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Location of Ambulance Bases for the Attention of Traffic Accidents in Mexico City

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Abstract

INTRODUCTION: This paper studies the problem of choosing the location of motorcycle ambulance bases in Mexico City, seeking to have an effective response to traffic accidents. In order to quickly attend the requirements of the attention of accidents, it is desirable to have as much infrastructure as possible. However, this implies high costs.

OBJECTIVES: This document addresses the problem of locating ambulance bases and determining the number of emergency vehicles in order to respond effectively to traffic accidents.

METHODS: The problem considers criteria that imply two levels of decision that control the installation of the bases and the deployment of ambulances, respectively. The decision on the location leads the hierarchical process and decides the installation of bases considering the costs associated with the opening. Deployment of ambulances, which is the next in the decision process, is responsible for assigning the accidents that will be attended to by the units. With both decisions involved, we suggest a two-level program to model the problem. The model is solved through an algorithm based on the decomposition of Benders.

RESULTS: We formulated the problem as a bi-level programming problem. The model was used to locate ambulance bases in Mexico City. In solving the model, We identified five bases to cover 95% of the city's accidents.

CONCLUSIONS: We developed a model to locate motorcycle ambulance bases and obtained a proposal for the allocation of services. We proposed a bi-level programming model that is a good approach to solving the problem since it considers two decisions that are made hierarchically. The goal was to minimize the total cost associated with installed bases and patient care.

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1. Introduction

A facility location problem involves many choices at different levels, like deciding the amount and placement of new facilities, distribution of demand nodes to the facilities situated, and planning a transportation network, so the most objectives of the system are met. These objectives embrace minimizing total travel time, operational costs, or maximizing market coverage. One application for facility location problems includes the placement of emergency medical services.

In healthcare, the implications of poor location selections transcend price and client service concerns. If few facilities are used or not well-placed, increases in mortality and morbidity will occur. Therefore, facility location modeling becomes even more important when applied to the location of healthcare facilities [1].

Emergency medical services organizations (EMS) are vital parts of health systems, as they are accountable for

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the pre-hospital services of health systems that consist of medical aid and transportation activities performed from the arrival of an emergency call to a patient's release or transfer to a hospital [2]. Therefore, the ability of an EMS to respond efficiently to emergency calls will have a significant impact on health, recovery, and even survival of patients.

Road traffic injuries are a public health problem in Mexico. The economic and social costs we have to pay are very high, so it is necessary to create an emergency response system that categorizes the resources available to serve them. This categorization implies rapid and adequate transportation, as well as medical care on-site and during transportation. However, these systems are expensive, so alternatives must be sought to minimize costs and meet the requested standards.

The emergency service system for responding to traffic accidents is a critical element of an EMS. On the one hand, it is necessary to produce a rapid service to scale back the death rate, and so, it is desirable to have adequate capability to deploy the service, but it could represent high costs. Thus, a balance has to be effected between these two components.

This document addresses the problem of locating ambulance bases and determining the number of emergency vehicles in order to respond effectively to traffic accidents. Due to the nature of accidents, demands cannot be known precisely, so possible service demands are considered uncertain. Equity is considered a measure of coverage, as proposed in [3].

The events leading to the intervention of an emergency vehicle at the scene of an incident includes the following steps: (1) incident detection and reporting, (2) call detection, (3) vehicle deployment, and (4) actual paramedic intervention. Decisions made in EMS are related to step two and step three. During the call selection process, the severity of the incident and its degree of urgency must be determined in order to decide on the type of vehicle to be sent [4]. The U.S. Emergency Medical Services Act of 1973 sets some standards: in urban areas, 95 percent of requests must be answered within 10 minutes of the call; in rural areas, they must be answered within 30 minutes. It is, therefore, necessary to model the location and transfer of emergency vehicles. Besides, considering that uncertainty is an essential component of this problem.

Considering that urban areas are often congested and that response time is a determining factor for the safety and survival of patients, this paper will consider the use of traditional emergency vehicles (slower moving ambulances, with at least two paramedics) and motor ambulances (faster moving vehicles, with one paramedic and less equipment).

In recent decades, research into the location of emergency medical services has been extensive. In [4–6] literature reviews in the field of emergency medical services location are presented. According to the level at which decisions are made, the main models developed are presented in [2]. Some specific proposals can be found at [7–10].

As a bi-level model, in [11], they propose a location model within which the leader chooses from a series of potential locations to be able to install a service. They consider one or more followers who select their location points once the leader's decision has been made. They present some computational results comparing the formulations and Benders decomposition.

Health care systems require efficient use of resources based on clear policies that can be followed. Some of these policies are determined at the strategic level. In [12], a framework for EMS policy-making and the use of real-time data analysis and alerts to support decision making is proposed.

Considering the randomness of demand, in [2], present a work where probabilistic and stochastic models for health services are proposed. Considering stochastic demands, in [13], the authors propose to use sampling to make the model useful. It proposes to consider samples of scenarios. In the end, a sample of solutions and a sample of values are obtained.

In Emergency Medical Systems, operators install emergency vehicles in a set of strategic locations to respond to emergency calls to minimize service requests with slow response times. In [14], they propose stochastic formulations for the problem of ambulance deployment. They use emergency call data to model uncertainty. In [15], they propose a two-stage stochastic programming model for relocating and deploying ambulances to maximize expected coverage. Their model restricts the staff workload and incorporates call priority levels.

Considering the cooperation between ground ambulances and helicopters in emergency medical rescues in [16], they propose a two-stage coverage location model. First, a coverage model was developed to achieve the maximum coverage and the minimum total cost of installing emergency rescue facilities. Then, for specific emergency sites, an emergency scheduling mode matrix was constructed to meet the limitations of response time and total rescue time.

Specifically, considering traffic accidents, a stochastic scheduling model is proposed in [17] to optimize the operation of an emergency system by adjusting the scheduling plan to locate ambulances when any of them are temporarily unavailable.

In Mexico, there are some proposals for emergency care using mathematical models. In [18], they consider a model for the Emergency Medical Services (EMS) in Tijuana, Mexico. They then look for the optimal location of ambulances for the Red Cross. The proposal seeks to satisfy all the limits states in all demand scenarios simultaneously.

Related to the previous work, in [19], they present the benefits and drawbacks of using various approaches to solve the emergency location problem for the Tijuana Red Cross. They evaluate different solution methods, all of them based on the Double Standard Model (DSM) for ambulance location.

Considering the Mexican Red Cross as well, except in the Monterrey Metropolitan Area, Mexico, a model is presented in [20] to reduce the ambulance response times. The authors suggest a two-stage scheme, consisting of a statistical analysis and mathematical modeling. The second stage consist on the application of the Standard Dual Model (SSM).

In this work, a bi-level localization model is proposed for dealing with traffic accidents in an urban area, considering that two types of vehicles can be used. The bi-level programming model is solved through the Benders decomposition method, with the contributions:

- We propose a formulation for the location of ambulance bases and their deployment that is a bi-level location model.
- We considered the data of traffic accidents in Mexico City to make a functional proposal for the installation of ambulance bases.
- The model is an extension of the traditional models of location and coverage, which considers two levels of decisions.

The rest of this work is organized as follows: in Section 2, the description of the problem and its formulation as a bi-level programming problem is presented. In section 3, a solution method for the problem based on the Benders decomposition method is developed, and the results of the computational tests are shown. At the end of this work, some conclusions are presented.

2. Problem Formulation

Optimization techniques of Bi-level Programming are useful in systems where decision-makers of the first level are influenced by the behavior of the subordinate. These models partition the control variables at hierarchical levels and deal with optimization problems that have another optimization problem as part of their constraints. The higher hierarchy target will be called "leader" and the subordinate "follower".

Formally, bi-level programming problems are mathematical programming problems where the total set of variables $x = (x_1, x_2, ..., x_n) \in \mathbb{R}^n$ Is partitioned into 2 levels. The linear bi-level programming problem can be written as:

$$\begin{array}{llcl} \min\limits_{x} & f_1(x,y) & = & c_1^t x + d_1^t y \\ s.\,t.: & A_1 x + B_1 y & \leq & b_1 \\ & \min\limits_{y} \quad f_2(x,y) & = & c_2^t x + d_2^t y \\ & s.\,t.: & & A_2 x + B_2 y \leq b_2 \\ & & & x \in X^{n_1},\ y \in Y^{n_2} \end{array} \tag{1}$$

Sets X^{n_1} y Y^{n_2} add restrictions such as dimensions, integrality conditions, and so on.

2.1. Formulation as a Bi-level Location Model

Location models must indicate at least how many facilities should be installed, where and how they should serve users, considering the minimization of costs, but attending to emergencies as quickly as possible.

The emergency service system for responding to traffic accidents is an important component of an EMS:

- The system must provide a rapid service to reduce the mortality rate, and therefore it is desirable to have sufficient capacity to deploy the service wherever an incident occurs.
- It is necessary to balance these two aspects.

We address the problem of choosing the number of emergency vehicles and the location of their bases in order to have an effective response to traffic accidents. Due to the nature of the problem, there are two levels of decision. The first is related to the installation of the ambulance bases and the second to the deployment of ambulances. In consequence, for this problem, the primary objective is to determine the number and location of ambulance bases at minimal cost, while minimizing the response time to accidents in a network.

In this section, we present the notation and formulation of the facilities location model for the design of emergency services networks for the attention of accidents.

Sets, parameters, and decision variables used in the proposed model are shown in 1:

The last two parameters can be used to define the next set:

$$I_j \quad = \{i \in I : t_{ij} \leq T\}$$

With these considerations, the problem can be formulated as:

Table 1. Notation

I	Set of eligible locations for emergency vehicle bases
J	Set of demand nodes
f_i	Fixed cost of installing a base in the location $i \in I$
w_i	Number of vehicles in the location $i \in I$
λ	Minimum coverage required
m	Maximum number of bases that can be installed
t_{ij}	Travel time of vehicles from base $i \in I$ to accident point $j \in J$
T	Maximum time allowed for arrival to an accident
x_j	$\begin{cases} 1 & \text{If the installation is located on the candidate site } i \in I \\ 0 & \text{In another case} \end{cases}$
y_{ij}	Demand proportion of the node i that is attended from the facility in j

$$min \quad F = \sum_{i \in I_j} f_i x_i \tag{2}$$

$$s.\ t.: \quad \sum_{i \in I_j} x_i \leq m \tag{3}$$

$$x_i \in \{0,1\} \qquad i \in I_i \tag{4}$$

$$minimize \quad f = \sum_{i \in I_j} \sum_{j \in J} d_j t_{ij} y_{ij} \tag{5}$$

$$s.\ t.: \quad y_{ij} \leq x_i \quad \forall\ i \in I_j,\ \forall\ j \in J \tag{6}$$

$$\sum_{i \in I_j} y_{ij} \geq \lambda \quad \forall\ j \in J \tag{7}$$

$$\sum_{j \in J} d_j y_{ij} \leq w_i \forall\ i \in I_j \tag{8}$$

$$y_{ij} \in [0,1] \quad \forall\ i \in I_j,\ j \in J \tag{9}$$

The leader objective function seeks to minimize the fixed costs of the installation of the bases and placement of emergency vehicles on them. Constraint (3) limits the number of bases that can be opened. Constraints (4) limit variables x_i to be binary.

The follower objective function seeks to minimize the costs of accident care. Constraints (6) restrict service only to open bases. The constraints (7) force the solution to meet a minimum level of coverage. With (8), we limit the number of services available to existing vehicles of each type. Restrictions (9) limit the variables y_{ij} to take values between zero and one since it is the proportion of the demand that will be met.

3. Solution Method

As in our problem, in numerous bi-level programming issues, a subset of the variables is limited to taking discrete values. Considering this structure, in [21], [22] and [23] are displayed branch and bound calculations for problems with binary and integer variables. Furthermore, Edmunds et al. [24] created a branching bound algorithm to fathom binary nonlinear mixed-integer problems.

Gümüş and Floudas [25] proposed a reformulation and linearization algorithm for the general bi-level mixed-integer problem with continuous variables within the follower. Within the work of Dempe [26], it is pointed out that branching bound strategies require convex functions at the lower level of the bi-level problem. Vicente et al. [27] propose penalty function strategies to solve discrete bi-level problems. Faísca et al. [28] propose an algorithm to solve the binary quadratic problem and the mixed-integer - linear one, based on parametric programming. More recently, Domínguez and Pistikopoulos [29] utilize two algorithms based on multiparametric programming to fathom binary integer problems with integer variables controlled by the first level.

Köppe et al. [30] proposed an algorithm based on multiparametric programming for binary mixed-integer problems where the follower solves an integer problem. Mitsos [31] presents a procedure for the global optimization of mixed-integer bi-level nonlinear problems generating a convergent lower bound and an optimal upper bound. Xu and Wang [32] propose an exact algorithm for the linear mixed-integer binary problem with some simplifications. Sharma et al. [33] considers integer binary linear-fractional problems at the first level and a linear. They propose an iterative algorithm of the generation of cuts to solve the problem.

Based on Benders decomposition, Saharidis and Ierapetritou [34] propose an algorithm to solve the mixed-integer linear bi-level problem. With this method, the target values are bounded, and the Karush-Kuhn-Tucker (KKT) conditions are used. Based on the last proposal, Fontaine and Minner [35] and Caramia and Mari [36] propose the use of Benders decomposition with a continuous subproblem.

For our formulation, partial cooperation (or optimistic approach) is assumed [37], where, if the follower has alternative optimal solutions, he chooses the one that is best for the leader. Besides, When the lower-level problem is linear, it can be reformulated by replacing the lower-level problem with its Karush-Kuhn-Tucker (KKT) [38, 39]. With these considerations, our bi-level location problem can be formulated as one of one level, and Benders decomposition can be used to solve the problem [40].

Generally speaking, a bi-level problem can be written as:

$$\begin{aligned} \min_{x,y} \quad & c_1x + d_1y \\ s.\,t.: \quad & A_1x + B_1y \le b_1 \\ & \min_{y} \quad c_2x + d_2y \\ & s.\,t.: \quad A_2x + B_2y \le b_2 \\ & \qquad\quad x \in \{0,1\},\ y \ge 0 \end{aligned} \tag{10}$$

where $c_1, d_1 \in \mathbb{R}^{n_1}$, $c_2, d_2 \in \mathbb{R}^{n_2}$, $b_1 \in \mathbb{R}^p$, $b_2 \in \mathbb{R}^q$, $A_1 \in \mathbb{R}^{p\times n_1}$, $B_1 \in \mathbb{R}^{p\times n_2}$, $A_2 \in \mathbb{R}^{q\times n_1}$, $B_2 \in \mathbb{R}^{q\times n_2}$.

Reformulated with its KKT conditions the problem (10) can be written as:

$$\min_{x,y} \quad c_1x + d_1y \tag{11}$$
$$s.\,t.: \quad A_1x + B_1y \le b_1 \tag{12}$$
$$A_2x + B_2y \le b_2 \tag{13}$$
$$-\lambda^T B_2 \le d_2 \tag{14}$$
$$d_2y = \lambda^T A_2 x - \lambda^T b_2 \tag{15}$$
$$x \in \{0,1\},\ y, \lambda \ge 0 \tag{16}$$

Considering the problem (11)-(16), the term $\lambda x = \mu = [\mu_1 ..., \mu_{n_1}]$, where μ_i is the i-th column of μ, can be linearized [35, 41, 42] and constraint (15) can be rewritten as the following equivalent level problem:

$$\min_{x,y} \quad c_1x + d_1y \tag{17}$$
$$s.\,t.: \quad A_1x + B_1y \le b_1 \tag{18}$$
$$A_2x + B_2y \le b_2 \tag{19}$$
$$-\lambda^T B_2 \le d_2 \tag{20}$$
$$d_2y = \sum_{i=1}^{n_1} \mu_i^T A_{2i} - \lambda^T b_2 \tag{21}$$
$$\mu_{li} \ge \lambda_l - M(1 - x_i)\ l = 1, ..., q,\ i = 1, ..., n_1 \tag{22}$$
$$\mu_i \le \lambda \quad i = 1, ..., n_1 \tag{23}$$
$$\mu_l^T \le Mx \quad l = 1, ..., q \tag{24}$$
$$\mu \ge 0 \tag{25}$$
$$x \in \{0,1\},\ y, \lambda \ge 0 \tag{26}$$

where M is a large positive number.

With constraints (22) - (25) it is ensured that the variables μ_{li} take value zero if $x_i = 0$ and value λ_l if $x_i = 1, I = 1, ..., n_1, l = 1, ..., q$.

Benders decomposition [43] consists of decomposing the problem into a master problem and a subproblem and solving them iteratively. The decision variables are divided into complicated variables, which in this case are the binary variables that make up the vector x, and a set of easy variables, or the continuous variables entries of the vectors y, λ, μ. At each iteration, the master problem determines a possible decision, which is used by the subproblem to generate optimality cuts and feasible solutions for feasibility cuts added to the master problem.

Setting x in $\bar{x}$, the Benders subproblem can be constructed as:

$$\min_{y} \quad c_1\bar{x} + d_1y \tag{27}$$
$$s.\,t.: \quad B_1y \le b_1 - A_1\bar{x} \tag{28}$$
$$B_2y \le b_2 - A_2\bar{x} \tag{29}$$
$$-\lambda^T B_2 \le d_2 \tag{30}$$
$$d_2y - \lambda^T b_2 + \sum_{i=1}^{n_1} \mu_i^T A_{2i} = 0 \tag{31}$$
$$\lambda_l - \mu_{li} \le M(1 - \bar{x}_i)\ l = 1, ..., q,\ i = 1, ..., n_1 \tag{32}$$
$$-\lambda + \mu_i \le 0 \quad i = 1, ..., n_1 \tag{33}$$
$$\mu_l^T \le M\bar{x} \quad l = 1, ..., q \tag{34}$$
$$y, \lambda, \mu \ge 0 \tag{35}$$

With dual variables $\alpha_1 \in \mathbb{R}^p$, $\alpha_2 \in \mathbb{R}^q$, $\beta \in \mathbb{R}^{n_2}$, $\gamma \in \mathbb{R}$, and $\delta_1,\ \delta_2,\ \delta_3 \in \mathbb{R}^{q\times n_1}$ the dual subproblem can be written as:

$$max \quad \alpha_1(b_1 - A_1\bar{x}) + \alpha_2(b_2 - A_2\bar{x}) + d_2\beta^T + \tag{36}$$
$$+ \sum_{l=1}^{q} (\delta_{1l}(M(1 - \bar{x})) + \delta_{3l}M\bar{x}) \tag{37}$$
$$s.\,t.: \quad \alpha_1 B_1 + \alpha_2 B2 + \gamma d_2 \le d_1 \tag{38}$$
$$-B_2\beta^T - \gamma b_2 + \sum_{i=1}^{n_2} (\delta_{1i} - \delta_{2i}) \le 0 \tag{39}$$
$$\gamma A_2 - \delta_1 + \delta_2 + \delta_3 \le 0 \tag{40}$$
$$\alpha_1, \alpha_2, \beta, \delta_1, \delta_2, \delta_3 \le 0 \tag{41}$$

If this problem is feasible for $\alpha_1^*, \alpha_2^*, \beta^*, \gamma^*, \delta_1^*, \delta_2^*, \delta_3^*$ the optimality following cut is added to the master problem

$$\begin{aligned} & c_1x + \alpha_1^*(b_1 - A_1x) + \alpha_2^*(b_2 - A_2x) + d_2\beta^{*T} + \\ & + \sum_{l=1}^{q} (\delta_{1l}^*(M(1 - x)) + \delta_{3l}^*Mx) \le \eta \end{aligned} \tag{42}$$

If the subproblem is not bounded, a new constraint that bounds the objective function with a large number M_2 is added. M_2 is large enough to limit only the extreme rays:

$$\alpha_1(b_1 - A_1\bar{x}) + \alpha_2(b_2 - A_2\bar{x}) + d_2\beta^T + + \sum_{l=1}^{q}(\delta_{1l}(M(1-\bar{x})) + \delta_{3l}M\bar{x}) \leq M_2 \tag{43}$$

The solution to this problem generates the following feasibility cut for the master problem:

$$c_1x + \alpha_1^*(b_1 - A_1x) + \alpha_2^*(b_2 - A_2x) + d_2\beta^{*T} + + \sum_{l=1}^{q}(\delta_{1l}^*(M(1-x)) + \delta_{3l}^*Mx) \leq 0 \tag{44}$$

The master problem can be defined as:

$$\begin{aligned} min \quad & c_1x + \eta \\ s.\,t.: \quad & \alpha_1^*(b_1 - A_1x) + \alpha_2^*(b_2 - A_2x) + d_2\beta^{*T} + \\ & + \sum_{l=1}^{q}(\delta_{il}^*(M(1-x)) + \delta_{3l}^*Mx) \leq \eta \\ & \forall(\alpha_1^*, \alpha_2^*, \beta^*, \gamma^*, \delta_1^*, \delta_2^*, \delta_3^*) \in C_o \\ & c_1x + \alpha_1^*(b_1 - A_1x) + \alpha_2^*(b_2 - A_2x) + d_2\beta^{*T} + \\ & + \sum_{l=1}^{q}(\delta_{il}^*(M(1-x)) + \delta_{3l}^*Mx) \leq 0 \\ & \forall(\alpha_1^*, \alpha_2^*, \beta^*, \gamma^*, \delta_1^*, \delta_2^*, \delta_3^*) \in C_f \\ & x \in \{0, 1\} \end{aligned} \tag{45}$$

where C_o is the set of solutions that correspond to optimality cuts, and C_f is the set of solutions corresponding to feasibility cuts.

The main structure of a Benders algorithm is as follows:

Algorithm 1 Benders decomposition method

1: $LB = -\infty$, $UB = \infty$
2: **while** $LB < UB - \epsilon$ **do**
3: obtain a solution to the master problem
4: get solution to master problem
5: update the value of LB
6: solve the sub-problem
7: **if** the sub-problem is feasible **then**
8: update UB
9: generate an optimality cut
10: **else**
11: generate a feasibility cut
12: **end if**
13: Add cuts to the master problem
14: **end while**

4. Case Study

According to data from the National Institute of Public Health (INSP), in 2017, Mexico ranked seventh worldwide and third in Latin America in deaths from road accidents, with 22 deaths of young people between 15 and 29 years a day, and 24 thousand deaths per year on average. Road crashes are the leading cause of death in young people between 5 and 29 years of age and the fifth in the general population [44].

Mexico, like other developing countries, faces complex public health problems in the context of the growing demand for emergency services, mainly for injuries from external causes. Once an accident occurs, death, severe injury, and disability can be mitigated through timely and appropriate intervention by trained persons. In many cases, the speed of emergency care and the transfer of injured victims from the scene of an incident to a health care facility can save lives, reduce the incidence of disability in the short term and significantly reduce the consequences.

Based on the government proposal [45] for the integration of the Model of Prehospital Medical Care, where it is considered as a specific objective to reduce pre-hospital care times, with the model proposed in this paper, it is intended to find an alternative solution for improving response times of pre-hospital services, so that the social impact generated by traffic accidents becomes lower.

Since most traffic accidents occur in urban areas [46] and the most congested city in the country is Mexico City [47], the latter was selected to test the functioning of the proposed model.

The main points where accidents occur are primary and secondary road cruises; these define the demand nodes or J set of the model. Sixteen accident zones were identified.

The candidate sites for the location of the bases for emergency vehicles are modules of citizen attention in charge of the government of Mexico City, which is in charge of the deployment of emergency services at the pre-hospital level. Seventy-one candidate sites (I) were identified.

Both sets of nodes are shown in the figures 1 and 2.

In this problem, the deployment of motorcycle ambulances was considered. The care costs per type of vehicle were calculated based on [48]. The number of accidents per area per day was calculated based on the data from [46].

Based on this information, the model was solved, and the following results were obtained:

- In order to cover 95% of the demand, five ambulance bases are required, located as shown in figure 3.

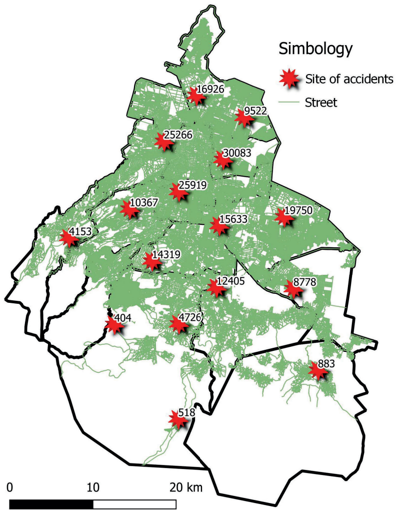

Figure 1. Main intersections with accidents Source: Own preparation

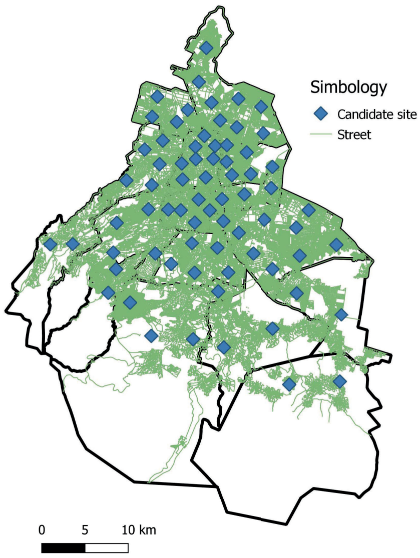

Figure 2. Modules of citizen assistance. Source: Own preparation

- The coverage of each base (in percentage of demand served) is shown in the table 2 and figure 3.

- The vehicles required per base are shown in table 3.

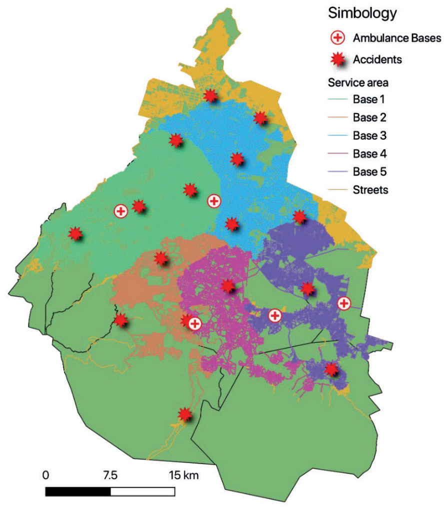

Figure 3. Location of ambulance bases. Source: Own preparation

Base	Motorcycle Ambulances
1	22
2	9
3	5
4	1
5	5

Table 3. Vehicles required per base

5. Conclusions

The location of emergency vehicle bases and the assignment of services to points of demand is one of the most critical aspects of health systems. In this work, we developed a model to locate bases for motorcycle ambulances and obtained a proposal for the allocation of services. We used a decomposition method to resolve the resulting model.

We proposed a bi-level model for the problem location of a set of bases for emergency vehicles that is a good approach to solving the problem, since it considers two decisions that are made in a hierarchical way. The problem is solved to cover a region considering two levels of decision making. The goal was to minimize the total cost associated with installed bases and patient care. A coverage restriction was imposed based on the U.S. Emergency Medical Services Act of 95%.

The operation of the model was developed and illustrated with an application in an urban area of Mexico City. The research was conducted considering a bi-level structure, which makes the model difficult to solve; however, the proposed solution method worked for the application shown.

i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.95		0.95			0.81	0.95			0.95	0.925					
2		0.95		0.95	0.95	0.14			0.23							
3													0.95	0.5		0.95
4											0.025			0.45		
5								0.95	0.72			0.95			0.95	

Table 2. Coverage per base

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