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The Casualty Stabilization–Transportation Problem in a Large-Scale Disaster

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Abstract: We address the problem of picking up, stabilizing, and transporting casualties in response to mass-injury disasters. Our proposed methodology establishes the itinerary for collecting, on-site stabilization, and transporting victims considering capacitated vehicles and medical care centers. Unlike previous works, we minimize the time required to achieve on-site stabilization of each victim according to his age and level of severity of the injuries for their subsequent transfer to specialized medical centers. Thus, more critical patients will be the first to be stabilized, maximizing their chances of survival. In our methodology, the victims' age, the injuries' severity level, and their deterioration over time are considered critical factors in prioritizing care for each victim. We tested our approach using simulated earthquake scenarios in the city of Iquique, Chile, with multiple injuries. The results show that explicitly considering the on-site stabilization of the vital functions of the prioritized victims as an objective, before their transfer to a specialized medical center, allows treating and stabilizing patients earlier than with traditional objectives.

Keywords: disaster response; casualty transportation; on-site stabilization; emergency response services; mass casualty incident; humanitarian logistics

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1. Introduction

Between 1998 and 2017, geophysical and climate-related disasters caused direct economic losses valued at USD 2908 billion, with 4.4 billion injured, displaced, or in need of emergency assistance, and 1.3 million people killed [1]. Some of the events that caused the significant casualties were earthquakes and tsunamis, which have sudden and large-scale onsets, and can cause severe damage in large geographical areas with mass deaths and injuries. Faced with these events, one of the main concerns of those responsible for disaster response management is to reduce deaths and suffering caused by a lack of timely medical attention and treatment [2]. Moreover, it is a well-known fact that the survival probability of casualties is related to the response time of rescue teams, the medical services they provide to the injured [3,4], and their rapid transfer to medical centers. However, the available time and resources for these tasks are limited.

The literature contains several approaches to address this problem. Often, the focus is on methodologies to reduce response times in collecting and transferring the injured to specialized medical care centers, establishing a sequence of care through some rule of prioritizing the injured. Most approaches address this response time as an objective or restriction by minimizing the total sum of response times or setting maximum thresholds or time windows to care for casualties. Nevertheless, for a group of patients that need medical attention and whose injuries present different severity levels, minimizing total pickup and transport times to specialized centers may not be particularly suitable.

This traditional approach allows the wounded with less severe injuries to be cared for before more serious ones. The main goal is that the injured collected are admitted to a medical center as soon as possible, regardless of how they were collected and stabilized. Furthermore, when two or more victims are in the same place and are picked up by one or more vehicles, medical personnel first stabilize the most critical patients and then transport them to a medical facility. Traditional methodologies do not consider this situation. By stabilization, we mean providing casualties with medical and first-aid care to keep them alive by using adequate medical equipment and staff, stabilizing their vital functions for subsequent transport to a specialized medical center. We include in our methodology the on-site stabilization time according to the range of age (as an indicator of vulnerability) and patients' level of severity of the injuries (LSI) during collection to correct these issues, thus maximizing the probability of survival. On the other hand, the LSI sustained is often used to prioritize the order in which medical care is provided, which may or may not include survival probabilities concerning time. However, as stated in [5], traditional methodologies do not consider quantitative metrics linking response time and human survival in large-scale disasters.

So, we address the problem of collecting and transporting casualties after a large-scale disaster, specifying the order they should be collected, stabilized, and the medical center that they should be transported to minimize the time needed for stabilization and transport for each casualty. To prioritize medical assistance, we consider the age range and the casualties' severity level and their deterioration over time through non-decreasing functions that depend on each patient's waiting time. Moreover, we incorporate the required time for on-site stabilization according to the characteristics of each victim. Our methodology proposes establishing a Casualty Pickup, on-site Stabilization, and Transport Schedule (*CPST Schedule*) with a heterogeneous fleet of emergency vehicles, considering capacitated vehicles and medical centers, minimizing the time required to achieve on-site stabilization and transport casualties. We solve the problem through a heuristic procedure based on an optimization model that allows updating the CPST program and the priority assigned to each victim according to changes in demand and/or availability of emergency vehicles over time.

Considering explicitly the time needed for on-site stabilization of casualties, plus the care prioritization based on the injury's severity sustained, age range, and the casualty's deterioration over time is new in the specialized literature of operations research that focuses on the pickup and transport of casualties after a large-scale disaster. The rest of the article is organized as follows: Section 2 reviews the literature. Section 3 describes the problem to be addressed, while Section 4 details the proposed methodology, which is tested in Section 5 on a simulated earthquake scenario in the city of Iquique, Chile. Finally, Section 6 presents the study conclusions.

2. Literature Review

Disaster management has been a widely discussed issue in the operational research literature. Vast reviews of these contributions can be found in [6–12] and more recently in [5,13,14]. These studies show that, in the phase of response to disasters, the main problems investigated are the transportation and distribution of supplies [15–18], inventory management [19–22], route recovery [15,23], evacuation of the population [24], and casualty transport. The casualty transportation problem has been addressed by several authors, who may or may not have included the transport of supplies together with casualties, and may or may not have considered the deterioration of patients' health over time.

By considering the transportation of casualties and the distribution of aid supplies, [25] present a model for assigning and distributing injured people in helicopters, minimizing the costs of assigning pilots, the number of used helicopters, and the duration of routes. The authors in [26] break down the problem into two stages: creating vehicle routes and transporting multiple products and casualties, minimizing the weighted sum of unsatisfied demand, both in terms of supplies and unattended casualties. The authors in [24] present a two-stage model that minimizes unsatisfied demand, adding the option of having temporary medical centers and split delivery operations. The authors in [27] present a model that minimizes unsatisfied demand for supplies delivering, pickup, and transport casualties, regardless of their severity. The author in [17] proposes a hierarchical model that coordinates the helicopters transporting supplies and medical assistance. Subsequently, [28] uses a network model with a hierarchical cluster and routing approach to coordinate vehicle routes distributing supplies and evacuation activities. The authors in [29] minimize the number of unattended casualties, unsatisfied demand, and the number of dispatched vehicles through stochastic modeling. The authors in [30] develop a dynamic dispatch and routing model in disaster situations, minimizing the total waiting time of casualties and the transport time of supplies.

Transporting casualties separately from aid distribution in the face of extreme events was first considered by [31]. The authors propose a dynamic allocation model, which minimizes the total number of casualties. The authors in [32] design a model for casualty dispatch and routing in disasters, maximizing the number of attended casualties with minimum service times. The authors in [33] present an assignment model for disaster rescue situations, maximizing the number of survivors. The authors in [34] propose two models. The first minimizes the total travel and waiting time of casualties heading to existing medical centers. In contrast, the second activates the implementation of field hospitals depending on the number of unattended casualties. The authors in [35] propose an ambulance routing model that minimizes the time needed for casualties to reach the hospital. The authors in [36] present a mixed-integer programming model for ambulance distribution, casualty assignment to hospitals, and their care sequence, minimizing the overall time when casualties receive treatment. The authors in [37] address the transport of casualties to hospitals after a disaster in highly populated areas, thus maximizing their survival rate.

The deterioration of casualties' health status over time and care prioritization is addressed in Medical Emergency Literature through the mass-casualty triage issue (a review can be found in [38,39]). In Operations Research literature, this topic has been treated rarely. The authors in [40,41] consider that each patient has a random life whose probability distribution depends on the type of patient. If patients fail to receive medical care before their lifetime, they die; otherwise, they survive. The authors in [42] propose a multi-objective route selection method that considers equity and casualty prioritization by using time limits representing the in-transit tolerable suffering duration according to the degree of severity of the casualty's injuries. The authors in [43] develop policies for casualty transportation by assigning ambulances to patients and medical centers, considering survival rates and care times for different types of injuries. The authors in [44] propose a model for evacuating casualties to hospitals that maximizes the expected number of survivors in response to a mass casualty incident, considering available resources, the severity of casualties, and their deterioration over time, using survival probabilities. The authors in [45] address the issue of on-site casualty prioritization for transport to a hospital. They formulate a model that considers the availability of resources and the deterioration of patients over time according to a decreasing probability function of survival. The authors in [46] maximize the expected number of survivors and minimize the operating cost of ambulances and helicopters. The equitable distribution of medical resources is considered in conjunction with the severity of the injuries and the casualty's health deterioration using survival probabilities.

Like [44–46], we also consider the severity of the victims and their deterioration over time, in collecting and transferring casualties to medical centers. However, we incorporate the on-site casualties' stabilization time where they are collected, with the transport time, as the objective to be minimized to maximize the survival of the patients.

3. The Casualty Pickup and Transport Problem: Description

After a large-scale disaster with mass casualties, the authorities' response begins by gathering information on the availability of the health network, including emergency vehicles and the capacity of health care centers. A single operation center coordinates them, called the medical aid coordination center (MACC). All logistics associated with casualty transport and care are coordinated and controlled by the MACC. The MACC, with the information available, requires allocating the resources available for the timely care of victims through a Casualty Pickup, Stabilization, and Transport Schedule (CPST *Schedule*). Our objective is to help with this target.

We consider a fleet of airborne (helicopter) and land-based (ambulance) emergency vehicles for casualty pickup and transport procedures. The CPST schedule must be determined for each vehicle by identifying the trip itinerary they must follow until all victims have been assisted. Each trip begins and ends at an MCC. For each trip, the start and end MCC, the patients to collect, the waiting assignment time, stabilization time, and the arrival time to the MCC for each patient are identified. The demand for casualty transport from any node of the network, expressed as the number of casualties according to the LSI requiring transport to a specialized MCC, can be satisfied with different emergency vehicles on multiple visits. At nodes with several casualties, total or partial pickup is also possible. The following explains how to prioritize victims and count attention, waiting, and stabilization times.

3.1. Casualty Prioritization

Medical assistance to casualties is generally provided first by the nearby population, the area's police, and firefighters [47], who request the victims to be transported to an MCC and provide the necessary information to establish the patient's LSI. Numerous works analyze and determine ways to classify casualties according to their LSI (see [44,48]). There are several important reasons to consider each patient's LSI and the MCC's ability to treat such injuries. First, a lack of information can cause many patients to be sent to the nearest MCC, which is not necessarily specialized to deal with the casualty's injuries, generating congestion in the facility, long waiting times, and the redistribution of patients across the health network. Second, the probability of survival decreases over time and depends on each casualty's type of injury and physical condition (see [3,49–51]). Thus, casualties with a higher LSI should be the first to be stabilized and transported to an MCC to maximize their survival chances. Third, the time required for casualty stabilization on-site depends on each injury's casualty type and age [52]. Fourth, the emergency vehicle arrival with appropriate medical equipment and personnel at the incident scene allows the LSI to be confirmed. The casualty is stabilized for their subsequent transport to a specialized MCC. Thus, although the arrival time at the medical center is the same for all patients transported in the same emergency vehicle, the waiting time and the moment at which each patient is stabilized will be different according to their LSI.

Let λ_k^{ag} be a *transport priority index* of casualty k of age a and severity g when requesting assistance. λ_k^{ag} can be formulated, for each casualty k the age a, as follows:

$$\lambda_k^{ag} = \sum_{\{l \in L/g \leq l\}} \left[PG^{al} + f^{al}(\alpha_k - \pi_l^{ag}) \right] \theta_k^{agl} \left(1 - \theta_k^{ag(l+1)} \right) \tag{1}$$

where PG^{ag} is a *factor of the severity of the injuries*, $f_k^{ag}(\cdot)$ is a function of deterioration of the injuries of the victim k of age a, which depends on the initial LSI g and the waiting time α_k from when he requests medical assistance until he is assigned to the itinerary of an emergency vehicle. π_l^{ag} the time when a casualty's LSI of severity g and age a change to a higher LSI $l \in L$, with L as the set of severity levels (for $g = l$, $\pi_l^{ag} = 0 \; \forall a$). We use the binary parameter θ_k^{agl} to relate α_k to the time required to increase in severity from g to l for a victim k of age a. Thus $\theta_k^{agl} = 1$ if $\alpha_k \geq \pi_l^{ag}$, and 0 if not, $\forall g, l \in L/g \leq l \wedge \forall a \in A$. If $l > |L|$, then $\theta_k^{agl} = 0$.

λ_k^{ag} considers the increase in LSI by PG^{ag} ($PG^{al} < PG^{as} \; \forall l < s/l, s \in L$) and the deterioration function of the victim's injuries. Therefore, casualties with greater LSI will have higher PG^{ag} than those with a lower LSI. Between two victims with the same LSIs, priority is given to the one with the most significant deterioration of their injuries based on waiting time. Our methodology allows the use of different forms for $f_k^{ag}(\cdot)$.

3.2. Total Medical Attention, Waiting, and Stabilization Times for Casualties

Figure 1 represents the *total time of medical attention provided to casualty k* (TTA_k), at the beginning when casualty k appears in the system (TA_k), with k representing any person in the zone. Then, the *MACC* is prompted to transport casualty k to an MCC, and the time the casualty checks into the assigned MCC (TL_k). The TTA_k is composed of the wait time α_k as described above, and the *pickup, stabilization, and transport time of casualty k* (β_k). That is, β_k represents the time it takes for the emergency vehicle, from the moment it is allocated to casualty k (TF_k), to arrive at the location (TB_k), finish the stabilization (TS_k), and the time to move them to an *MCC* (D_k). Since the planning horizon of the vehicle's *CPST Schedule* can have several scheduled trips before visiting casualty k, β_k will be the sum of the vehicle's previous trips, plus the time of the trip to pick up casualty k. The *time until casualty stabilization k (C_k) is achieved,* is defined as the time from when the emergency vehicle is assigned (TF_k), until casualty k (TS_k) is stabilized. When two or more casualties are in the same node, and are picked up by the same vehicle, medical staff stabilizes one patient at a time according to each casualty's LSI and age. The time needed to stabilize casualty k of age range a and severity g is determined as follows:

$$TS_k^{ag} = \sum_g \sum_a GR_k^g A_k^a TP^{ag} \tag{2}$$

where TP^{ag} is the casualty's stabilization time of age range a and severity g, GR_k^g is equal to 1 if casualty k has a severity of g and 0, if otherwise, and A_k^a is equal to 1 if casualty k is in the a age range or 0, if otherwise.

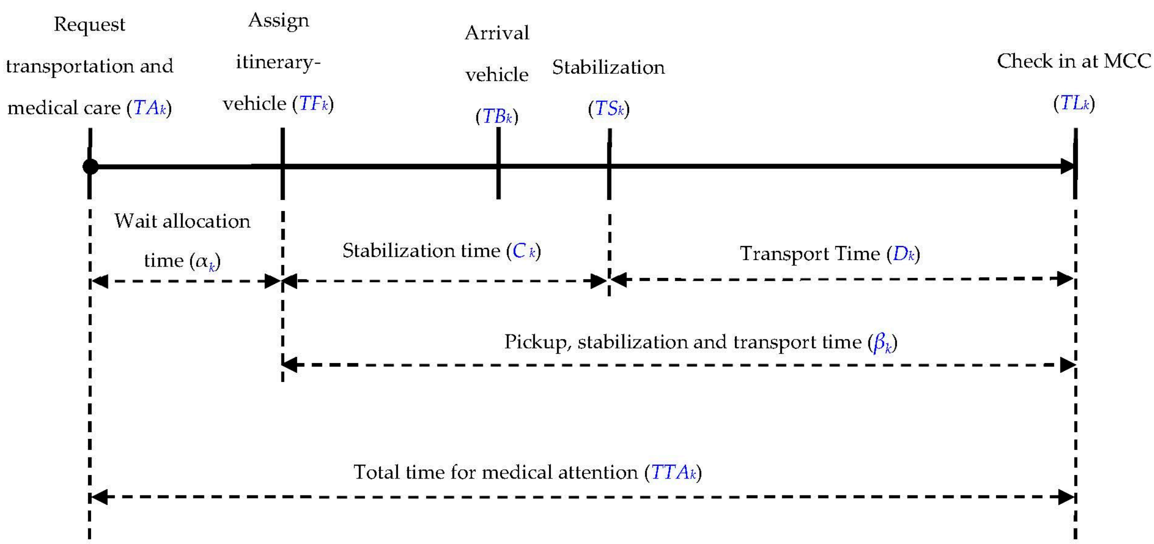


Figure 1. Total attention time TTA_k (waiting, pickup, stabilization, and transport of casualties).

4. Proposed Methodology

4.1. Method Description

We propose a 5-stage methodology that allows solving the problem of casualty collection, on-site stabilization, and transportation in the face of disasters with mass casualties. For an accurate method description, we will establish some preliminary definitions.

Let there be a directed transport network $G'(N',A')$, where A' is the network's set of arcs and N' is the set of nodes. Additionally, let H be the set of nodes where the MCCs are located, and Cb be the set of nodes that can be accessed by helicopters. Between each pair of nodes $i \in N'$, $h \in H$ and $c \in Cb$, we calculate S_{ij}^e which represents the minimum expected travel time by vehicle type $e \in E$ (ambulance and helicopter) through a minimum route problem. Figure 2 shows the procedure through an example. Figure 2a shows a directed transport network $G'(N',A')$. We consider the calculation of the arcs of the network $G(N,A)$ to access node 9. In the case of ambulances (Figure 2b), the routes are determined considering the trip by land over the transport network. For the case of helicopters (Figure 2c), the route is determined considering the air travel from node $h \in H$ to the node $c \in Cb$ closest to node $i \in N'$ (from h_1 to c_1 in Figure 2c), plus the expected travel time on foot between node $c \in Cb$ and node $i \in N'$ by the medical team (from c_1 to node 9 in Figure 2c). As a result, we obtain an auxiliary graph $G(N,A)$, with $N = H \cup Cb \cup N'$ and A the set of arcs representing the routes of minimum expected travel time. Therefore, for each pair of nodes $i, j \in N$ and type of vehicle $e \in E$, there is an arc $(i,j)^e \in A$ (Figure 2d,e in the example).

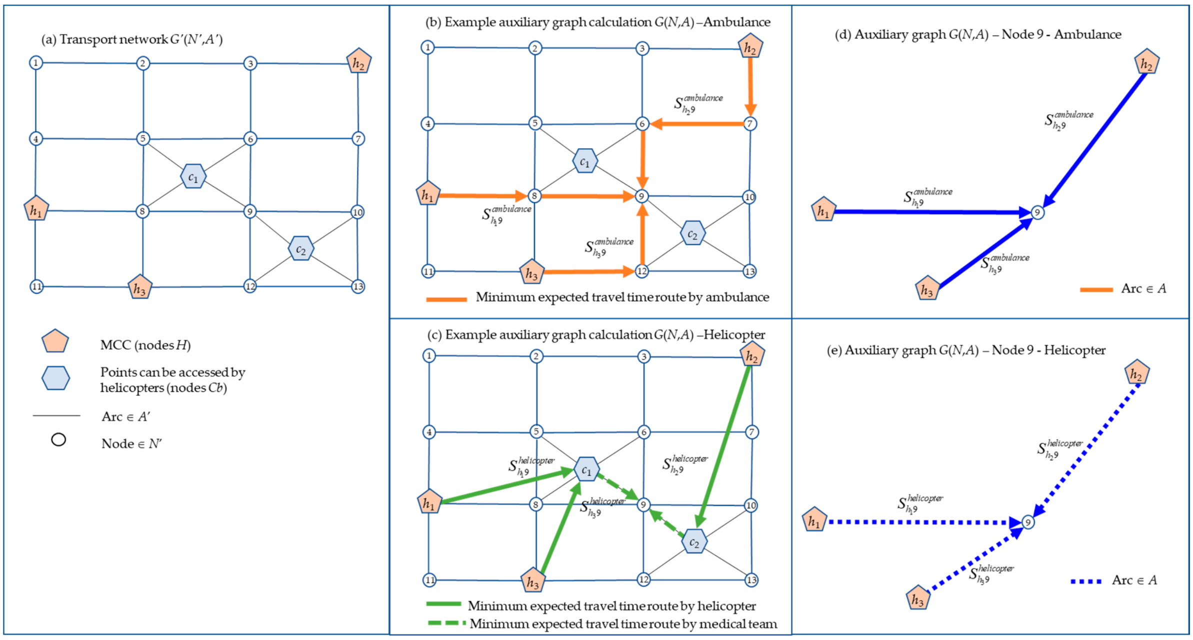


Figure 2. Example of construction of the auxiliary network. Calculation of access arcs to node 9 of the auxiliary network $G(N,A)$ from network $G'(N',A')$. (**a**) Transport Network $G'(N,A)$, (**b**) Example of calculation of auxiliary graph $G(N,A)$ for Node 9—ambulance case, (**c**) Example of calculation of auxiliary graph $G(N,A)$ for Node 9—helicopter case, (**d**) Resulting auxiliary graph $G(N,A)$ for Node 9, helicopter case, and (**e**) Resulting auxiliary graph $G(N,A)$ for Node 9, ambulance case.

Now a short description of the method. The first stage is the initialization of the data set and the construction of the auxiliary graph. In the second stage, the casualties are characterized (location, age, and severity of the injuries), and care priority is established. In the third stage, we work with the auxiliary network. Specifically, we reduce the graph by eliminating all those arcs that begin or end in nodes of N′ that do not contain casualties, considerably reducing the complexity of the problem to be solved in the next stage. In the fourth stage, we solve the Casualty Pickup, on-site Stabilization, and Transport optimization model (CPST Model). Finally, the system is evaluated, and the stopping criterion is established.

4.2. Resolution Procedure

The definition of the method parameters is provided in the next subsection for more clarity.

Stage one: Initialization and construction of the auxiliary network

Plot auxiliary graph $G(N,A)$.

Initially, the set of casualties U^p who need to be transported to an MCC is empty and the pickup, on-site stabilization and transport time of casualty β_k is a very large (infinite) number, $U^{p=0} = \{\varnothing\}$ y $\beta_k = \infty\ \forall k \in U^{p=0}$.

TT^0 = Current time.

Stage two: New period start, classifying and prioritizing casualties

$p = p + 1$,

TT^p = Start time of period $p \in P$.

$U^{Aux} = U^p$

- Identification of casualties transported to an MCC and in the process of being transported during the previous period:
  1. Set of casualties transported to an MCC in period $p-1$: $U^- = \left\{k \in U^{p-1}/\beta_k \leq TT^p\right\}$
  2. Casualties who are in the process of being transported in period $p-1$: $U^+ = \left\{k \in U^{p-1}/\beta_k > TT^p\right\}$
- Updating the set U^p: $U^p = U^{Aux} \cup U^+$ For each casualty $k \in U^p$ proceed as follows:
  1. Identify PA_k and GR_k^g. $PA = \{PA_k\ /k \in U^p\}$.
  2. Determine the wait-allocation time of each casualty k at the beginning of period $p \in P$ as follows: $\alpha_k = TT^p - TA_k$
  3. Calculate λ_k^{ag} with Equation (1)
  4. Sort casualties in ascending order according to their transport priority index λ_k^{ag}.

Stage three: Update and reduction in the modeling network

(a) Identification of the origin node of the vehicle $m \in M$, O^m.

- Identify the last trip performed by vehicle $m \in M$ (σ^m) as follows: $\sigma^m = \underset{v \in V}{Max}\{v/(TT^{p-1} + T^{mv} \leq TT^p)\}$ If $u^{m(\sigma^m+1)} = 0$, then, otherwise $O^m = \left\{h \in H/z_h^{m(\sigma^m+1)} = 1\right\}$ where TT^p is the time at which the planning period $p \in P$ begins and T^{mv} the time needed by vehicle $m \in M$ to complete trip $v \in V$.

(b) Update the values of K_h^g the maximum capacity of patients with g-type LSI $\in L$ that can be attended by MCC $h \in H$. Proceed as follows:

- $K_h^{gp} = K_h^{g(p-1)} - \sum_{k \in U^{p-1}} \left[\sum_{m \in M/u^{m(\sigma^m+1)}=0} \sum_{v=1}^{\sigma^m} y_{kh}^{mv} GR_k^g + \sum_{m \in M/u^{m(\sigma^m+1)}>0} \sum_{v=1}^{\sigma^{m+1}} y_{kh}^{mv} GR_k^g\right]$
- $K_h^g = K_h^{gp}$ where K_h^{gp} is the available capacity in MCC $h \in H$ to attend casualties of severity $g \in L$ at the beginning of the period $p \in P$, and y_{kh}^{mv} is equal to 1 if vehicle $m \in M$ transports the casualty k to medical center h on trip v, and 0 otherwise.

(c) Perform $N = H \cup PA$, build a new auxiliary network $G(N,A)$ and update values S_{ij}^e.

(d) Update TD^{me} (time required by e-type $\in E$ vehicle $m \in M$ to start operations) for vehicles in use.

- $\forall\ e \in E1/\delta^{me} = 1$ proceed as follows: If $u^{m(\sigma^m+1)} = 0$, then: $TD^{me} = T^{m\sigma^m} - TT^p$ If not, $TD^{me} = T^{m(\sigma^m+1)} - TT^p$
- $\forall\ e \in E2/\delta^{me} = 1$ proceed as follows: If $u^{m(\sigma^m+1)} = 0$, then: $TD^{me} = T^{m\sigma^m} - TT^p + TDS^e$ If not, $TD^{me} = T^{m(\sigma^m+1)} - TT^p + TDS^e$ where $E1$ is the set of land-based vehicles (ambulances), $E2$ is the set of airborne vehicles (helicopters), and δ^{me} is equal to 1 if vehicle $m \in M$ is of type $e \in E$, and 0 otherwise.

(e) Availability of emergency vehicles m. $\Omega^{mp} = 1$ if vehicle $m \in M$ is available at the beginning of period $p \in P$, and 0 if otherwise. Thus, $M = m\ /\Omega^{mp} = 1$.

Stage four: CPST Model

Solve Casualty Pickup, on-site Stabilization and Transport Model (4)–(29), *CPST Model*. In general, the input elements are the MCC and vehicle capabilities, operating times, and preference factors depending on the severity of the victim. In addition, the output elements are associated with decisions in the vehicles, which casualty is served by conveyance, and the time required for on-site rehabilitation.

The detailed mathematical model is presented in the next subsection.

Stage five: System Evaluation

If new casualties are identified, return to stage 2. In the event of any alteration in the system's response capacity, such as the incorporation or removal of emergency vehicles, or the appearance of new casualties, return to stage 2. Otherwise, keep the CPST *Schedule* obtained in stage 4.

4.3. Casualty Pickup, On-Site Stabilization, and Transport (CPST) Mathematical Model

This subsection describes the sets, parameters, and decision variables used in the 5-step resolution procedure and the mathematical formulation for the Casualty Pickup, on-site Stabilization, and Transport Model (CPST Model).

Sets:

N': Set of nodes of the direct transport network $G'(N',A')$.

H: Set of medical centers.

Cb: Set of nodes where helicopters may land.

N: Set of nodes in the auxiliary network $G(N,A)$. Where $N = H \cup Cb \cup N'$

L: Set of severity categories for casualties.

P: Set por periods.

U^p: Set of casualties who need to be transported to an MCC at the beginning of the execution period $p \in P$.

M: Set of available emergency vehicles (airborne and land-based). The set M represents the number of available vehicles, regardless of the type of vehicle. This set is updated in each iteration of the method (see stage 3, Section 4.2).

V: Set of trips itineraries.

E: Set of vehicle types ($E = E1 \cup E2$).

$E1$: Set of land-based vehicles (ambulances)

$E2$: Set of airborne vehicles (helicopters)

D: Set of age range.

Parameters:

K_h^{gp}: The available capacity in MCC $h \in H$ to attend casualties of severity $g \in L$ at the beginning of the period $p \in P$.

PA_k: Node $\in N'$ where casualty $k \in U^p$ is located.

GR_k^g: 1 if casualty $k \in U^p$ has an LSI $g \in L$, and 0 otherwise.

λ_k^{ag}: Transport priority index of casualty $k \in U^p$ with $g \in L$ severity.

D_k: Transport time of victim k from the moment he is stabilized until he enters the MCC.

O^m: Origin node (location) of the vehicle m. $m \in M$. (See Section 4.2, stage 3).

K_h^g: Maximum capacity of patients with g-type LSI $\in L$ that can be attended by MCC $h \in H$.

TT^p: Time at which the planning period $p \in P$ begins. Every casualty appears after $TT^0 = 0$.

TD^{me}: Time required by e-type $\in E$ vehicle $m \in M$ to start operations.

TDS^e: Time required for the take-off of e-type vehicle $e \in E$.

δ^{me}: 1 if vehicle $m \in M$ is of type $e \in E$, and 0 otherwise.

S_{ij}^e: Expected travel time between node $i \in N$ and node $j \in N$ in e-type vehicle $e \in E$.

q^e: Capacity of e-type vehicle $e \in E$.

TAT^e: Time required for the landing of e-type vehicle $e \in E$.

ε: Parameter that represents the level of preference given in relation to stabilization time.

B_2: Maximum capacity among all vehicles. $B_2 = \max_{e \in E}\{q^e\}$

l_k: Node $l \in Cb$ closest to the location of casualty k when picked up by helicopter.

t_{lk}: Expected travel time on foot of the paramedics from the pickup node l_k to the location PA_k of casualty k.

η^{e}_{ij}: General expression to represent the operation and travel time of an e-type vehicle, incorporating elements such as take-off and landing time in the case of aerial vehicles. Thus, it is total operation time between node i and node j in an e-type vehicle, and it can be expressed as:

$$\eta^{e}_{ij} = TDS^{e} + S^{e}_{ij} + TAT^{e} \tag{3}$$

Decision Variables:

$$y^{mv}_{kh} = \begin{cases} 1 & \text{If vehicle } m \in M \text{ transports casualty } k \in U^{p} \text{ to medical center } h \in H \text{ on trip } v \in V \\ 0 & \text{e.o.c} \end{cases}$$

$$z^{mv}_{h} = \begin{cases} 1 & \text{If the vehicle } m \in M \text{ completes the trip } v \in V \text{ at the medical center } h \in H \\ 0 & \text{e.o.c} \end{cases}$$

$$u^{mv} = \begin{cases} 1 & \text{If vehicle } m \in M \text{ does the trip } v \in V \\ 0 & \text{e.o.c} \end{cases}$$

$T^{mv:}$: Time needed by vehicle $m \in M$ to complete trip $v \in V$.

β_k: Pickup, on-site stabilization and transport time of casualty $k \in U^{p}$.

$$x^{mv}_{ij} = \begin{cases} 1 & \text{If vehicle } m \text{ on trip } v \text{ travels from node } i \text{ to node } j \\ 0 & \text{e.o.c} \end{cases}$$

$$w^{mv}_{k} = \begin{cases} 1 & \text{If casualty } k \in U^{p} \text{ is attended by vehicle } m \in M \text{ on trip } v \in V \\ 0 & \text{e.o.c} \end{cases}$$

C_k: Time needed for the on-site stabilization of casualty $k \in U^{p}$.

Next, the mathematical formulation for the CPST model is exposed:

- Objective Function:

$$\sum_{a \in D} \sum_{g \in L} \sum_{k \in N} \lambda^{ag}_{k} C_k \tag{4}$$

This function minimizes the time required to stabilize victims on site considering their LSI and wait time. The transport priority index λ^{ag}_{k} is given by the expression (1). Note that $\beta_k = C_k + D_k$, where D_k is the transport time of victim k from the moment he is stabilized until he enters the MCC (see Figure 1).

- Constraints:

The following group of constraints establishes that every casualty must be attended by only one vehicle on a single trip (5), and in (6), it is prevented that emergency vehicles exceed their capacity.

$$\sum_{v \in V} \sum_{m \in M} w^{mv}_{k} = 1 \quad \forall k \in U^{p} \tag{5}$$

$$\sum_{k \in U^{p}} w^{mv}_{k} \leq \sum_{e \in E} q^{e} \delta^{me} \quad \forall m \in M, \forall v \in V \tag{6}$$

Restrictions (7)–(10) establish the sequence of casualty pickups, starting and ending each trip itinerary in an MCC $h \in H$, except for the first trip, which begins at the start node O^{m} $\forall m \in M$ (constraint (8)). The equations in (9) represent flow conservation constraints. The restrictions in (11) prevent a trip from returning to an already visited node, while (12) avoid trips between MCCs. In constraint (7), the parameter V_{MAX} limits the trips to be evaluated and considerer the vehicle autonomy in terms of operation time.

$$z^{mv}_{h} = \sum_{i \in N} x^{m(v+1)}_{hi} \quad \forall m \in M, \forall h \in H, v \in V : v < V_{MAX} \tag{7}$$

$$\sum_{j \in N} x^{m1}_{O^{m}j} = 1 \quad \forall m \in M \tag{8}$$

$$\sum_{i \in N/i \neq r} \sum_{v \in V} x_{ir}^{mv} - \sum_{j \in N/j \neq r} \sum_{v \in V} x_{rj}^{mv} = 0 \quad \forall r \in N', \forall m \in M, \forall v \in V \tag{9}$$

$$\sum_{h \in H} z_h^{mv} = 1 \quad \forall m \in M, \forall v \in V \tag{10}$$

$$x_{ii}^{mv} = 0 \quad \forall i \in N', \forall m \in M, \forall v \in V \tag{11}$$

$$x_{ij}^{mv} = 0 \quad \forall i, j \in H, \forall m \in M, \forall v \in V/i \neq j \tag{12}$$

Restrictions (13) and (14) define the sequence of the trip's itineraries and the assignment of casualties to vehicles on each trip, while (15) ensures that if there are no victims, the vehicle does not make the trip.

$$u^{mv} \geq u^{m(v+1)} \quad \forall m \in M, \forall v \in V \backslash v < V_{MAX} \tag{13}$$

$$u^{mv} \geq w_k^{mv} \quad \forall j \in U^p, \forall m \in M, \forall v \in V \tag{14}$$

$$u^{mv} \leq \sum_{k \in U^p} w_k^{mv} \quad \forall m \in M, \forall v \in V \tag{15}$$

Restrictions (16) and (17) can be used to determine the time required for a vehicle to complete each trip. Constraints (16) are used for the first trip ($v = 1$). The first term registers the time to start the operations by each vehicle type since the trip's origin. The second term includes the time used to travel between nodes. The third term of the equation considers the on-site stabilization time required for a casualty of a determined age and severity and the time needed for each vehicle type to get where the casualty is. Finally, the fourth term counts the time to arrive at the MCC. While the constraints (17) are for the next trips, so the first term on the right side includes the previous time needed for each vehicle type to complete each trip. The rest of the terms are like the constraints (16), not including the time to start the operations by each vehicle type.

$$\begin{aligned} T^{m1} = & \sum_{j \in N'} \sum_{e \in E} (TD^{me} + TAT^e) \delta^{me} x_{O^m j}^{m1} + \sum_{i \in N} \sum_{j \in N} \sum_{e \in E} S_{ij}^e \delta^{me} x_{ij}^{m1} + \sum_{k \in U^p} \left(\sum_{g \in L} \sum_{a \in A} TS_k^{ag} + \sum_{e \in E2} \delta^{me} t_{l_k} \right) w_k^{m1} + \\ & + \sum_{e \in E} (TDS^e + TAT^e) \delta^{me} \left[\sum_{i \in N'} \sum_{j \in N' \backslash l_i \neq l_j, \forall l \in Cb} x_{ij}^{m1} + \sum_{j \in N'} \sum_{h \in H} x_{jh}^{m1} \right] \quad \forall m \in M \end{aligned} \tag{16}$$

$$\begin{aligned} T^{mv} = & T^{m(v-1)} + \sum_{i \in N} \sum_{j \in N} \sum_{e \in E} S_{ij}^e \delta^{me} x_{ij}^{mv} + \sum_{k \in U^p} \left(\sum_{g \in L} \sum_{a \in A} TS_k^{ag} + \sum_{e \in E2} \delta^{me} t_{l_k} \right) w_k^{mv} + \\ & + \sum_{e \in E} (TDS^e + TAT^e) \delta^{me} \left[\sum_{i \in N'} \sum_{j \in N' \backslash l_i \neq l_j, \forall l \in Cb} x_{ij}^{mv} + \sum_{j \in N'} \sum_{h \in H} \left(x_{hj}^{mv} + x_{jh}^{mv} \right) \right] \quad \forall m \in M, \forall v \in V/v \neq 1 \end{aligned} \tag{17}$$

The restrictions in (18) determine each casualty's pickup, stabilization, and transport times until their admittance into the assigned MCC.

$$\beta_k \geq T^{mv} - B(1 - w_k^{mv}) \quad \forall k \in U^p, \forall m \in M, \forall v \in V \tag{18}$$

The restrictions in (19) establish the capacity limits of the MCCs. The restrictions in (20) force a vehicle that has picked up a casualty to take it to a medical center, while (21) states that a vehicle can transport the casualties to a medical center only if it ends its journey in the aid center.

$$\sum_{k \in U^p} \sum_{m \in M} \sum_{v \in V} y_{kh}^{mv} GR_k^g \leq K_h^g \quad \forall g \in L, \forall h \in H \tag{19}$$

$$\sum_{i \in N} x_{iPA_k}^{mv} = \sum_{h \in H} y_{kh}^{mv} \quad \forall k \in U^p, \forall m \in M, \forall v \in V \tag{20}$$

$$\sum_{k \in U^p} y_{kh}^{mv} \leq B_2 z_h^{mv} \quad \forall h \in H, \forall m \in M, \forall v \in V \tag{21}$$

Constraints (22) and (23) establish the relationship between the decision variables.

$$w_k^{mv} = \sum_{i \in N} x_{iPA_k}^{mv} \quad \forall k \in U^p, \forall m \in M, \forall v \in V \tag{22}$$

$$\sum_{i \in N} x_{ih}^{mv} = z_h^{mv} \quad \forall h \in H, \forall m \in M, \forall v \in V \tag{23}$$

The restrictions in (24)–(27) allow determining the stabilization time of the casualties considering the different situations that can appear (several casualties in the same node, casualties in different nodes, vehicles with capacities to attend several victims, and the number of the trip). Constraint (24) is used to calculate the time needed for a vehicle to attend the first casualty in the first trip (v = 1). The first term in (24) considers the time to start operations; the second terms register the stabilization time needed, including the time needed by the paramedics to get the casualties when they arrived by helicopter. The last two terms are used to bound or not the time according to the use of the vehicles attending the casualties and traveling between nodes. Constraint (25) considers cases where two or more casualties are simultaneously in the same node and are attended by the same vehicle. Similarly, is consider the on-site stabilization time of each victim, the time used by the paramedics to arrive where the casualties are, and a term (the last one) to bound the time if the vehicle is used. The restrictions in (26) consider the case of a vehicle aiding two casualties located in different nodes on the same trip using a helicopter due to its capacity (ambulances only can take one casualty). In contrast, (27) calculates the stabilization time of the first casualty of a trip when the trip is not the first in the casualty pickup plan.

$$C_k \geq \sum_{e \in E} (TD^{me} + \eta_{O^m PA_k}^e)\delta^{me} + \left(\sum_{g \in L} \sum_{a \in A} TS_k^{ag} + \sum_{e \in E2} \delta^{me} t_{l_k} \right) - B(1 - w_k^{m1}) - B(1 - x_{O^m j}^{m1}) \\ \forall k \in U^p, \forall h \in H, m \in M \tag{24}$$

$$C_k \geq C_d + \sum_{e \in E2} \delta^{me}(t_{l_d} + t_{l_k}) + \sum_{g \in L} \sum_{a \in A} TS_k^{ag} + B\left(\sum_{v \in V} x_{PA_d PA_k}^{mv} - 1 \right) \quad \forall d,k \in U^p, \forall m \in M / PA_d = PA_k \tag{25}$$

$$C_k \geq C_d + \sum_{e \in E2} \delta^{me}(t_{l_d} + t_{l_k}) + \sum_{e \in E} \delta^{me}(\eta_{PA_d PA_k}^e) + \sum_{e \in E2 / l_d \neq l_k, \forall l \in Cb} \delta^{me}(TDS^e + TAT^e) \\ + \sum_{g \in L} \sum_{a \in A} TS_k^{ag} + B(\sum_{v \in V} x_{PA_d PA_k}^{mv} - 1) \quad \forall d,k \in U^p / PA_d \neq PA_k, \forall m \in M \tag{26}$$

$$C_k \geq T^{m(v-1)} + \sum_{e \in E} \delta^{me}(TDS^e + TAT^e + \eta_{ij}^e) + \sum_{g \in L} \sum_{a \in A} TS_k^{ag} + \sum_{e \in E2} \delta^{me} t_{l_k} - B(1 - w_k^{mv}) - B(1 - z_h^{m(v-1)}) \\ \forall k \in U^p, \forall h \in H, m \in M, v \in V \backslash v \neq 1 \tag{27}$$

Restrictions (28) and (29) show the nature of the decision variables.

$$x_{ij}^{mv}, y_{kh}^{mv}, z_h^{mv}, w_k^{mv}, u^{mv} \in \{0,1\} \quad \forall i,j \in N, \forall k \in U^p, \forall h \in H, \forall v \in V, \forall m \in M \tag{28}$$

$$C_k, T^{mv}, \beta_k \geq 0 \quad \forall m \in M, \forall v \in V, \forall k \in U^p \tag{29}$$

5. Methodology Implementation

5.1. Numerical Example

To test the performance of our methodology, we generated a small numerical example with three MCCs and five casualties (identified by V1 to V5). V1 and V5 are in the same node, as are V3 and V4. The performance of both an ambulance (with a capacity for one patient) and a helicopter with three patients is evaluated. Additionally, the impact of considering different LSI and age ranges is tested by minimizing both the time required to stabilize the victims (C_k) and the total time of each trip β_k. MCC 1 is the only one that can treat victims with LSI 3. Helicopters start their operations from a heliport. Table 1 shows the ambulance and helicopter travel times between medical care centers (MCCs) and casualties, and Table 2 shows the time required to stabilize casualties of different age ranges and severity, TS_k^{ag}.

Table 1. Ambulance and helicopter travel times between medical care centers (MCCs) and casualties. Numerical example.

	Ambulance Travel Times (min)									Helicopter Travel Times (min)							
	MCC 1	MCC 2	MCC 3	V1	V2	V3	V4	V5		MCC 1	MCC 2	MCC 3	V1	V2	V3	V4	V5
V1	29.19	23.91	36.64	0	6.67	8.33	8.33	0	V1	7.42	6.78	7.89	0	5.46	5.51	5.51	5
V2	27.46	20.96	32.64	6.67	0	6.61	6.61	6.67	V2	7.1	6.47	7.51	5.46	0	5.46	5.46	5.46
V3	22.63	18.21	30.09	8.33	6.61	0	0	8.33	V3	6.93	6.29	7.43	5.51	5.46	0	0	5.51
V4	22.63	18.21	30.09	8.33	6.61	0	0	8.33	V4	6.93	6.29	7.43	5.51	5.46	0	0	5.51
V5	29.19	23.91	36.64	0	6.67	8.33	8.33	0	V5	7.42	6.78	7.89	0	5.46	5.51	5.51	0

Table 2. Average stabilization time (minutes) according to age range and LSI.

ID Age Range	Age Range (Years)	Stabilization Time According to LSI (min)		
		LSI 1	LSI 2	LSI 3
1	0–14	14.98	42	93.3
2	15–59	15.04	29.9	62.14
3	60 or more	9.3	27.6	65

Table 3 shows the results after the implementation of the methodology considering four scenarios: (a) casualties with equal LSI, (b) casualties with equal LSI and different age ranges, (c) casualties with different LSI and the same age range, and (d) casualties with different LSI and different age ranges. For better exposure, Figure 3 shows the results for the scenarios (a) and (c).

Scenario (a) Casualties with equal LSI (Table 3a and Figure 3): By using only an ambulance, the same solution is obtained by minimizing each objective function (C_k and β_k). The closest casualties are treated first (V3 and V4), then V2, and finally V1 and V5, requiring an itinerary of five trips (one trip for each patient). When only the helicopter is used, by minimizing C_k, three patients are collected and stabilized in the first trip (V3, V4, and V1), and in a second trip, the other victims are stabilized and transported (V2 and V5). However, when the objective is to minimize patients' arrival time at the MCC, β_k, each casualty is transported independently (five different trips). This situation is since the transfer times are significantly shorter than the stabilization times (ca. 7 min vs. 62.14 min), so it is more convenient for the model to perform more trips so as not to increase the time of arrival at the MCC of the casualties to the detriment of postponing their stabilization.

Scenario (b) Casualties with the same LSI and different age ranges (Table 3b): We modified the age range for casualties V2, V3, and V5, which modifies the time needed to stabilize the victims and the priority index for transporting. The same results are obtained for ambulance use by minimizing C_k and β_k. The order of visits prioritizes the care of victims with lower age ranges who require longer stabilization times. In the case of helicopters, by minimizing C_k, the first trip's collection and stabilization sequence consider victims of higher priority λ_k^{ag} (V2 and V3) and V4, which is in the same node as V3. By minimizing β_k, again, we opt for five trips (one for each patient), favoring the rapid arrival at the MCC and not the casualty's stabilization (TS_k).

Table 3. (**a**) Casualties with equal LSI. (**b**) Casualties with equal LSI and different age ranges. (**c**) Casualties with different LSI and the same age range. (**d**) Casualties with different LSI and different age ranges.

Ambulance with 1 patient capacity									Helicopter with capacity for 3 patients												
					Min *Ck*									**Min *Ck***				**Min β k**			
Casualty ID Code	**LSI**	**Age Range**	λ_k^{ag}	TS_k^{ag} **(min)**	**Trip (*v*)**	TB_k **(min)**	TS_k **(min)**	TL_k **(min)**	**Casualty ID Code**	**LSI**	**Age Range**	λ_k^{ag}	TS_k^{ag} **(min)**	**Trip (*v*)**	TB_k **(min)**	TS_k **(min)**	TL_k **(min)**	**Trip (*v*)**	TB_k **(min)**	TS_k **(min)**	TL_k **(min)**
V1	3	2	5.1	62.1	5	482.6	544.7	573.9	V1	3	2	5.1	62.1	1	8.1	70.3	206.3	1	8.1	70.3	75.1
V2	3	2	5.1	62.1	3	243.3	305.4	332.9	V2	3	2	5.1	62.1	2	213.8	275.9	357.9	4	229.4	291.6	299.0
V3	3	2	5.1	62.1	1	23.6	85.8	108.4	V3	3	2	5.1	62.1	1	72.9	135.0	206.3	2	80.7	142.9	148.5
V4	3	2	5.1	62.1	2	131.0	193.2	215.8	V4	3	2	5.1	62.1	1	138.5	200.7	206.3	3	154.2	216.4	222.0
V5	3	2	5.1	62.1	4	362.1	424.2	453.4	V5	3	2	5.1	62.1	2	285.6	347.8	357.9	5	309.1	371.3	381.4

(**a**)

Ambulance with 1 patient capacity									Helicopter with capacity for 3 patients												
					Min *Ck*									**Min *Ck***				**Min β k**			
Casualty ID Code	**LSI**	**Age Range**	λ_k^{ag}	TS_k^{ag} **(min)**	**Trip (*v*)**	TB_k **(min)**	TS_k **(min)**	TL_k **(min)**	**Casualty ID Code**	**LSI**	**Age Range**	λ_k^{ag}	TS_k^{ag} **(min)**	**Trip (*v*)**	TB_k **(min)**	TS_k **(min)**	TL_k **(min)**	**Trip (*v*)**	TB_k **(min)**	TS_k **(min)**	TL_k **(min)**
V1	3	2	5.1	62.1	4	424.4	486.5	515.7	V1	3	2	5.1	62.1	2	282.1	344.2	426.5	3	219.7	281.9	286.7
V2	3	1	8.7	93.3	2	167.0	260.3	287.8	V2	3	1	8.7	93.3	1	109.5	202.8	277.3	2	114.6	207.9	215.0
V3	3	1	8.7	93.3	1	23.6	116.9	139.6	V3	3	1	8.7	93.3	1	9.0	102.3	277.3	1	9.0	102.3	107.5
V4	3	2	5.1	62.1	3	310.4	372.6	395.2	V4	3	2	5.1	62.1	1	210.0	272.1	277.3	4	291.8	354.0	359.2
V5	3	3	5.1	65.0	5	544.9	609.9	639.1	V5	3	3	5.1	65.0	2	351.3	416.3	426.5	5	369.3	434.3	444.5

(**b**)

Ambulance with 1 patient capacity									Helicopter with capacity for 3 patients												
					Min Ck									**Min *Ck***				**Min β k**			
Casualty ID Code	**LSI**	**Age Range**	λ_k^{ag}	TS_k^{ag} **(min)**	**Trip (*v*)**	TB_k **(min)**	TS_k **(min)**	TL_k **(min)**	**Casualty ID Code**	**LSI**	**Age Range**	λ_k^{ag}	TS_k^{ag} **(min)**	**Trip (*v*)**	TB_k **(min)**	TS_k **(min)**	TL_k **(min)**	**Trip (*v*)**	TB_k **(min)**	TS_k **(min)**	TL_k **(min)**
V1	3	2	5.1	62.1	2	137.6	199.7	228.9	V1	3	2	5.1	62.1	1	8.2	70.3	175.6	1	8.2	70.3	75.1
V2	2	2	0.9	29.9	4	320.6	350.5	371.5	V2	2	2	0.9	29.9	2	182.7	212.6	250.0	4	193.6	223.5	230.0
V3	2	2	0.9	29.9	3	251.5	281.4	299.6	V3	2	2	0.9	29.9	1	140.5	170.4	175.6	3	152.7	182.6	187.2
V4	3	2	5.1	62.1	1	23.7	85.8	108.4	V4	3	2	5.1	62.1	1	74.9	137.0	175.6	2	80.3	142.4	147.6
V5	1	2	0.4	15.0	5	395.4	410.4	434.3	V5	1	2	0.4	15.0	2	224.3	239.3	250.0	5	239.6	254.6	264.1

Table 3. *Cont.*

(**c**)

Ambulance with 1 patient capacity					Min Ck				Helicopter with capacity for 3 patients					Min Ck				Min β k			
Casualty ID Code	**LSI**	**Age Range**	λ_k^{ag}	TS_k^{ag} **(min)**	**Trip (v)**	TB_k **(min)**	TS_k **(min)**	TL_k **(min)**	**Casualty ID Code**	**LSI**	**Age Range**	λ_k^{ag}	TS_k^{ag} **(min)**	**Trip (v)**	TB_k **(min)**	TS_k **(min)**	TL_k **(min)**	**Trip (v)**	TB_k **(min)**	TS_k **(min)**	TL_k **(min)**
V1	3	2	5.1	62.1	2	168.8	230.9	260.1	V1	3	2	5.1	62.1	1	107	169.1	224.5	2	112.3	174.4	179.2
V2	2	1	1.9	42.0	3	287.5	329.5	350.5	V2	2	1	1.9	42.0	1	175.4	217.4	224.5	3	186.3	228.3	234.7
V3	2	2	0.9	29.9	4	368.7	398.6	416.8	V3	2	2	0.9	29.9	2	229.6	259.5	289.0	4	239.3	269.2	273.7
V4	3	1	8.7	93.3	1	23.6	116.9	139.6	V4	3	1	8.7	93.3	1	9	102.3	224.5	1	9	102.3	107.5
V5	1	3	0.4	9.3	5	440.7	450.0	473.9	V5	1	3	0.4	9.3	2	269.5	278.8	289.0	5	283.2	292.5	302.0

(**d**)

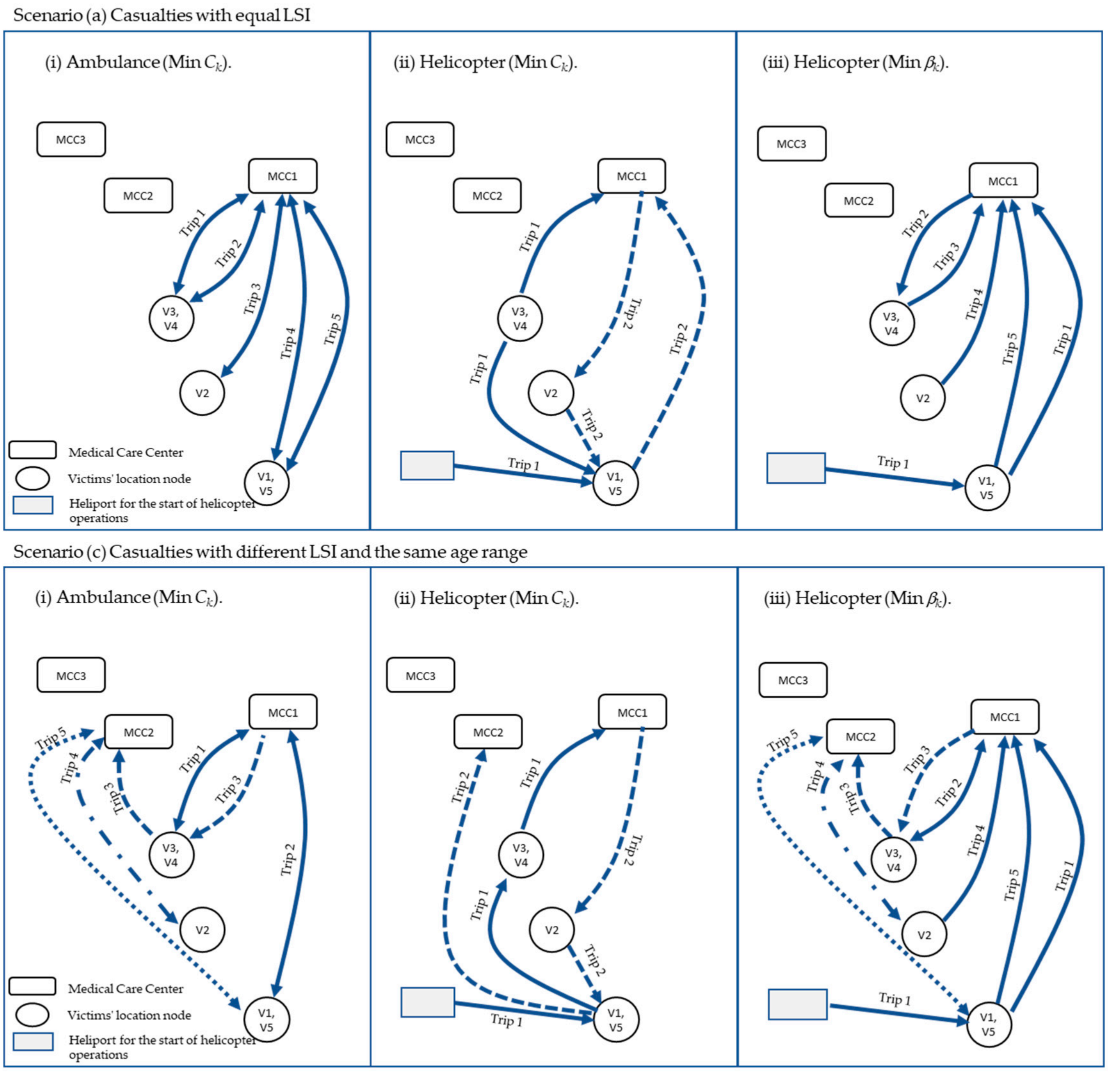


Figure 3. Graphical results of itineraries for the scenario (a) casualties with equal LSI, and (c) casualties with different LSI and the same age range. For both scenarios (a, c): (i) Only ambulance, minimizing C_k, (ii) Only helicopter, minimizing C_k, and (iii) Only helicopter, minimizing β_k.

Scenario (c) Casualties with different LSI and the same age range: We now consider that victims V2 and V3 have LSI2 and V5 LSI1 (Table 3c and Figure 3). Note that this again alters the priority index λ_k^{ag}. As in previous cases, the same results are obtained when using an ambulance by minimizing C_k or β_k. In both cases, the most severe victims are prioritized. Considering the use of a helicopter, by minimizing the casualties' stabilization time, C_k, in the first round, the two casualties with the highest LSI (V1 and V3) are treated together with the V4 victim in the same node as V3. By minimizing β_k, again, it is chosen to make five trips, minimizing the time at which the casualties arrive at the MCC, but not the moment of stabilization. This reduces the probability of survival of the casualties.

Scenario (d) Casualties with different LSI and different age ranges: Casualties of low age (age range 1) and greater severity should be prioritized. From Table 3d, it is observed that, when using an ambulance, the three most severe and vulnerable victims are always prioritized according to their age, attending first to V4 with LSI2 and age range 1, then V1 with LSI3, and then V2 with LSI2 and age range 1. This effect is also observed when using a helicopter. In this case, minimizing Ck effectively the V4, V1, and V2 casualties who are treated in the first trip, thus prioritizing their stabilization. As before, minimizing β_k prioritizes the rapid arrival of patients to the MCCs and not their stabilization, postponing the stabilization of all victims.

5.2. Case Study: Iquique, Chile

The proposed methodology was implemented in AMPL and tested in Iquique, Chile, with CPLEX 12.9.0.0, using a PC with an Intel Core i-7, 3.4 GHz processor with 6 Gb of RAM. This city is located at the center of the seismic gap that causes large-scale seismic events in northern Chile. The subduction zone along the coast of northern Chile has been broken twice; mega-earthquakes with a magnitude of the seismic moment (M_w) of ~8.8 in 1877 [53], Mw 8.2 in 2014. However, experts agree that this last earthquake is not the last to be expected and that an even bigger one can still take place in northern Chile and southern Peru [54]. Given these antecedents, the Research Center for Integrated Disaster Risk Management (CIGIDEN) in Chile has established a set of seismic scenarios for the north of the country, with magnitudes ranging from M_w 8.42 to M_w 8.95 [55]. To implement our methodology, we used the scenario for an earthquake with M_w 8.95, an epicenter 102 km southwest of Iquique, in the morning rush hour (7:30–8:30 a.m.), on a working day. This scenario produces the highest casualties from all simulated scenarios [55].

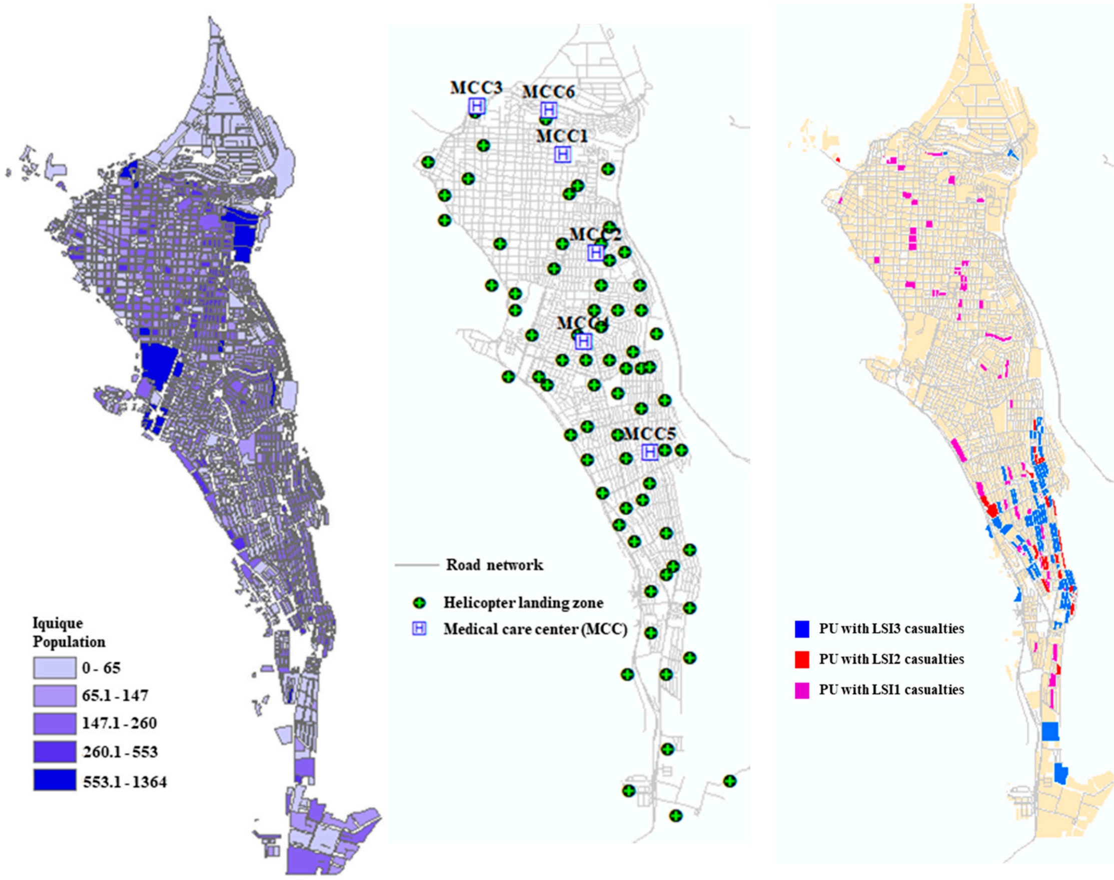
5.3. Iquique Population, Health Network, and Other Modeling Parameters

Figure 4a shows the geographical distribution of the Iquique population. The city has 163,281 inhabitants, distributed across 1652 population units (PU) used to group the population. Each PU is represented as a point on the map where the population is aggregated. Table 4 shows the population of Iquique by age range. We considered the strategic road network, medical care centers, and feasible helicopter landing areas that can be seen in Figure 4b. The transport network is made up of 464 nodes and 1141 arcs. Each arc of the network features information about its length and operating speed under normal conditions at different times of day [56]. Seventy-two feasible landing areas were identified for helicopters inside the city, mainly sports facilities in educational and municipal establishments.

We considered three LSI sustained by casualties, corresponding to those used in [57]. The health network has six available MCCs, eight ambulances, and three helicopters with a capacity of one patient each [57]. Table 5 shows the capacity of each MCC by LSI, represented by the number of available beds. LSI1 corresponds to minor injuries that do not require hospitalization but do require transportation to an MCC; LSI2 shows injuries that require a greater degree of medical care than LSI1; LSI3 includes injuries that may be life-threatening unless appropriately treated. A casualty may only have one LSI at a time, which may worsen in time unless medical attention is provided. Without loss of generality, casualties who died immediately after the event are not considered in the CPSTS. However, they could easily be incorporated as a type 4 LSI. Table 6 determines the average stabilization time of the casualties according to their age range and LSI, which was based on a thorough review of the specialized literature, which summarizes the times needed to stabilize patients with different types of injuries according to their age range (see [52,58–69]).

The travel times of ambulances after an earthquake were determined considering that the operating speed of each arc in the network is only 30% of its speed under normal conditions at the time of the event [70,71]. Operating speeds gradually return to normal soon after.

We considered an average travel speed of 4 km/h [71] to estimate the expected time of travel by land (t_{l_i}) of paramedics from the collection node l_i closest to i until the location node of the casualty i. Finally, TD^{m1} = 1 min, TD^{m2} = 5 min, and $TDS^1 = TAT^1$ = 0.75 min is assumed. For the estimation of λ_j^g, we considered the expression (1) as an exponential deterioration function of the type $f_k^{ag}(\alpha_k) = \kappa^{ag} e^{\varpi^{ag} + \varphi^{ag}\alpha_k}$, with κ^{ag}, ϖ^{ag} and φ^{ag} parameters to be calibrated according to LSI, with $g \in L$ and $a \in D$. $\pi_{1\text{–}2}$ = 2880, $\pi_{2\text{–}3}$ = 360 min, $TDS^1 = TAT^1$ = 0.75 min.



(**a**) (**b**) (**c**)

Figure 4. (**a**) Population density, city of Iquique; (**b**) Road network, MCC locations, and areas enabled for helicopter landing, city of Iquique, Chile; (**c**) Location of 212 casualties by LSI in each Population Unit (PU) in the city of Iquique, a simulated scenario with an M_w 8.95 earthquake.

Table 4. Population of the city of Iquique separated by category, according to age range.

ID Age Range	Age Range (Years)	Population (Persons)
1	0–14	41.163
2	15–59	106.744
3	60 or more	15.374

Table 5. Medical care center (MCC) capacity according to LSI [57].

Medical Care Center ID	Capacity (No. of Beds)		
	LSI1	LSI2	LSI3
MCC1	23	30	20
MCC2	24	21	0
MCC3	24	21	0
MCC4	16	19	0
MCC5	24	21	0
MCC6	25	22	0

Table 6. People injured by LSI. Simulated scenario, earthquake M_w 8.9.

Age Range ID	Age Range (Years)	People Injured by LSI		
		LSI 1	LSI 2	LSI 3
1	0–14	24	23	3
2	15–59	72	75	7
3	60 or more	2	5	1

5.4. Requirements for Pickup, Stabilization, and Transport of Casualties in a M_w 8.95 Scenario

Table 6 and Figure 1c show the estimated number and location of casualties according to their LSI for the simulated earthquake scenario of M_w 8.95, whose epicenter is 102 km southwest of Iquique, at 07:30 a.m. on a business day [55]. A total of 606 casualties were estimated, of which 492 have LSI1, 103 LSI2, and 11 LSI3. Without loss of generality, and to better present the results, we assumed that 80% of casualties with LSI1 go to MCCs either by their own means, or with the help of relatives and neighbors, and are treated in emergency rooms without making use of the bed capacity shown in Table 5. The remaining 20% require specialized transportation (98 people), either due to difficulty moving or lack of means. All casualties with LSI2 (103 people) and LSI3 (11 people) require specialized transportation by ambulance or helicopter. Thus, a total of 212 people will require pickup, stabilization, and transport services to an MCC during an emergency.

5.5. Methodology Implementation

Not all casualties appeared immediately after the earthquake. Although the methodology can be applied every time a new casualty appears, or there is a change in the supply of the health network, to present the results, we have simulated the appearance of casualties and the calculation of the CPST program by executing our algorithm in seven different moments after the earthquake, updating the number and status of the casualties and the CPST program with the itineraries of each vehicle. Table 7 shows the evaluated scenarios. The first two columns of the table show the identification number and the start time of the methodology according to the simulation. Columns three to six show the total number of casualties and casualties by the LSI that requires medical attention at the beginning of each period. The number of medical care centers, ambulances, and helicopters that we assume are available at the beginning of each period is shown in columns seven to nine (identified with the initials MCC, A, and H followed by a consecutive number, respectively). The decreased percentage in the road network's operating speed for each period is shown in column ten.

5.6. Casualty Pickup, Stabilization, and Transport Schedule (CPST Schedule)

We consider that the earthquake starts at exactly 7:30 a.m. After a few minutes, the MACC begins receiving requests for medical assistance. At 7:41 a.m. our methodology is executed, obtaining the results of Table A1 in Appendix A and Figure 5. Note that, according to Table 7, when executing our methodology, there are 64 injured and the availability of 3 MCC, 4 ambulances, and 2 helicopters. We have arranged Table A1 according to the resulting itinerary for each vehicle and sequence of care for the injured. The first column shows the vehicle identification code (four ambulances and two helicopters). Columns two to five show the identification code, the location node (l_i), the age range, and the LSI of each of the 64 reported casualties. Column six shows the time necessary to stabilize each victim according to their age and LSI (see Table 5), while column seven shows the transport priority index according to equation (1). Column eight shows which trip (v) of the vehicle's itinerary cares for the casualty. Columns nine to twelve show the time the patient is assigned to a collection schedule (TF_k), the time of arrival of the vehicle at the patient's location (TB_k), the time at which the patient was stabilized (TS_k), and time at which the patient is checked into the medical care center (TL_k). The MCC allocated to the casualty can be seen in the last column.

Table 7. Number of casualties who require transport to an MCC, availability of the health network, and decrease in the speed of operation of the road network for each modeling period.

Period ID	Period Start Time	Number of Casualties (People)				Availability of the Health Network			% Decrease in Speed
		Total	LSI 1	LSI 2	LSI 3	Available MCCS	Ambulances Available	Helicopters Available	
Period 1	07:41	64	32	27	5	3 (MCC1, 2 and 3)	4 (A1, A2, A3, A4)	2 (H1, H2)	70%
Period 2	09:26	44	20	22	2	5 (MCC 1, 2, 3, 4, 5)	5 (A1, A2, A3, A4, A5)	2 (H1, H2)	70%
Period 3	11:46	41	22	18	1	6 (MCC 1, 2, 3, 4, 5, 6)	7 (A1, A2, A3, A4, A5, A6, A7)	3 (H1, H2, H3)	50%
Period 4	13:26	31	14	15	2	6 (MCC 1, 2, 3, 4, 5, 6)	7 (A1, A2, A3, A4, A5, A6, A7)	3 (H1, H2, H3)	50%
Period 5	15:36	17	4	12	1	6 (MCC 1, 2, 3, 4, 5, 6)	7 (A1, A2, A3, A4, A5, A6, A7)	3 (H1, H2, H3)	30%
Period 6	18:16	12	6	6	0	6 (MCC 1, 2, 3, 4, 5, 6)	7 (A1, A2, A3, A4, A5, A6, A7)	3 (H1, H2, H3)	30%
Period 7	19:36	5	2	3	0	6 (MCC 1, 2, 3, 4, 5, 6)	8 (A1, A2, A3, A4, A5, A6, A7, A8)	3 (H1, H2, H3)	10%

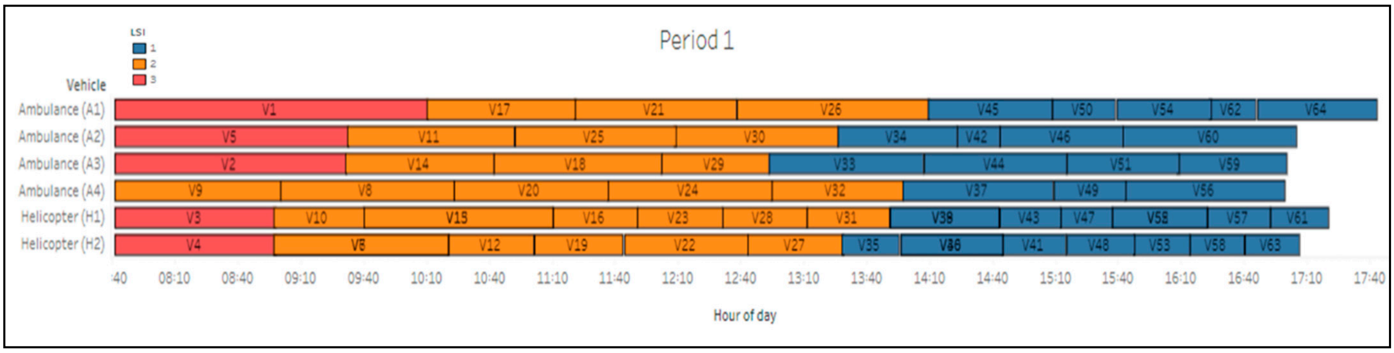


Figure 5. Casualty Pickup, Stabilization and Transport Schedule (CPST Schedule), Period 1 (start 07:41).

On the other hand, Figure 5 graphically shows the CPST program for each vehicle. Towards the right, each rectangle represents a casualty, and the length is the time from when the vehicle begins its journey towards the victim until the latter is entered into the MCC. The red color represents the most severe casualties (LSI3), and the blue represents the least severe casualties (LSI1). Thus, we can see that our methodology prioritizes casualties with higher LSI in their injuries, first serving LSI3 victims, then LSI2, ending with LSI1 casualties.

To illustrate the results, consider the itinerary of the A1 ambulance from Table A1 and Figure 5. The first trip began at 7:41 a.m., arriving at casualty V1 (less than 14 years old, LSI 3) at 09:15:18. The casualty needed 93.3 min to stabilize (see Table 2), achieving stabilization of her vital signs at 09:42:46. The patient V1 was admitted into MCC1 at 10:10:14, thereby completing the first trip in 89 min. The second trip of the A1 itinerary begins from MCC1, arriving at patient V17 at 10:40:08, achieving stabilization at 11:02:45. Finally, patient V14 is admitted to MCC2 at 11:20:58. A1′s itinerary includes seven more trips, attending casualties V21, V26, V45, V50, V54, V64, and V62. If there are no modifications to the system, this ambulance is expected to complete its operations at 17:43:12, that is, 10 h and 2 min after initiating its activities. The other available rescue vehicles (ambulances A2, A3, and A4; helicopters H1 and H2) follow the itinerary as laid out in Table 6 until all the casualties entered the system have been taken care of. Thus, the pickup, stabilization, and transport operations for the 64 patients reported at the beginning of period 1 (07:41 a.m.) will conclude when the last patient (V63) transported by the helicopter H1 is admitted into MCC1.

If two or more casualties with different LSI are in the same place, our methodology favors stabilizing those with more severe injuries. In turn, between two casualties of the same LSI but of different ages, our methodology favors the stabilization of those most vulnerable according to their age. This is the case of casualties located in node ID 36020 of Table 8. Casualties V2 and V4, both with LSI3, are prioritized over the other casualties in the itinerary of ambulance A3 and helicopter H1, respectively. The aid sequence for the rest of the casualties follows this same logic, continuing with LSI2 casualties and ending with LSI1. Moreover, when two casualties have the same LSI, priority is given to the person that has been waiting for the longest.

Table 8. Excerpt. Casualty pickup, stabilization, and transport activity at node 36020. Period 1.

Vehicle ID Code	Casualty ID Code	Node ID (l_i)	Age Range	LSI	TS_k^{ag} (min)	λ_k^{ag}	*Trip* (v)	TF_k	TB_k	TS_k	TL_k	MCC Assigned
A3	V2	36020	≥60	3	65	5.105	1	7:41:00	8:04:18	9:09:18	9:31:36	MCC1
H2	V4	36020	15–59	3	62.14	5.105	1	7:41:00	7:50:02	8:52:10	8:57:51	MCC1
A1	V17	36020	15–59	2	29.9	0.895	2	7:41:00	10:32:51	11:02:45	11:20:58	MCC2
A3	V18	36020	15–59	2	29.9	0.895	3	7:41:00	11:07:28	11:37:22	12:02:17	MCC1
A2	V25	36020	15–59	2	29.9	0.895	3	7:41:00	11:15:18	11:45:12	12:08:30	MCC1
H1	V28	36020	15–59	2	29.9	0.895	6	7:41:00	12:36:40	13:06:34	13:11:35	MCC2
H1	V38	36020	15–59	1	15.04	0.372	8	7:41:00	13:58:27	14:13:29	14:43:07	MCC2
H1	V39	36020	15–59	1	15.04	0.372	8	7:41:00	14:20:54	14:35:56	14:43:07	MCC2

After obtaining the first CPST program (7:41 a.m.) and while rescue operations are scheduled, new casualties appear in the system, and new rescue vehicles and MCCs are incorporated. All these changes modify the conditions in which the initial CPST schedule was established for each vehicle (period 1), so it is necessary to redefine them in consideration of the LSI of the new victims and the deterioration of those casualties who have not yet been taken care of. Table A2 and Figure 6 show the results after the methodology execution according to Table 7.

At the start of period 2 (09:26), all vehicles in operation were carrying out casualty stabilization and transport activities. Our methodology takes this into account and, for each vehicle, reschedules activities from the first trip that ends after 9:26 a.m. This is represented from the start time of each period in Figure 6. From then on, the new schedule begins. To better illustrate this, consider the operations of helicopter H1, shown in Figures 5 and 6. Under the itinerary developed in period 1 (Table A1 and Figure 5), H1 began operations by aiding casualties V3 with LSI3, and then sequentially a set of casualties with LSI2 and LSI1, where the first casualties LSI2 were V10, V15, V13, and V16. The reprogramming of H1′s routes occurs as it transports casualties V10 with LSI2 (see period 2 from Figure 6). Once this route has finished, their activities are prioritized to aid the new casualty V66, who has an LSI3, delaying the care of V15 with LSI2, who is assigned to ambulance A1. The prioritization of critical patients to the detriment of those less serious is clearly observed in our methodology. Consider casualty V33, who, according to the schedule for period 1 (Table A1), should be stabilized at 14:07:16 by ambulance A3 personnel on their fifth trip. However, given the appearance of more serious casualties, the care and transport of casualty V33 is postponed until period 6, at 18:52:38 (Table A2), by ambulance A5, accumulating a wait of almost 5 h.

In many real situations, such long waiting times for low-severity casualties encourage transport via alternative forms of transportation, such as transport by neighbors or relatives at their own expense. However, we chose not to include these phenomena, which are easy to consider showing the effects on waiting times and possible changes in the casualty LSI using the proposed methodology. Thus, prioritizing casualties of greater severity to the detriment of those with lower LSI, or with longer wait-allocation time when they have an equal LSI, may cause a deterioration in the injuries of waiting casualties, which is also considered in our methodology.

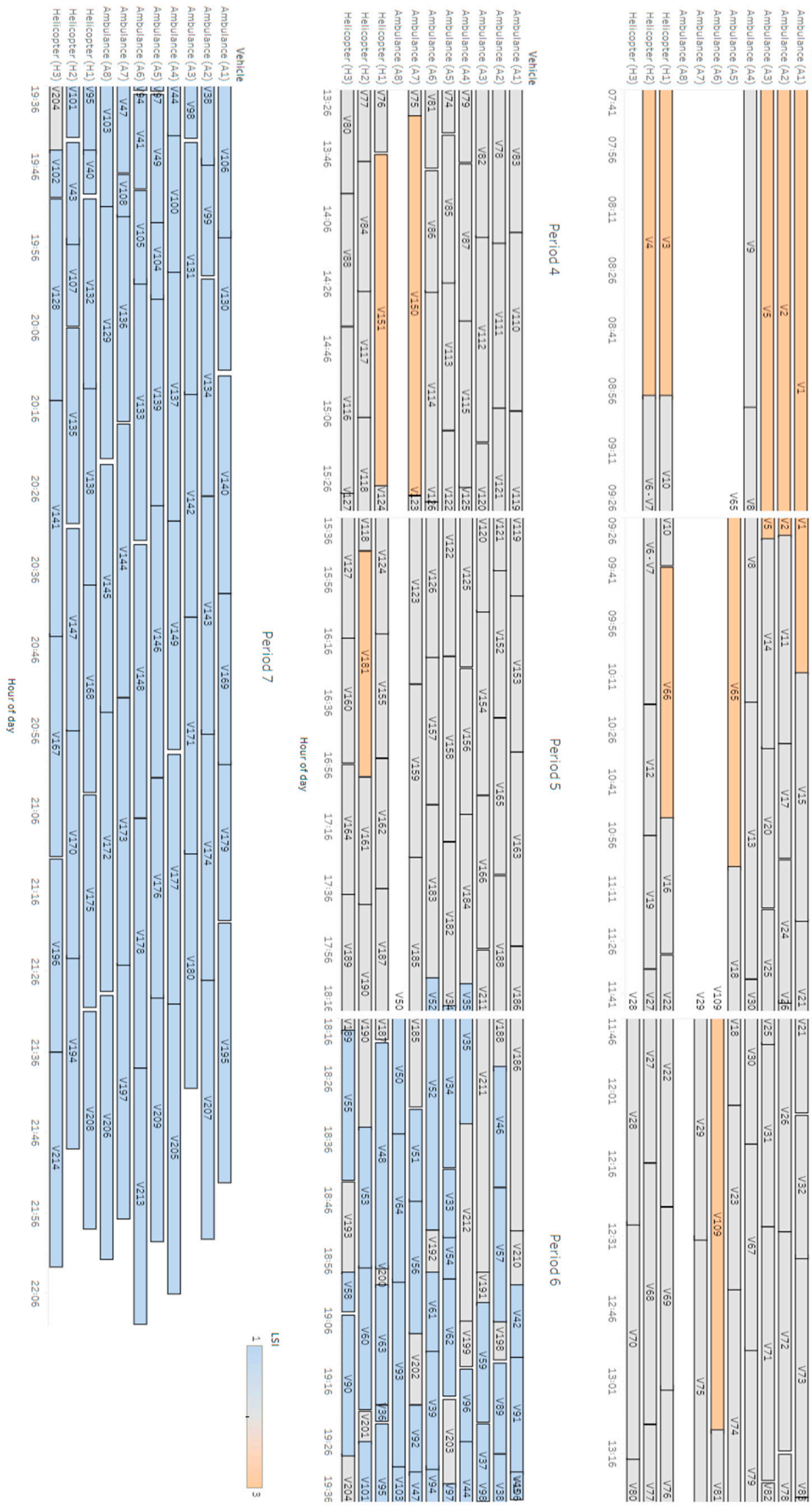


Figure 6. Casualty Pickup, Stabilization, and Transport Schedule, after an execution of 7 periods.

6. Conclusions

We propose a new approach to the problem of collecting and transporting casualties in response to mass-casualty incidents. Our methodology allows the creation of a schedule that minimizes pickup time, on-site stabilization, and casualty transport while considering the availability of emergency vehicles and the capacity of the medical care centers. We consider the LSI and how it deteriorates as time is spent waiting and include on-site stabilization time by age range and severity of the casualties as one of the significant variables to determine priority.

Our methodology allows creating a Casualty Pickup, Stabilization, and Transport Schedule (CPST Schedule) for each vehicle. All casualties are included in one of the routes in the collection schedule. The start and end MCC, the casualties to be collected, the sequence of visits, the waiting time, the stabilization and transport of the casualties, and their arrival at an MCC are all defined for each trip. Our procedure has five stages based on a mixed-integer programming model, which may be executed whenever a change in the health system's offer or demand for casualty transport. We tested the methodology in a numerical example and in a real simulated earthquake scenario in the city of Iquique, Chile, to verify its effectiveness.

The findings show that our methodology prioritizes casualties with higher LSI in their sustained injuries. If two or more casualties with different LSI are in the same place, our methodology guarantees that those with greater severity are stabilized first. Moreover, when two casualties have the same LSI, the one waiting for the longest is given priority.

When new victims appear in the system, or new MCCs or vehicles are incorporated into rescue activities, the conditions in which the initial CPST schedule of each vehicle was established, making it necessary to reset them by considering the LSI of the new casualties, the waiting time to be assigned to the itinerary of a vehicle and deterioration times of the casualties that have not yet been aided. Our methodology also considered this by determining the corresponding priority for each casualty. The results show that the new CPST schedule prioritized casualties with greater severity and waiting times. The injuries of some casualties also worsened while waiting for treatment.

Our methodology can significantly contribute to decision makers, allowing them to allocate resources when collecting and transporting casualties better, maximizing survival by prioritizing and stabilizing the most severe cases. For example, when faced with an event with several injuries, our methodology will make it possible to generate itineraries for all available emergency vehicles in such a way as to minimize the time for stabilization of vital functions and subsequent transfer of each victim. The decision maker may recalculate as many times as he wishes such itineraries according to the appearance of new victims or changes in the capacity of the MCCs or the number of available vehicles.

This study can be extended in several ways. Our methodology could benefit from updating the capacity of medical care centers by incorporating discharged casualties. Moreover, letting field hospitals assist casualties when there is no more capacity in the health network could be an interesting improvement to consider. Our methodology can easily include this type of situation where there is an increase in the medical care capacity for casualties. Another interesting aspect to consider is the existence of many national and international actors who must coordinate and cooperate to achieve an adequate response to disasters. Our methodology can be modified to include different modes of operation in emergencies where different actors must collaborate to coordinate through a single command center.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Methodology implementation. Casualty Pickup, Stabilization, and Transport Schedule

Table A1. Casualty Pickup, Stabilization and Transport Schedule (CPST Schedule). Period 1, start 07:41 a.m.

Vehicle ID Code	Casualty ID Code	Node ID (I_i)	Age Range	LSI	TS_k^{ag} (min)	λ_k^{ag}	Trip (v)	TF_k	TB_k	TS_k	TL_k	MCC Assigned
A1	V1	44030	0–14	3	93.3	5.105	1	7:41:00	8:09:28	9:42:46	10:10:14	MCC1
	V17	36020	15–59	2	29.9	0.895	2	7:41:00	10:32:51	11:02:45	11:20:58	MCC2
	V21	38080	0–14	2	42	0.895	3	7:41:00	11:38:37	12:20:37	12:38:16	MCC2
	V26	41050	0–14	2	42	0.895	4	7:41:00	12:56:18	13:38:18	14:09:47	MCC3
	V45	43020	15–59	1	15.04	0.372	5	7:41:00	14:38:55	14:53:57	15:08:53	MCC2
	V50	37040	15–59	1	15.04	0.372	6	7:41:00	15:16:26	15:31:28	15:39:00	MCC2
	V54	10190	0–14	1	14.98	0.372	7	7:41:00	15:53:56	16:08:55	16:23:50	MCC2
	V64	11200	15–59	1	15.04	0.372	8	7:41:00	16:27:30	16:42:32	16:46:11	MCC2
	V62	29080	0–14	1	14.98	0.372	9	7:41:00	17:02:28	17:17:27	17:43:12	MCC1
A2	V5	42030	15–59	3	62.14	5.105	1	7:41:00	8:06:05	9:08:13	9:32:17	MCC1
	V11	38060	15–59	2	29.9	0.895	2	7:41:00	9:57:12	10:27:06	10:52:00	MCC1
	V25	36020	15–59	2	29.9	0.895	3	7:41:00	11:15:18	11:45:12	12:08:30	MCC1
	V30	44030	15–59	2	29.9	0.895	4	7:41:00	12:32:31	13:02:25	13:26:26	MCC1
	V34	39060	15–59	1	15.04	0.372	5	7:41:00	13:51:14	14:06:16	14:23:11	MCC2
	V42	42050	0–14	1	14.98	0.372	6	7:41:00	14:25:53	14:40:52	14:43:34	MCC2
	V46	42050	15–59	1	15.04	0.372	7	7:41:00	14:58:30	15:13:32	15:42:41	MCC3
	V60	37040	15–59	1	15.04	0.372	8	7:41:00	16:16:36	16:31:38	17:05:33	MCC3
A3	V2	36020	≥60	3	65	5.105	1	7:41:00	8:04:18	9:09:18	9:31:36	MCC1
	V14	43030	≥60	2	27.6	0.895	2	7:41:00	9:53:17	10:20:53	10:42:34	MCC1
	V18	36020	15–59	2	29.9	0.895	3	7:41:00	11:07:28	11:37:22	12:02:17	MCC1
	V29	44030	15–59	2	29.9	0.895	4	7:41:00	12:11:02	12:40:56	12:53:28	MCC3
	V33	39060	≥60	1	9.3	0.372	5	7:41:00	13:25:43	13:35:01	14:07:16	MCC3
	V44	44020	15–59	1	15.04	0.372	6	7:41:00	14:39:39	14:54:41	15:15:10	MCC2
	V51	42030	15–59	1	15.04	0.372	7	7:41:00	15:34:31	15:49:33	16:08:54	MCC2
	V59	42050	15–59	1	15.04	0.372	8	7:41:00	16:27:19	16:42:21	17:00:45	MCC2
A4	V9	42060	15–59	2	29.9	0.895	1	7:41:00	8:12:05	8:41:59	9:00:12	MCC2
	V8	42010	0–14	2	42	0.895	2	7:41:00	9:18:24	10:00:24	10:23:02	MCC1
	V20	59088	15–59	2	29.9	0.895	3	7:41:00	10:44:43	11:14:37	11:36:18	MCC1
	V24	41030	15–59	2	29.9	0.895	4	7:41:00	12:02:46	12:32:40	12:54:42	MCC2
	V32	41010	≥60	2	27.6	0.895	5	7:41:00	13:12:21	13:39:57	13:57:36	MCC2
	V37	37040	15–59	1	15.04	0.372	6	7:41:00	14:23:42	14:38:44	15:09:15	MCC1
	V49	42050	15–59	1	15.04	0.372	7	7:41:00	15:18:51	15:33:53	15:43:29	MCC1
	V56	42050	15–59	1	15.04	0.372	8	7:41:00	16:14:00	16:29:02	16:59:33	MCC1
H1	V3	39060	15–59	3	62.14	5.105	1	7:41:00	7:50:02	8:52:10	8:57:51	MCC1
	V10	42050	15–59	2	29.9	0.895	2	7:41:00	9:04:34	9:34:28	9:40:33	MCC2
	V15	36030	15–59	2	29.9	0.895	3	7:41:00	9:45:10	10:15:04	11:10:36	MCC2
	V13	4030	0–14	2	42	0.895	3	7:41:00	10:21:24	11:03:24	11:10:36	MCC2
	V16	41030	15–59	2	29.9	0.895	4	7:41:00	11:15:13	11:45:07	11:50:51	MCC3
	V23	41020	15–59	2	29.9	0.895	5	7:41:00	11:56:51	12:26:45	12:31:38	MCC2
	V28	36020	15–59	2	29.9	0.895	6	7:41:00	12:36:40	13:06:34	13:11:35	MCC2
	V31	36030	15–59	2	29.9	0.895	7	7:41:00	13:16:28	13:46:22	13:51:15	MCC2
	V38	36020	15–59	1	15.04	0.372	8	7:41:00	13:58:27	14:13:29	14:43:07	MCC2
	V39	36020	15–59	1	15.04	0.372	8	7:41:00	14:20:54	14:35:56	14:43:07	MCC2
	V43	59061	0–14	1	14.98	0.372	9	7:41:00	14:50:19	15:05:18	15:12:29	MCC2
	V47	43030	0–14	1	14.98	0.372	10	7:41:00	15:17:24	15:32:23	15:37:18	MCC2
	V55	42050	≥60	1	9.3	0.372	11	7:41:00	15:42:12	15:51:30	16:22:23	MCC2
	V52	40030	15–59	1	15.04	0.372	11	7:41:00	16:00:10	16:15:12	16:22:23	MCC2
	V57	42050	15–59	1	15.04	0.372	12	7:41:00	16:29:35	16:44:37	16:52:27	MCC1
	V61	37040	15–59	1	15.04	0.372	13	7:41:00	16:58:32	17:13:34	17:20:09	MCC3

Table A1. *Cont.*

Vehicle ID Code	Casualty ID Code	Node ID (l_i)	Age Range	LSI	TS_k^{ag} (min)	λ_k^{ag}	Trip (v)	TF_k	TB_k	TS_k	TL_k	MCC Assigned
H2	V4	36020	15–59	3	62.14	5.105	1	7:41:00	7:50:02	8:52:10	8:57:51	MCC1
	V6	42060	15–59	2	29.9	0.895	2	7:41:00	9:02:18	9:32:12	10:20:48	MCC3
	V7	41040	0–14	2	42	0.895	2	7:41:00	9:33:56	10:15:56	10:20:48	MCC3
	V12	42010	15–59	2	29.9	0.895	3	7:41:00	10:26:20	10:56:14	11:01:46	MCC3
	V19	36030	15–59	2	29.9	0.895	4	7:41:00	11:08:03	11:37:57	11:44:15	MCC3
	V22	41040	0–14	2	42	0.895	5	7:41:00	11:53:00	12:35:00	12:43:21	MCC1
	V27	41050	15–59	2	29.9	0.895	6	7:41:00	12:51:11	13:21:05	13:28:55	MCC1
	V35	37080	15–59	1	15.04	0.372	7	7:41:00	13:35:00	13:50:02	13:56:07	MCC1
	V36	37070	0–14	1	14.98	0.372	8	7:41:00	14:00:34	14:15:33	14:44:29	MCC2
	V40	41060	15–59	1	15.04	0.372	8	7:41:00	14:22:15	14:37:17	14:44:29	MCC2
	V41	42030	15–59	1	15.04	0.372	9	7:41:00	14:51:51	15:06:53	15:15:17	MCC3
	V48	42050	15–59	1	15.04	0.372	10	7:41:00	15:24:03	15:39:05	15:47:52	MCC3
	V53	10070	15–59	1	15.04	0.372	11	7:41:00	15:53:54	16:08:56	16:14:32	MCC1
	V58	42050	15–59	1	15.04	0.372	12	7:41:00	16:19:48	16:34:50	16:40:06	MCC1
	V63	28060	15–59	1	15.04	0.372	13	7:41:00	16:45:35	17:00:37	17:06:06	MCC1

Table A2. Casualty Pickup, Stabilization, and Transport Schedule (*CPST Schedule*), after execution of 7 periods.

Period	Vehicle ID Code	Casualty ID Code	Node ID (l_i)	Age Range	LSI	TS_k^{ag} (min)	λ_k^{ag}	Trip (v)	α_k	TF_k	TB_k	TS_k	TL_k	MCC ASSIGNED
1	A1	V1	44030	0–14	3	93.30	5.10	1	0	7:41	8:09	9:42	10:10	MCC1
	A2	V2	36020	60+	3	65.00	5.10	1	0	7:41	8:04	9:09	9:31	MCC1
	A3	V5	42030	15–59	3	62.14	5.10	1	0	7:41	8:06	9:08	9:32	MCC1
	H1	V3	39060	15–59	3	62.14	5.10	1	0	7:41	7:50	8:52	8:57	MCC1
	H2	V4	36020	15–59	3	62.14	5.10	1	0	7:41	7:50	8:52	8:57	MCC1
	A4	V9	42060	15–59	2	29.90	0.90	1	0	7:41	8:12	8:41	9:00	MCC2
	A4	V8	42010	0–14	2	42.00	0.90	2	0	7:41	9:18	10:00	10:18	MCC2
	H1	V10	42050	15–59	2	29.90	0.90	2	0	7:41	9:04	9:34	9:40	MCC2
	H2	V6	42060	15–59	2	29.90	0.90	2	0	7:41	9:02	9:32	10:19	MCC2
	H2	V7	41040	0–14	2	42.00	0.90	2	0	7:41	9:33	10:15	10:19	MCC2
2	H1	V66	40050	15–59	3	62.14	5.10	3	0	9:26	9:44	10:46	10:51	MCC1
	A5	V65	40050	15–59	3	62.14	5.10	1	0	9:26	9:41	10:44	11:05	MCC1
	A2	V11	38060	15–59	2	29.90	1.35	2	105	7:41	9:56	10:26	10:30	MCC5
	A3	V14	43030	≥ 60	2	27.60	1,35	2	105	7:41	9:53	10:21	10:31	MCC4
	H2	V12	42010	15–59	2	29.90	1.35	3	105	7:41	10:23	10:53	10:56	MCC5
	A2	V17	36020	15–59	2	29.90	1.35	3	105	7:41	10:31	11:01	11:03	MCC5
	A3	V20	59088	15–59	2	29.90	1.35	3	105	7:41	10:41	11:11	11:17	MCC5
	A1	V15	36030	15–59	2	29.90	1.35	2	105	7:41	10:40	11:10	11:20	MCC5
	H1	V16	41030	15–59	2	29.90	1.35	4	105	7:41	10:57	11:26	11:30	MCC5
	H2	V19	36030	15–59	2	29.90	1.35	4	105	7:41	11:00	11:30	11:34	MCC5
	A4	V13	4030	0–14	2	42.00	1.35	3	105	7:41	10:44	11:26	11:37	MCC5
	A2	V24	41030	15–59	2	29.90	1.35	4	105	7:41	11:08	11:38	11:43	MCC5
	A3	V25	36020	15–59	2	29.90	1.35	4	105	7:41	11:19	11:49	11:51	MCC5
	A5	V18	36020	15–59	2	29.90	1.35	2	105	7:41	11:30	12:00	12:04	MCC5
	A1	V21	38080	0–14	2	42.00	1.35	3	105	7:41	11:22	12:04	12:06	MCC5
	A4	V30	44030	15–59	2	29.90	1.35	4	105	7:41	11:39	12:09	12:12	MCC5
	H2	V27	41050	15–59	2	29.90	1.35	5	105	7:41	11:40	12:10	12:16	MCC5
	H1	V22	41040	0–14	2	42.00	1.35	5	105	7:41	11:36	12:18	12:25	MCC5
	A2	V26	41050	0–14	2	42.00	1.35	5	105	7:41	11:46	12:28	12:30	MCC5
3	A6	V109	45010	15–59	3	62.14	5.10	1	0	11:46	11:52	12:54	13:11	MCC1
	H3	V28	36020	15–59	2	29.90	2.68	1	245	7:41	11:55	12:24	12:28	MCC5
	A3	V31	36030	15–59	2	29.90	2.68	5	245	7:41	11:55	12:25	12:29	MCC5
	A7	V29	44030	15–59	2	29.90	2.68	1	245	7:41	11:57	12:27	12:31	MCC6
	A1	V32	41010	≥60	2	27.60	2.68	4	245	7:41	12:07	12:34	12:35	MCC5
	A5	V23	41020	15–59	2	29.90	2.68	3	245	7:41	12:08	12:38	12:42	MCC5
	A4	V67	36020	15–59	2	29.90	1.59	5	140	9:26	12:18	12:48	12:54	MCC5
	H1	V69	4050	15–59	2	29.90	1.59	6	140	9:26	12:28	12:58	13:02	MCC4
	H2	V68	36020	0–14	2	42.00	1.59	6	140	9:26	12:21	13:03	13:10	MCC4
	A2	V72	28060	15–59	2	29.90	1.59	6	140	9:26	12:34	13:04	13:16	MCC4
	H3	V70	4050	15–59	2	29.90	1.59	2	140	9:26	12:37	13:07	13:17	MCC4
	A3	V71	42050	0–14	2	42.00	1.59	6	140	9:26	12:32	13:14	13:22	MCC4
	A1	V73	59049	15–59	2	29.90	1.59	5	140	9:26	12:42	13:12	13:25	MCC4
	A7	V75	42060	15–59	2	29.90	1.59	2	140	9:26	12:51	13:21	13:34	MCC4
	A5	V74	59048	15–59	2	29.90	1.59	4	140	9:26	12:54	13:23	13:40	MCC4
	H1	V76	41040	15–59	2	29.90	1.59	7	140	9:26	13:09	13:39	13:46	MCC4
	H2	V77	41040	15–59	2	29.90	1.59	7	140	9:26	13:14	13:44	13:48	MCC4
	A4	V79	36010	0–14	2	42.00	1.59	6	140	9:26	12:57	13:39	13:49	MCC4
	A6	V81	41050	15–59	2	29.90	1.59	2	140	9:26	13:16	13:46	13:51	MCC6
	H3	V80	36010	15–59	2	29.90	1.59	3	140	9:26	13:23	13:53	13:58	MCC4
	A1	V83	24100	15–59	2	29.90	1.59	6	140	9:26	13:33	14:03	14:10	MCC4
	A3	V82	18030	15–59	2	29.90	1.59	7	140	9:26	13:32	14:02	14:11	MCC4
	A2	V78	41040	0–14	2	42.00	1.59	7	140	9:26	13:24	14:06	14:13	MCC4

Table A2. *Cont.*

Period	Vehicle ID Code	Casualty ID Code	Node ID (l_i)	Age Range	LSI	TS_k^{ag} (min)	λ_k^{ag}	Trip (v)	α_k	TF_k	TB_k	TS_k	TL_k	MCC ASSIGNED
	H1	V151	42050	0–14	3	93.30	5.10	8	0	13:26	13:49	15:22	15:28	MCC1
	A7	V150	36020	0–14	3	93.30	5.10	3	0	13:26	13:41	15:14	15:31	MCC1
	A5	V85	23080	15–59	2	29.90	2.61	5	240	9:26	13:47	14:17	14:25	MCC4
	A6	V86	40040	15–59	2	29.90	2.61	3	240	9:26	13:54	14:24	14:28	MCC6
	H2	V84	24040	15–59	2	29.90	2.61	8	240	9:26	13:53	14:23	14:28	MCC4
	A4	V87	59047	15–59	2	29.90	2.61	7	240	9:26	13:56	14:26	14:37	MCC2
	H3	V88	36020	15–59	2	29.90	2.61	4	240	9:26	14:03	14:33	14:39	MCC2
	A2	V111	42060	15–59	2	29.90	1.32	8	100	11:46	14:24	14:54	15:04	MCC4
	A1	V110	42030	15–59	2	29.90	1.32	7	100	11:46	14:20	14:50	15:05	MCC2
	H2	V117	42050	15–59	2	29.90	1.32	9	100	11:46	14:32	15:02	15:07	MCC2
	A5	V113	41030	≥60	2	27.60	1.32	6	100	11:46	14:33	15:00	15:11	MCC2
	A3	V112	42060	0–14	2	42.00	1.32	8	100	11:46	14:20	15:02	15:15	MCC2
4	A4	V115	42050	15–59	2	29.90	1.32	8	100	11:46	14:48	15:18	15:28	MCC2
	H3	V116	42050	0–14	2	42.00	1.32	5	100	11:46	14:44	15:26	15:30	MCC2
	A6	V114	41030	15–59	2	29.90	1.32	4	100	11:46	14:47	15:17	15:33	MCC2
	H2	V118	42020	15–59	2	29.90	1.32	10	100	11:46	15:12	15:42	15:47	MCC2
	A2	V121	44020	15–59	2	29.90	1.32	9	100	11:46	15:12	15:42	15:53	MCC2
	A1	V119	42020	15–59	2	29.90	1.32	8	100	11:46	15:18	15:48	16:01	MCC2
	A3	V120	41030	15–59	2	29.90	1.32	9	100	11:46	15:26	15:56	16:06	MCC2
	H1	V124	36020	15–59	2	29.90	1.32	9	100	11:46	15:36	16:05	16:13	MCC1
	H3	V127	36010	15–59	2	29.90	1.32	6	100	11:46	15:37	16:07	16:15	MCC1
	A5	V122	44020	0–14	2	42.00	1.32	7	100	11:46	15:25	16:07	16:21	MCC2
	A6	V126	42010	15–59	2	29.90	1.32	5	100	11:46	15:42	16:12	16:21	MCC2
	A4	V125	42010	15–59	2	29.90	1.32	9	100	11:46	15:41	16:11	16:25	MCC2
	A7	V123	36020	15–59	2	29.90	1.32	4	100	11:46	15:45	16:15	16:30	MCC1
	H2	V181	41070	15–59	3	62.14	5.10	11	0	15:36	15:51	16:54	17:00	MCC1
	A2	V152	42050	15–59	2	29.90	1.51	10	130	13:26	16:01	16:31	16:41	MCC1
	A1	V153	36030	15–59	2	29.90	1.51	9	130	13:26	16:11	16:41	16:52	MCC1
	H1	V155	36020	15–59	2	29.90	1.51	10	130	13:26	16:18	16:48	16:54	MCC1
	H3	V160	42050	15–59	2	29.90	1.51	7	130	13:26	16:20	16:50	16:56	MCC1
	A3	V154	37050	0–14	2	42.00	1.51	10	130	13:26	16:14	16:56	17:06	MCC1
	A6	V157	28040	15–59	2	29.90	1.51	6	130	13:26	16:29	16:59	17:09	MCC1
	A4	V156	42050	≥60	2	27.60	1.51	10	130	13:26	16:32	17:00	17:12	MCC1
	A5	V158	42050	0–14	2	42.00	1.51	8	130	13:26	16:29	17:11	17:21	MCC1
	A7	V159	40040	15–59	2	29.90	1.51	5	130	13:26	16:43	17:13	17:26	MCC1
	A2	V165	42010	15–59	2	29.90	1.51	11	130	13:26	16:52	17:21	17:32	MCC1
	H1	V162	42050	15–59	2	29.90	1.51	11	130	13:26	17:00	17:30	17:36	MCC1
	H3	V164	42050	15–59	2	29.90	1.51	8	130	13:26	17:02	17:32	17:38	MCC1
	H2	V161	42050	15–59	2	29.90	1.51	12	130	13:26	17:05	17:35	17:41	MCC1
5	A1	V163	37050	0–14	2	42.00	1.51	10	130	13:26	17:02	17:44	17:55	MCC1
	A3	V166	42010	15–59	2	29.90	1.51	11	130	13:26	17:16	17:46	17:56	MCC1
	A6	V183	42050	15–59	2	29.90	0.90	7	0	15:36	17:22	17:52	18:05	MCC1
	A4	V184	42060	15–59	2	29.90	0.90	11	0	15:36	17:24	17:54	18:07	MCC1
	A5	V182	42030	15–59	2	29.90	0.90	9	0	15:36	17:33	18:02	18:14	MCC1
	H3	V189	36010	15–59	2	29.90	0.90	9	0	15:36	17:43	18:13	18:18	MCC1
	H1	V187	36010	15–59	2	29.90	0.90	12	0	15:36	17:43	18:13	18:20	MCC1
	A2	V188	41050	15–59	2	29.90	0.90	12	0	15:36	17:43	18:13	18:24	MCC1
	A7	V185	42030	0–14	2	42.00	0.90	6	0	15:36	17:37	18:19	18:31	MCC1
	H2	V190	41070	0–14	2	42.00	0.90	13	0	15:36	17:47	18:29	18:34	MCC1
	A1	V186	36020	15–59	2	29.90	0.90	11	0	15:36	18:08	18:38	18:51	MCC1
	A6	V192	42050	15–59	2	29.90	0.90	9	0	15:36	18:16	18:46	18:58	MCC1
	A3	V191	42030	0–14	2	42.00	0.90	13	0	15:36	18:09	18:51	19:03	MCC1
	A4	V35	37080	15–59	1	15.04	0.50	12	475	7:41	18:17	18:32	18:33	MCC5
	A5	V34	39060	15–59	1	15.04	0.50	10	475	7:41	18:25	18:40	18:41	MCC5
	H3	V193	42060	15–59	2	29.90	1.74	11	160	15:36	18:23	18:53	18:58	MCC6
	H1	V200	42010	15–59	2	29.90	0.90	14	0	18:16	18:25	18:55	19:00	MCC6
	A2	V198	42060	15–59	2	29.90	0.90	15	0	18:16	18:34	19:03	19:13	MCC1
	A4	V199	42060	15–59	2	29.90	0.90	14	0	18:16	18:34	19:03	19:14	MCC6
	A7	V202	37080	15–59	2	29.90	0.90	9	0	18:16	18:40	19:10	19:20	MCC6
	H2	V201	36010	0–14	2	42.00	0.90	16	0	18:16	18:39	19:21	19:26	MCC6
	A5	V203	16020	15–59	2	29.90	0.90	14	0	18:16	18:53	19:23	19:33	MCC6
	H3	V204	42050	15–59	2	29.90	0.90	14	0	18:16	19:06	19:36	19:44	MCC6
	A5	V33	39060	≥60	1	9.30	0.55	11	635	7:41	18:42	18:51	18:52	MCC5
	A1	V42	42050	0–14	1	14.98	0.55	13	635	7:41	18:56	19:11	19:12	MCC2
6	H1	V36	37070	0–14	1	14.98	0.55	16	635	7:41	19:05	19:20	19:23	MCC5
	A6	V39	36020	15–59	1	15.04	0.55	11	635	7:41	19:11	19:26	19:30	MCC5
	A1	V45	43020	15–59	1	15.04	0.55	15	635	7:41	19:18	19:33	19:36	MCC5
	A3	V37	37040	15–59	1	15.04	0.55	15	635	7:41	19:17	19:32	19:36	MCC5
	A4	V44	44020	15–59	1	15.04	0.55	16	635	7:41	19:25	19:40	19:42	MCC5
	A2	V38	36020	15–59	1	15.04	0.55	17	635	7:41	19:26	19:41	19:45	MCC5
	A7	V47	43030	0–14	1	14.98	0.55	11	635	7:41	19:30	19:45	19:47	MCC5
	A6	V41	42030	15–59	1	15.04	0.55	13	635	7:41	19:32	19:47	19:49	MCC5
	H1	V40	41060	15–59	1	15.04	0.55	18	635	7:41	19:29	19:44	19:50	MCC5
	A5	V49	42050	15–59	1	15.04	0.55	16	635	7:41	19:36	19:51	19:53	MCC3
	H2	V43	59061	0–14	1	14.98	0.55	18	635	7:41	19:34	19:49	19:55	MCC5

Table A2. *Cont.*

Period	Vehicle ID Code	Casualty ID Code	Node ID (l_i)	Age Range	LSI	TS_k^{ag} (min)	λ_k^{ag}	Trip (v)	α_k	TF_k	TB_k	TS_k	TL_k	MCC ASSIGNED
7	A3	V211	41030	≥60	2	27.60	0.90	12	0	9:36	18:20	18:47	18:58	MCC6
	A1	V210	41030	15–59	2	29.90	0.90	12	0	9:36	18:19	18:49	19:00	MCC6
	A4	V212	41030	15–59	2	29.90	0.90	13	0	9:36	18:26	18:56	19:06	MCC6
	A8	V50	37040	15–59	1	15.04	0.58	1	715	7:41	18:18	18:33	18:35	MCC1
	H3	V55	42050	≥60	1	9.30	0.58	10	715	7:41	18:29	18:39	18:43	MCC5
	A2	V46	42050	15–59	1	15.04	0.58	13	715	7:41	18:27	18:42	18:44	MCC5
	A7	V51	42030	15–59	1	15.04	0.58	7	715	7:41	18:29	18:44	18:46	MCC5
	A6	V52	40030	15–59	1	15.04	0.58	8	715	7:41	18:32	18:47	18:51	MCC5
	H1	V48	42050	15–59	1	15.04	0.58	13	715	7:41	18:36	18:51	18:57	MCC5
	H2	V53	10070	15–59	1	15.04	0.58	14	715	7:41	18:39	18:54	18:57	MCC5
	A8	V64	11200	15–59	1	15.04	0.58	2	715	7:41	18:38	18:53	18:59	MCC6
	A5	V54	10190	0–14	1	14.98	0.58	12	715	7:41	18:42	18:57	18:59	MCC5
	H3	V58	42050	15–59	1	15.04	0.58	12	715	7:41	18:46	19:01	19:05	MCC5
	A2	V57	42050	15–59	1	15.04	0.58	14	715	7:41	18:48	19:03	19:06	MCC5
	A7	V56	42050	15–59	1	15.04	0.58	8	715	7:41	18:49	19:04	19:08	MCC5
	A6	V61	37040	15–59	1	15.04	0.58	10	715	7:41	18:52	19:07	19:11	MCC4
	A5	V62	29080	0–14	1	14.98	0.58	13	715	7:41	19:00	19:15	19:19	MCC4
	H1	V63	28060	15–59	1	15.04	0.58	15	715	7:41	19:01	19:16	19:20	MCC4
	H2	V60	37040	15–59	1	15.04	0.58	15	715	7:41	19:01	19:16	19:21	MCC4
	A3	V59	42050	15–59	1	15.04	0.58	14	715	7:41	19:07	19:22	19:23	MCC5
	A4	V96	24010	0–14	1	14.98	0.54	15	610	9:26	19:09	19:24	19:26	MCC6
	A2	V89	42010	0–14	1	14.98	0.54	16	610	9:26	19:07	19:22	19:28	MCC2
	H3	V90	42010	15–59	1	15.04	0.54	13	610	9:26	19:08	19:23	19:28	MCC4
	A8	V93	42020	15–59	1	15.04	0.54	3	610	9:26	19:09	19:24	19:30	MCC4
	A1	V91	45040	15–59	1	15.04	0.54	14	610	9:26	19:10	19:25	19:31	MCC4
	A7	V92	42020	15–59	1	15.04	0.54	10	610	9:26	19:11	19:26	19:31	MCC4
	A5	V97	42050	15–59	1	15.04	0.54	15	610	9:26	19:20	19:35	19:37	MCC4
	A6	V94	39060	0–14	1	14.98	0.54	12	610	9:26	19:17	19:31	19:37	MCC4
	A3	V98	42050	15–59	1	15.04	0.54	16	610	9:26	19:23	19:38	19:43	MCC4
	H2	V101	41070	15–59	1	15.04	0.54	17	610	9:26	19:24	19:39	19:43	MCC4
	H1	V95	39060	15–59	1	15.04	0.54	17	610	9:26	19:25	19:40	19:44	MCC4
	H3	V102	9040	15–59	1	15.04	0.54	15	610	9:26	19:31	19:46	19:50	MCC2
	A8	V103	9040	15–59	1	15.04	0.54	4	610	9:26	19:33	19:48	19:51	MCC4
	A7	V108	36010	15–59	1	15.04	0.54	12	610	9:26	19:34	19:49	19:52	MCC4
	A1	V106	36020	15–59	1	15.04	0.54	16	610	9:26	19:34	19:50	19:54	MCC2
	A4	V100	36010	15–59	1	15.04	0.54	17	610	9:26	19:37	19:52	19:59	MCC4
	A2	V99	36020	0–14	1	14.98	0.54	18	610	9:26	19:36	19:51	20:00	MCC2
	A6	V105	4230	15–59	1	15.04	0.54	14	610	9:26	19:40	19:55	20:00	MCC2
	A5	V104	9040	15–59	1	15.04	0.54	17	610	9:26	19:41	19:56	20:02	MCC2
	H2	V107	36020	15–59	1	15.04	0.54	19	610	9:26	19:47	20:02	20:06	MCC2
	A1	V130	41070	15–59	1	15.04	0.50	17	470	11:46	19:56	20:11	20:12	MCC2
	H1	V132	41070	15–59	1	15.04	0.50	19	470	11:46	19:51	20:06	20:13	MCC2
	A3	V131	38060	15–59	1	15.04	0.50	17	470	11:46	19:50	20:05	20:14	MCC2
	H3	V128	42050	0–14	1	14.98	0.50	16	470	11:46	19:55	20:10	20:15	MCC2
	A7	V136	42010	0–14	1	14.98	0.50	13	470	11:46	19:57	20:12	20:18	MCC2
	A8	V129	42050	0–14	1	14.98	0.50	5	470	11:46	19:59	20:14	20:23	MCC2
	A2	V134	42010	0–14	1	14.98	0.50	19	470	11:46	20:06	20:21	20:27	MCC2
	A5	V139	41030	0–14	1	14.98	0.50	18	470	11:46	20:08	20:23	20:28	MCC2
	A4	V137	38060	15–59	1	15.04	0.50	18	470	11:46	20:07	20:22	20:30	MCC2
	H2	V135	42010	15–59	1	15.04	0.50	20	470	11:46	20:11	20:26	20:31	MCC2
	A6	V133	47020	0–14	1	14.98	0.50	15	470	11:46	20:09	20:24	20:33	MCC2
	H1	V138	36030	15–59	1	15.04	0.50	20	470	11:46	20:18	20:33	20:38	MCC2
	A1	V140	36020	0–14	1	14.98	0.50	18	470	11:46	20:18	20:33	20:39	MCC2
	A3	V142	24010	15–59	1	15.04	0.50	18	470	11:46	20:20	20:35	20:42	MCC2
	H3	V141	36020	0–14	1	14.98	0.50	17	470	11:46	20:22	20:37	20:44	MCC2
	A7	V144	42050	0–14	1	14.98	0.50	14	470	11:46	20:27	20:42	20:52	MCC1
	A8	V145	42050	15–59	1	15.04	0.50	6	470	11:46	20:29	20:44	20:53	MCC1
	H2	V147	36030	15–59	1	15.04	0.50	21	470	11:46	20:35	20:50	20:56	MCC1
	A2	V143	42050	15–59	1	15.04	0.50	20	470	11:46	20:33	20:48	20:56	MCC1
	A4	V149	24010	15–59	1	15.04	0.50	19	470	11:46	20:36	20:51	20:59	MCC1
	A1	V169	40040	15–59	1	15.04	0.47	19	370	13:26	20:43	20:58	21:00	MCC6
	A5	V146	36030	0–14	1	14.98	0.50	19	470	11:46	20:38	20:53	21:02	MCC2
	H1	V168	42050	15–59	1	15.04	0.47	21	370	13:26	20:43	20:58	21:04	MCC1
	A6	V148	41030	0–14	1	14.98	0.50	16	470	11:46	20:42	20:57	21:07	MCC1
	A3	V171	42010	15–59	1	15.04	0.47	19	370	13:26	20:47	21:02	21:11	MCC1
	H3	V167	28040	15–59	1	15.04	0.47	18	370	13:26	20:50	21:06	21:12	MCC1
	A1	V179	41010	15–59	1	15.04	0.47	20	370	13:26	21:02	21:17	21:20	MCC6
	H2	V170	36020	15–59	1	15.04	0.47	22	370	13:26	21:02	21:17	21:24	MCC1
	A7	V173	36030	0–14	1	14.98	0.47	15	370	13:26	21:01	21:16	21:25	MCC6
	A2	V174	36030	15–59	1	15.04	0.47	21	370	13:26	21:04	21:19	21:27	MCC1
	A8	V172	42040	15–59	1	15.04	0.47	7	370	13:26	21:04	21:19	21:29	MCC1
	A5	V176	42050	15–59	1	15.04	0.47	20	370	13:26	21:07	21:22	21:29	MCC1
	A4	V177	42050	15–59	1	15.04	0.47	20	370	13:26	21:07	21:22	21:30	MCC1
	H1	V175	42050	15–59	1	15.04	0.47	22	370	13:26	21:10	21:25	21:31	MCC1
	H3	V196	36010	15–59	1	15.04	0.43	19	240	15:36	21:17	21:32	21:36	MCC1
	A6	V178	37080	0–14	1	14.98	0.47	17	370	13:26	21:15	21:30	21:38	MCC1
	A3	V180	36010	15–59	1	15.04	0.47	20	370	13:26	21:19	21:34	21:41	MCC1
	H2	V194	42030	15–59	1	15.04	0.43	23	240	15:36	21:28	21:43	21:48	MCC1
	A1	V195	36020	15–59	1	15.04	0.43	21	240	15:36	21:29	21:44	21:52	MCC1
	A7	V197	41050	0–14	1	14.98	0.43	16	240	15:36	21:34	21:49	21:57	MCC1

Table A2. *Cont.*

Period	Vehicle ID Code	Casualty ID Code	Node ID (l_i)	Age Range	LSI	TS_k^{ag} (min)	λ_k^{ag}	Trip (v)	α_k	TF_k	TB_k	TS_k	TL_k	MCC ASSIGNED
	H1	V208	42050	15–59	1	15.04	0.39	23	80	18:16	21:36	21:51	21:58	MCC6
	A2	V207	42050	15–59	1	15.04	0.39	22	80	18:16	21:36	21:51	22:00	MCC6
	A5	V209	42050	15–59	1	15.04	0.39	21	80	18:16	21:37	21:52	22:00	MCC6
7	A8	V206	38090	15–59	1	15.04	0.39	8	80	18:16	21:38	21:53	22:01	MCC1
	H3	V214	36010	15–59	1	15.04	0.37	20	0	19:36	21:42	21:57	22:03	MCC6
	A4	V205	38090	15–59	1	15.04	0.39	21	80	18:16	21:40	21:55	22:06	MCC6
	A6	V213	37040	15–59	1	15.04	0.37	18	0	19:36	21:46	22:01	22:09	MCC6

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