Localización de ambulancias para sistema de emergencias médicas de Cúcuta

Location of ambulances for Cucuta's emergency medical system

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Resumen

Introducción. La localización de las bases de ambulancias es una decisión estratégica en el sistema de emergencias médicas (SEM), que impacta el tiempo de respuesta y la probabilidad de salvar vidas o dejar secuelas en los pacientes que sufren accidentes de tránsito o crisis de una enfermedad.
Objetivo. El propósito de la investigación fue proponer la localización de bases de ambulancias para el SEM, que mejore la oportunidad en la atención pre-hospitalaria en Cúcuta.
Metodología. Primero, se utilizó el método del centro de gravedad para segmentar la ciudad en sub-cuadrantes y determinar ubicaciones alternativas. Segundo, se empleó el sistema de calificación de factores de la localización para evaluar las ubicaciones alternativas. Tercero, se diseñó un modelo programación lineal entera que determinó la localización óptima de ambulancias, que minimiza el número de bases para atender los accidentes de tránsito en un tiempo de respuesta de 8 minutos o menos. Finalmente, Para determinar los tiempos de respuesta se desarrolló un código en Python que utilizó el servicio web Direction API de Google Maps.
Resultados. Se propusieron dos alternativas óptimas de localización, las cuales reducirían el tiempo de respuesta promedio de la situación actual de 10,96 minutos a 5,39 y 5,72, equivalentes a una mejora del 50,82% y 47,81%, respectivamente, y el porcentaje de pacientes atendidos en un tiempo de respuesta de 8 minutos o menos se incrementaría a 85,19% y 78,84%, mejorando el 30,82% de la situación actual.
Conclusiones. Se sugiere la segunda propuesta de localización que consideró cuatro bases, porque facilitaría al SEM el control y la gestión logística de las ambulancias, y mejoraría la oportunidad en la atención pre-hospitalaria en Cúcuta.

Palabras clave

Atención pre-hospitalaria; Servicios de emergencias médicas, Investigación de operaciones; Logística hospitalaria; Optimización; Sistema de emergencias médicas.

Abstract

Introduction: The location of ambulance bases is a strategic decision in the emergency medical system (EMS), which impacts the response time and the probability of saving lives or leaving sequelae in patients who suffer traffic accidents or disease crises.

Objective: The research proposed the location of ambulance bases for EMS to improve the timeliness of pre-hospital care in Cucuta.
Method: First, this research used the center of gravity method to segment the city into sub-quadrants and determine alternative locations. Second, the location factors scoring method was employed to evaluate alternative sites. Third, an integer linear programming model was designed to select the optimal location of ambulances in Cucuta that minimizes the number of ambulance bases to care for traffic accidents in a response time of 8 minutes or less. Finally, a code was developed using Python 3.8.2 and the Google Maps Direction API web service to determine the response times.
Results: This paper proposed two optimal location alternatives, reducing the average response time from 10.96 minutes to 5.39 and 5.72, an improvement of 50.82% and 47.81%, respectively. In addition, the patients cared for in a response time of 8 minutes or less would increase to 85.19% and 78.84%, improving the 30.82% of the current situation.
Conclusions: The second location proposal, which considered four bases, was suggested because it would facilitate EMS control and logistics management of ambulances and enhance the timeliness of pre-hospital care in Cúcuta.

Key Words

Pre-hospital care; Emergency Medical Services; operations research; hospital logistics; optimization; emergency medical system.

I. INTRODUCCIÓN

In pre-hospital care, response time greatly affects patients' survival rate and quality of life [1], [2]. A rapid ambulance response can effectively reduce the disability, morbidity, and mortality of emergency patients [3]. The time of care and response is directly proportional to the population's mortality rate. In the most severe cases, response time becomes crucial to the patient's health and recovery [4]. For these reasons, reducing the response time is relevant, mainly when most of the events handled are of high priority, as was presented in Bogota in 2018, where 65% of the accidents that used ambulances were high severity [1].

Response time is from the reception of an emergency call at the EMS communications center until an ambulance arrives at the patient's location [2], [5]. There are several definitions of response time [6]. This research considered the ambulance travel time from its location to where the service is required, according to [6]–[8].

Ambulance response time is a pre-established standard as a key EMS performance indicator. Each country has a different metric; in the U.S. was established that 95% of emergency calls should be attended to within 10 minutes and 30 minutes in urban and rural areas, respectively. In Montreal, 7 minutes is required for 90% of events [9]. In England, the national standard indicates that response time should not exceed 8 minutes in 75% of life-threatening cases. In South Korea should be 5 minutes or less in 74% of emergency calls. In California, the response time should not exceed 8 minutes in 90% of events. Internationally, several EMS authorities recommend a maximum of 8 minutes in at least 90% of the events treated [2]. In Colombia, no standard response time regulated by the authorities was identified [10].

In Bogotá, Colombia, the average ambulance response time was above the international standard [1]. For example, for stroke patients, the median was 13 and 12 minutes in 2013 and 2014, respectively [11], much higher than the maximum 8 minutes recommended by the American Heart Association/American Stroke Association [12]. In Medellín, average response times of 7 and 8 minutes were evidenced in 2013 and 2015, respectively [13], [14]. In the literature, the minimization of response time has received considerable attention [1], [3], [4], [6], [15]–[22]; however, in Cúcuta, there was no study of the location of ambulance bases in the EMS.

The performance of emergency medical services (ambulances) is usually measured by ambulance response time [3]. Emergencies should be handled in short travel times to achieve excellent logistic performance [23]. Therefore, ambulance response time is a critical indicator in EMS management [20]. EMS provides initial emergency care to patients who have been victims of diseases, traffic accidents, occupational accidents, severe trauma, cardiac or respiratory arrest, diabetic coma, congestive heart failure, severe reactive airway disease, and poisoning [24]. These diagnoses put life or physical integrity at risk. The EMS comprises mechanisms for notifying medical emergencies, providing pre-hospital and emergency services, basic and medicalized transport, hospital care, and the work of the regulatory centers for emergencies (CRUE), among others. Therefore, EMS development, operation, and improvement are essential to ensure a better patient care experience [25], [26].

The importance and sensitivity of decision-making in EMS have been recognized by operations research scientists, EMS planners, and healthcare professionals who studied problems in EMS management [17]. These problems can be classified into strategic, tactical, and operational, according to the levels of decision-making. The ambulance bases location is a strategic decision [15], [16], [18], [19], which has been the main problem of interest for operations research [5] and consists of selecting the possible waiting locations to ensure adequate coverage of the population [18].

The optimal location of ambulances in a given coverage area is a crucial element in reducing EMS response time [4], [6], [20]. The dispatch policy and the ambulance location model significantly impact response time [3], [9]. To ensure a rapid response in pre-hospital care, optimizing the location of bases and the distribution of available ambulances [21] is necessary without increasing existing ambulances [1].

The following researchers studied the optimal ambulance location: Van Den Berg et al. [21] designed a mathematical maximum expected coverage location model (MEXCLP) for the optimal distribution of bases and number of ambulances in Vestfold, Norway; Liu et al. [22] proposed a new integer linear programming (ILP) mathematical model for the location of ambulances and the allocation of patients to hospitals to maximize the covered demand points in Songjiang, China; Azizan et al. [9] presented a solution to locate ambulances in Johor Bahru, Malaysia, which maximizes coverage, using OpenStreetMap, the Dijkstra, and Quick Hull algorithms to find the shortest route, and the Greedy Adding algorithm to solve the problem; Ferrari et al. [4] analyzed the location of ambulance bases in Rio de Janeiro, using a mathematical model to maximize the population covered and to minimize the number of ambulance bases and the distances from demand points to dispatch centers; Segura et al. [27] propose a methodology to optimize the location of ambulances in the Valley of Mexico based on the set coverage location model (LSCP) and the p-median model.

In Colombia, Zapata & Baldoquin [6] proposed two variants of a mixed linear programming model (MILP) to locate heterogeneous fleet vehicles and support different types of emergency medical care services of a company in Cali. Villegas et al. [28] determined the location and the number of ambulances needed to care for emergencies in Medellín through a model based on MEXCLP. They evaluated several scenarios and identified improvement strategies for the city's pre-hospital care. Leuro [29] determined the location of the bases and the number of ambulances in Bogotá by applying deterministic location models, such as Diamond Covering, P-centers, and Simultaneous Location of facilities, to care for an emergency in less than 10 min. Finally, Rojas et al. [30] designed a methodology using linear programming to determine the optimal location and the number of ambulances in Bogotá. They used simulation to validate the results and improve response time.

This research proposed the optimal location of ambulance bases for the Cúcuta EMS, using the center of gravity method, the factor rating system, and an LSCP model, which minimizes the number of bases to meet the demand in a response time of 8 minutes or less. This article has the following sections: the second presents the methods and tools applied; the third shows the segmentation of the city into sub-quadrants, the selection of one location per sub-quadrant, the ILP model, two proposals for the location of ambulance bases, and finally discussions, conclusions, and future work.

II. METHODS

Fig. 1 shows the activities developed in the research, in which several methods and tools were used to determine the optimal location of ambulances in Cúcuta. Each of the activities is described below.

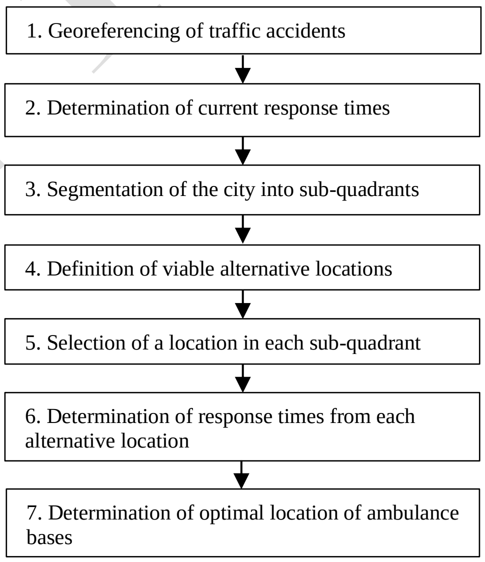


Fig. 1. Activities carried out for the optimal location of ambulances

In the first activity of Fig. 1, the traffic accidents presented in 2019 were georeferenced according to historical data provided by the Traffic and Transportation Office of Cúcuta through Google My Maps. Second, a code in Python 3.8.2 programming language was developed, using Google Maps Direction API web service to determine the response times from the current location of the ambulances to each accident point. Third, the city was segmented into sub-quadrants using the center of gravity method. This mathematical technique is used to locate single facilities that serve several demand points, considering the distance between them and the volumes of goods to be distributed, to minimize transportation costs [31]. Fourth, viable alternative locations in each sub-quadrant were determined by consulting with paramedics and the authors' judgment and knowledge of the city.

In the fifth activity of Fig. 1, the factor rating system was used, a widely used location technique because it allows consideration of several factors or criteria using simple point rating scales [31]. In this fifth step, according to his judgment, the Cúcuta EMS director weighed location factors, evaluated alternative locations, and selected the best one in each sub-quadrant. Sixth, the response times were determined from each location chosen in each sub-quadrant to each accident point using Python code. Finally, a mathematical model of ILP based on the LSCP model was designed, known in the literature as the Set Covering Location Problem, which minimizes the number of servers needed to fully cover the demand in a region, considering a maximum response time. This model assumes unlimited capacity in the localized ambulance bases (it does not consider system occupancy) [32]. JuliaPro software version 1.0.5-2 was used to solve the model [33].

III. RESULTS AND DISCUSSION

The results of applying methods and tools to solve the problem of the optimal location of ambulance bases of the Cúcuta EMS are presented below

A. Data collection and current situation

The Cúcuta EMS does not have an ambulance location study. In coordination with the Departmental Health Institute of Norte de Santander, the EMS directors subjectively defined that ambulances should be located in a single place in the eastern center of the city, Libertadores Avenue, Las Cascadas Theater (Fig. 2a).

The data on the 425 traffic accidents presented in 2019 included the time, event location, and the type of vehicle involved. However, without event location coordinates and actual response times, the latitude and longitude of each accident were determined via Google My Maps. Moreover, The Python code was used to determine the response times from the current location of the ambulances to each accident point. These times were selected from the variable ("duration_in_traffic") since it considers dynamic aspects such as the traffic that affect it at different times of the day.

The code was applied during hours of high vehicular flow (12:40 p.m. and 6:30 p.m.) and low vehicular flow (10:30 p.m.). The average response times, standard deviation, and percentage of events cared for with times of less than 8 minutes were 10.96 minutes, 4.83 minutes, and 30.82%, respectively, in high vehicular flow, and 9.14 minutes, 4.38 minutes, and 48.24% in low vehicular flow. According to the current location of the ambulances, the percentage of coverage is lower than the international standards established in the USA, Canada, England, and South Korea and recommended by EMS authorities [2], [9]; therefore, the current location of the ambulances is not suitable.

B. Segmentation of the city into sub-quadrants and estimation of alternative locations

Fig. 2a shows the traffic accidents presented in Cúcuta in 2019. Then, in Fig. 2b, a general center of gravity was calculated, which was considered the origin of the Cartesian plane, to segment the city into four quadrants. Next, to segment the city into 16 sub-quadrants (Fig. 2c), a center of gravity for each quadrant was calculated, considering the accidents presented in each. Finally, the centroids in each sub-quadrant were computed, considering the accidents presented in each (Fig. 2d). The centroids were determined using (1) and (2).

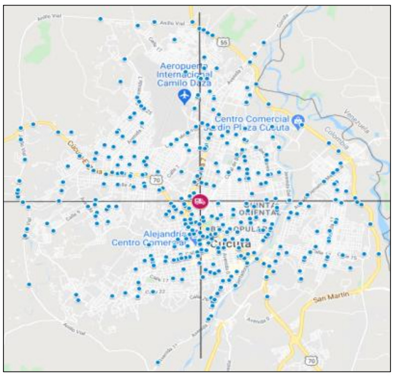
$$Cx = \frac{\sum dix * Vi}{\sum Vi} \qquad (1)$$

$$Cy = \frac{\sum diy * Vi}{\sum Vi} \qquad (2)$$

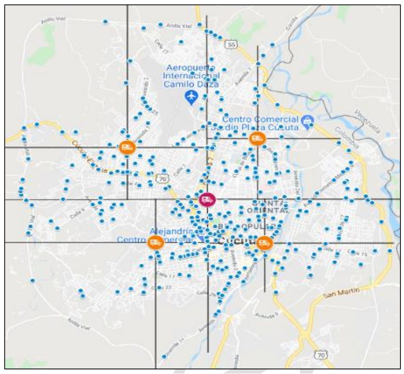
Where:
$Cx =$ coordinate x of the centroid
$Cy =$ coordinate y of the centroid
dix = coordinate x of locality i
diy = coordinate y of locality i
$Vi =$ volume of goods transported to or from location i

Sixteen centers of gravity were located in private areas or without vehicular access (Fig. 2d). Therefore, the paramedics and the authors' criteria and knowledge of the city determined viable alternative locations in each sub-quadrant. The city's central area, where the transport terminal is located, was not considered because of the high vehicular congestion and the lack of fast access roads. Fig. 2e shows the alternative locations in 15 sub-quadrants.

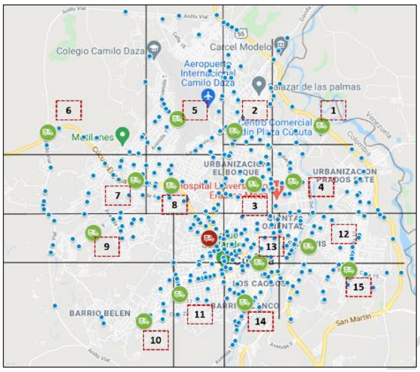
(a) Current location



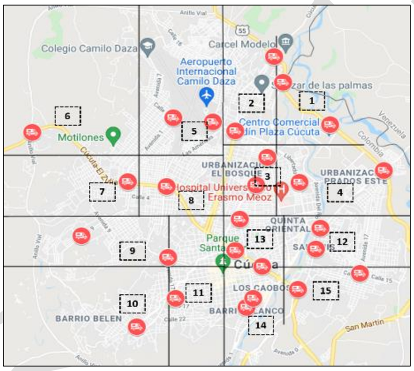
(b) General center of gravity



(c) Center of gravity by quadrants



(d) Center of gravity by sub-quadrants



(e) Decision alternatives by sub-quadrants

Fig. 2. Segmentation of the city into sub-quadrants and generation of location alternatives
Source: Prepared by the authors based on Google My Maps.

C. Selection of a location alternative in each sub-quadrants

The factor rating system was used to evaluate the viable alternatives in each sub-quadrant (Fig. 2e) and select the best one [31]. Authors initially defined location-relevant factors as the quality of access roads, safety, the land use plan (POT) guidelines, communications coverage, and mobility (Table 1). Then, using a percentage scale, the Cúcuta EMS director assigned each factor's weight or importance. Next, the director evaluated the alternatives in each sub-quadrant through a rating on a scale of one to ten, where ten is the highest score. Finally, the products between the relevant factor and the rating were added. The results for quadrant #4, sub-quadrants 12 through 15 (Fig. 2e), are presented in Table 1, and the alternative locations selected in each sub-quadrant are shown in Table 2.

Table 1. Rating by Factors - Quadrant 4 Location Alternatives

Location-relevant factors	Relative weight	Quadrant 4								
		Sub-quadrant 12		Sub-quadrant 13			Sub-quadrant 14		Sub-quadrant 15	
		Av. 3 calle 13 (Iglesia San Luis)	Redoma los Panches	Diagonal Santander, Cerca de Gino Passcalli	Calle 5 con diagonal Santander	Av. 0, calle 2N, frente a Olímpica	Av. 2, calle 19, Parque de los niños	Calle 17, Av. 0, Iglesia Carmelitas	Redoma San Mateo	Redoma cancha Vallester
Access roads	20%	10	7	10	8	7	10	7	8	10
Safety	15%	10	7	10	8	7	10	7	10	8
POT	5%	5	5	5	5	5	5	5	5	5
Communication	30%	8	8	8	8	8	8	8	8	8
Mobility	30%	10	7	10	8	7	10	7	7	10
TOTAL	100%	9,15	7,2	9,15	7,85	7,2	9,15	7,2	7,85	8,85

Table 2. Selected location alternative by sub-quadrant

Sub-quadrant (i)	Latitude	Longitude	Direction
1	7,9232	-72,47989	Centro comercial Jardín Plaza
2	7,92174	-72,5064	Redoma berlinas
3	7,90838	-72,49681	Cancha el diablo, Ceiba II (Canal Bogotá con Av. 3E)
4	7,90905	-72,48689	Av. Libertadores - Col - Mercedes
5	7,92486	-72,51588	Av. 1 con Calle 25 - Buenos Aires
6	7,92139	-72,54834	Avenida 70 # 23-76 - Anillo vial Cúcuta-Zulia
7	7,90935	-72,52639	Redoma Claret
8	7,90803	-72,51751	Redoma Atalaya (palustre)
9	7,89608	-72,53703	Calle 9 - frente Colegio Rodulfo Eloy (nuevo horizonte)
10	7,87376	-72,52441	Av. 25 con Calle 22 cancha 13 de Junio (Gaitán)
11	7,88064	-72,51544	Redoma Cementerio Central
12	7,89274	-72,48318	Av. 3 con calle 13 esquina (Iglesia San Luis)
13	7,88846	-72,49549	Diagonal Santander, Cerca de Gino Passcalli
14	7,87852	-72,49919	Av. 2 Con calle 19 (Parque los niños)
15	7,88681	-72,47308	Redoma Cancha Vallester

D. Mathematical model for optimal location of ambulance bases

The following is the ILP mathematical model that determined the optimal location of ambulance bases for the attention of traffic accidents in a response time of 8 minutes or less in Cúcuta.

Definition of the sets.
i: Ambulance base in the sub-quadrant i, where $i = 1,\dots, n$.
j: Emergency in the sub-quadrant j, where $j = 1,\dots, m$.

Definition of constant parameters
S_{ij}: takes the value of 1 if the emergency in sub-quadrant j is handled in 8 minutes or less from the ambulance base in sub-quadrant i. (See Table 3).

Definition of decision variables
X_i: *Binary variable, where*:
$X_i = 1$, If the ambulance base is assigned to sub-quadrant *i*.
$X_i = 0$, otherwise

Objective function. Minimize the number of ambulance bases required (3).

$$Min\ Z = \sum_i X_i \qquad \forall i \in \{1, \dots, n\} \qquad (3)$$

Problem constraints.

Coverage constraints. This constraint ensures that at least one ambulance base is located 8 minutes or less from all sub-quadrants (4).

$$\sum_j S_{ij} * X_j >= 1 \quad \forall i \in \{1, \dots, n\}, j \in \{1, \dots, n\} \qquad (4)$$

Binary auxiliary variable restriction. Equation (5) refers to the auxiliary variables of the model X_i that must take binary values.

$$X_i \in \{0,1\} \qquad \forall i \in \{1, \dots, n\} \qquad (5)$$

Solution of the mathematical model. The code was designed in *JuliaPro* software version 1.0.5-2.

Constraint (4) was formulated using the average response times from each alternative ambulance base location (Table 2) to each emergency presented in each sub-quadrant. These times were determined during high-traffic flow hours using the code developed in Python. Table 3 shows the average response times from each alternative ambulance base location in sub-quadrant *i* to each emergency in sub-quadrant *j*.

Table 3. Average response time from each ambulance base in *i* to each emergency in *j*

Ambulance base in the sub-quadrant (*i*)	Emergency in the sub-quadrant (*j*)														
	Average response time (min)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	4,38	7,83	10,00	6,19	13,31	16,97	18,51	14,64	21,20	21,03	16,59	7,79	11,16	11,48	11,86
2	6,71	3,35	3,98	9,53	6,75	11,09	11,36	6,60	14,07	14,72	10,96	12,20	10,93	13,27	15,52
3	9,28	7,49	3,00	8,56	11,95	14,59	13,87	8,05	16,65	15,98	12,04	11,38	7,23	11,72	14,84
4	7,85	7,47	5,27	6,24	11,82	16,18	16,48	11,15	19,09	19,10	15,22	8,88	9,77	10,95	12,15
5	14,65	11,54	11,86	17,52	7,03	8,76	9,34	10,30	12,58	18,86	16,02	20,05	15,42	17,76	22,21
6	14,69	14,30	16,99	19,82	11,67	5,88	6,25	11,98	9,92	18,22	16,27	21,52	15,78	17,71	22,43
7	14,88	11,56	11,19	16,53	7,93	5,51	4,13	6,25	6,94	13,39	10,56	17,51	10,17	12,37	17,27
8	15,38	11,78	10,13	15,42	9,99	8,89	7,72	5,26	9,88	12,46	8,73	15,89	8,41	10,65	15,64
9	21,85	18,35	18,16	23,30	14,57	11,74	8,21	12,96	5,76	13,36	14,65	24,43	17,07	19,04	24,32
10	20,72	18,23	16,57	19,17	19,76	19,38	16,38	12,66	12,63	3,92	5,96	18,75	15,72	11,91	18,35
11	18,43	15,93	14,58	16,91	17,35	17,08	14,83	10,18	11,81	5,08	3,39	16,60	13,33	8,98	15,89
12	8,63	11,12	10,09	5,68	15,94	19,21	18,83	14,41	20,78	17,90	13,59	4,96	7,79	8,48	6,50
13	14,31	13,85	9,45	11,06	15,31	15,20	14,05	9,60	16,74	13,31	8,91	9,90	4,69	5,05	9,97
14	13,47	15,62	13,72	10,12	18,58	18,99	16,97	13,14	16,77	11,86	6,99	9,54	8,95	4,36	8,72
15	12,56	15,67	15,76	9,86	21,14	24,18	24,30	19,70	26,68	23,24	18,69	6,82	12,86	13,36	6,19

The mathematical model did not consider the costs of building ambulance bases because it was assumed they could be located in available public sites such as squares, parks, and parking lots, similar to what was proposed in Sao Paulo [34].

E. Proposed ambulance base locations

Table 4 shows the current location results in the scenario of high vehicular flow and two proposals based on the solution of the mathematical model, where is presented the number of ambulance bases, the location, and the sub-quadrants that each of them would cover. Proposal 1 considered coverage to all sub-quadrants in a response time of 8 minutes or less, and Proposal two was relaxed to 9 minutes. Both proposals require changing the location of the current ambulance bases to improve the average response time and coverage percentage to 8 minutes or less. In contrast, four of the five existing bases in Norway required small changes since they are located close to the mathematical optimum [21].

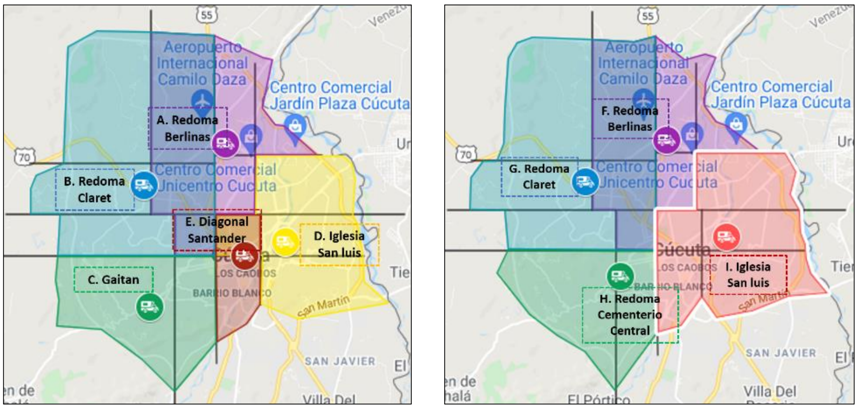
Proposals 1 and 2 would reduce the average response time of the current situation by 5.57 minutes and 5.24 minutes, equivalent to 50.82% and 47.81%, respectively. This improvement is similar to that obtained in Sao Paulo, where current response times were reduced by 41%, going from 27 to 16 minutes [34]. Furthermore, the improvement proposed in this research would favor pre-hospital care, as reducing the response time by five minutes doubles a patient's chance of survival [28].

The first proposal would increase the percentage of patients served in a response time of 8 minutes or less by 54.37%, and the second by 48.02%, compared to the current situation (Table 4). Both proposal results are higher than Rio de Janeiro, where the proposed model would increase the number of people served by 6.4% [4]. Regarding the maximum response time for 75%, 90%, and 95% coverage of traffic accidents, in both proposals, it would be reduced by approximately 50% compared to the current situation. Moreover, it would be very close to the international standards established in the USA, Canada, and England and what EMS authorities recommend [2], [9]. However, this time would exceed the results obtained in Bogota in 2018, where the average ambulance response time at the 95th percentile was 45.90 minutes [1]. Figure 2 shows the proposed optimal location of the ambulance bases and the sub-quadrants they would cover in Cúcuta.

Table 4. Proposed comparisons with the current situation and international standards

Situation	Average response time	% of cases with a response time of 8 minutes or less	Response time (min)			No. Bases	Base location		Sub-quadrants to be covered
			75%	90%	95%		Sub-quadrant	Address	
Current	10,96	30,82 %	14,12	18	19,42	1	12	Av. Libertadores. Teatro las cascadas	Todos
Proposal 1	5,39	85,19%	6,8	8,45	9,87	5	2	(A) Redoma Berlinas	1-2-3-5
							7	(B) Redoma Claret	6-7-8-9
							10	(C) Av. 25 con Calle 22 cancha 13 de junio (Gaitán)	10-11
							12	(D) Av. 3 con calle 13 esquina (Iglesia San Luis)	4-12-15

							13	(E) Diagonal Santander, Cerca de Gino Passcalli	13-14
Proposal 2	5,72	78,84%	7,48	8,95	10,2	4	2	(F) Redoma Berlinas	1-2-3-5
							7	(G) Redoma Claret	6-7-8-9
							11	(H) Redoma Cementerio Central	10-11
							12	(I) Av. 3 con calle 13 esquina (Iglesia San Luis)	4-12-13-14-15
USA [9]			-	-	10				
Montreal [9]			-	7	-				
England [2]			8	-	-				
South Korea [2]			5 (74%)	-	-				
California [2]			-	8	-				
Recommendation [2]			-	8	-				



(a) **Proposal 1** (b) **Proposal 2**

Fig. 2. Proposed ambulance base locations
Source: Prepared by the authors based on Google My Maps.

IV. CONCLUSION

This research proposed two optimal locations of ambulance bases using the methodologies of the center of gravity, the factor rating system, and integer linear programming. Furthermore, technological tools, such as Python and Google Maps web services, were used to improve the timeliness in pre-hospital care of traffic accidents in Cúcuta. Although the study considered the available data on traffic accidents, these occurred in all city sectors; therefore, the results can be inferred for any event in Cúcuta.

The first proposal considered five ambulance bases and would reduce the average response time from 10.96 minutes to 5.39 minutes, with an improvement of 50.82%. Moreover, the percentage of patients cared for in 8 minutes or less would be increased from 30.82% to 85.19%. The second proposal considered four ambulance bases and would reduce the average response time to 5.72 minutes, with an improvement of 47.81% compared to the current situation. The percentage of patients seen in 8 minutes or less would increase to 78.84%. These improvements would positively impact the quality of pre-hospital care, resulting in fewer health problems for patients cared for by EMS.

Finally, considering four ambulance bases, the second proposal is suggested because it would facilitate EMS control, governance, and logistics management of ambulances. In addition, this proposal would have an estimated average response time of fewer than 6 minutes and coverage of patients cared for in 8 minutes or less, approximating the international standard mentioned in the literature. Based on the results of this research, a future study could determine the number of ambulances required at each base for each hour of the day through a discrete event simulation model, which considers different demand rates and response times during the day. In addition, other ambulance location methods could also be applied, and the results contrasted with those obtained in this research.

V. CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Álvaro Junior Caicedo-Rolón: Conceptualización, Metodología, Software, Supervisión, Escritura – Borrador original, Escritura – Revisión y edición**. Jaime Hernando Ayala-Arciniegas:** Conceptualización, Análisis formal, Investigación, Visualización, Escritura – Borrador original. **Jhoan Enrique Tovar-Flórez:** Conceptualización, Análisis formal, Investigación, Visualización, Escritura – Borrador original.

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