

Research Article

Two-Stage Humanitarian Logistics Deprivation Model for the Planning of Scarce KN-95 Facemask Supplies under Agent's Cooperation

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Received 13 December 2020; Revised 31 March 2021; Accepted 22 June 2021; Published 2 July 2021

Academic Editor: Yong Wang

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Humanitarian logistics encompasses a wide spectrum of conditions or constraints for supply chains, yet its focus on mitigating human suffering efficiently is what has motivated organizations and governments to make rapid decisions in real time. In this article, through the approach to an emergency such as COVID-19, we propose a two-stage model capable of considering human suffering, the cost of humanitarian logistics, and the benefit obtained by the interaction of suppliers that generally behave as oligopolies through a mathematical programming model and one of the cooperative games. Our main finding was the adaptability of a previously validated model for humanitarian logistics to the ongoing COVID-19 pandemic, where the externalities had greater relevance in social costs than private costs.

1. Introduction

In terms of attention to the occurrence of disasters or emergency situations similar to COVID-19, it is important to guarantee effective and efficient processes for the correct delivery of goods and services as well as meet the survival requirements of the affected population [1–3]. In this context, it is important to properly define operational models that optimize the logistics' behavior of the stakeholders.

The logistics processes involved either in disaster relief or in the health emergency caused by COVID-19 are made up of different stages and considerations in terms of humanitarian aid and critical supplies, according to Van Wassenhove [4] and Holguín-Veras et al. [5]. The components of international trade and incoterms are important aspects to consider because they can represent the free passage of supplies or the restriction of the same due to the reliability of the origin of the goods [1, 6]. Likewise, taking into account that the main objective is to satisfy and prioritize the attention of the affected population [7–9], there is a social cost related to the human suffering produced by the lack of access to goods or services.

This article develops an extension to an operational model that was initially conceived for humanitarian logistics by Franco et al. [10] towards an environment where the actors involved share market participation and there is direct competition at the horizontal level in the logistics chain. The objective is to minimize logistics and social costs, considering penalties associated with the latter (deprivation costs). As an integral part of the model, cooperative participation is considered through cooperative games between the different suppliers (national or international) as a mechanism to optimize the processes and operating costs involved in the supply chain in order to obtain a global benefit [11-13]. In this order of ideas, the model to be treated in this article consists of 2 stages: a programming model and a cooperative games model. In the first, the distribution schemes are established along the supply network without considering last-mile activities; however, human suffering over time (deprivation) is considered. In the second model, the information resulting from the previous stage is taken, starting

from the fact that the actors involved in the first stage receive benefits from the deliveries made and different cooperation scenarios are recreated. The purpose of these scenarios is to analyze the interaction between the participants and draw conclusions about the distribution strategies adopted by the different possible coalitions.

2. Literature Review

In this article, we seek to relate or compare the behavior of the actors in the supply chains from an emergency or disaster situation that affects the population and makes the supply of goods and services necessary, so we focus on publications of related situations such as those experienced in the humanitarian logistics environment and the consequences in global supply chains. Despite the fact that the research related to the COVID-19 emergency is recent and has had a boom mainly in the health sciences [14], the impact it has caused on the behavior of the global supply chains and the economy has been notorious [15], which is why some authors have focused on the medium- and longterm effects on supply chains [16]. Complementary to the above and considering the fact that the emergency currently experienced is scalable or comparable to the humanitarian logistics response stage, there is a limited amount of goods or services (critical supply or humanitarian aid) that are necessary to overcome the eventualities of the emergency and whose lack of access or poor condition has consequences on the daily life of the affected population [17-19], considering sanitary regulations and measures adopted by governments and international organizations.

Despite the fact that humanitarian logistics is a subject with a relatively shorter study time than commercial logistics, the interest it has aroused due to its lack of effectiveness in previous years has led us towards the belief that the vision of commercial logistics could mean a contribution to humanitarian logistics in terms of supply chain performance [4]. Complementarily, the budgetary support of organizations for disaster response indicates the need to develop efficient preparedness and response models [20]. Humanitarian logistics encompasses an extensive field of study, so it would not be correct to isolate it as apart from conventional logistics. It is worth noting the operating conditions in which organizations are involved in the response and recovery stages: scarcity of resources and urgent demand from the affected population [5]. In this article, we develop a humanitarian approach to a problem where suppliers generally behave like oligopolies, taking into consideration the profit obtained by the participants when carrying out their activity and the social cost (mainly deprivation costs) incurred in the attention of the affected areas.

Deprivation is understood as being in the absence of goods or services for a certain time, and then, the deprivation cost is defined as that caused by human suffering in the absence of humanitarian aids or critical supplies. Some interpret it as the externality impact of transport costs, paralleling the private cost of travel [21–23]; on the other hand, some define it as the willingness to pay for access to goods or services after a certain time [10].

The nonlinear behavior of deprivation costs implies approximations to represent the increment in human suffering over time; some authors adopted a perspective that proposes the use of penalties for incurring relatively high deprivation costs compared to expectations [24], while others developed variable penalties according to the level of deprivation to which the affected population is exposed [25]. It is worth highlighting the fact that hysteresis or the development of sequelae in the well-being of people due to the deprivation costs is not considered. In our contribution, we decided to relax the nonlinear complexity of deprivation into statistically grounded linear approximations that are representative of behavior caused by human suffering.

The conceptual differences with respect to some models developed with problems related to our contribution are shown in Table 1.

In relation to the interaction between actors, the need to share information and more effective supply chains has been seen in previous emergencies when supplying demand [10]. Additionally, the investigative contribution would be useful if we consider all these components in a single emergency: international commerce, relative shortage of critical supplies, human suffering caused by the lack of access, and the possible horizontal cooperation between suppliers that generally behave as oligopolies.

3. Model Description

This section describes the model's development, its limitations, and the research contribution, taking into account the aforementioned problem. The objectives to be met are based on minimizing the global costs of a humanitarian supply network under possible cooperation schemes and the benefit obtained by the participants.

3.1. First Stage: Programming Model. A mixed integer nonlinear programming operational model is developed, which proposes minimizing the social costs inherent to emergency care at the local level. The associated human suffering is taken into account as the deprivation cost; that is, given a known function of the deprivation costs, a series of thresholds are proposed over the time horizon and the penalty associated with delivery time is modified according to the elapsed time. The model considers variable penalties, which can be representative of the nonlinear nature of the deprivation costs [21]; consequently, the penalty value varies each time the time in deprivation exceeds one of the thresholds, having a terminal value where the growth in deprivation costs is diminished and the concavity of the function would begin to occur after the said value, also known as "value of life." Concerning the supply chain, the traditional aspects of any network in commercial logistics are preserved, with the addition of considering duality in transport costs; that is, for a given transport, its cost is divided into a logistics component whose value is commonly associated with payment for the transport activity and a social component associated with the value of time seen as human suffering, since during transport, the affected people remain in lack of goods or service (deprivation status).

Model to compare	Type of programming model	Stage within the humanitarian logistics cycle	Savings in cooperation	Competitive advantages
			The cost savings in transportation can	It is assumed that each supplier has strength, with is given as follows: a Supplier A: lower production
Franco et al. [10]	Tactical	Response	be based on productivity—saving time—and competitive costs of vehicle fleets.	costs. b Supplier B: larger capacities. c Supplier C: lower transportation cost.
Pérez-Rodríguez [26]	Operational	Preparation/ response	Not captured, it focuses on last-mile distribution based on the fact that they already have inventories available.	There are no competitive advantages.
Cotes and Cantillo [27]	Operational	Response	Not captured, the model developed mentions cooperation but does not express it in the form of coalitions.	There are no competitive advantages.
Our contribution	Operational	Response	The savings in transportation costs come from economies of scale (quantity discount) and the valuation of time is subject to priorities.	There are no predefined competitive advantages for the participants, so we leave the value of the contribution in the coalitions to free will so as not to rule out the existence of a subadditive game.

TABLE 1: Comparative table between the contribution made against different models developed.

Model assumptions: the demand is known, based on estimates in the affected area; there is knowledge of the demand and its behavior. The offer is also known, based on the fact that there is a group of commercially constituted manufacturers, which provide information on the quantities that they would be willing to mobilize. Horizontal cooperation is possible, in contrast to the previously validated model for a humanitarian environment—where a good part of the entities was non-for-profit—and for a commercial environment, it is necessary to establish coalitional interactions between the actors that in natural conditions represent oligopolies in their market sector. The supply network is predefined, since this article does not include location models and the previous existence of a supply network through which the products would be mobilized is assumed.

The social cost is penalized according to time, in the sense that there is a limited value of human suffering due to deprivation time. To avoid incurring in this situation, thresholds are established (considerably lower in time); in case of breaching a certain threshold, late deliveries would be subject to variable penalties, depending on the time elapsed above this [21]. The product used is not perishable over the time horizon so that the product condition does not become a risk factor in terms of cargo loss due to expiration. Last-mile distribution is not considered, since it is a programming model independent of an allocation model and it is assumed that the points of demand house groups of affected people; consequently, there is consolidated demand in those areas. Last but not least, a convex nature in deprivation costs is considered, since once the deprivation cost function and its convexity are known, people would not develop sequelae after remaining deprivation of goods or services, for which their state of well-being would not be affected in time by secondary effects (hysteresis).

As previously mentioned, our model was validated with that developed by Franco et al. [10] with an extension to the problem of the COVID-19 emergency, for which we summarize the conceptual changes made as; unlike the model proposed by Franco et al. [10], our contribution went from taking a tactical model to an operational programming model that would be developed during the emergency response stage.

One of the most notable differences that we propose is related to the savings from belonging to a coalition and being in cooperation with other participants, where the time of the shipments and their respective rate vary according to the established priority. On the other hand, our model does not establish predefined competitive advantages, so we leave the contribution value of each participant to free will so as not to rule out the existence of a cooperative game of a subadditive nature.

The model is made up of several levels: manufacturers (I) and points of demand (J), according to Figure 1. Manufacturers refer to the suppliers of the products (water, food, medicines, etc.) necessary to supply the needs in the emergency (K). These suppliers represent direct competition in their natural market conditions and their interaction could mean economies of scale when forming a coalition (S). The points of demand would be the affected areas that could be cities or communities, where the impact to be considered is that resulting from the deprivation of the goods or services.

Considering the demand (D_{kj}) and the offer (O_{ki}) , we propose a supply network in which the response capacity is



FIGURE 1: Graphic description of the programming model. The red line represents the consolidation of cargo from cooperation, while the black line represents an individualistic distribution scheme.

sufficient to meet the needs at the local level; in the case of unmet demand, we will denote it by UF_{kj} . Shipments made (X_{kiqjt}) over time (*T*) are subject to priority parameters (*Q*) in transport cost (CT_{kiqj}) and their contribution in time to deprivation (TV_{kiqj}) at the time of being delivered at points of demand, so the deprivation is weighted in quantity delivered (Y_{kjt}) and time elapsed (TE_{kjt}) . Regarding the nonlinear nature of deprivation, we opted to do a linear relaxation $(\beta(t)_{kt'})$ through a piecewise function whose segments (T') represent an approximation to the deprivation function (G_{kt}) , according to Holguín-Veras et al. [21] such that

$$\beta(t)_{kt'} = \beta_{1kt'} * t + \beta_{2kt'}.$$
 (1)

According to equation (1), it is considered that $\beta_{1kt'}$ and $\beta_{2kt'}$ are parameters of the linear regression performed on the deprivation function, remaining in the form of a piecewise function and depending on time. Additionally, of all the possible functions from the regression segments, there is a regression function that best fits a given period (*T*), which we will denote by G_{kt} . If there are shipments in a period (*T*), we check it in a binary way (BE_{kjt}), where the value of 1 is assumed in case of shipments, and apply the respective deprivation cost (G_{kt}) and 0 otherwise. In the case of unmet demand, the deprivation to be assigned would be equivalent to the maximum willingness to pay by the individual, which we will denote by *P* [21].

For its part, membership in a coalition (PC_{is}) is evaluated in a binary way, adopting the value of 1 when a player or manufacturer (*I*) is a participant in a specific coalition (*S*) and 0 otherwise. When applying the discount rates by quantity in the transports carried out by a coalition (DC_c) , we choose to delimit the quantity intervals with lower (LI_c) and higher (LS_c) limits to select the rate to be applied in a binary way (BT_{sc}) , which assumes the value of 1 when the quantity mobilized belongs to an interval and applies the corresponding rate (*C*) and 0 otherwise.

For the total cost of the objective function, we will denote it as follows:

$$\begin{split} \operatorname{Min} F &= \sum_{K} \sum_{I} \sum_{Q} \sum_{J} \sum_{T} \sum_{S} \sum_{C} X_{kiqjt} * \\ CT_{kiqj} &= \sum_{K} \sum_{I} \sum_{Q} \sum_{J} \sum_{T} X_{kiqjt} * PC_{is} * BT_{sc} * DC_{c} * \\ CT_{kiqj} + \sum_{K} \sum_{J} P * UF_{kj} + \sum_{K} \sum_{J} \sum_{T} Y_{kjt} * G_{kt}, \end{split}$$

$$\end{split}$$

$$\end{split}$$

subject to

$$\sum_{Q} \sum_{J} \sum_{T} X_{kiqjt} \le O_{ki}, \quad \forall k \in K, i \in I,$$
(3)

$$Y_{kjt} = \sum_{I} \sum_{Q} X_{kiqj(t-TV_{kiqj})}, \quad \forall k \in K, \ j \in J, t \in T: \ t > TV_{kiqj},$$

$$(4)$$

$$UF_{kj} + \sum_{T} Y_{kjt} = D_{kj}, \quad \forall k \in K, j \in J,$$
(5)

$$UF_{kj} \le D_{kj}, \quad \forall k \in K, j \in J,$$
 (6)

$$Y_{kjt} \le M * BE_{kjt}, \quad \forall k \in K, j \in J, t \in T,$$
(7)

$$TE_{kjt} = t * BE_{kjt}, \quad \forall k \in K, j \in J, t \in T,$$
(8)

$$\beta \left(TE_{kjt} \right)_{kt'} \le G_{kt}, \quad \forall k \in K, j \in J, t \in T, t' \in T',$$
(9)

$$\sum_{K} \sum_{I} \sum_{Q} \sum_{J} \sum_{T} X_{kiqjt} * PC_{is} \leq M * (1 - BT_{sc}) + LS_{c} * BT_{sc},$$

$$\forall s \in S, c \in C,$$
(10)

$$\sum_{K} \sum_{I} \sum_{Q} \sum_{J} \sum_{T} X_{kiqjt} * PC_{is} \ge -M * (1 - BT_{sc}) + LI_{c} * BT_{sc}$$

$$\forall s \in S, c \in C,$$

$$\sum_{C} BT_{sc} = 1, \quad \forall s \in S,$$
(12)

$$X_{kiqjt}, Y_{kjt}, UF_{kj}, G_{kt}, TE_{kjt} > 0.$$
 (13)

In equation (2), the objective function is found, where it is sought to minimize the social cost, either by the logistics cost component (related to the variables X_{kiqjt} and Y_{mjkt}), by the penalty applied to not meeting the demand (related to UF_{kj}), or by that from deprivation costs (related to G_{kt}); additionally, quantity discounts are considered in the rates of some national transports, right at the end of equation (2) [21]. The response capacity (offer) by producers is shown in equation (3), in which the flow of supplies is evidenced in equation (4). For its part, equations (5) and (6) describe the fulfillment of the demand. Equations (7)-(9) assign a delivery time and an equivalent deprivation cost, evaluated within all the piecemeal functions available to capture deprivation. Equations (10) and (11) evaluate the intervals for which it is possible to assign a rate, having M as a large value (big M). For its part, equation (12) is in charge of assigning discount rates by quantity based on the quantity of goods that a specific coalition has mobilized, which is palpable in the objective function. Finally, equation (13) proposes the nonnegativity of the variables.

Based on the results obtained from the previous programming model and assuming that the participants in the supply chain received benefits for the deliveries, the information would be used as input for a cooperative gaming model. The purpose of this would be related to the interaction between actors involved in the supply chain (national or international) to justify the existence or not of coalitions between players, based on the total benefit obtained.

3.2. Second Stage: Cooperative Games Model. A series of scenarios are established, for which cooperation would imply benefits or cost reductions for some of the players. Next, the Shapley value is used to obtain information on the contributions provided by the players belonging to a specific coalition and make inferences regarding the expected value of the contribution for each player [28, 29]. To calculate the value of the contribution, we will use the following equation:

$$\phi_i(v) = \sum_{S \subseteq N \setminus \{i\}} \frac{|S|! (n - |S| - 1)!}{n!} [v(S \cup \{i\}) - v(S)], \quad (14)$$

where *S* is a specific coalition within the set of feasible coalitions *N*, for its part, *n* is the total number of players, v(S) is the value of the coalition *S*, and finally, *i* is the player who is being calculated by the Shapley value.

Our contribution to the research is based on how the cooperation between participants—who generally behave like oligopolies—can impact a commonly humanitarian problem either by generating economies of scale or by sharing information to generate benefits.

4. Case Study

To put the proposed model into practice, different scenarios were simulated, taking as a reference the emergency of COVID-19 due to the supply of protection elements for the areas of Barranquilla and Cali, Colombia, as of March 11, 2020. In this context, the national regulations declared the mask as a "not available vital medical device," according to INVIMA [30]. In the following days, the country began to experience an over demand for protection products for the general population and imports had increased, with which the Government of Colombia found it necessary to impose taxes on the import of masks in order to protect national production and regulate prices, in accordance with Dinero [31, 32] and DANE [33]. The effects of uncertainty and social behavior were essential factors to address this case, since demand is encouraged by the consequences of the cultural environment in which the population lives, according to Gómez et al. [34].

Figure 2 shows the supply network used by national manufacturers and treated with a personal protection product (face mask); for transport costs, the tool of the Colombian transport ministry Sice-Tac was used. Finally, to determine the deprivation costs, the function developed by Macea et al. [35] and linear approximations were made in a piecewise function under a confidence level of 95%, according to Figure 3. The application case is made up of the following links: national producers, which are regional textile companies from the departments (provinces) of Antioquia and Cundinamarca and also points of demand which would be located in the cities of Barranquilla and Cali. Also, the product to be mobilized would be KN-95 reference

face masks (with a relatively good average performance) which should be delivered at the points of demand. The time horizon was discretized in 20 segments of 12 hours, for a total of 240 hours (10 days), thus ensuring a linear scaling to the nonlinear deprivation function; in the same way, the priorities in the shipments behave in the same way as follows: the higher the priority, the higher the cost of shipping and the shorter the travel time, classified under the categories of low, medium, and high priority. At the same time, as the quantity mobilized by a coalition increases, transport rates are exposed to reductions due to economies of scale, made up of 3 quantity intervals in our case.

In summary, there is a group of national manufacturers clustered in 2 regions (Antioquia and Cundinamarca) where a good part of the textile production is concentrated due to their considerable market share; these producers have autonomy in the mobilization of their products due to exclusive contracts with cargo operators. Likewise, there are a group of cities in a condition of deprivation of the mentioned product (KN-95 mask) whose demand must be supplied with the lowest possible overall cost (understood as the set of monetary costs and deprivation costs). Shipments made from the producing regions are subject to cost-time and quantity-cost rates in the form of priority shipments and quantity discounts.

Figure 4 shows the relationship of deaths per week at the national level from March 2 to October 4, 2020, leaving a balance of 29,787 confirmed deaths from COVID-19, where a peak of activity is seen for the month June [36]. Additionally, the impact of the measures adopted for emergency care is reflected in the population with the greatest vulnerability, taking into account that more than 85% of deaths come from socioeconomic classes with middle or low income [37], added to the threat of the hoarding of critical supplies and possible price speculation by suppliers or intermediaries, in accordance with the Superintendency of Industry and Commerce [38].

In an unfortunate and coincidental way, the peak of activity in deaths is probably due to the social indiscipline that had flooded the country in that period of time, where the national authorities intervened around 4 thousand social meetings and celebrations during a period of 2 weeks, which was becoming a risk factor in accordance with Portafolio [39] and El Tiempo [40]. Complementary to the above, we decided to apply the methodology based on the fact that the Colombian government had made the determination to protect the national production of masks, reducing or discouraging their imports, leading to the possible presence of an oligopoly in this market sector.

A series of scenarios are established, for which cooperation could imply benefits or cost reductions for some of the players. In scenario 1, the participants do not cooperate, and the players corresponding to the production of the regions of Antioquia (A) and Cundinamarca (B) act separately; in scenario 2, participants A and B cooperate.

The cooperation of the different manufacturers implies a consolidation of cargo or a greater volume to be mobilized in the different coalitions (depending on the number of members). By belonging to a coalition, the members have



FIGURE 2: Georeferencing the supply network: manufacturers are located in the areas pointed in red, while the points of demand are located in the areas pointed in blue.

access to different national transport rates; due to the quantity discounts, each transport rate includes an interval for which a discount is applied, and the amount to be taken into account is the one mobilized by the coalition.

4.1. Results. The first stage model belongs to a mixed integer nonlinear programming problem; it was solved by coding

the General Algebraic Modeling System (GAMS) program and it was executed on the Network-Enabled Optimization System (NEOS) platform for approximately 9,000 variables and just over 15,000 constraints for each scenario, making computational execution time span less than 100 seconds to show the optimal supply network that minimizes social costs. The second stage model uses the outputs resulting from the first stage to define the value of each participant's



FIGURE 3: Comparison of the behavior between the nonlinear deprivation function ΔE (EC) and the linear regressions of the proposed piecewise function.



FIGURE 4: Weekly deaths from confirmed and suspected COVID-19 according to DANE [36, 37] (the time horizon between March 2 and October 10, 2020.).

contribution, according to the quantities mobilized in the first stage and the market value of the critical supply.

The results obtained from the aforementioned information can be seen in Tables 2 and 3, from which it can be inferred that there were scenarios where, due to the weighing of costs, the manufacturers chose to consolidate deliveries in a single period, acting separately and incurring a lower overall cost, in accordance with scenario 1. On the other hand, in scenario 2, we notice a change in the quantities to be distributed by the manufacturers mainly due to the economies of scale to which they would access; a longer delay in the delivery of the masks can also be noted, which would imply a higher cost associated with deprivation. Regarding the priorities of shipments, a low level of alert or concern about carrying out the mobilizations of masks may be noted, which responds to the problem of over demand and a possible case of "bullwhip effect," which would be understandable due to the fact that the valuation given to this product comes mainly from the care of life and not precisely because of its monetary value, in accordance with Figure 3 where the incremental behavior of human suffering is explained over time. Surprisingly, the scenario that incurred the lowest total cost was the one where the participants decided not to cooperate (scenario 1).

Regarding the cooperative game model, it is assumed that the players or participants would receive benefits for their activity [9], which commonly happens in a commercial environment in the presence of oligopolies. The results obtained for the cooperation scenarios can be seen in Tables 4 and 5.

Paradoxically, scenario 2 coincided in having the highest social cost incurred in the objective function and the highest benefit obtained in the cooperative game, so the possibility that the benefits of coalitions are adversely related to social costs is not ruled out. With the above, it is implied that there must be control over the number of members that would make up the coalitions, since they could not guarantee the lowest social cost.

Table 5 describes the Shapley value of each of the players, assuming that they belonged to the AB coalition and their respective contributions to the coalition in a percentage way, where the national producer (located in Antioquia) obtains around 80% of the total benefits from the coalition.

4.2. Sensitivity Analysis. Likewise, Figure 5 shows the sensitivity analysis carried out on the programming model, where a change of up to 100 times the value of the objective function can be noticed with only varying less than 5% of the time horizon (10 hours), so the proposed model is capable of capturing the nonlinear behavior of delays to delivery

	Individualistic scer	nario (A-B)			F (\$COP)
Variable X (k , i , q , j , t)	MB	U	TS	TL	
Antioquia-Low-Barranquilla	А	1,072,350	5	28	
Antioquia-Low-Cali	А	1,519,650	16	28	
Cundinamarca-Low-Barranquilla	В	0	_	_	\$ 895,918,833,000
Cundinamarca-Low-Cali	В	461,450	14	28	
Total		3,053,450			

TABLE 2: Results of the programming model under scenario 1.

MB: player or participant; U: units mobilized; TS: period of delivery of the supply; TL: period of receipt of the supply; F: value of the objective function.

TABLE 3: Results of the programming model under scenario 2.

Cooperation scenario (AB)					F (\$COP)
Variable X (k , i , q , j , t)	MB	U	TS	TL	
Antioquia-Medium-Barranquilla	А	208,350	5	25	
Antioquia-Low-Cali	А	1.981,100	12	24	
Cundinamarca-Medium-Barranquilla	В	864,000	121	143	¢ 11 200 000 000 000
Cundinamarca-Baja-Cali	В	0	_	_	\$ 11,200,890,000,000
Total		3,053,450			

MB: player or participant; U: units mobilized; TS: period of delivery of the supply; TL: period of receipt of the supply; F: value of the objective function.

TABLE 4: Benefits obtained (\$COP) by the players in each of the scenarios.

Scenario 2
AB
\$1,611,435,200
\$690,940,800
\$2,302,376,000

TABLE 5: Calculation of the Shapley value (\$ COP and percentage) for each of the players.

Player	\$ (<i>w</i>)	%
А	\$ 1,920,533,217, 50	83,42
В	\$ 381.842.782, 50	16,58
Total	\$ 2,302,376,000, 00	100



FIGURE 5: Sensitivity analysis performed on delivery times.

times—generally attributed to disruptions in the supply network—and its contribution as a deprivation cost in the objective function. The cost-time relationship coincided with that proposed by Arellana et al. [41], where a proportional behavior is expressed between travel times and the



FIGURE 6: Sensitivity analysis performed on transportation costs.

impact of transport externalities; in this case, it is attributed to the nonlinear nature of deprivation costs.

In addition, what is expressed by Figure 5 reflects the opportunity cost of not having opted for foreign trade, where delivery times are generally longer, and therefore the associated deprivation, leaving us with the following contrast: by allowing imports of critical supplies, we expose ourselves to a possible spread of the disease and higher social costs due to delivery times, while reducing or prohibiting them will result in the possible hoarding, price speculation, and greater socioeconomic vulnerability of the affected population.

On the other hand, by varying the transport costs, an incremental relationship was obtained in the social costs, according to Figure 6, where by varying the size of the transport costs 5 times, an increase of just over 20% was obtained in the social costs.

In summary, we found a behavior in the social costs derived from transport where private costs have a relatively minor importance compared to the externalities caused by delays in deliveries. Finally, considering that the local response capacity was sufficient to meet the demand, the formation of coalitions allowed access to economies of scale in transportation and reductions in social cost.

5. Conclusions and Future Research

Regarding the proposed approach, the methodology offers a tool to evaluate the distribution networks of critical supplies from a humanitarian perspective, avoiding last-mile distribution, but it is capable of considering the nonlinear impact of time on total costs of the distribution strategy, where a slight change to delivery times generated a drastic change to total costs, due to deprivation costs. Likewise, the approach analyzes the risks to which the affected population is exposed when considering the possible participation of international suppliers as well as the possible hoarding of critical supplies by actors that generally behave as oligopolies. The information pertaining to the COVID-19 emergency could be represented through the proposed and statistically based approach towards deprivation costs, which played a fundamental role in the decision-making of the programming model, in accordance with the trend on the part of the players to make the deliveries as early as possible efficiently, showing a behavior in transport costs where the externalities caused by deprivation time obtained greater importance than private costs. By adding delays equivalent to 5% of the time horizon, we obtained a change in social costs of more than 100 times its value, while by varying up to 5 times the value of private costs, we obtained a change of little more than 20% in social costs.

On the other hand, the recreation of possible cooperation scenarios allowed the evaluation of the different types of coalitions regarding the benefit that they could offer to the players; by not ruling out the possibility of a subadditive game, it is probable that some participants could reduce the global benefit when participating in a coalition. Additionally, the proposal of a possible contrast between the benefit obtained and the overall cost of the distribution schemes proved that having the highest benefit does not guarantee the lowest social cost.

For future research, we hope to improve the parameters' accuracy, which involve human suffering since they are approximations. We also contemplate the possibility of additional disruptions to the supply networks while the response stage is developing, either in the transport routes or in the number of actors involved (usually due to regulations), uncertainty in demand and supply, and lastmile distribution. Last, but not least, we hope to recreate scenarios where there are variations in the price of critical supply and the deprivation cost function over the time horizon, in relation to the changes that occur in reality regarding foreign trade policies and the impact they would have on global costs, the benefit obtained, and the affected population.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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