, among others. Execution of the model produces the best locations for the distribution centers and the types of vehicles to be used based on their capacity and the optimal routes for transporting a company's goods.

Keywords: logistics network; distribution; optimization; optimal routes; distribution centers.

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1. Introduction

Logistics plays a key role in decision-making. It is a discipline that manages materials, people, and information to ensure the delivery of products within the established specifications and time frames at the lowest cost [1].

A major focus of corporate logistics management is the distribution network for goods, which forms the core of the process, offering a high level of service at the lowest cost possible [2]. The decision of where to locate the various supply chain elements is very important, especially in the case of a distribution center (DC), because it is responsible for consolidating and distributing the goods, for regulating the number of vehicles to be used, and for redirecting the goods received from different locations. They also help optimize transportation logistics operations because they redistribute large volumes of cargo based on certain variables, such as distance, load size, and product type, among others [3].

In this sense, modeling distribution logistics systems provide companies useful insights to resolve network design problems. Additionally, the tool assists in deciding on the physical location as part of a corporate strategy of locating warehouses or distribution to achieve a given service level and arrive at an optimal solution to minimize logistics costs [4].

This study will design a distribution logistics model based on a case study of a Colombian transportation company in the metalworking sector that enables making the best decision on the location of two (2) new distribution centers ensuring lower logistics costs. It will also consider demand, supply, factory capacity, the possible distribution centers and the stores, and their respective costs. It also includes system restrictions identified by the customer to simulate its behavior and find the optimal solution [5].

2. State of the art

Supply chain management covers numerous processes and operations that transform raw materials into products and distribute them through retail sales. Consequently, the supply chain involves numerous parties, including suppliers, manufacturers, distributors, retailers, and customers, to improve coordination and collaboration between the parts of the chain [6].

[7] propose a mixed-integer multi-period programming model that minimizes logistics network costs for a veterinary products distributor in Colombia. The configuration of the logistics network model considers the cost associated with out-of-stock inventories and opening and closing facilities over the planning horizon defined by the company.

In the transportation sector, there is a robust location-routing approach that considers simultaneous decisions on vehicle routes and the location of loading stations to design strategic networks of electric logistics fleets. To this effect, [8] assess the problem with different levels of uncertainty by creating an algorithm; based on the results, they analyze the benefits of a robust planning approach regarding operational feasibility and overall costs savings for the planning problem.

For product allocation to different distribution centers in retail logistics networks, authors by [9] resolve the problem using a MIP solution approach. They create a MIP model that reflects the inter-dependencies of incoming and outgoing transportation and the store's logistics, immobilized inventory capital and the difference in selection costs between the stores. The result of application of this model is operating cost savings of 6%.

3. Methodology

The development of a distribution logistics model for the distribution centers of the metalworking industry requires a methodology based on the definition and programming of the model, to which end three phases will be used to support the analysis and results that provide a solution to the problem posed by the case study company.

The system identification and diagnosis (phase 1) recognize the various actors of the case study, including their components, variables, capacities, and characteristics, and drawing a general chart of their behavior. It is also important to characterize the variables and actors by gathering the data required to develop the model, such as costs, transportation capacity, demand, routes, and production capacity. During this stage, it is important to have a meeting on the characterization of the system with the company.

The second phase (Model definition) defines the parameters, variables, restrictions, and the target equation, based on the information collected during the diagnosis, this requires holding a meeting to study the information and review the costs, corporate policies, the distribution process, and the system's variables to identify all the aspects of the model.

The model programming (phase 3) stage consists in developing the algorithm that will perform the iteration of the variables and conditions of the study to find the optimal solution. Based on the results obtained, alternatives are proposed for distribution centers that will minimize the associated costs.

4. Formulation

This case study is aimed at assisting in the decision to select two sites to build two distribution platforms in such a manner that enables satisfying the demand from stores (3) at an affordable logistics cost, based on the company's policies and restrictions, such as production capacity, inventory policies (only one product type is received from the same distribution center), the use of a single type of truck per route, among others.

Based on the diagnosis of the company, the following system was identified (See Fig. 1):

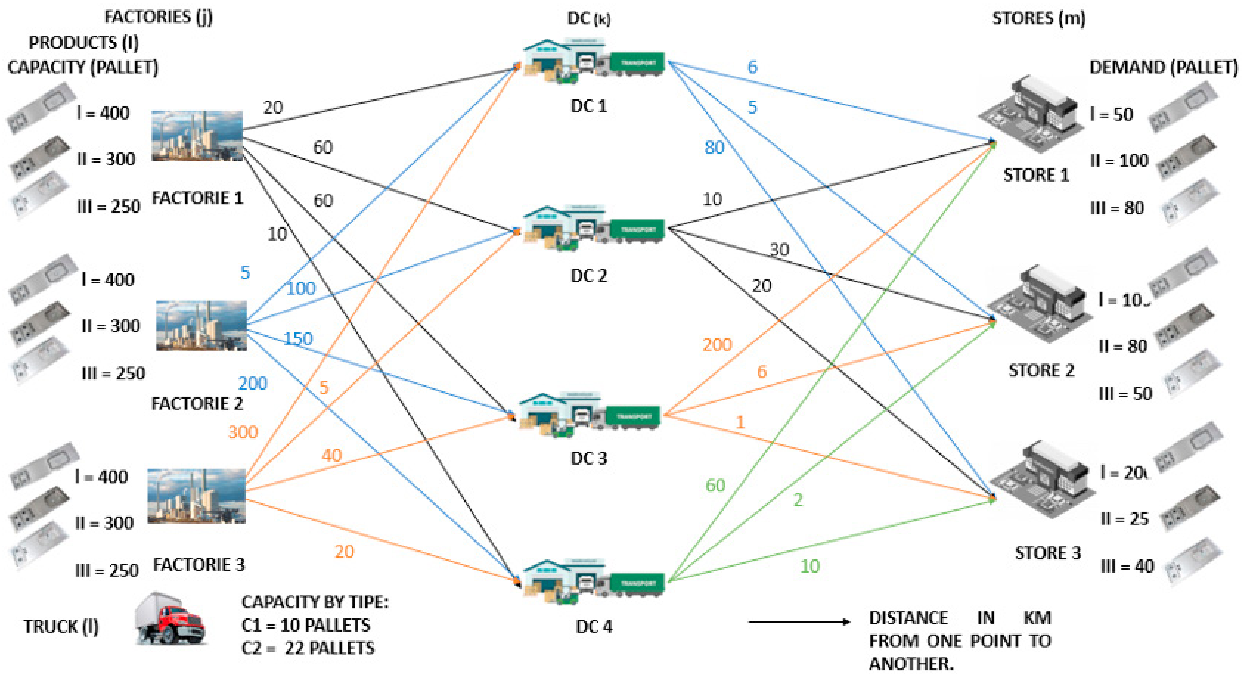

Fig. 1. Diagnosis of the studied company's system.

Fig. 2 displays the behavior of supply (production capacity of the factories) and demand by the store for three different products: 180x52 dishwasher with kitchen (P1), 150x52 dishwasher with kitchen (P2), and 120x52 dishwasher with kitchen (P3). It also indicates the kilometers to be traveled, considering the three factories, the four options of sites to build the distribution centers, and the three stores to be shipped to Store 1, Store 2, and Store 3. It also indicates the transportation capacity in pallets for two types of company trucks: truck 1 (C1) and truck 2 (C2).

Also, given that the company's objective is to make a decision that reduces costs, the transportation costs were identified by the type of truck, production costs by product and factory, and the fixed costs of each distribution center. The following input data of the model is shared in the following **Input Data Link.**

Based on the above, the Gusek tool (software that generates linear programming solutions) was run to produce the solution, considering that it is open-source software that supports ampl. To this end, the following sets of the system were identified, the parameters were defined, taking into consideration the diagnosis made at the company, and the system's variables are designed taking into consideration the factors that have an incidence in decision-making for the problem. The definition of groups (sets), parameters, and variable is shared in the following **Parameters Link.**

Once the variables and parameters have been defined, the target function is developed, which is formulated as follows (Equation 1):

$$Minimize = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L} CP_{ij} * x_{ijkl} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L} C1_{jkl} * cam_{ijkl} + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{l=1}^{L} C2_{kml} * cbm_{ikml} + \sum_{k=1}^{K} CF_{k} * z_{k} \tag{1}$$

However, to find a solution that is consistent with the problems faced by the company, restrictions in the system's environment must be programmed to delimit the number of options available for finding the optimal solution. The following are the restrictions (See Table 1):

Table 1. Definition of restriction.

Restriction	Equation	
Restriction 1: truck capacity from i to k.	$x_{ijkl} \le CV_{l} * cam_{ijkl} \forall i,j,k,l$	(2)
Restriction 2: truck capacity from k to m.	$y_{ikml} \le CV_{l} * cbm_{ikml} \forall i,k,m,l$	(3)
Restriction 3: opening of DC k.	$\sum_{k=1}^{K} z_{k} = 2$	(4)
Restriction 4: supply from the factory.	$\sum_{k=1}^{K}\sum_{l=1}^{L} x_{ijkl} \le CAP_{ij} \forall i,j$	(5)
Restriction 5: demand from stores.	$\sum_{k=1}^{K}\sum_{l=1}^{L} y_{ikml} \ge D_{im} \forall i,m$	(6)
Restriction 6: cross-docking.	$\sum_{j=1}^{J}\sum_{l=1}^{L} x_{ijkl} = \sum_{m=1}^{M}\sum_{l=1}^{L} y_{ikml} \forall i,k$	(7)
Restriction 7: restriction to distribution center flow.	$\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{l=1}^{L} y_{ikml} \le NM * z_{k} \forall k$	(8)
Restriction 8: One store is covered by only one DC.	$\sum_{k=1}^{K} w_{km} = 1 \forall m$	(9)
Restriction 9: restriction of sending from non-selected distribution centers to stores.	$\sum_{i=1}^{I}\sum_{l=1}^{L} y_{ikml} \le NM * w_{km} \forall k,m$	(10)
Restriction 10: Only one type of truck for the route from factory to DCs.	$\sum_{l=1}^{L} v1_{jkl} \le 1 \forall j,k$	(11)
Restriction 11.	$\sum_{i=1}^{I} x_{ijkl} \le NM * v1_{jkl} \forall j,k,l$	(12)
Restriction 12: Only one type of truck for the route from distribution center to store.	$\sum_{l=1}^{L} v2_{kml} \le 1 \forall k,m$	(13)
Restriction 13.	$\sum_{i=1}^{I} y_{ikml} \le NM * v2_{kml} \forall k,m,l$	(14)

Restriction 14: Prevent selecting the type of truck for the route from DC to store if DC is not active.	$$\sum_{l=1}^{L} v2_{kml} \leq w_{km} \forall k,m$$	(15)
Restriction 15: Prevent selecting the type of truck for the route from factory to store if DC is not active.	$$\sum_{l=1}^{L} v1_{jkl} \leq z_k \forall j,k$$	(16)

Based on this information, the data are input into Gusek to run the model and find the solution. The data must be input in connection with predefined parameters because the solution will be found based on the variables to find the lowest cost.

5. Computerized results

Once the model was run, it was found that the target function yields a minimum total cost associated with the model for $ 1,076,776,818. To achieve this optimal value, the model yields the results for each associated variable.

One of the problem's restrictions is that only two distribution centers are to be opened (Equation 4); consequently, the selected distribution centers were DC1 and DC4, and these shall be responsible for performing the process of linking the factories to the demand from stores, using a cross-docking logistics strategy.

Based on the selected distribution centers, the distribution of the number of pallets type i to be sent from factory j to DC k in the truck's type ($xijkl$) can be summarized in Table 5. Also, given the volume capacity of the truck's type, is obtained the number of trucks to be shipped from factory j to DC k. (See Table 2):

Table 2. Transportation of goods and number of trucks from the factory to the distribution center.

FACTORIES	PRODUCT TYPE	DC 1		DC 4	
		Number of pallets in the truck's type	Number of trucks	Number of pallets in the truck's type	Number of trucks
FACTORY 1	180x52 dishwasher with kitchen (P1)	150 pallets in Type 2 TRUCK	6.81 ~ 7 trucks type 2	200 pallets in Type 2 TRUCK	9.09 ~ 10 trucks type 2
	150x52 dishwasher with kitchen (P2)	0	0	0	0
	120x52 dishwasher with kitchen (P3)	0	0	0	0
FACTORY 2	180x52 dishwasher with kitchen (P1)	0	0	0	0
	150x52 dishwasher with kitchen (P2)	180 pallets in Type 2 TRUCK	8.18 ~ 9 trucks type 2	0	0
	120x52 dishwasher with kitchen (P3)	130 pallets in Type 2 TRUCK	5.90 ~ 6 trucks type 2	0	0
FACTORY 3	180x52 dishwasher with kitchen (P1)	0	0	0	0
	150x52 dishwasher with kitchen (P2)	0	0	25 pallets in Type 2 TRUCK	1.13 ~ 2 trucks type 2
	120x52 dishwasher with kitchen (P3)	0	0	40 pallets in Type 2 TRUCK	1.81 ~ 2 trucks type 2

As a result of the problem formulation, it was found that the type of truck used to transport the different types of pallets from the factories to the distribution centers could only ship one type of pallets in each trip because this is established in the variable itself ($xijkl$).

It was also found that the type of truck to be used for the routes from the various factories to the distribution centers is truck type 2, because transportation costs are proportionately lower ($3,000), given that this type of truck can ship a larger number of pallets (22 pallets), compared to truck type 1 ($2,000 for capacity of 10 pallets).

Regarding the number of pallets type i shipped from DC k to store m in truck's type ($yikml$), the results are below in Table 7. Also, given the volume capacity of trucks type 2, the results indicating the number of trucks to be shipped from DC k to store m. (See Table 3)

Table 3. Transportation of goods and number of trucks from distribution centers to stores.

DC	PRODUCT TYPE	STORE 1		STORE 2		STORE 3	
		Number of pallets in the truck's type	**Number of trucks**	**Number of pallets in the truck's type**	**Number of trucks**	**Number of pallets in the truck's type**	**Number of trucks**
DC 1	180x52 dishwasher with kitchen (P1)	50 pallets in Type 2 TRUCK	2.27 ~ 3 trucks type 2	100 pallets in Type 2 TRUCK	4.54 ~ 5 trucks type 2		
	150x52 dishwasher with kitchen (P2)	100 pallets in Type 2 TRUCK	4.54 ~ 5 trucks type 2	80 pallets in Type 2 TRUCK	3.63 ~ 4 trucks type 2		
	120x52 dishwasher with kitchen (P3)	80 pallets in Type 2 TRUCK	3.63 ~ 4 trucks type 2	50 pallets in Type 2 TRUCK	2.27 ~ 3 trucks type 2		
DC 4	180x52 dishwasher with kitchen (P1)					200 pallets in Type 2 TRUCK	9.09 ~ 10 trucks type 2
	150x52 dishwasher with kitchen (P2)					25 pallets in Type 2 TRUCK	1.13 ~ 2 trucks type 2
	120x52 dishwasher with kitchen (P3)					40 pallets in Type 2 TRUCK	1.81 ~ 2 trucks type 2

As a result of the restriction that says that each store's demand must be covered by only one DC (Equation 8), DC1 will cover demand from STORE 1 and STORE 2, whereas DC4 will cover demand from STORE 3.

6. Computerized results

This study developed a distribution logistics model based on a case study, which enabled decision-making to ensure the lowest logistics cost, considering demand, supply, factory capacity, possible sites to build distribution centers, and the stores. The model identified the customer's restrictions and simulated their behavior using data processing using the Gusek tool in such a manner as to establish the optimal solution when the model is run.

The model indicates a minimum total cost associated with the model of $1,076,776,818, considering that only two distribution centers were selected: DC 1 and DC 4. These distribution centers will supply the stores, where DC 1 will cover demand from STORE 1 and STORE 2, whereas DC 4 will cover demand from STORE 3. Additionally, the goods will be shipped using truck type 2 because transportation costs are proportionately lower ($3,000), given its capacity to carry 22 pallets.

In future studies, it may be useful to study retail companies that specialize in consumer products or in commercializing large quantities of uniforms for customers to supply the stores. Also, meta-heuristic algorithms may be considered to compare their performance against current algorithms and improve the quality of the solutions [10]. It would be useful to consider other target functions, such as environmental or social factors, and to solve the model using a multiple objective optimization approach.

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