University of the Aegean

Business School

Department of Financial and Management Engineering

Supply planning in natural disasters: Modelling and analysis

Michael E. Fragkos

Supervisor: Prof. Ioannis Minis

Committee Members: Dr. Vasileios Zeimpekis

Vasileios Koutras, Assistant Prof.

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To my family

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Εκτενής Περίληψη

Εισαγωγή

Τα τελευταία χρόνια παρατηρείται μια ανοδική τάση του πλήθους των καταστροφικών γεγονότων που συμβαίνουν παγκοσμίως. Οι επακόλουθες καταστροφές αυτές είναι είτε φυσικές είτε τεχνολογικές και έχουν σημαντικές επιπτώσεις σε απώλειες ζωής, τραυματισμούς, απώλειες δημόσιας και ιδιωτικής περιουσίας.

Αύξηση παρατηρείται επίσης και στην παγκόσμια υποστήριξη και παροχή βοήθειας σε πληγέντες. Κρίσιμο ρόλο στην αποτελεσματική και αποδοτική μείωση των επιπτώσεων που έχει μια καταστροφή στο άμεσο μέλλον διαδραματίζουν τα logistics καταστάσεων έκτακτης ανάγκης [5]. Τα τελευταία μπορούν να περιγραφούν από τον εξής ορισμό *''Διαδικασία σχεδιασμού, διοίκησης και ελέγχου των ροών, των πληροφοριών και της διανομής σε μέρη που έχουν ανάγκη, με σκοπό να αντιμετωπιστούν οι ανάγκες που δημιουργούνται σε ανθρώπους έπειτα από μια κατάσταση έκτακτης ανάγκης''* [5].

Στην επαύριο κατάστασης έκτακτης ανάγκης, είναι σημαντικό να διασφαλιστεί η αποτελεσματική τροφοδοσία αγαθών, σε επαρκείς ποσότητες στους πληγέντες που βρίσκονται σε χώρους συγκέντρωσης-καταφύγια, καθώς και σε ομάδες διάσωσης το συντομότερο δυνατό, ώστε να αποφευχθεί έλλειψη στοιχειωδών αγαθών στους εμπλεκόμενους.

Ο σκοπός της παρούσας διπλωματικής είναι να προτείνει ολοκληρωμένο μεθοδολογικό πλαίσιο για τον σχεδιασμό της παροχής των απαραίτητων αγαθών σε καταφύγια και σε ομάδες διάσωσης στον ελάχιστο δυνατό χρόνο κατόπιν κατάστασης έκτακτης ανάγκης. Η προτεινόμενη προσέγγιση συνίσταται στην ανάπτυξη μαθηματικού μοντέλου Μικτού Ακέραιου Γραμμικού Προγραμματισμού (ΜΑΓΠ), την ευρετική επίλυση του αντίστοιχου προβλήματος, και εφαρμογή σε Μελέτη Περίπτωσης και σε πληθώρα τυχαία δημιουργημένων προβλημάτων που εξετάζουν την εγκυρότητα της ευρετικής προσέγγισης.

Ορισμός Προβλήματος

Το πρόβλημα που εξετάζεται είναι Πρόβλημα Διανομής Προμηθειών σε καταστάσεις Έκτακτης Ανάγκης χρησιμοποιώντας Ετερογενή Στόλο οχημάτων, εφεξής ΠΔΠΕΑΕΣ (Emergency Supply using Heterogeneous Fleet Problem-ESHFP). Το μαθηματικό μοντέλο που προτείνεται για το συγκεκριμένο πρόβλημα έχει ως στόχο την ελαχιστοποίηση του χρόνου διανομής, καθορίζοντας τα κατάλληλα δρομολόγια που την επιτυγχάνουν. Παράλληλα τηρούνται περιορισμοί σχετικά με τα δρομολόγια, με τους χρόνους διανομής, με την χωρητικότητα των οχημάτων, με την προσφορά, κλπ.

Στο ΠΔΠΕΑΕΣ χρησιμοποιείται ετερογενής στόλος οχημάτων όσον αφορά τη χωρητικότητα τους και τον τύπο τους, καθότι φύση του προβλήματος απαιτεί να χρησιμοποιηθεί οποιοδήποτε διαθέσιμο όχημα.

Δεδομένα Προβλήματος

Για να βρεθεί η βέλτιστη λύση για το ΠΔΠΕΑΕΣ, είναι απαραίτητο να χρησιμοποιηθούν οι παρακάτω κατηγορίες δεδομένων

- Αγαθά προς διανομή (τύποι, κωδικοί, διαστάσεις)
- Σουπερμάρκετ (ή αποθήκες) που παρέχουν τα αγαθά αυτά (συντεταγμένες, διαθέσιμο απόθεμα ανά κωδικό προϊόντος)
- Καταφύγια (συντεταγμένες, συνολική ζήτηση ανά κωδικό προϊόντος) στα οποία παρέχονται τα προϊόντα
- Οδικό δίκτυο (χρόνοι μετάβασης μεταξύ των κόμβων)
- Διαθέσιμα οχήματα (συντεταγμένες σημείων εκκίνησης, χωρητικότητες, αριθμοί κυκλοφορίας)

Ευρετική Προσέγγιση Επίλυσης για το ΠΔΠΕΑΕΣ

Η επίλυση του ΠΔΠΕΑΕΣ αποτελεί πολύπλοκο πρόβλημα εξαιτίας και της διάστασης του. Συνήθως τα προβλήματα αυτού του τύπου απαιτούν μη-ρεαλιστικό χρόνο για τη βέλτιστη επίλυση ([13], [14]). Για το λόγο αυτό, μια κοινή πρακτική είναι ο σχεδιασμός ευρετικών αλγορίθμων, οι οποίοι μπορούν να προσδιορίσουν ποιοτικά πολύ καλή λύση σε λογικό χρόνο. Ο ευρετικός αλγόριθμος για το ΠΔΠΕΑΕΣ αναπτύχθηκε και παρουσιάζεται στην εργασία.

Ο αλγόριθμος αυτός έχει σαν στόχο να καθορίσει το σύνολο των δρομολογίων και των οχημάτων που θα τα εκτελέσουν, με κύριο σκοπό την ελαχιστοποίηση του συνολικού χρόνου που χρειάζεται για να ολοκληρωθεί η διανομή προμηθειών σε ομάδες διάσωσης και πυρόσβεσης καθώς και σε κατοίκους περιοχών που έχουν εκκενωθεί, και βρίσκονται σε καταφύγια. Κατά την επίλυση του αλγορίθμου, λαμβάνονται υπόψιν περιορισμοί που αφορούν τα δρομολόγια, την χωρητικότητα των οχημάτων, την ζήτηση που δημιουργείται καθώς και την προσφορά προμηθειών.

Στον αλγόριθμο αρχικά δημιουργούμε λίστα με τα διαθέσιμα οχήματα, είτε είναι Ιδιωτικής Χρήσης (ΙΧ) είτε είναι Δημοσίας Χρήσης (ΔΧ), εφεξής AVL, η οποία είναι ταξινομημένη με φθίνουσα σειρά σύμφωνα με την χωρητικότητα τους. Πρέπει να αναφερθεί εδώ ότι κατά την δημιουργία της AVL, δίνεται προτεραιότητα στην επιλογή των διαθέσιμων ΔΧ οχημάτων σε σχέση με τα ΙΧ ασχέτως της χωρητικότητας τους. Αυτό γίνεται διότι υπάρχει αβεβαιότητα σε σχέση με την άμεση διαθεσιμότητα των ΙΧ οχημάτων. Έπειτα, ομαδοποιούμε τα καταφύγια, σύμφωνα με την γεωγραφική τοποθεσία τους. Η ομαδοποίηση αυτή, επιτυγχάνεται με τον αλγόριθμο *K-Means*. Η ομάδα καταφυγίων που έχει συνολικά τη μεγαλύτερη ζήτηση από όλες, θα είναι και αυτή που θα επιλεχθεί πρώτη από τον αλγόριθμο προς εξυπηρέτηση. Στη συνέχεια επιλέγεται όχημα της *AVL*, που έχει την μικρότερη χωρητικότητα μεταξύ των οχημάτων που μπορούν να καλύψουν τη συνολική ζήτηση της προεπιλεγμένης ομάδας καταφυγίων. Σε περίπτωση που δεν υπάρχει τέτοιο όχημα με αυτήν την δυνατότητα, επιλέγεται το όχημα της AVLμε την μεγαλύτερη χωρητικότητα. Ακολουθούν τα εξής:

- Δημιουργείται ένα δρομολόγιο μόνο για τα καταφύγια της επιλεγμένης ομάδας χρησιμοποιώντας τον αλγόριθμο *Clark & Wright Savings* και επιλέγονται οι κόμβοι που εντέλει θα εξυπηρετηθούν (Εάν το όχημα, δεν μπορεί να εξυπηρετήσει όλους τους κόμβους, αναγκαστικά, επιλέγονται μόνο αυτοί που το όχημα μπορεί να εξυπηρετήσει).
- Δημιουργείται δρομολόγιο μόνο για τα σημεία ανεφοδιασμού όπως πχ: supermarkets που παρέχουν την μεγαλύτερη ποσότητα των προϊόντων που είναι αναγκαία να συλλεχθούν, χρησιμοποιώντας και εδώ τον αλγόριθμο *Clark & Wright Savings*. Για βελτιστοποίηση αυτού του δρομολογίου, χρησιμοποιείται ο αλγόριθμος *2-opt*. Το επιλεγμένο όχημα τότε δρομολογείται στα επιλεγμένα σημεία ανεφοδιασμού και φορτώνει τις προκαθορισμένες ποσότητες ανά κωδικό προϊόντος. Κατόπιν, κατευθύνεται προς τα καταφύγια εκτελώντας το προκαθορισμένο του δρομολόγιο παραδίδοντάς τα απαραίτητα προϊόντα σε κάθε κόμβο. Όταν το όχημα αδειάσει, τότε θεωρείται ως διαθέσιμο για να εκτελέσει νέο δρομολόγιο.

Μετά την δρομολόγηση του πρώτου οχήματος, η παραπάνω διαδικασία επαναλαμβάνεται (από το βήμα επιλογής ομάδας καταφυγίων) έως ότου η ζήτηση σε όλα τα καταφύγια να έχει εκμηδενιστεί.

Η εγκυρότητα του αλγορίθμου, καθώς και ποιες είναι οι παράμετροι που επηρεάζουν σημαντικά τον συνολικό χρόνο εξυπηρέτησης μελετήθηκαν επιλύοντας σειρά τυχαίων προβλημάτων που αναπτύχθηκαν για το σκοπό αυτό.

Μελέτη Περίπτωσης

Η μελέτη περίπτωσης σχετίζεται με το Τερουέλ, το οποίο είναι πρωτεύουσα της ομώνυμης επαρχίας της Αραγονίας στα βορειοανατολικά της Ισπανίας. Μελετάται η περίπτωση κατά την οποία εκδηλώνεται δασική πυρκαγιά, η οποία επεκτείνεται δυναμικά, απειλώντας τα χωριά Tramacastiel, Rubiales και El Campillo, αναγκάζοντας τους κατοίκους να τα εκκενώσουν και να μεταφερθούν σε καταφύγιο. Ταυτόχρονα, οι ομάδες πυρόσβεσης εγκαθίστανται στα χωριά Villel, San Blas και Mas De La Cabrera.

Έτσι λοιπόν πρέπει να ενεργοποιηθεί το σχέδιο άμεσης διανομής αγαθών σε όλους τους εμπλεκόμενους είτε ανήκουν στους εκκενωθέντες είτε στις ομάδες πυρόσβεσης. Για πιο ρεαλιστική μελέτη του παραπάνω σχεδίου, παρουσιάζονται δύο διαφορετικά σενάρια. Το πρώτο αντιμετωπίζει το ΠΔΠΕΑΕΣ σε ημερήσια βάση λαμβάνοντας υπόψη ότι η δασική πυρκαγιά διαρκεί επτά ημέρες και πρέπει κάθε μέρα να εφοδιάζονται όλοι οι εμπλεκόμενοι με τα απαραίτητα αγαθά. Στο δεύτερο σενάριο, η λύση του ΠΔΠΕΑΕΣ, παρουσιάζεται μόνο για την πρώτη μέρα μετά από την εκδήλωση της πυρκαγιάς.

Επίλογος

Η εργασία αυτή παρουσιάζει και αναλύει το ΠΔΠΕΑΕΣ, το οποίο καθορίζει τη διανομή αγαθών σε καταφύγια έπειτα από κατάσταση έκτακτης ανάγκης. Τα αγαθά συλλέγονται από πολλαπλές τοποθεσίες (αποθήκες/σουπερμάρκετ) στον ελάχιστο δυνατό χρόνο. Αναπτύσσεται αρχικά μαθηματικό μοντέλο ΜΑΓΠ το οποίο όμως, λόγω της πολυπλοκότητας του, είναι δύσκολο να επιλυθεί σε πρακτικά χρονικά πλαίσια. Ως εκ τούτου, αναπτύχθηκε ευρετικός αλγόριθμος, που έχει σαν στόχο να καθορίσει τα δρομολόγια και τα οχήματα που θα τα εκτελέσουν, με σκοπό να ελαχιστοποιηθεί ο χρόνος που χρειάζεται για να ολοκληρωθεί η διανομή των αγαθών στον πληθυσμό των κατοίκων που βρίσκονται σε καταφύγια αλλά και στις δυνάμεις παρέμβασης σε συγκεκριμένες τοποθεσίες.

Ο προτεινόμενος ευρετικός αλγόριθμος εφαρμόστηκε στην μελέτη περίπτωσης του Τερουέλ, όπως επίσης και σε αρκετά προβλήματα που δημιουργήθηκαν μέσω γεννήτριας προβλημάτων. Τέλος αξίζει να αναφερθεί ότι το μαθηματικό μοντέλο όπως επίσης και ο ευρετικός αλγόριθμος, μπορούν να χρησιμοποιηθούν για οποιοδήποτε τύπο έκτακτης ανάγκης αφού εισαχθούν τα κατάλληλα δεδομένα.

Abstract

The thesis deals with modeling and analysis of supply planning during or immediately after a natural disaster. In post emergency response planning, the supply of consumable and non-consumable provisions for both civilians, who evacuate residential areas, and intervention groups at the corresponding shelters, is of immediate importance. In this thesis, provisions supply is modeled and analyzed by introducing the Emergency Supply using Heterogeneous Fleet Problem (ESHFP).

Initially, a Mixed Integer Linear Programming (MILP) mathematical model is introduced for the ESHFP. In order to solve this problem, we have developed a novel heuristic algorithm, which aims in determining the set of routes and the vehicles that can be used to minimize the total supply time, respecting constraints concerning routing, timing, capacity and supply.

Since the corresponding MILP is difficult to be solved to optimality in reasonable time, we have introduced a novel heuristic approach for ESHFP which minimizes the total time needed to collect provisions from available pick up locations and (by using appropriate vehicles among those available) to deliver provisions to a) evacuees at shelters and b) intervention groups at their accommodation sites. The proposed heuristic approach takes into account all necessary constraints described in the MILP model.

To validate the effectiveness this approach, we have applied the proposed algorithm to a series of examples, generated randomly. Furthermore, we have used the proposed algorithm to deal with a real case study involving a significant forest fire in the Province of Teruel in Spain. The results of both the tests and the case study are very encouraging, attesting to the comprehensiveness of the proposed model and the efficiency of the new solution heuristic.

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List of Abbreviations

Abbreviation	Description
MILP	Mixed Integer Linear Programming
1-PDTSP	One-Commodity Pickup and Delivery Traveling Salesman Problem
AVL	Available Vehicles List
CRED	Centre for Research on the Epidemiology of Disasters
CTSPPD	Capacitated Traveling Salesman Problem with Pickups and Deliveries
CVRP	Capacitated Vehicle Routing Problem
CVRPPD	Capacitated Vehicle Routing Problem with Pickups and Deliveries
CWS	Clark and Wright Savings algorithm
ESHFP	Emergency Supply using Heterogeneous Fleet Problem
FEMA	Federal Emergency Management Agency
GPDP	General Pickup and Delivery Problem
HFVRP	Heterogeneous Fleet Vehicle Routing Problem
MDVRP	Multi Depot Vehicle Routing Problem
MDVRPTW	Multi Depot Vehicle Routing Problem with Time Windows
MILP	Mixed Integer Linear Programming
PDP	Pick-up and Delivery Problem
SCVRPPD	Split Delivery Vehicle Routing Problem with Pickups and Deliveries
SVRPPD	Single Vehicle Routing Problem with Pickups and Deliveries
TSP	Traveling Salesman Problem
VRP	Vehicle Routing Problem
VRPPD	Vehicle Routing Problem with Pickups and Deliveries
VRPTW	Vehicle Routing Problem with Time Windows

Chapter 1. Introduction

The number of both natural and man-made disasters striking all over the world has accelerated world-wide. Disasters affect human lives and have significantly adverse economic effects. The Federal Emergency Management Agency of the United States (FEMA) claims that the first 72 hours after a disaster are the most critical ones [1], [2], [3], since actions and responses during this period can determine whether lives are saved, as well as the effective and humane treatment of the survivors.

According to the Centre for Research on the Epidemiology of Disasters (CRED) [4], 3,784 natural disasters and 2,193 technological disasters were reported worldwide in the last decade (2007-2016). The number of human loses caused by natural disasters during the same period is 730,860 and the total people affected were more than 1.9 billion. As for the technological disasters, there were 68,844 deaths and more than 675 thousand people affected. The above data are presented extensively for each one of the years between 2007 and 2016 in Appendix I.

On the other hand, global support is also increasing over the last decades, using emergency logistics as a significant lever [5]. Emergency logistics may be defined as: *''A process of planning, managing and controlling the efficient flows of relief, information, and services from the points of origin to the points of destination to meet the urgent needs of the affected people under emergency conditions''* [5].

Based on the above, it is important to ensure efficiency of supplying necessary commodities in sufficient quantities to the victims of an emergency, who are evacuated at shelters, as well as to intervention groups. Speed of supply is critical in relief operations.

The scope of this thesis is to provide an integrated methodological framework for planning the supply of all required provisions throughout the theatre of the disaster in the minimum time, respecting several constraints.

The contribution of the thesis consists in introducing a novel approach for supplies distribution planning which addresses important characteristics of the problem beyond the existing literature. The main differences of the proposed approach include consideration of an heterogenous fleet of vehicles, of multiple commodities, of multiple supply origins and of multiple demand destinations. To address this problem, we developed a novel Mixed Integer Linear Programming (MILP) model that maps accurately all problem characteristics. We have also proposed a new heuristic algorithm to solve this problem. After testing and validating the heuristic approach through several randomly generated problems, we applied it to a real case study concerning supply of provisions to evacuees and intervention groups after a natural disaster occurrence at the Province of Teruel in Spain.

1.1. Problem Description

At the immediate aftermath of a natural disaster, and if necessary, local authorities implement appropriate evacuation plans. Evacuees are transported into shelters in safe areas, and simultaneously, intervention groups are dispatched to deal with the effects of the emergency and are based in strategic locations in the theatre of the emergency. Thereafter, it is important to develop a provisions supply plan in order to deliver the appropriate emergency supplies to evacuees at shelters and to intervention groups at the related accommodation sites. These supplies could include consumable goods such as food and water or non-consumable goods, such as mattresses and hygiene kits. The commodities can are supplied by warehouses or supermarkets based on a pre-specified arrangements. As for the vehicles which will transfer the commodities, they can start from different originating points, visit the appropriate supply locations, pick up the necessary commodities and transfer them to the corresponding sites. Vehicles can execute more than one route, and supply more than one sites. Under the aforementioned circumstances, the problem of collecting and delivering the necessary supplies after an emergency can be characterized as a special Pick-up and Delivery problem.

To deal with such a problem and in order to efficiently design a provisions supply plan, the decision maker must be aware of data concerning: (a) Commodities, (b) Supply Points (i.e. supermarkets), (c) Shelters, (d) Road Network and (e) Available vehicles. The problem dealt by this thesis is characterized by certain special assumptions: (a) more than one commodities are to be supplied; (b) the total supply offered at supply points is higher than the total demand, although each supply site may store a fraction of the demand; (c) there is at least one shelter for the evacuees and at least one accommodation site for the intervention groups; (d) the road network is known; (e) the vehicles used in the supply operation are heterogeneous. Given the aspects mentioned above, we can formulate the *Emergency Supply using Heterogeneous Fleet Problem*, hereafter referred ESHFP to deal with provisions supply after a disaster.

In order to model the above problem, we have developed a Mixed Integer Linear Program (MILP), the objective of which is to minimize the time needed to provide the required provisions to both evacuees and intervention groups at the corresponding shelters. Constraints model important aspects of the problem, such as routing, timing, capacity and availability of supply. Since usually such a problem is NP-hard, and in order to derive a solution of good quality in reasonable time, we propose a heuristic algorithm for the ESHFP, that aims to determine the set of routes and the vehicles that can be used to minimize the total time needed to provide all required provisions to evacuees and to intervention groups, respecting all the corresponding constraints of the MILP.

1.2. Literature Review

As already mentioned, the problem at hand can be considered as a Pickup and Delivery Problem (PDP), a special category of the well-known Vehicle Routing Problem (VRP), in which commodities or people have to be transported between origins and destinations [6]. The VRP was introduced by Dantzig and Ramser in 1959 as the "*Truck Dispatching Problem*" and dealt with delivering gasoline between a terminal and stations [7]. The general notation used to describe the VRP is the following [8]:

Let

- V be a set of nodes
- K be the set of available vehicles
- $V\backslash S$ be the set of all nodes apart from the nodes that are in S
- $r(S)$ be the least number of vehicles that need to serve all nodes of S

The objective function of VRP is defined as follows:

$$min \sum_{(i,j)\in V} d_{ij}x_{ij} \tag{1.1}$$

s.t.

$$\sum_{i\in V} x_{ij} = 1, \quad j \in V\backslash 0 \tag{1.2}$$

$$\sum_{j\in V} x_{ij} = 1, \quad i \in V\backslash 0 \tag{1.3}$$

$$\sum_{j\in V} x_{0j} = K \tag{1.4}$$

$$\sum_{i\in V} x_{i0} = K \tag{1.5}$$

$$\sum_{i\in V\backslash S}\sum_{j\in V} x_{ij} \geq r(S), \quad \forall S \subseteq V\backslash 0, S \neq \emptyset \tag{1.6}$$

$$x_{ij} \in \{0,1\}, \quad i \in V\backslash 0 \tag{1.7}$$

Over the years, researchers have proposed numerous variants of the VRP. One of the most extensively studied problems is the Capacitated VRP (CVRP), in which every vehicle has limited capacity [9]. In [10] the authors present a number of heuristics for the VRP with Pickups and Deliveries (VRPPD) in which customers may both receive and send goods. Pickups and deliveries can be either simultaneous, i.e. a node can receive and send goods simultaneously or mixed. A similar problem is the 1-VRPPD in which many vehicles are routed for carrying a single type of commodity [11]. There also exist problems where pickups come only after deliveries are finished. In case that the available fleet for pick up and deliveries consists of just one vehicle, the problem is converted into Capacitated Traveling Salesman Problem with Pickups and Deliveries problem (CTSPPD) [12]. In [12] also, the authors present two polynomial-time approximation algorithms for the latter problem.

In [13] the authors propose a mixed integer linear programming model for the Single VRP with Pickups and Deliveries (SVRPPD) which consists of designing a route in terms of cost for a vehicle of capacity Q. Each customer can be visited once or twice, and the route starts and ends at the depot. In [14], the authors propose a Tabu algorithm for the Split Delivery VRP (SDVRP), in which a fleet of homogeneous vehicles has to serve a set of customers by minimizing the total distance. There is also a capacity constraint which does not let the sum of the quantities delivered in each tour to exceed the capacity of the vehicles. No constraint on the number of the available vehicles is considered, but there is only one depot, and each vehicle has to start and end its tour at that depot. Another assumption is that each customer can be visited more than once and the demand of each customer can be greater than the capacity of the vehicles.

In [15] and [16], the authors address the Multi Depot VRP (MDVRP) and Multi Depot VRP with Time Windows (MDVRPTW) where several depots are taken into consideration. The latter also considers the constraints imposed by Time Windows. VRPTW has also been studied extensively, and it is an extension of the Capacitated VRP where the service at each customer must start within an associated time window [17]. In [18] and [19] the authors illustrate the VRP with backhauls, and [20] deals with the Traveling Salesman Problem (TSP) with delivery and backhauls.

An interesting approach on pick-up and delivery problem is the One-Commodity Pickup and Delivery TSP (1-PDTSP) which is a generalization of the well-known TSP. In 1-PDTSP cities correspond to customers providing or requiring known amounts of a product, and the only vehicle that is routed, has a known capacity. Each customer must be visited only once by the vehicle serving the demands on the aim of the problem is to minimize the total travel distance. It is also assumed that any unit of product collected from a pickup customer can be delivered to any delivery customer [21].

Another problem studied in literature is the Heterogeneous Fleet VRP (HFVRP) in which the customers are served by a heterogeneous fleet of vehicles with various capacities. HFVRP consists of designing a set of vehicle routes, each starting and ending at the depot and such that each customer is visited exactly once [22]. There are also a few papers which present and address classical as well as modern Heuristics for the VRP such as the Clark and Wright Savings algorithm, and the Fisher and Jaikumar algorithm which is well-known as cluster-first, route second algorithm [23], [24] and [25]. In [26] the authors consider route first-cluster second methods for the vehicle routing problem.

As for Pickup and Delivery Problems (PDPs), there exists an extensive literature. In [27], the authors suggest that in the PDP each transportation request specifies a single origin and a single destination and all vehicles depart from and return to a central depot. They also focus in the General Pickup and Delivery Problem (GPDP).

In addition to the general PDP, a usual classification of the PDPs concerns the number of origins and destinations of the commodities to be transported. In many-to-many problems, any node can either serve as a supply point or a demand point for any commodity. In [28], a single vehicle of unit capacity is used for transporting objects from many origins to many destinations. Additionally in this category, there can be found problems where the pick-up and delivery locations sets can have common elements [29].

Another issue that affects the classification of PDPs is the information on how pickup and delivery is performed at demand nodes. Finally, PDPs can be classified according to the number of vehicles used, or according to other factors, such as the number of commodities to be transported.

In one-to-many-to-one problems, commodities that are initially available at a depot have to be transported to customers and commodities that are available at customer locations have to be transported to the depot. On the other hand, in *one-to-one* problems, each commodity has a certain origin and a certain destination. Such problems can arise in courier operations or in door-to-door transportation for elderly or disabled people [30].

From the above review, we have concluded that the problems which are closer to ESHFP are those discussed in [11], [13], [14], [17] and [31]. However, we have distinguished certain differences between the ESHFP and literature approaches. These differences highlight the necessity of developing a new mathematical model such as ESHFP. The most important differences are the following:

- In ESHFP, there are more than one vehicles, which are heterogeneous, and are selected among an available vehicle fleet, for the supply operation as opposed to [13] and [14] which address cases with only one available vehicle.
- In [11] and [31], the authors examine their case with a single commodity; in ESHFP multiple types of commodities must be delivered.
- In ESHFP, pick-up nodes and shelters can be visited more than once contrary to [31] in which both the customers and the depot must be visited exactly once. The same goes for [17] in which each customer is assigned to exactly one vehicle route.

Consequently, in this thesis, we propose a new model that takes into account these differences as well as all other features of ESHFP. The mathematical model introduced as well as the proposed heuristic approach are designed in order determine the set of routes and vehicles to operate for providing commodities to both evacuees and intervention groups.

1.3. Thesis Structure

The remainder of the thesis is organized as follows: In Chapter 2 the mathematical formulation for the ESHFP is proposed. In Chapter 3 we propose the solution approach and the corresponding heuristic algorithm for ESHFP. Chapter 4 presents the computational results for the validation of the proposed heuristic. A case study concerning provisions supply to evacuees and intervention groups in case of a natural disaster at the Province of Teruel is presented in Chapter 5. Finally, Chapter 6 includes the conclusions and suggestions for future work.

Chapter 2. Mathematical model for the ESHFP

The objective of ESHFP is to minimize the time span needed to provide the required provisions in case of a disaster to both evacuees and intervention groups at the corresponding shelters and crew accommodation sites. More specifically, ESHFP aims in determining the set of routes and the corresponding vehicles for providing consumable and non-consumable commodities to shelters and intervention groups' accommodation sites. The abovementioned time span consists of traveling time of vehicles, loading time of commodities at supply points and unloading time at delivery points. Among the possibly multiple solutions with the minimum supply time, the one with the minimum operational cost (time) is selected. To deal with ESHFP, a Mixed Integer Linear Programming Problem is formulated.

2.1. Notation

Let

- $P = \{p_1, \dots, p_r\}$ be the set of shelters (including accommodation sites), hereafter called demand points, in which the provisions for the evacuees and the intervention groups will be transported to
- $K = \{1, \dots, u\}$ be the set of available vehicles, assuming that u is the total number of available vehicles both public and private, each of capacity $Q_k, k \in K$. Note that all vehicles start and finish their routes from/to different locations (depots),
- $O = \{o^k | k \in K\}$ be the set of originating locations of the vehicles
- $E = \{e^k \big| k \in K\}$ be the set of the ending locations. Each of these locations may be considered as a single parking space. The locations are used in order to address the requirement to separate the total vehicle operation time (or operational cost) from the supply time; note that the supply time is defined by the time the last required unit of commodity arrives to a shelter, and the total operation time is the sum of the operation times of all vehicles (till they return to the ending depots).
- S be the set of all supermarkets, hereafter called pick-up nodes.
- $C = \{1, \dots, m\}$ be the different types of commodities to be supplied to the evacuees and to the intervention groups
- $U^c, c \in C$ be the volume per unit of commodity type c.
- M_i^c denote the availability of commodity $c \in C$ at supermarket $\in S$,
- h_j^c be the demand for commodity $c \in C$ at demand point $j \in P$.

- $V^k = \left\{v_1^k, v_2^k, \dots, v_{|V^k|}^k\right\}, k \in K$ be an ordered set containing the possible trips of each vehicle k, assuming that $\left|V^k\right| = \left\lceil \frac{\sum_{j \in P} \sum_{c \in C} h_j^c U^c}{Q_k} \right\rceil, k \in K$, i.e. the maximum number of trips required to deliver all the supplies by (utilizing the full capacity of) vehicle k. Note that a vehicle trip is the route of the vehicle between two consecutive visits to shelters.
- $\bar{V} = \bigcup_{k \in K} V^k$, be the set of all possible trips.
- $Q^v = Q_k, v \in V^k, k \in K$ denote that the capacity of the trips is equal to the capacity of the corresponding vehicle making the trip.

We formalize now the definition of directed graph $G(N, A)$, in which $N = P \cup S \cup O \cup E$ is the set of nodes, A is the arc set connecting the nodes of N and $\bar{A} = A_O \cup A_S \cup A_P \cup A_E$ is a set of triplets, with each triplet comprising an arc and a trip. Thus

- $A_O = \left\{\left(o^k, j, v_1^k\right) \middle| j \in S \cup \{e^k\}, k \in K\right\}$ contains the triplets that include a) the arcs starting from the originating location of each vehicle k and b) the corresponding first trip. The first trip may be directed to a pick-up node, or to the ending location. The latter is used to model the idle vehicles (if any).
- $A_S = \{(i, j, v) | i \in S, j \in (S \backslash \{i\}) \cup P, v \in V^k \backslash \{v_{|V^k|}^k\}, k \in K\}$ be triplets containing arcs connecting each pick-up node $i \in S$ to all other pick-up nodes and to the demand points by all trips, excluding the last trip. The latter is dedicated to the return of the vehicle to its ending location
- $A_P = \{(i, j, v) | i \in P, j \in S \cup \{P \backslash \{i\}\}, v \in V^k \backslash \{v_1^k, v_{|V^k|}^k\}, k \in K\}$ be triplets containing arcs between the demand points to all pick-up nodes (supermarkets) and to all other demand points by all trips besides the first and the last ones
- $A_E = \left\{\left(i, e^k, v_{|V^k|}^k\right) \middle| i \in P, k \in K\right\}$ be triplets comprising of arcs connecting the demand points with the ending location of each vehicle by its last trip

Additionally, we define a set of pairs comprising trips related to certain nodes of the directed graph. Thus, we define set $\bar{N} = N_O \cup N_S \cup N_E$, where:

- $N_O = \{(o^k, v_1^k) | k \in K\}$ includes pairs that contain the first trip of each vehicle and the corresponding originating location. Note that this set is used for formulation purposes only to indicate that only the first trip of each vehicle starts from the vehicle's associated location

- $N_S = \{(j, v) | j \in S \cup P, v \in V^k \backslash \{v^k_{|V^k|}\}, k \in K\}$ includes pairs that contain all trips except the last trip of each vehicle. These trips may arrive at a pick-up location and a demand point.
- $N_E = \{(e^k, v) | v \in \{v^k_1, v^k_{|V^k|}\}, k \in K\}$indicates that the first and/or the last trip of each vehicle may arrive at the corresponding ending location; an idle vehicle will be directed from the originating location to its ending location at its first trip, though a non-idle vehicle will make its last trip to its ending location.

Let $t^v_{ij}, (i, j, v) \in \bar{A}$ be the minimum travel time between nodes i and j by trip v. Let also:

- $w^v_i, (i, v) \in \bar{N}$ be the time that trip v arrives to node i
- $q^c_{iv}, (i, v) \in \bar{N} \backslash N_O, c \in C$ be the quantity of commodity $c \in C$ on board a vehicle just before its arrival to node i during trip v
- $d^c_{iv}, (i, v) \in \{\bar{N} | i \in S\}, c \in C$ be the quantity of commodity c picked up from pick up node i during trip v
- $\hat{d}^c_{iv}, (i, v) \in \{\bar{N} | i \in P\}, c \in C$ be the quantity of commodity c delivered to delivery node (point) i during trip v
- $x^v_{ij}, (i, j, v) \in \bar{A}$ be assigned the value 1 if arc $(i, j) \in A$ is traversed by trip v, and 0 otherwise
- T_{sup} be the duration of the supply process, i.e. the time span defined by the start of the supply procedure until the time the last item of the demand at the shelters is delivered.

2.2. Model Formulation

The objective function of ESHFP is defined as follows:

$$TC = \min \left\{ T_{sup} + \frac{1}{L} \sum_{(i,j,v) \in \bar{A}} t^v_{ij} x^v_{ij} \right\} \tag{2.1}$$

The first term refers to the supply time of operation while the second term is the total vehicle operation time (cost) and L ensures that the first term of objective function (2.1) dominates lexicographically the second term, the total supply time that is the objective time. Setting $L > \sum_{(i,j,v) \in \bar{A}} t^v_{ij}$ ensures that in case of multiple solutions with the same supply time the one with the lowest total travel time among all, will be preferred [31], [32].

Optimization of (2.1) is subject to:

Routing constraints

$$\sum_{j\in N|(o^k,j,v_1^k)\in\bar{A}} x_{o^k j}^{v_1^k} = 1, \qquad k \in K \tag{2.2}$$

$$\sum_{v\in\bar{V},j\in(i,j,v)\in\bar{A}} x_{ij}^{v} \geq 1, \qquad i \in P \tag{2.3}$$

$$\sum_{i\in N|(i,l,v_n^k)\in\bar{A}} x_{il}^{v_n^k} = \sum_{j\in N|(l,j,v_{n+1}^k)\in\bar{A}} x_{lj}^{v_{n+1}^k}, \qquad n = 1,\dots,|V^k|-1, k \in, K\ l \in P \tag{2.4}$$

$$x_{o^k e^k}^{v_1^k} + \sum_{i\in P} x_{ie^k}^{v_{|V^k|}^k} = 1, \qquad k \in K \tag{2.5}$$

$$x_{o^k e^k}^{v_1^k} + \sum_{i\in N|(i,j,v)\in\bar{A}} x_{ij}^{v} = 1, \qquad v \in V^k \backslash \{v_{|V^k|}^k\}, k \in K, j \in P \tag{2.6}$$

$$\sum_{i\in N|(i,l,v)\in\bar{A}} x_{il}^{v} = \sum_{j\in N|(l,j,v)\in\bar{A}} x_{lj}^{v}, \qquad l \in S, v \in V^k \backslash \{v_{|V^k|}^k\}, k \in K \tag{2.7}$$

Timing constraints

$$T_{sup} \geq w_j^v, \qquad v \in \{v_{|V^k|-1}^k | k \in K\}, j \in P \tag{2.8}$$

$$w_i^v + t_{ij}^v - B(1 - x_{ij}^v) \leq w_j^v, \qquad (i,j,v) \in \bar{A}, i \in O \cup S \tag{2.9}$$

$$w_l^{v_n^k} + t_{lj}^{v_{n+1}^k} - B(1 - x_{lj}^{v_{n+1}^k}) \leq w_j^{v_{n+1}^k}, \qquad \begin{array}{l}(l,j,v_{n+1}^k) \in \bar{A},\\ n = 1,\dots,|V^k|-1,\\ k \in K, j \in S \cup P \cup \{e^k\}, l \in P\end{array} \tag{2.10}$$

$$0 \leq w_j^v \leq B \sum_{(i,j,v)\in\bar{A}} x_{ij}^v, \qquad (j,v) \in \bar{N} \tag{2.11}$$

Capacity constraints

$$q_{iv}^c + d_{iv}^c - B\left(1 - x_{ij}^v\right) \leq q_{jv}^c, \qquad (i,j,v) \in \bar{A}, i \in S \cup, c \in C \tag{2.12}$$

$$\sum_{c\in C} q_{iv}^c U^c + \sum_{c\in C} d_{iv}^c U^c \leq Q^v, \qquad (i,j,v) \in \bar{A}, i \in S \tag{2.13}$$

$$q_{iv_n^k}^c - \hat{d}_{iv_n^k}^c - B\left(1 - x_{ij}^{v_{n+1}^k}\right) \le q_{jv_{n+1}^k}^c, \quad \begin{array}{l} (i,j,v_{n+1}^k) \in \bar{A}, \\ n = 1, \dots, |V^k| - 1, \\ k \in K, j \in S \cup P \cup \{e^k\}, i \in P \end{array} \tag{2.14}$$

Supply constraints

$$\sum_{v \in \bar{V} | (i,v) \in \bar{N}} d_{iv}^c \le M_i^c, \quad c \in C, i \in S \tag{2.15}$$

$$\sum_{v \in \bar{V} | (j,v) \in \bar{N}} \hat{d}_{jv}^c \ge h_j^c, \quad c \in C, j \in P \tag{2.16}$$

$$d_{iv}^c \in \mathbb{N}_0 \quad c \in C, i \in S \cup O, (i,v) \in \bar{N} \tag{2.17}$$

$$\hat{d}_{jv}^c \in \mathbb{N}_0 \quad c \in C, j \in P, (i,v) \in \bar{N} \tag{2.18}$$

Other constraints

$$\sum_{c \in C} \sum_{k \in K} q_{e^k v_{|V^k|}^k}^c + \sum_{c \in C} \sum_{k \in K} w_{s^k}^{v_1^k} = 0, \tag{2.19}$$

$$\sum_{c \in C} q_{jv_1^k}^c \le B\left(1 - x_{ij}^{v_1^k}\right), \quad (i,j,v) \in \bar{A}, i \in O, j \in S \tag{2.20}$$

$$x_{ij}^v \in \{0,1\}, \quad (i,j,v) \in \bar{A} \tag{2.21}$$

Regarding the **routing constraints**: Constraint (2.2) ensures that the first vehicle trips should depart from the originating depot. Constraint (2.3) denotes that the demand points should be visited at least once. Constraint (2.4) indicates that when a vehicle trip arrives at a demand point the next vehicle trip should depart from it. Constraint (2.5) ensures that the first or the last trip should arrive at the ending depot. Constraint (2.6) ensures that the trips of non-idle vehicles should arrive at the demand points, or idle vehicles should be headed directly to the ending location. Constraint (2.7) indicates that if a vehicle arrives at a pick-up location (supermarket) it should also depart from this node within the same trip.

Regarding the **timing constraints**: Inequality (2.8) ensures that the supply time is greater than the last visit to any demand point. Constraint (2.9) defines the change of the arriving time at any node other than the ending locations for each trip (demand points), where $B \gg 1$. Correspondingly, constraint (2.10) defines the change of the arriving time for each next trip that departs from a demand point. Constraint (2.11) ensures that the time of arrival to any node will be greater or equal to zero, with $B \gg 1$, and, specifically, it will be equal to zero if the location is not visited.

Regarding the **capacity constraints**: Inequality (2.12) defines the change of the load after an originating or a pick-up location for each trip, where $B \gg 1$. Additionally, inequality (2.13) ensures that the capacity of a vehicle is not violated, while inequality (2.14) defines the change of the load for each trip after a visit to a demand point, where $B \gg 1$.

Regarding the **supply constraints**: Inequalities (2.15) and (2.16) refer to the total supplies to be picked up and delivered; no more than the available commodities may be picked-up from any pick-up location during all vehicle trips; the demand of supplies should be satisfied for all demand points correspondingly. Constraint (2.17) defines the nature of the pick-up quantity variable and constraint (2.18) defines the nature of the delivery quantity variable.

Regarding the **rest of the constraints**: Inequality (2.19) ensures that each vehicle trip starts at time equal to zero, and ends empty at the ending location. Constraint (2.20) ensures that a vehicle starts empty from its originating location. Finally, constraint (2.21) defines the binary nature of the arc variables at each trip v.

2.3. Required inputs for ESHFP

In order to apply the model presented in Section 2.2, the following 5 categories of data need to be provided: (a) Commodities, (b) Pickup locations (supermarkets), (c) Demand points (shelters), (d) Road Network, (e) Available vehicles.

More specifically, regarding the commodities to be picked up and delivered to the evacuees and the intervention groups, the Stock Keeping Unit (SKU or part number, i.e. mineral water) and the volume (or weight) of the storage unit (i.e. each, carton, pallet) per commodity should be provided in order to optimally plan the loading of the vehicles.

Regarding the nodes of the network, the pick-up locations (supermarkets), and their exact location should be provided. The same holds for the starting and ending locations of each vehicle, as well as of the shelters. For the network arcs, input data required include the distances a) between the originating points of available vehicles and the pick-up locations, b) between each pick-up location and the other pick up locations, as well as all shelters, c) between each shelter and the other shelters, as well as the ending locations of each vehicle. Note that when possible, any alternative arcs should be also being provided.

Regarding the available vehicles either public or private, input information should include for each vehicle, the capacity (in volume or weight) and their originating and ending locations.

Chapter 3. Solution Framework for ESHFP

Due to its complexity, ESHFP is very difficult to be solved to optimality in a reasonable time. In order to efficiently solve the aforementioned problem in reasonable time, we have developed a heuristic algorithm. This algorithm aims in determining the set of routes and the vehicles to operate them that minimize the total time to supply all required provisions to evacuees and intervention groups at the corresponding shelters with respect to constraints concerning routing, timing, capacity, demand and supply.

The important data for ESHFP include the following categories:

- Commodities
- Supply Points
- Shelters
- Road Network
- Available vehicles

Heuristic Approach for the ESHFP

In the proposed algorithm, firstly we create a list of all available vehicles, thereinafter called AVL, which is sorted in descending order with respect to their capacity. It is necessary to note that during the creation of AVL, the public vehicles have priority in AVL against private vehicles. This is because there is uncertainty about immediate availability of private vehicles after an emergency. When AVL is created, the abovementioned priority ceases to apply, and all vehicles are utilized with the same way. Following that, all shelters that will be served are grouped into clusters according to their geographic location. Each cluster will be served by one (or more if necessary) vehicles. The well-known $K-means$ algorithm is used for clustering. The cluster with the highest total demand is selected to be served first. Then, we select the vehicle from AVL with the smallest capacity among the vehicles that are concluded in AVL that can cover the total demand of the selected cluster. If there is no such vehicle in the AVL, the vehicle with the highest capacity among all vehicles (both public and private) in AVL is selected instead. Subsequently

- We create a route for the nodes (shelters) in the selected cluster using the *Clark & Wright Savings* algorithm and we select the nodes of the given route that the vehicle may serve by using the parameters X & Y that are used to decide on whether a vehicle should continue its supply trip to a subsequent shelter after it has delivered to the current shelter. Threshold X is the remaining capacity which a vehicle can have in order for the algorithm to continue planning its loading. Threshold Y is the maximum allowable time distance needed for traveling from a shelter to another, so as for the algorithm to continue planning vehicle's loading. The decision of continuing planning examines both these thresholds. If the remaining capacity of a vehicle is lower than X and the triangular time distance between two shelters and the temporary point is lower than Y, then the algorithm plans vehicle's loading for both shelters.

- We create a route for the supply points that can provide the higher amount of commodities for serving the current cluster using the *Clark & Wright Savings* and 2-*opt* algorithms. The selected vehicle is then routed to the selected supply points and collects the inventory. Next, the vehicle is routed to the first node of the route set for the selected cluster, and the needed commodities are unloaded. When the vehicle finishes its route, it becomes available again.

After routing the first vehicle, the entire process is repeated until the total demand of all shelters is met.

Since the objective of the algorithm is to minimize the time span of the entire operation, all selected vehicles start their first routes at time zero.

The proposed algorithm works as follows:

Step 0. (Preparatory Step) Compute the center of gravity of supply points, identify the supply point that is closest to it and set that supply point as $Temporary\ Point$ (TP). This will be the reference point for vehicles to return when they complete a route. Select also the appropriate vehicles among all available, to create AVL. More specifically, if the Total Demand is higher than Total Capacity of all vehicles (both public and private), then insert all into AVL, else include vehicles in AVL, until their Total Capacity exceeds the Total Demand by picking first the public and then the private vehicles (see above).

Step 1. (Clustering) Create a matrix named $Clusters$ by grouping the shelters into clusters; two options are provided: a) the user creates the clusters manually, b) using the *K-means* algorithm

Step 2. (Initialization) Convert all the amounts of commodities into cubic meters and create AVL which includes all vehicle information (such as capacity, traveled time and vehicle ID)

Step 3. (Assignment) Set the cluster with the highest demand as $Current\ Cluster$ and set as $Current\ Vehicle$ the vehicle with the lowest capacity that can cover the total demand of the selected cluster. In case there is no such vehicle, select the vehicle with the highest capacity among all. Note that the $Current\ Vehicle$, will be routed only to $Current\ Cluster$, even though its capacity far exceeds the total demand of that cluster.

Step 4. (Delivery route) Create a route for all shelters of the $Current\ Cluster$, using the *Clark & Wright Savings* algorithm. The $Temporary\ Point$ (TP), will be used as the starting and the ending point of that route simultaneously. The entire route or part of it will be served by $Current\ Vehicle$. Compute the necessary inventory to be collected from supply points

Step 5. (Commodities picking) Select the supply points that can supply the necessary inventory so as to be visited by Current Vehicle. Then, set a route for visiting supply points by using *Clark & Wright Savings* algorithm and use *2-opt* algorithm to improve it. Execute the route and load the vehicle with appropriate commodities from each supply point

Step 6. (Commodities delivering) Execute the shelter route and deliver the planned amount of commodities at each shelter

Step 7. (Termination) Update $Clusters$ by removing the shelters that are fully served.

If $Total\ Demand$ is still higher than zero

Go to **Step 3.**

Else

Compute $Total\ Supply\ Time$ as the maximum service time among all shelters

End

The pseudo code of the algorithm as well as the necessary notation, is given in the following:

Notation

- Let F be the number of clusters to create for grouping shelters
- Let $Clusters$ be a matrix containing F clusters (rows). The non-zero elements of row $i = 1, \dots, F$ are the shelters grouped into cluster i
- Let h be the demand matrix for shelters (elements in units)
- Let s be the supply matrix for supply points (elements in units)
- Let vol_h be the demand in volume (m^3)
- Let CP be a matrix with the IDs and current point of each vehicle
- Let CV be the current vehicle
- Let AVL be a list including all available vehicles along with their ID, their total traveling time and their capacity (m^3)
- Let $loading\_time \equiv uloading\_time$ be 9 min for loading 3 m^3 (assumption)
- Let Var_Map be a matrix including the following
  [# $of\ public\ vehicles$, # $of\ private\ vehicles$, # of shelters, # of supply points, # of Reference Points]

- Let VL be the on board inventory per commodity for a vehicle
- Let SM_route be the initial sequence of visits to supply points
- Let SM_Final_Route be an improved version of SM_route
- Let $nearestSM$ be a matrix with the distances of each supply point from the reference point
- Let T be a matrix with the total service time for each shelter
- Let $Total\_Demand$ be the total demand of all shelters (m^3)
- Let $Final\ Routes$ be the routes of supply plan
- Let $Travel\_Times$ be the traveling times between all nodes
- Let $Total\_Supply\_Time$ be the time that is needed for covering the total demand
-

Pseudocode

- Compute the coordinates of reference point
- Initialize $nearest\ SM$

For $i = 1$: number of supply points

$nearestSM(i, 1)$ = the ID of supply point i

$nearestSM(i, 2)$ = the Euclidean distance from supply point i to reference point

End

- Set as ID of the reference point the ID of its nearest supply point
- Initialize Var_Map, $Travel\_Times$, CP, T, h, s, Final_Routes
- Call subroutine **Clustering** to group the shelters into clusters
- Call subroutine **Commodities_Conversion_into_Volume** in order to convert all the amounts of commodities into volume
- Compute $Total\_Demand$ using vol_h
- Call subroutine **AVL_Creation** in order to select the appropriate vehicles to operate the supply process

While $Total\_Demand > 0$

  - Call subroutine **Cluster_Selection** to select the cluster to be served
  - Call subroutine **Vehicle_Selection** to select the vehicle to serve the selected cluster
  - Set the selected vehicle as CV
  - Call subroutine **Shelters_CWS** to create an optimal route for all shelters inside the selected cluster
  - Call subroutine **Shelters_Selection_For_Route** in order to select which nodes of the selected cluster will be served during each route

- Initialize the load of CV per commodity (matrix VL)
- Call subroutine **Supermarket_Selection_For_Route** to select which supply points will be visited by CV
- Call subroutine **Supermarkets_CWS** in order to create a route for the selected supply points (SM_route)
- Call subroutine **2-opt_for_sm** in order to optimize the resulted route of subroutine **Supermarkets_CWS (**SM_Final_Route)
- Initialize $loading\_time$
- Call subroutine **SM_Route_Execution_and_Vehicle_Loading** to execute the routes for the selected supply points and load CV with the appropriate amounts per commodity
- Initialize $unloading\_time$
- Call subroutine **Shelters_Route_Execution** to execute the routes for shelters of the selected cluster and unload the appropriate amounts of commodities at each shelter
- Call subroutine **Clusters_Update** in order to update $Clusters$ matrix by deleting shelters that have been already served
- Update $Total\_Demand$

End

- $Total\_Supply\_Time \ = maxelement(T)$

A detailed description of the algorithm and the pseudocode of each subroutine as well as the flowchart of the proposed algorithm are presented in Appendix II.

Chapter 4. Computational Results

In order to validate the proposed algorithm, various problem instances have been solved both manually and using the algorithm coded in MATLAB. More specifically we solved five problems. In Section 4.1. we present one of these examples. In addition to validating the algorithm, the purpose of these tests is also to examine whether the provisions supply plan provided by the proposed algorithm is efficient or any improvements should be introduced. The experiments indicate that the proposed heuristic (both routing and loading \ unloading subroutines) performs well and the derived supply plans are in fact efficient.

4.1. Validation of Proposed Heuristic

To validate the proposed algorithm, consider an instance of the ESHFP problem with three shelters grouped into two clusters. Let's also assume that two vehicles (one public and one private) with the same starting point are available for collecting and delivering supplies. The supplies consist of two different commodities, collected from five supply points. Table 4.1 presents in detail the supply-related input for the algorithm, Table 4.2 presents the shelter-related input for the algorithm, and Table 4.3 provides input concerning the pick-up locations. Vehicle-related information and the road network are presented in Tables 4.4 and 4.5 respectively.

Table 4.1. *Commodities-related input for the for the validation example*

Type	ID	Dimensions (m) per item (commodity)		
		Length	Width	Height
Agua mineral (1,5lt)	887	0.0650	0.0700	0.3400
Sandwiches	884	0.3000	0.0700	0.0600

Table 4.2. *Shelter-related input for the validation example*

Shelters	ID	Cluster	Coordinates		Demand (units) Per Commodity ID		Demand (m^3) Per Commodity ID	
			Latitude	Longitude	887	884	887	884
1	9928	1	38.86297	22.43984	6300	3000	9.7461	3.78
2	9984	2	38.83657	22.44121	3000	1000	4.641	1.26
3	9957	2	38.86297	22.43984	1000	1000	1.547	1.26

Table 4.3. *Supply point-related input for the validation example*

Supply points	ID	Coordinates		Supplies (Stock in Units) Per Commodity ID		Supplies (Stock in m^3) Per Commodity ID	
		Latitude	Longitude	887	884	887	884
1	3352	45,3112	1,513769	2100	1000	3.2487	1.26
2	3361	45,3055	1,517245	2100	0	3.2487	0
3	3341	45,3082	1,530034	2100	2000	3.2487	2.52
4	3389	45,3088	1,562497	1900	1000	2.9393	1.26
5	3374	45,3143	1,560761	2100	1000	3.2487	1.26

Table 4.4. *Vehicle-related input for the validation example*

Vehicle	ID	Capacity (m^3)	Starting Point 's Coordinates		Starting Point ID
			Latitude	Longitude	
Public Vehicles					
1	4452	15	40,33302	-1,08217	7784
Private Vehicles					
2	5568	7	40,33302	-1,08217	7712

Table 4.5. *Network* (distances in *min*) *input for the validation example*

From	To	Network (min)									
		Public Vehicles' Starting Points	Private Vehicles' Starting Points	Shelters			Supply points				
	IDs	7784	7712	9928	9984	9957	3352	3361	3341	3389	3374
Public Vehicles' Starting Points	7784	0	-	-	-	-	3	7	2	16	18
Private Vehicles' Starting Points	7712	-	0	-	-	-	19	21	16	2	1
Shelters	9928	-	-	0	30	29	6	10	1	30	30
	9984	-	-	30	0	2	30	30	30	3	2
	9957	-	-	29	2	0	30	30	30	4	4
Supply points	3352	-	-	6	30	30	0	4	5	30	30
	3361	-	-	10	30	30	4	0	9	30	30
	3341	-	-	1	30	30	5	9	0	30	30
	3389	-	-	30	3	4	30	30	30	0	2
	3374	-	-	30	2	4	30	30	30	2	0

Based on the heuristic algorithm (see also Table 4.6) the public vehicle, which has the highest capacity, should be routed to cluster 1 which requires the highest demand, and the private vehicle should be routed to cluster 2. However, according to its capacity, the private vehicle cannot pick up the total demand needed at cluster 2. Thus, cluster 2 should be visited again by one of the vehicles. Due to the travel times of the abovementioned routes, the private vehicle is the first that becomes available again and thus this is the vehicle to revisit cluster 2.

The public vehicle visits three supply points to collect the required demand of cluster 1, and the private vehicle visits two supply points until its capacity is met. The demand of cluster 2 is not satisfied by the first trip of the private vehicle, since the demand is higher than the vehicle's capacity, and a second trip for cluster 2 is performed by the private vehicle (which is the first of the two vehicles that becomes available). The private vehicle, on its second trip, visits one supply point that can provide the rest of the supplies for cluster 2 and thereafter it delivers its load to terminate the entire supply process. The total supply time is determined by the time that the public vehicle needs to pick up and deliver the required supplies in cluster 1. In Table 4.6, the output of the proposed algorithm is provided.

Note that the results provided by the algorithm are the expected ones, since firstly the routes are indeed constructed according to the algorithm's concept (vehicle with the highest capacity routed to the cluster with the highest demand). Beyond this, according to capacities and demand, cluster 2, which is assigned to the private vehicle, needs indeed two routes to be served. Finally, the algorithm manages to satisfy the entire demand of each shelter.

Table 4.6. *Supply plan for the validation example*

Number of Route	1			2			3		
Vehicle ID	4452			5568			5568		
Route Starting Time	0			0			66		
Ending Time	116			62			88		
	ID of Supply point / Shelter	**Commodity ID**	**Quantity (m^3)**	**ID of Supply point / Shelter**	**Commodity ID**	**Quantity (m^3)**	**ID of Supply point / Shelter**	**Commodity ID**	**Quantity (m^3)**
Supply points	3361	887	3.249	3389	887	2.491	3389	887	0.448
		884	0		884	0		884	1.26
	3352	887	3.249	3374	887	3.249	3374	887	-
		884	1.26		884	1.26		884	-
	3341	887	3.249	-	887	-	-	887	-
		884	2.52		884	-		884	-
Shelters	9928	887	9.747	9984	887	4.641	9984	887	0.448
		884	3.78		884	1.26		884	1.26
	-	887	-	9957	887	1.099	9957	887	-
		884	-		884	0		884	-

Cluster	**Shelter ID**		**Shelter Service Time (in min)**		**Total Supply Time**
1	9928	-	116	-	**116**
2	9984	9957	51	88	

4.2. Problem Generator

In order to test the performance of the proposed algorithm in different ESHFP configurations, a problem generator was developed to generate multiple problem instances.in order to study the effects of critical problem parameters on the value of the problem's objective function.

4.2.1. Problem Generator Description

To generate the test problems we generated needed data (inputs) for the following 5 categories: (a) Commodities, (b) Supply points, (c) Shelters, (d) Available vehicles, (e) Road network.

Furthermore, to examine the behavior of the solution with respect to significant problem characteristics, we defined suitable normalized parameters based on the above input data.

4.2.2. Definition of Normalized Parameters

We have defined the following normalized parameters based on the inputs used to generate the problems. These parameters characterize the significant features of each problem, and are used to study the behavior of the solution (in terms of the value of the objective function) based on the problem features/characteristics.

1) Parameter "S" is the ratio of the number of shelters over the number of supply points (e.g. supply points):

$$S = \frac{\#\ of\ shelters}{\#\ of\ supermarkets}, \quad S = 1,2 \tag{4.1}$$

2) Parameter "P" is the ratio of total demand over total supply:

$$P = \frac{Total\ Demand}{Total\ Supply}, \quad P = 0.05, 0.1, \dots, 0.9, 0.95 \tag{4.2}$$

3) Parameter "D" is the ratio of total demand over the total capacity of vehicles that will be used in the algorithm:

$$D = \frac{Total\ Demand}{Total\ Capacity}, \quad D = 0.1, 0.2, 0.3, 0.4, 0.5, 1, 2 \tag{4.3}$$

4) Parameter "σ" quantifies the distribution of commodities at supply points. More specifically it quantifies whether:
   4.a. commodities are distributed (almost) uniformly among supply points
   4.b. commodities are distributed non-uniformly among supply points

$$\sigma^2 = \sum_{c \in C} s_c^2 \tag{4.4}$$

where $C = \{1, \dots, m\}$ is the set of types of commodities to be supplied to the evacuees and to the intervention groups.

For example, for the commodity water, the deviation is given as follows):

$$s_{water} = \sqrt{\frac{\left(s_1^{water} - \frac{d_{water}}{n}\right)^2 + \left(s_2^{water} - \frac{d_{water}}{n}\right)^2 + \dots + \left(s_n^{water} - \frac{d_{water}}{n}\right)^2}{(n-1)}}$$

where

- s_i^{water} is the units of mineral water provided by supply point i,
- d_{water} is the he total demand for mineral water (in units)
  n is the number of supply points

If the commodities are distributed (almost) uniformly among supply points, σ^2 is low and if the commodities are distributed non-uniformly among supply points, σ^2 is high. For every single problem and for each commodity, we generate the inventory of the supply points randomly 100 times and we compute σ^2. The cases with supply point's inventory resulting to the highest and lowest values of σ^2 are chosen.

Considering all the above, and combining the values of the mentioned parameters, we address the following cases (Table 4.7.):

Table 4.7. *The four main groups of problem categories that are generated.*

$S = \frac{\# \, of \, shelters}{\# \, of \, supermarkets} = 1$	$\sigma^2 = high$		
$S = \frac{\# \, of \, shelters}{\# \, of \, supermarkets} = 1$	$\sigma^2 = low$	$P = \frac{Total \, Demand}{Total \, Supply}$	$D = \frac{Total \, Demand}{Total \, Capacity}$
$S = \frac{\# \, of \, shelters}{\# \, of \, supermarkets} = 2$	$\sigma^2 = high$	$P = 0.5, 0.1, 0.15, 0.2, \ldots, 0.95$	$D = 0.1, 0.2 \ldots 0.5, 1, 2$
$S = \frac{\# \, of \, shelters}{\# \, of \, supermarkets} = 2$	$\sigma^2 = low$		

The combination of the above creates 532 different cases.

Note that 100 problems are solved for each different case and the analysis considers the mean $Total \; Supply \; Time$, and the mean km travelled by vehicles.

The sample problems are generated based on the following:

Step 1. Generator 's constants

- Parameters X are Y are 0 and 10, respectively.
- The commodities and their characteristics are provided in Table 4.8:

Table 4.8. *Commodities-related input for the generator*

Type	ID	Dimensions (m) per item (commodity)		
		Length	Width	Height
Agua mineral (1,5lt)	334	0.0650	0.0700	0.3400
Dairy products, juices	339	0.0900	0.0600	0.2100
Fruits (oranges, apples…)	336	0.1000	0.1000	0.1000
Sandwiches	338	0.3000	0.0700	0.0600
Hygiene kits	335	0.2000	0.1800	0.0500
Mattrers or landing mat	331	1.8000	0.6000	0.0500

- Personal Demand (items per person) as in Table 4.9:

Table 4.9. Daily d*emand per commodity per person*

Type	Mineral Water (1,5lt)	Dairy products, juices	Fruits (oranges, apples,…)	Sandwiches	Hygiene kits	Mattrers or landing mat
Personal Demand (Items per Person)	5	2	3	3	1	1

- Assumptions:

  $Pallet\ Volume\ = 0.96m^3$.

  $Pallet\ Dimensions$: $1.2\ m \times 0,.8\ m \times 1\ m$.
- We compute the volume of demand per person
- The Total Demand is generated initially into pallets. The number of pallets is generated, and follows Normal Distribution with $\mu = 30$ pallets and $\sigma = 2$. We also accept number of pallets higher or equal to 25. This step is done for generator's implementation. More specifically, by forcing each problem to have similar Total Demand with the other problems, we have objectivity between all the problems. Thus, the Total Supply Time of a problem will not be differentiated from the other 99 problems of the same case.
- We generate the Total Demand into pallets using normal distribution with $\mu = 30$ and $\sigma = 2$.
- We compute the volume of Total Demand (into m^3)
- We compute the total number of people that will be served my dividing the total volume of demand with the volume of demand per person.

Step 2. Number of Supply points

- It is generated from the Uniform Distribution, U (2,5).

Step 3. Shelters

- We compute the number of Shelters according to Parameter "S"
- The shelter coordinates follow a Uniform Distribution and their Euclidian distance from (0,0) is between 30 and 50. (Figure 4.1 indicates the area that shelters are placed)
- The number of people in each shelter is created randomly maintaining the total number of people in all centers constant as discussed above
- The number of clusters follows the Uniform Distribution, U (1,3, and is smaller or equal to the number of shelters

Step 4. Supply points (Other Information)

- Supply points' coordinates follow a Uniform Distribution and their Euclidian distance from (0,0) is between 0 and 20. (Figure 4.1 indicates also the area of the supply points)

- As for the inventory, it is generated in accordance with the current case and / or sub case.

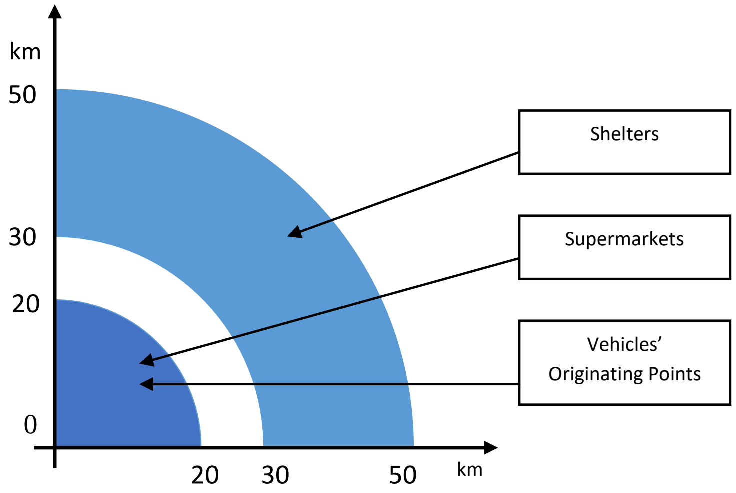


Figure 4.1. *Geographical Representation of the space that the nodes are located*

Step 5. Vehicles

- Number of Vehicles (Total number of vehicles) is generated from the Uniform Distribution, U (2,5).
- The coordinates of the origins of the public and private vehicles follow a uniform distribution and their Euclidian distance from (0,0) is between 0 and 20.
- The vehicle capacities are generated in accordance with parameter D which refers to the total capacity of the case
- The mean speed of both Public and Private vehicles is generated form the Uniform Distribution, U (45,55).

Step 6. Network

- We calculate the Euclidian distance from each node to all others
- We compute the time distance using the Euclidian distance from each node to all others, and the mean speed of vehicles that is generated in the previous step

4.2.3. Test Results

In the first set of experiments, the commodities are distributed non-uniformly ($\sigma^2 = high$) among supply points and there is an equal number of shelters and supply points ($S = \frac{\#\ of\ shelters}{\#\ of\ supermarkets} = 1$). The results are shown in Table 4.10, and in Figure 4.2. Lower Total Supply Time (T) is achieved for $D = 1$ where Total Demand is equal to Total Capacity of all vehicles, independently of P. On the other hand, $Total\ Supply\ Times$ reveals a peak for $D = 2$.

In the second set of experiments, the commodities are distributed (almost) uniformly ($\sigma^2 = low$) among supply points and there is an equal number of shelters and supply points ($S = \frac{\#\ of\ shelters}{\#\ of\ supply\ points} = 1$). The results are shown in Table 4.11 and in Figure 4.3. The lowest time in this case is 197.4 minutes and is achieved for D=1 and $P = 0.2$. Under these parameter values all vehicles will be used approximately once, and the vehicles will visit a low number of supply points. On the other hand, the highest time is 337.63 minutes and comes when $D = 2$ and $P = 0.9$. This is because the vehicles are forced to execute multiple routes to satisfy the demand, and simultaneously, they will visit multiple supply points per route (in this case total demand is 90% of total supply).

In the third set of experiments, the commodities are distributed non-uniformly ($\sigma^2 = high$) among supply points and the number of shelters is twice the number of supply points ($S = \frac{\#\ of\ shelters}{\#\ of\ supply\ points} = 2$). The results are shown in Table 4.12 and in Figure 4.4. Lower Total Supply Time (T) is achieved for $D = 1$, independently of the value of P. On the other hand, Total Supply Times reveals a peak when $D = 2$, because here also, the vehicles are forced to execute multiple routes to cover the demand.

In the last set of experiments, the commodities are distributed (almost) uniformly ($\sigma^2 = low$) among supply points and the number of shelters is twice the number of supply points $\left(S = \frac{\#\ of\ shelters}{\#\ of\ supply\ points} = 2\right)$. The results are shown in Table 4.13 and in Figure 4.5. The lowest time is 231.57 minutes and is achieved for $D = 1$ and $P = 0.2$. On the other hand, the highest time is 375.32 minutes for $D = 2$ and $P = 0.9$. In this case the vehicles not only are forced to execute multiple routes, but they have to visit a larger number of supply points.

Overall it can be observed that the value of $Total\ Supply\ Time$ is varying in almost the same manner for all groups of problems. For instance, for $D = 0.1$ to $D = 0.5$ there is a slight fluctuation of $Total\ Supply\ Time$ (T). On the other hand, T achieves its lowest values for $D = 1$, while T increases for $D = 2$. The most favorable case relates to $D = 1$ since:

- The vehicles can collect all the needed demand by executing about one trip
- All vehicles operate in parallel

As for parameters S, P, D and σ, we can conclude the following:

- The increase of the number of shelters causes an expected increase of $Total\ Supply\ Time$ as we can see in Figure 4.6 and 4.7.

- The increase of Total Demand in terms of Total Supply, as we can see in Figures 4.2-4.5, is responsible for a slight increase of $Total\,Supply\,Time$ because more commodities have to be collected and subsequently more time for loading and unloading is needed.
- The capacity of vehicles has the most critical effect on $Total\,Supply\,Time$. If it is lower than Total demand, some vehicles are forced to execute more than one routes. If Total capacity of all vehicles is lower than Total Demand, the algorithm will not use all of them, which means that the vehicles that will be used, are forced to visit multiple supply points to collect the necessary commodities while others will not be used at all.
- The cases where commodities are distributed (almost) uniformly among supply points results in lower $Total\,Supply\,Time$ versus the cases where the commodities are distributed non-uniformly (see Figures: 4.8 and 4.9). This is because vehicles may have to visit more supply points in the former case, to collect the proper commodities then route to shelters.
- Uneven distribution of commodities across supply points increases *Total Supply Time.*

Concerning the above, it can be claimed that the proposed Heuristic Algorithm is somehow greedy as far vehicle loading concerns. A smarter loading approach may improve its performance.

Table 4.10. *Generator Results for the first group of problems (S=1,* $\sigma^2 = high$*)*

P = Total Demand / Total Supply	D = Total Demand / Total Capacity: 0,1	0,2	0,3	0,4	0,5	1	2
0,05	243,29	251,44	254,73	246,8	238,58	221,34	312,87
0,1	254	243,56	255,64	258,69	245,29	234,01	323,99
0,15	259,42	258,55	256,65	242,79	250,28	224,59	323,42
0,2	256,41	261,91	267,19	249,32	252,39	223,85	330,98
0,25	269,23	266,12	258,37	259,42	259,6	227,09	340,51
0,3	260,03	252,61	264,81	262,49	247,47	241,4	331,3
0,35	271,06	267,17	266,49	253,19	253,34	231,99	333,9
0,4	260,38	259,92	261,71	261,53	251,21	227,84	339,63
0,45	270,57	254,71	263,11	263,93	255,88	218,52	343,41
0,5	254,48	260,38	259,31	261,42	253,6	240,53	335,16
0,55	256,85	268,31	257,22	265,77	259,97	232,67	347,6
0,6	255,71	261,6	263,55	248,06	269,92	231,51	345,79
0,65	247,63	257,72	264,83	267,08	251,47	226,07	343,82
0,7	258,31	262,27	260,43	269,4	247,55	233,08	339,62
0,75	249,7	261,98	241,52	265,9	251,82	230,98	340,05
0,8	259,83	261,92	262,25	253,58	265,18	235,5	337,83
0,85	262,23	262,13	258,14	253,47	254,93	234,09	337,45
0,9	261,49	268,02	254,76	250,63	251,17	228,71	341,26
0,95	261,08	258,7	252,3	265,55	267,19	240,7	346,93

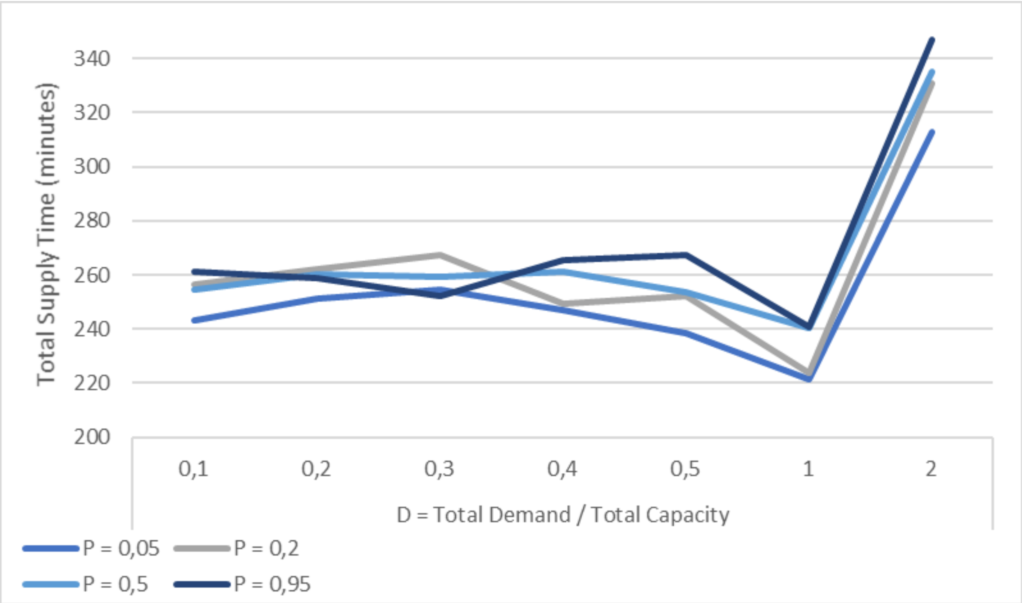


Figure 4.2. *Generator Results for the first group of problems (S=1,* $\sigma^2 = high$*)*

Table 4.11. *Generator Results for the second group of problems (S=1, σ^2 = low)*

P = Total Demand / Total Supply	D = Total Demand / Total Capacity						
	0,1	**0,2**	**0,3**	**0,4**	**0,5**	**1**	**2**
0,05	220,06	228,58	237,9	229,24	221,7	208,54	307,53
0,1	234,85	232,86	219,42	218,25	227,6	207,19	303,93
0,15	221,91	231,4	227,07	226,4	221,6	201,16	300,28
0,2	233,63	230,8	235,7	221,21	233,94	197,4	291,44
0,25	244,24	237,21	241,69	231,5	220,57	216,91	307,52
0,3	233,98	232,18	232,58	242,24	227,38	201,95	293,74
0,35	230,36	252,77	231,65	243,67	225,02	203,79	293,27
0,4	232,57	234,01	240,51	233,55	238,08	209,1	313,88
0,45	237,96	235,65	244,9	233,63	235,54	212,49	314,84
0,5	238,28	246	245,19	241,1	243,42	209,89	313,98
0,55	254,29	234,37	243,1	241,67	250,3	204,09	306,14
0,6	245,22	244,84	242,88	245,53	246,53	217,35	329,15
0,65	254,19	252,79	244,88	238,59	240,33	208,16	328,49
0,7	258,15	249,38	256,94	248,52	253,81	217,4	325,42
0,75	261,91	268,75	242,85	251,67	254,79	220,07	326,06
0,8	247,09	247,29	257,17	251,83	243,4	216,69	322,09
0,85	256,37	257,45	261,04	243,7	257,12	226,56	322,34
0,9	271,62	260,39	262,07	253,89	249,12	233,58	337,63
0,95	245,72	263,01	266,55	260,2	264,37	220,57	323,18

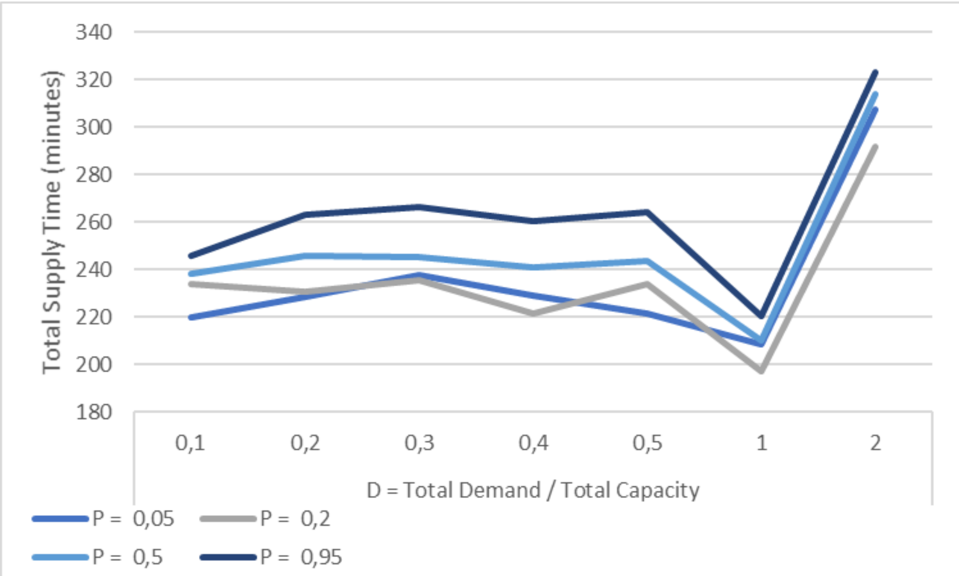


Figure 4.3. *Generator Results for the second group of problems (S=1, σ^2 = low)*

Table 4.12. *Generator Results for the third group of problems (S=2, $\sigma^2 = high$)*

P = Total Demand / Total Supply		D = Total Demand / Total Capacity						
		0,1	**0,2**	**0,3**	**0,4**	**0,5**	**1**	**2**
	0,05	284,25	282,9	284,1	287,55	280,4	238,89	355,54
	0,1	292,07	296,44	288,29	291,16	292,33	255,28	375,21
	0,15	300,68	280,43	286,78	292,45	304,28	260,98	367,32
	0,2	292,45	288,39	307,51	291,15	293,5	251,16	362,09
	0,25	303,96	306,94	281,62	297,12	304,81	256,47	373,8
	0,3	289,88	297,23	296,5	304,18	298,29	270,24	379,41
	0,35	285,86	285,35	283,24	287,34	285,4	250,15	381,9
	0,4	290,74	287,96	301,79	288,93	290,32	254,95	396
	0,45	293,51	306,25	291,35	311,69	280,72	289,76	382,78
	0,5	310,87	294,6	288,37	317,61	302,53	267,21	376,59
	0,55	303,27	298,01	313,66	298,08	290,92	265,88	391,99
	0,6	300,03	303,33	308,4	287,72	290,99	273,31	386,49
	0,65	296,6	295,09	302,69	290,2	284,85	268,75	402,23
	0,7	303,91	318,05	292,08	294,75	292,61	267,42	396,37
	0,75	304,72	298,32	309,67	314,07	298,16	267,13	381,67
	0,8	299,98	301,99	300,12	300,31	294,43	266,17	369,79
	0,85	284,64	302,16	297,8	294,04	294,83	266,32	367,62
	0,9	299,44	305,57	288,65	304,98	307,82	263,01	373,8
	0,95	290,56	301,05	311,74	296,72	291,79	279,82	359,01

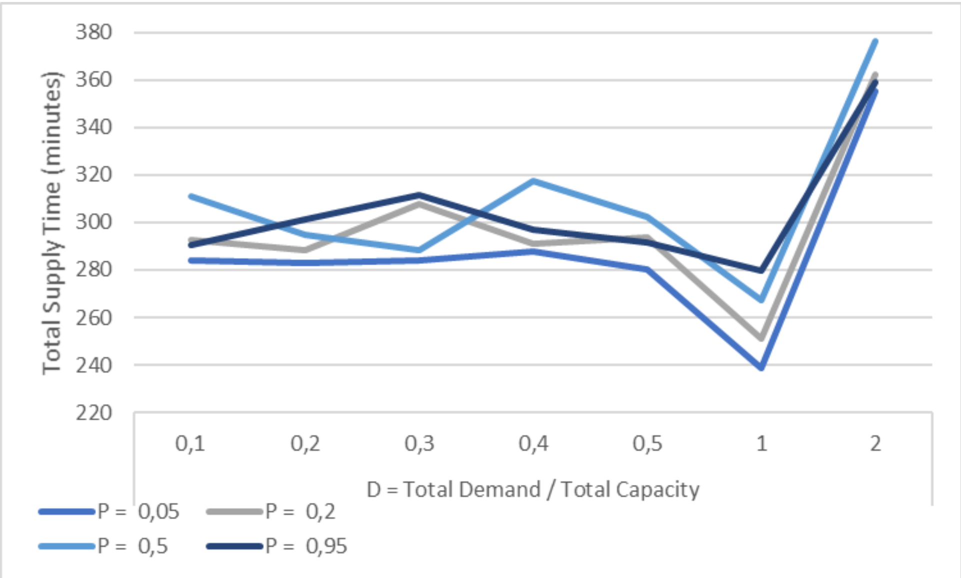


Figure 4.4. *Generator Results for the third group of problems (S=2, $\sigma^2 = high$)*

Table 4.13. *Generator Results for the last group of problems (S=2,σ^2 = low)*

		D = Total Demand / Total Capacity						
		0,1	**0,2**	**0,3**	**0,4**	**0,5**	**1**	**2**
P = Total Demand / Total Supply	**0,05**	273,73	268,29	267,22	258,13	271,61	237	326,61
	0,1	262,13	272,43	276,22	258,81	275,79	239,12	334,55
	0,15	270	258,05	263,26	261,02	261,67	236,3	341,7
	0,2	281,38	284,41	277,76	272,57	275,72	231,57	334,95
	0,25	273,71	256,01	259,78	271,7	262,06	237	345,82
	0,3	279,52	269,79	275,91	294,73	278,98	235,61	341,73
	0,35	269,48	267,1	280,46	268,76	266,08	237,6	338,4
	0,4	276,42	282,5	277,58	281,71	266,91	233,54	338,37
	0,45	281,49	292,79	299,54	275	266,14	239,58	327,21
	0,5	275,29	276,27	283,84	282,32	289,04	238,57	336,68
	0,55	279,4	289,13	294,65	284,2	273,07	237,74	332,11
	0,6	277,9	282,51	307,44	288,29	284,43	245,34	342,88
	0,65	293,8	280,59	285,16	275,06	288,42	240,63	360,06
	0,7	280,25	279,8	290,31	304,08	288,48	245,02	342,73
	0,75	305,26	290,13	290,1	288,41	277,64	241,08	347,85
	0,8	293,57	283,5	282,05	288,68	274,97	236,97	353,34
	0,85	289,95	293,47	301,88	287,59	297,99	248,42	352,21
	0,9	290,09	299,35	281,06	304,66	297,05	263	375,32
	0,95	287,89	292,77	306,48	292,36	299,44	253,86	356,01

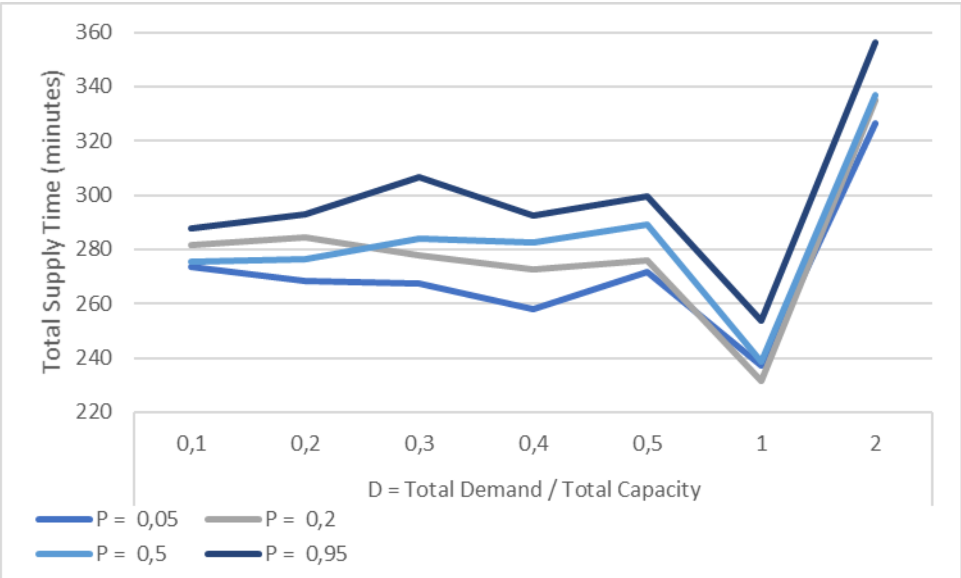


Figure 4.5. *Generator Results for the fourth group of problems (S=2, σ^2 = low)*

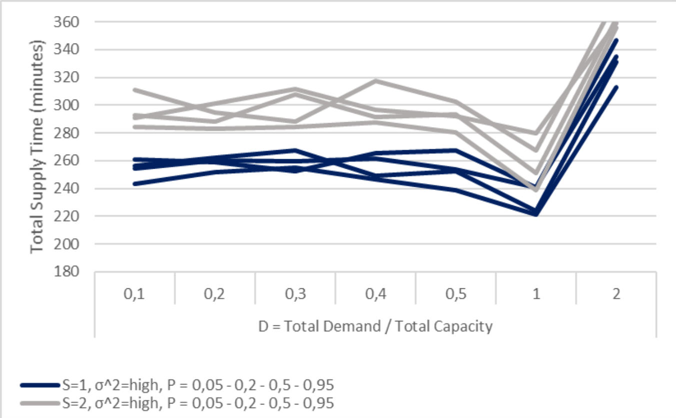


Figure 4.6. *Generator Results for the first and the third group of problems (S=1, S=2, $\sigma^2 = high$)*

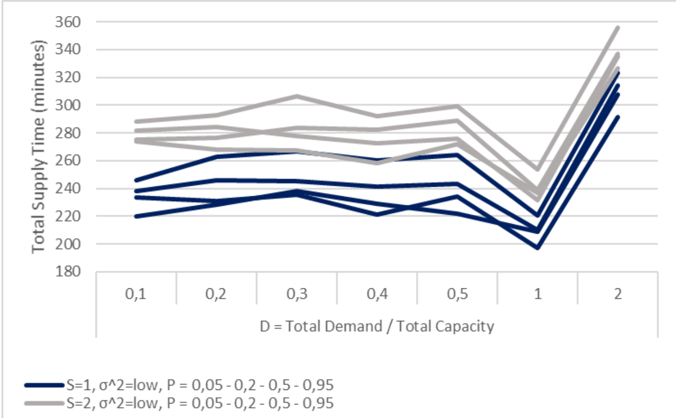


Figure 4.7. *Generator Results for the second and the fourth group of problems (S=1, S=2, $\sigma^2 = low$)*

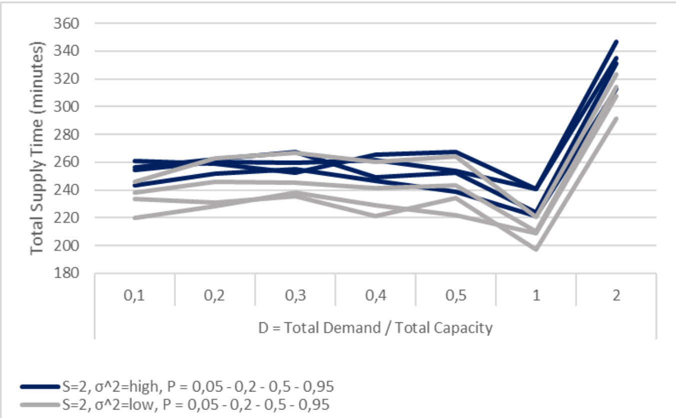


Figure 4.8. *Generator Results for the first and the second group of problems (S=1, $\sigma^2 = high, \sigma^2 = low$)*

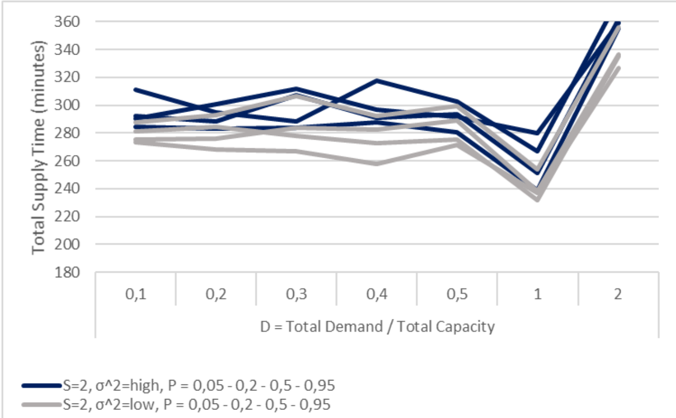


Figure 4.9. *Generator Results for the third and fourth group of problems (S=2, $\sigma^2 = high, \sigma^2 = low$)*

Chapter 5. Case Study

The case study considered in this thesis focuses on an emergency situation at the Province of Teruel. The emergency is caused by a forest fire which evolves dynamically. Under these circumstances, and due to the fact that some villages need to be evacuated to a shelter while intervention groups take action, a plan for providing the aforementioned population categories with the necessary supplies needs to be developed.

Two different scenarios are presented for the case study. The first one deals with solving ESHFP only for the first day of the forest fire. Note that this scenario was examined in the Pilot Test Event which was held in Teruel in September 2016. In the second scenario, the solution of ESHFP is presented for day-to-day supply, taking into account that the forest fire lasts for seven days. In this case evacuees, but also intervention groups, have to be supplied with provisions during the entire seven-day period.

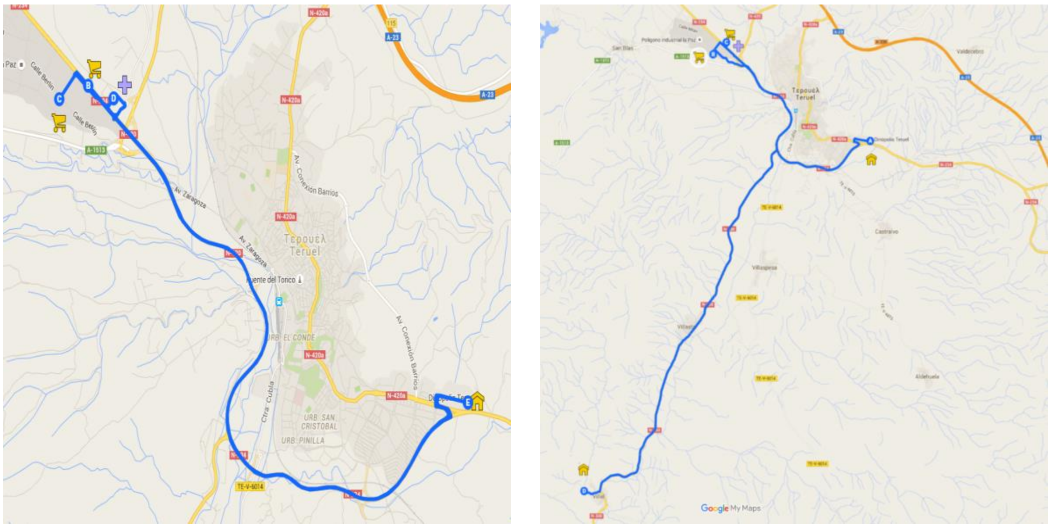
5.1. Scenario A: Solving ESHFP for the first day of the forest fire

Under this scenario, there are only two nodes that need to be served: the evacuees' shelter in Teruel and the accommodation site of the intervention groups during Day 1 in Villel. All vehicles will be available during the event. Note, that the abovementioned scenario was executed during a Pilot Test Event organized in September 2016, at Teruel, in order to test the results provided by the proposed algorithm for the ESHFP in real world circumstances.

The input data needed for this problem are shown in Appendix III. The solution, including the resulted provisions supply schedule for these two shelters, is shown in Table 5.1. Even though the single public vehicle can supply both sites, the algorithm uses two vehicles for the supply process. These vehicles operate simultaneously in order to reduce the total supply time. The routes to be operated for accomplishing the supply process are shown in Figure 5.1. A detailed map with the supermarkets and the shelters is also presented in Figure 5.2. Note that the map shows not only the supermarkets and the shelters that are included in supply routes for the Pilot Test Event Scenario, but all supermarkets and shelters included in Input Data for the Case Study.

In the first route, the vehicle with ID 9930 (public vehicle) is visiting supermarkets 77875, 77496 and 77857. Following that, it serves shelter 66546 which is in Teruel. The starting and ending time of the route, are 0 and 88 minutes respectively. As for the second route, it is executed by the vehicle with ID 8875 (private vehicle) which visits supermarkets 77875 and

77496. The route serves shelter 66789 in Villel and the total time needed for that route is 68 minutes. The total time needed for accomplishing the entire supply process is 88 minutes.



Route 1 **Route 2**

Figure 5.1. *Supply routes for the Pilot Test Event Scenario (Scenario A)*

Table 5.1. *Provisions supply plan (Scenario A)*

Number of Route	1			1		
Vehicle ID	9930 (PB)			8875 (PR)		
Route Starting Time	0			0		
Ending Time	88			68		
	ID of Supermarket / Shelter	**Commodity ID**	**Quantity (into cubic meters)**	**ID of Supermarket / Shelter**	**Commodity ID**	**Quantity (into cubic meters)**
Supermarkets	77875	334	0	77875	334	0
		339	0		339	0
		336	0		336	0
		338	0,363		338	0,345
		335	0		335	0
		331	0		331	0
	77496	334	0,743	77496	334	2,119
		339	0,218		339	0
		336	0,288		336	0,548
		338	0		338	0
		335	0		335	0
		331	0		331	0
	77857	334	0	-	-	-
		339	0		-	-
		336	0		-	-
		338	0		-	-
		335	0,173		-	-
		331	5,184		-	-
Shelters	66546 Teruel	334	0,743	66789 Villel	334	2,119
		339	0,218		339	0
		336	0,288		336	0,548
		338	0,363		338	0,345
		335	0,173		335	0
		331	5,184		331	0

Cluster	**Shelter ID**	**Shelter Service Time (in min)**	**Total Supply Time**
1	66546	88	**88**
2	66789	68	

*PB = Public Vehicle
*PR = Private Vehicle

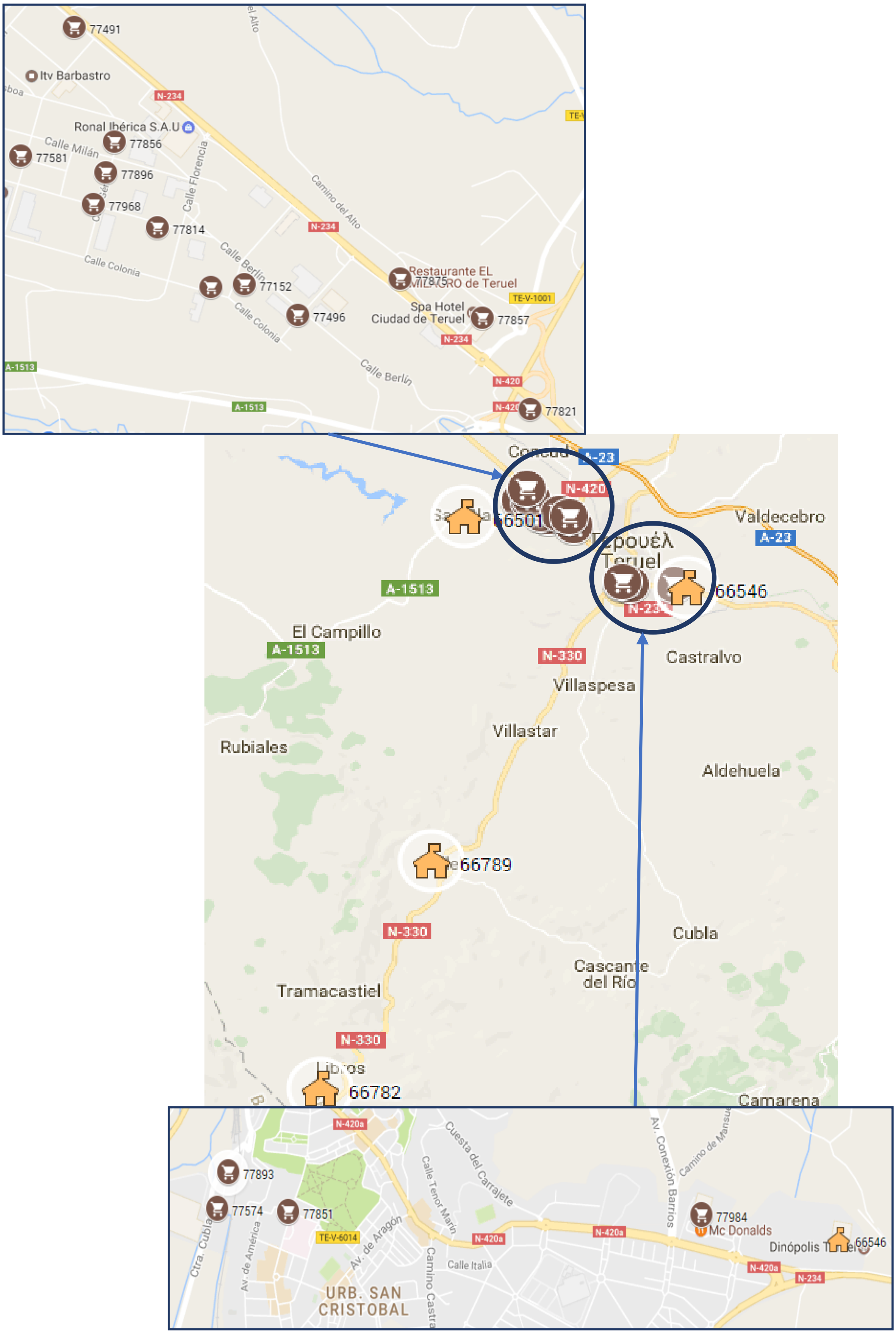


Figure 5.2. *Detailed map with the supermarkets and the shelters that participate in the Case Study*

5.2. Scenario B: Solving ESHFP solution for day-to-day supply

In this scenario, it is assumed that the fire evolves for seven days. During this period, firstly the population of all affected villages around the area of the fire needs to be evacuated. The evacuees are transported to a safe shelter at Teruel, where they need to be supplied with consumable and non-consumable provisions. Simultaneously, intervention groups, responsible for fire extinguishing, will also use shelters for their accommodation. These shelters need to be supplied with the appropriate provisions as well.

Therefore, ESHFP addresses the case of supplying consumable and non-consumable provisions to evacuees as well as to intervention groups during their stay to an accommodation site.

Table 5.2. *Shelters to be supplied during 7-day period*

Shelter	Duration of supply for shelter	
	Hours	**Days**
Teruel (Shelter for evacuees)	36	1 & 2
Mas de la Cabrera (Intervention group accommodation site)	12	1
Villel (Intervention group accommodation site)	30	1 & 2
San Blas (Intervention groups' accommodation site)	120	3, 4, 5, 6 & 7

Provisions for the intervention groups need to be supplied for the entire simulated period of seven days. As a consequence, a daily supply plan needs to be determined. Table 5.2 includes the shelters involved into the provisions supply problem per day. According to this, we have derived the daily demand per commodity for each shelter (in m^3), in order to identify the provisions to be supplied on a daily basis to evacuees and intervention groups. The corresponding daily demand is shown in Appendix IV, along with the rest of the required input data.

The solution including the provisions supply schedule for ESHFP for the first day is shown in Table 5.3, and contains two routes. In the first route, vehicle with ID: 9930 (public vehicle) visits supermarkets 77875, 77496 and 77857. Following that, it serves shelter 66546 which is in Teruel. The starting and ending time of the route, are 0 and 88 minutes respectively. As for the second route, it is executed by vehicle with ID 8875 (private vehicle) which visits supermarkets 77984 and 77893. In the same route, shelters 66782 and 66789 in Mas de la Cabrera and in Villel respectively, are served, and the total time needed for the route is 95 minutes. The total time needed for accomplishing the entire supply process is 95 minutes.

The solution for the rest of the days is shown in Appendix V. Note that based on the information included in Appendix IV, the demand at the accommodation sites of the intervention groups for Days 3 and 4 is exactly the same, and, thus, the same supply plan will be adopted for these two days. This also the case for Days 5, 6 and 7. Based on inputs and outputs of the algorithm, it is worth mentioning that the sole public vehicle which is available is capable of delivering the supply needs for each of days 3, 4, 5, 6, 7. Nevertheless, the algorithm uses two vehicles for the supply process, which operate simultaneously, for Day 1 and Day 2 (multiple shelters), resulting in reduction of the total supply time, which is the objective of the proposed algorithm.

Consequently, using the proposed algorithm, we provide a daily plan for provisions supply for evacuees and intervention groups for both scenarios. Note that the algorithm may respond to any changes regarding vehicles' availability or the road network by appropriately re-defining the input data.

Table 5.3. *Provisions supply plan for Day 1(Scenario B)*

Number of Route	1			1		
Vehicle ID	9930 (PB)			8875 (PR)		
Route Starting Time	0			0		
Ending Time	88			95		
	ID of Supermarket / Shelter	**Commodity ID**	**Quantity (into cubic meters)**	**ID of Supermarket / Shelter**	**Commodity ID**	**Quantity (into cubic meters)**
Supermarkets	77875	334	0	77984	334	1,075
		339	0		339	0
		336	0		336	0
		338	0,363		338	0,262
		335	0		335	0
		331	0		331	0
	77496	334	0,743	77893	334	0
		339	0,218		339	0
		336	0,288		336	0
		338	0		338	0,330
		335	0		335	0
		331	0		331	0
	77857	334	0	-	-	-
		339	0		-	-
		336	0		-	-
		338	0		-	-
		335	0,173		-	-
		331	5,184		-	-
Shelters	66546 Teruel	334	0,743	66782 Mas de la Cabrera	334	0,794
		339	0,218		339	0
		336	0,288		336	0,171
		338	0,363		338	0,215
		335	0,173		335	0
		331	5,184		331	0
		-	-	66789 Villel	334	0,281
		-	-		339	0
		-	-		336	0,091
		-	-		338	0,115
		-	-		335	0
		-	-		331	0

Cluster	**Shelter ID**		**Shelter Service Time (in min)**		**Total Supply Time**
1	66546	-	88	-	**95**
2	66782	66789	67	95	

*PB = Public Vehicle
*PR = Private Vehicle

Chapter 6. Conclusions

Due to the increasing number of both natural and man-made disasters, the development of efficient and effective disaster relief networks is a critical issue. At the post-disaster phase, it is important to ensure efficiency at delivering highly needed commodities either in sufficient quantities to civilians who evacuate residential areas, or to intervention groups.

This thesis introduces and addresses ESHFP, which aims in planning the supply of consumable and non-consumable provisions to both evacuees and intervention groups at the corresponding shelters after a case of emergency, from multiple inventory holding locations. To deal with the abovementioned problem a MILP model has been developed. A heuristic algorithm is proposed to solve this problem. The algorithm aims to determine the set of routes and select the vehicles that can be used to minimize the total time needed to provide all required provisions to evacuees and intervention groups at the corresponding sites. Important constraints concerning vehicle capacities, road network and total demand are respected.

To examine how the problem parameters affect the solution of the proposed algorithm, we applied it to multiple randomly generated problems and we can claim that increase of $Total\ Supply\ Time$, when one or more of the following occurs:

- When the number of shelters is high
- When Total Demand is increased in terms of Total Supply
- When there is uneven distribution of commodities across supply points
- When the Total capacity of the vehicles that are used for distribution, is not the same as the Total Demand because the loading approach of the heuristic algorithm is not that smart

Finally, it is worth mentioned that future research may be focused on the following:

- Develop a metaheuristic algorithm, such as a Tabu-based one, in order to obtain more efficient solutions
- Dynamic changes of the network can be also taken into account. Due to the nature of a disaster, a road connecting two nodes may be closed, e.g. due to fire. In such case it is worth examining how provisions distribution needs to be re-planed.

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Appendix I. Detailed Data for Natural and Technological Disasters (2007-2016)

Appendix I contains detailed data for Natural Disasters and Technological Disasters respectively, reported worldwide during the last decade

Table I.1. *Natural Disasters that reported worldwide from 2007 to 2016. Source: CRED,2/2017*

Natural Disasters							
Year	Occurrence	Total deaths	Injured	Affected	Homeless	Total Affected	Total damage ('000 $)
2007	450	22.422	73.127	211.621.445	1.169.731	212.864.303	74.420.257
2008	393	242.189	396.453	218.202.922	3.242.535	221.841.910	190.849.247
2009	388	16.021	47.978	201.230.991	510.312	201.789.281	46.776.393
2010	435	329.900	740.761	256.795.896	2.423.997	259.960.654	132.194.096
2011	361	34.143	50.814	210.776.553	1.964.972	212.792.339	364.093.168
2012	369	11.619	63.919	110.411.039	950.345	111.425.303	156.692.232
2013	355	22.225	124.421	96.450.897	328.923	96.904.241	119.484.189
2014	342	20.882	107.296	139.497.175	1.364.787	140.969.258	97.769.314
2015	394	23.834	169.340	110.112.431	619.992	110.901.763	72.759.136
2016	297	7.625	261.870	376.931.699	236.562	377.430.131	92.403.670
Total	3.784	730.860	2.035.979	1.932.031.048	12.812.156	1.946.879.183	1.347.441.702

Table I.2. *Technological Disasters that reported worldwide from 2007 to 2016. Source: CRED 2/2017*

Technological Disasters							
Year	Occurrence	Total deaths	Injured	Affected	Homeless	Total Affected	Total damage ('000 $)
2007	277	7.653	5.300	24.232	18.722	48.254	869.000
2008	260	6.946	4.503	24.773	9.496	38.772	0
2009	230	6.866	4.267	28.701	300	33.268	1.526.400
2010	235	6.745	5.621	19.463	11.531	36.615	20.353.000
2011	244	6.626	5.644	10.156	39.480	55.280	2.701
2012	188	6.052	10.090	13.504	800	24.394	31.000
2013	192	6.714	5.032	10.016	6.789	21.837	578.000
2014	205	6.389	4.233	284.893	7.200	296.326	0
2015	202	9.726	8.643	71.600	21.719	101.962	15.000
2016	160	5.127	3.809	14.828	242	18.879	0
Total	2.193	68.844	57.142	502.166	116.279	675.587	23.375.101

Appendix II. Heuristic Algorithm (Detailed Description – Flowchart and Pseudocode of Subroutines)

Appendix II contains the necessary notation, a detailed description of the heuristic algorithm and the corresponding flowchart (Figure II.1). The pseudocode of the heuristic algorithm subroutines is also provided here.

Notation

$G(N, A)$ is a directed graph where N is the set of all nodes related to the problem, and A is the set of arcs that connects the nodes.

Nodes and vehicles

- Let $R \subset N$ be the set of all supply points. In particular: $R = \{1,2, \dots, S\}$.
- Let $T \subset N$ be the set of all shelters. In particular: $T = \{1,2, \dots, P\}$.
- Let $K = \{1,2, \dots, v\}$ be the set of available vehicles
- Let $S^k \subset N, k \in K$ be the originating location of vehicle k. In particular: $S^k = \{s^1, s^2, \dots, s^v\}$
- Let $E^k \subset N, k \in K$ be the ending location of vehicle k. In particular: $E^k = \{e^1, e^2, \dots, e^v\}$

Arcs (travel times)

- $Travel\_Times$: Traveling times between all nodes. In particular, the non-zero sand non-empty entries of $Travel\_Times$ are entries
  - $[t_{ij}], i \in S^k, j \in R$
  - $[t_{ij}], i, j \in R, i \neq j$
  - $[t_{ij}], i \in R, j \in T$
  - $[t_{ij}], i, j \in T, i \neq j$

Other

- Let $Shelters' \ Matrix$ be a matrix with IDs, coordinates and demand (into units) per shelter and per commodity
- Let F be the number of clusters to create for grouping shelters
- Let $Clusters$ be a matrix containing F clusters (rows). The non-zero elements of row $i = 1, \dots, F$ are the shelters grouped into cluster i
- Let $Cluster\_Length$ be the number of non-zero elements for each row of $Clusters$
- Let C be the types of commodities

- Let dim be a matrix containing the dimensions of commodities (in meters: length, width, height)
- Let h be the demand matrix for shelters (elements in units).
- Let s be the supply matrix for supply points (elements in units)
- Let vol_h be the demand in volume (m^3)
- Let vol_s be the supply in volume (m^3)
- Let $Shelters\_Coordinates$: Matrix with the coordinates of Shelters
- Let CC denote the current cluster
- Let CC_D be the total demand of current cluster (m^3)
- Let f be a matrix with the ID and the total demand per cluster
- Let $Public\_Vehicle$ be a matrix with the ID, the capacity (m^3) and the coordinates of the starting points for all public vehicles
- Let $Private\_Vehicles$ be a matrix with the ID, the capacity (m^3) and the coordinates of the starting points for all private vehicles
- Let CP be a matrix with the IDs and current point of each vehicle
- Let CV be the current vehicle
- Let Q_k be the capacity of vehicle $k \in K$ (m^3)
- Let num_of_pub be the number of public vehicles
- Let num_of_priv be the number of private vehicles
- Let $Total\_capacity\_of\_public$ be the total capacity of all available public vehicles
- Let $Total\_capacity\_of\_private$ be the total capacity of all available private vehicles
- Let TP be a matrix containing the ID and the coordinates of a reference point. Note the reference point is at the center of gravity of supply points
- Let AVL be a list including all available vehicles along with their ID, their total traveling time and their capacity (m^3)
- Let $loading\_time \equiv uloading\_time$ be 9 min for loading 3 m^3 (assumption).
- Let Var_Map be a matrix including the following
  $[\#\ of\ public\ vehicles, \#\ of\ private\ vehicles, \#\ \text{of shelters}, \#\ \text{of supply points}, \#\ \text{of Reference Points}]$
- Let VL be the on board inventory per commodity for a vehicle
- Let d be a matrix containing the volume per commodity to be collected by a vehicle for each supply point
- Let $\hat{d}$ be a matrix containing the volume per commodity to be delivered by a vehicle for each shelter
- Let $Final\ Routes$ be the routes of supply plan
- Let $load\_t$ be the total loading time of a vehicle at a supply point

- Let $unloading\_time$: It is the time it takes a vehicle to unload commodities to a Shelter. Like $load\_t$, by default, it takes 9 minutes to unload 0-3 m^3, 18 minutes to unload 3-6 $m^3, etc.$
- Let SM_route be the initial sequence of visits to supply points
- Let SM_Final_Route be an improved version of SM_route
- Let NI be the useful inventory per supply point and per commodity
- $necessary\_inventory$ be the necessary at the current cluster amount of commodities which need to be collected by a vehicle
- Let x be a threshold for vehicle's remaining capacity
- Let y be a threshold for deciding on visiting a next note of a given route
- Let Dev be the total sum of commodities deviation ($necessary\_inventory - NI$) for all supply points
- Let SM_Selection be a matrix containing the supply points' IDs, the corresponding element of matrix Dev for each supply point, and the time distance from CV's CP to each supply point
- Let $nearestSM$ be a matrix with the distances of each supply point from the reference point
- Let T be a matrix with the total service time for each shelter
- Let $Total\_Demand$ be the total demand of all shelters (m^3)

The heuristic algorithm is executed according to the following steps:

Step 1. Define and create vectors and matrices to be used by the algorithms

Step 1.1. Define a reference point (noted as $Temporary\ Point$) which will be located at the area of supply points

Step 1.2. Create a vector named: Var_Map. It includes the number of vehicles (public and private), shelters and supply points

Step 1.3. Create $Travel\ Times$' matrix. It contains the road network and the related distances in minutes between all nodes and the $Temporary\ Point$

Step 1.4. Initialize vector $Current\ Point$. It includes vehicle-related information: vehicle ID (e.g. plate number) and originating location ID

Step 1.5. Group the shelters into clusters, either according to users' preferences or by using *K-means* algorithm

Step 1.6. Convert all the amounts of commodities (demand and inventory) into m^3

Step 1.7. Create AVL which includes all information needed for public and private vehicles, from all the available vehicles to be used by the algorithm. During vehicle selection, priority is given to public vehicles

Step 2. While the total demand of Shelters (into volume) is higher than zero

Step 2.1. Set the cluster with the highest demand as $Current\ Cluster$

Step 2.2. Set as $Current\ Vehicle$ the vehicle with the lowest capacity that can cover the total demand of the selected cluster. In case there is no such a vehicle, select the vehicle with the highest capacity among all

Step 2.3. Create a route for all nodes (shelters) of the $Current\ Cluster$, using the *Clark & Wright Savings* algorithm

Step 2.4. Select the shelters (of the given route in ***Step 2.3***) that $Current\ Vehicle$ can serve based on the vehicle's capacity and the demand of the shelters, and compute the necessary inventory that it can collect from supply points

Step 2.5. Create a route for supply points to be visited: While the sum of necessary inventory to be loaded on $Current\ Vehicle$ is higher than zero

i. Select the supply point that can provide the highest amount of commodities for serving the $Current\ Cluster$; in case there is more than one such supply points, select the nearest supply point to the $Current\ Point$ of $Current\ Vehicle$

ii. Set a route for visiting supply points by using *Clark & Wright Savings* algorithm

iii. Use *2-opt* algorithm to improve the supply point route

iv. Execute supply points' route and load the vehicle with appropriate commodities from each one

v. Execute shelters' route and unload the appropriate amount of commodities needed at each shelter

Step 2.6. Update $Clusters$ by removing the shelters that are fully served

Step 3. Compute $Total\ Supply\ Time$ as the maximum service time among all shelters

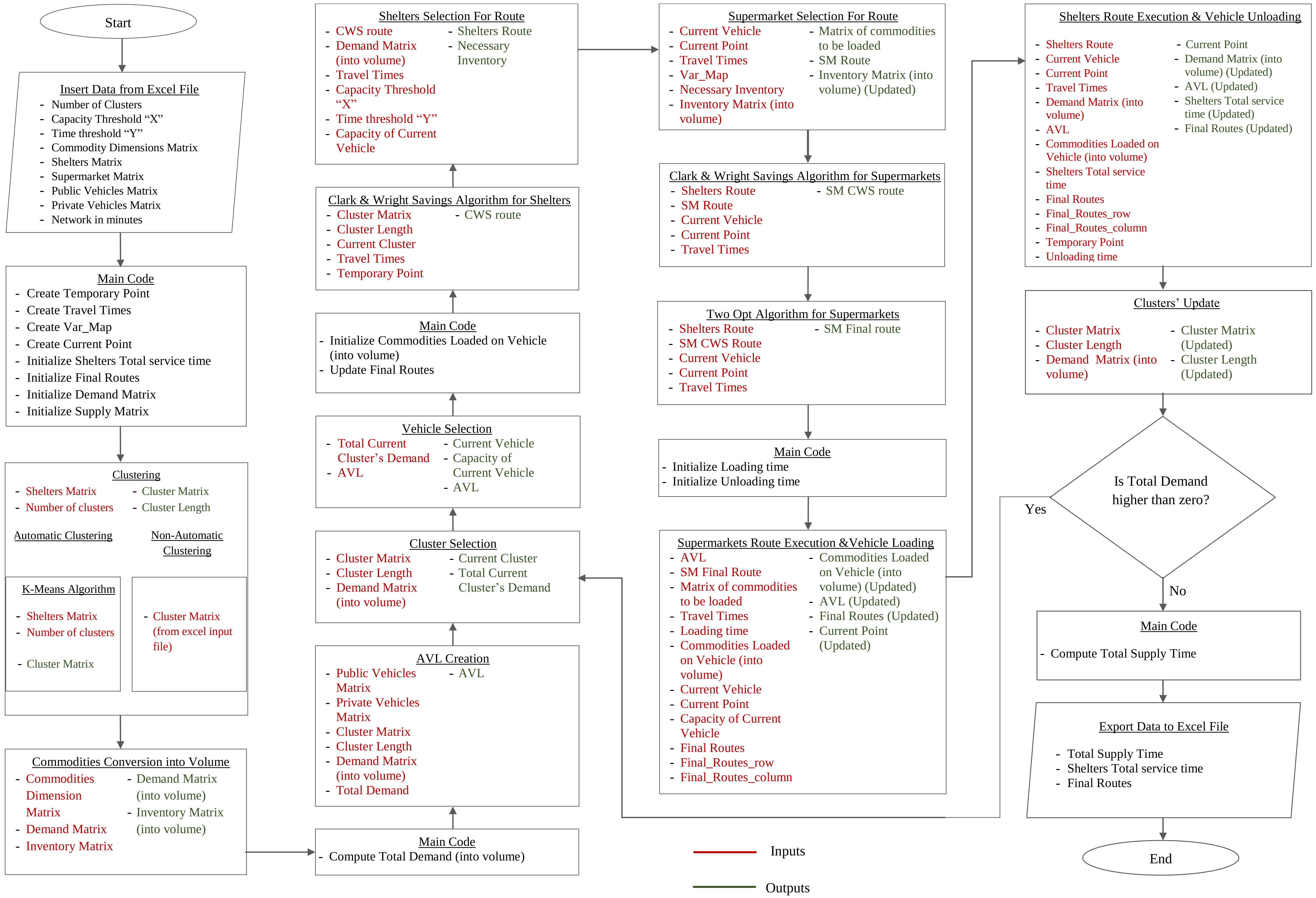

Figure II.1. *Flowchart for the heuristic algorithm for ESHFP*

Below we present the corresponding pseudo codes for the subroutines used by the main algorithm for solving ESHFP, apart from the very well-known Clark and Wright Savings-related routines (**Shelters_CWS, Supermarkets_CWS**).

Subroutines

1. Subroutine Clustering

If manual clustering is selected

- Matrix $Clusters$ is defined by the user by entering the shelters into clusters as desired
- Initialize $Cluster\_length = 0$

For $i = 1 : F$

For $j = 1$: number of columns of $Clusters$

If $Clusters(i, j)$ is not equal to zero

$Cluster\_length(i) = Cluster\_length(i) + 1$

End

End

End

Else if automatic clustering is selected

- Initialize $Shelters\_Coordinates$
- Call $kmeans$ function (matlab function) for grouping the shelters into clusters
- Initialize $Clusters$ and $Cluster\_length$
- Update $Clusters$ and $Cluster\_lengt$ according to the output of $kmeans$

End

2. Subroutine Commodities_Conversion_into_Volume

- Initialize vol
- Initialize vol_s
- Initialize vol_h

For each type of commodity

- Calculate volume per item
- Convert the demand of all shelters for each commodity into m^3
- Convert the supply of all supply points for each commodity into m^3

End

3. Subroutine AVL Creation

- Read for input data num_of_pub
- Read for input data num_of_priv
- Compute the total demand per cluster
- Sort matrix f in descending with respect to clusters' demand
- Compute Total_capacity_of_public
- Compute Total_capacity_of_private
- Initialize AVL $= [\,]$

If $Total\_Demand > Total\_capacity\_of\_public + Total\_capacity\_of\_private$

- Include all public and private vehicles in AVL

Else

- Sort the $Public\_Vehicles$ and $Private\_Vehicles$ in descending order, with respect to vehicles' capacity

For $i = 1 : F$

While $total\ demand\ of\ cluster\ i > 0$

If public vehicles are available (num_of_pub >0)

- Include public vehicle in AVL
- Update the number of available public vehicles

Elseif private vehicles are available (num_of_priv >0)

- Include private vehicle in AVL
- Update the number of available private vehicles

Else

Break

End

End

End

End

- Update AVL

4. Subroutine Cluster_Selection

- Initialize f
- Compute the total demand per cluster
- Set as current cluster (CC) the cluster with the highest demand
- Set as current cluster's demand (CC_D) the demand of CC

5. Subroutine Vehicle_Selection

- Determine the number of vehicles in AVL that have the same minimum traveling time and sort them in ascending order with respect to their capacity
- Set as CV the vehicle with the highest capacity among these vehicles

For $j = 1$: number of vehicle with the same minimum traveling time

If the capacity of vehicle j is higher than the demand of current cluster

- Set vehicle j as CV
- Break the loop

End

End

- Set the capacity of CV, Q_{CV}

6. Subroutine Shelters_Selection_For_Route

- Input: Route (CWS_Route) for shelters resulted by subroutine **Shelters_CWS**
- Set r_{Qcv} as the remaining capacity of CV. Initially $r_{Qcv} = Q_{CV}$
- Initialize $visited\_nodes$. (counter for nodes that will be visited by CV)
- Initialize $necessary\_inventory$

If total demand of first node in $CWS\_Route > r_{Qcv}$

For each commodity $c \in C$

If the demand of first node in CWS_Route for commodity $c \geq r_{Qcv}$

- CV loads $\mathrm{r_{Qcv}}$ m^3 of commodity c

Else

- CV loads the entire demand of first node in CWS_Route for commodity c

End

- Update r_{Qcv}

End

- $visited\_nodes = visited\_nodes + 1$

Else

- Set necessary_inventory = the demand of first node of CWS_Route
- $\mathrm{visited\_nodes} = \mathrm{visited\_nodes} + 1$
- Update r_{Qcv}

For each one (node i) of the remaining nodes in CWS_Route

If node's total demand $\leq r_{Qcv}$

- necessary_inventory = necessary_inventory + node's total demand
- $\mathrm{visited\_nodes} = \mathrm{visited\_nodes} + 1$
- Update $\mathrm{r_{Qcv}}$

Continue

End

If $r_{Qcv} < x\% \cdot Q_{CV}$

- Set time = the time distance needed from CWS_Route$(i-1)$ to CWS_Route(i)+ the time distance needed from CWS_Route(i) to reference point − the time distance needed from CWS_Route$(i-1)$ to reference point

If $time > y$

Continue

Else

If total demand of node $i \geq r_{Qcv}$

For each commodity $c \in C$

If the demand of node i for commodity $c \geq r_{Qcv}$

- Update $necessary\_inventory(c)$

Else

- CV loads the entire demand of node in CWS_Route for commodity c

End

- Update r_{Qcv}

End

- $visited\_nodes = visited\_nodes + 1$

Else

- $necessary\_inventory = necessary\_inventory +$ node's total demand
- $visited\_nodes = visited\_nodes + 1$

End

End

Else

For each commodity $c \in C$

If the volume of demand of node i for commodity $c \geq r_{Qcv}$

- Update $necessary\_inventory(c)$

Else

- CV loads the entire demand of i in CWS_Route for commodity c

End

- Update r_{Qcv}

End

- $visited\_nodes = visited\_nodes + 1$

End

End

End

- Set Shelters_Route = the first "visited nodes" of vector CWS_Route

7. Subroutine Supermarket_Selection_For_Route

- Initialize FPwhich is a copy of matrix CP
- Initialize SM_route
- Initialize matrix d
- Set a counter z=0

While sum of $necessary\_inventory$ > 0

- z=z+1
- Initialize NI
- Initialize Dev
- Initialize SM_Selection.

For all supply points $i \in R$

For all commodities $c \in C$

If $necessary\_inventory(c) > vol\_s(i, c)$

- $NI\ (i, c) = vol\_s(i, c)$

Else

- $NI\ (i, c)$= $necessary\_inventory(c)$

End

- Dev(i)= Dev(i)+ NI (i, c)

End

End

If the vehicle is at a supply point and the sum of NI for all commodities for this supply point > 0

- Set this supply point as CS

Else

- Sort matrix $SM\_Selection$ in ascending order with respect to the total deviation, and then sort it in ascending order with respect to the distance of each supply point from FP of CV
- CS = SM_Selection(1,1)

End

- SM_route(z) = CS

- d(of CS, for all commodities) = NI(of CS, for all commodities)
- FP (CV) = CS
- Update vol_s
- Update necessary_inventory

End

- Update SM_route

8. Subroutine 2-opt_for_sm

- Initialize $\text{best}_{\text{TD}} = 0$ (best total distance of a route)
- Initialize new_TD $= \infty$ (new total distance of a route).
- Initialize a vector named Existing_Route :
- [CP of CV, CWS_Route for supply points, the first shelter of CWS_Route for shelters]
- Determine the number of supply points in CWS_Route for supply points ($number\_of\_SMs$)

If $number\_of\_SMs = 1$

- SM_Final_Route = SM_CWS_Route

Else

While $best\_TD \neq new\_TD$

- best_TD = 0
- Update best_TD = the total distance of a route in Existing_Route
- Set changes = 0. Note that it will be raised to one if there are changes at the route with the best distance.
- Set New_Route = 0

For $i = 1 : number\_of\_SMs$

For $k = i + 1 : number\_of\_SMs + 1$

- $\text{New\_Route}(1{:}\text{i}) = \text{Existing\_Route}(1{:}\text{i})$

For $j = 1 : k - i + 1$

- $\text{New\_Route}(\text{i} + \text{j}) = \text{Existing\_Route}(\text{k} + 1 - \text{j})$

End

- $\text{New\_Route}(\text{k} + 1{:}\text{end}) = \text{Existing\_Route}(\text{k} + 1{:}\text{end})$
- Update new_TD=0
- Update new_TD the total distance of a route in New_Route

If $new\_TD < best\_TD$

- the New_Route = Existing_Route
- best_TD = new_TD
- changes = 1

Break

End

End

If $changes = 1$

- new_TD = Inf

Break

End

End

End

- SM_Final_Route = Existing_Route (2 : end − 1)

End

9. Subroutine SM_Route_Execution_and_Vehicle_Loading

For $i = 1$: number of supply points included in the SM_Final_Route

- Update AVL
- Update VL
- Compute $load\_t$
- Update AVL by adding the $load\_t$, to the traveled time of CV
- Update CP of CV
- Update Q_{CV}
- Include supply point i in $Final\_Routes$ and keep a record of the commodities collected by CV in supply point i

End

10. Subroutine Shelters_Route_Execution

For $j = 1 : length(CWS\_Route\ for\ shelters)$

- Update CV traveling time in AVL
- Set shelter j as CP of CV
- Initialize $\hat{d}$

For each commodity $c \in C$

If onboard amount of c > 0 **AND** demand of shelter j for c > 0

If (onboard amount of c ≥ demand of shelter j for c

- CV delivers the entire demand of shelter j for commodity c

Else

- CV delivers onboard amount of commodity c

End

- Update onboard amount of commodity c
- Update demand of shelter j for commodity c

Else

- Continue with the next commodity

End

End

- Update AVL according to the time needed for serving shelter j
- Update total service time of shelter j
- Update Final_Routes

End

If $Total\_Demand > 0$

- Update AVL
- CV returns to the reference point

End

11.Subroutine Clusters_Update

- Initialize Matrix New_Clusters.
- Initialize Matrix New_Cluster_Length.
- $w = 0$

For all cluster i

- w = w+1

For $j = 1: Clusters'\ Length(i)$

If the total demand of all shelters in $Clusters(i, j) > 0$

- $\text{New\_Clusters\_Length(w)} = \text{New\_Clusters\_Length(w)} + 1$
- Set $\text{New\_Clusters(w, New\_Clusters\_Length(w))} = \text{Clusters(i, j)}$

End

End

If the first column of $New\_Clusters(w) = 0$

- w = w-1

End

End

- Set $\text{Clusters} = \text{New\_Clusters}$ (from the first to the w^{th} row, and all the columns)
- Set $\text{Cluster Length} = \text{New\_Cluster\_Length}$ (from the first to the w^{th} element)

Appendix III: ESHFP: Input Data for the Pilot Test Event case

Necessary data for ESHFP for the Pilot Test Event

The following tables present the necessary data in terms of a) type of commodities that will be offered to the evacuees and the intervention groups for the 1st day at the shelters of Teruel and Villel, b) the available supermarkets that will supply the commodities, c) the shelters that will be used by the evacuees and the intervnetion groups, d) the transportation network that links the supermarkets with the shelters, e) the private and public fleet of vehicles available for the transportation of goods, for the ESHFP. Futher details about the input data are given in the following sections.

1. Commodities

Table III.1, presents the type of commodities, characterized by an ID number, that will be offered to the evacuees and the intervention groups. The table presents also their characteristics (e.g. storage unit, number of items per storage unit, etc).

Table III.1. *Type of commodities and unit characteristics*

Type		Dimensions (m) per item (commodity)			Storage unit (item, carton, pallet)	Number of items (commodity) per storage unit	Volume (in m^3 and in *lt*) per storage unit	Number of storage units per europallet
	Commodity 's ID	Length	Width	Height				
1. Agua mineral (1,5lt)	**334**	0.065	0.070	0.340	carton (plastic stretch film)	6	0.009 *(9)*	84
2. Dairy products. juices	**339**	0.090	0.060	0.210	carton (plastic stretch film)	6	0.007 *(7)*	125
3. Fruits (oranges, apples)	**336**	0.100	0.100	0.100	Wooden or cardboard Fruit Box	6	0.006 *(6)*	40
4. Sandwiches	**338**	0.300	0.070	0.060	cardboard box	15	0.019 *(19)*	40
5. Hygiene kits	**335**	0.200	0.180	0.050	Box	18	0.032 *(32)*	52
6. Mattress or landing mat	**331**	1.800	0.600	0.050	Warp plastic	2	0.108 *(108)*	48

2. Supermarkets

Table III.2, presents the exact location of each supermarket (i.e. address and coordinates) that will supply both the evacuees and the intervention groups along with their corresponding IDs. Furthermore, the daily stock per commodity in units is also presented.

Table III.2. *Location of supermarkets and daily stock per commodity (in units)*

Supermarket's ID	Detailed Address	Coordinates		Supplies (Stock in Units) Per Commodities' ID					
		Latitude	Longitude	334	339	336	338	335	331
77968	Alvimar SCL. Don Jate SA. Polígono La Paz, Calle Berlín, 128. 44195 Teruel	40.3617	-1.1521	1260	1725	2400	0	0	0
77581	Amela y Martín, SL. Polígono La Paz, Calle Irún, Parcela 177 Izq. 44195 Teruel	40.3634	-1.15536	13306	1200	0	0	0	0
77152	Bebinter SA. Polígono La Paz, Calle Estocolmo, 55. 44195 Teruel	40.3589	-1.14533	12096	0	0	0	0	0
77496	Coaliment Aragón SAU. Polígono La Paz, Calle Berlín-Dublín, 42. 44195 Teruel	40.3578	-1.14294	2318	375	2400	0	0	0
77814	Conpol SL. Polígono La Paz, Calle Berlín, 81. 44195 Teruel	40.3609	-1.14923	0	3075	0	0	0	0
77896	Frigoríficos Cervera SL. Polígono La Paz, Calle Génova, Parcela 139. 44195 Teruel	40.3628	-1.15156	29736	7125	0	0	0	0
77638	Frigoríficos La Perla, SL. Polígono La Paz, Calle Colonia, Parcela 62. 44195 Teruel	40.3588	-1.14684	0	26925	0	0	0	0
77574	Horno Paco Sanz SL. Carretera de Cubla, 4. Puerta 5. 44001 Teruel	40.3344	-1.11112	0	75	0	0	0	0
77856	José Galo SL. Polígono La Paz, Calle Génova, 142. 44195 Teruel	40.3639	-1.15116	0	0	0	0	0	0
77491	Logística Terdibe SL. Polígono La Paz, Parcela 246. 44195 Teruel	40.3679	-1.15295	655	1725	0	0	0	0
77821	Distribuciones Manuel Borque SL. Parque Industrial Carretera de San Blas, 10. 44195 Teruel	40.3545	-1.13249	7812	1725	0	0	0	0
77984	Hipermercado Simply. Avenida de Sagunto, s/n. 44002 Teruel	40.3338	-1.08859	958	900	2400	0	0	0
77851	Juancivi SL. Hotel Isabel de Segura. Ronda del Turia, 2. 44002 Teruel	40.3339	-1.10787	0	0	0	600	0	0
77893	Taller Cocina de Teruel SL. Carretera de Cubla, 4. 44001 Teruel	40.335	-1.1108	0	0	0	600	0	0
77875	Asociados Hosteleros de Teruel SL. Carretera Sagunto-Burgos, km 123. 44195 Teruel	40.3591	-1.13831	0	0	0	600	0	0
77857	Cruz Roja Teruel. Polígono Industrial La Paz. 162A. 44195 Teruel	40.3577	-1.13463	0	0	0	0	187	100

3. Shelters

Table III.3, presents the exact location of each shelter as well as the demand per commodity per person for the first day and its ID.

Table III.3. *Location of shelter and daily demand per commodity per person*

Location	ID	Coordinates		Total Demand (units) Per Commodities' ID					
		Latitude	Longitude	334	339	336	338	335	331
Teruel	**66546**	40.33302	-1.08217	480	192	288	288	96	96
Villel	**66789**	40.23628	-1.19423	1370	0	548	274	0	0

For Shelter in Teruel, the demand of supplies should be calculated for 96 citizens that will stay at the shelter for 36 hours (Days 1 and 2).

4. Network

Table III.4, presents the transport network (arcs) that connect the shelters with the supermarkets and the supermarkets themselves.

Table III.4. *Travel times between shelters and supermarkets*

From	To	Network (min)																									
		Public Vehicles	66546							Shelter		Supermarket															
	IDs	66546	66546	66546	66546	66546	66546	66546	66546	66546	66789	77968	77581	77152	77496	77814	77896	77638	77574	77856	77491	77821	77984	77851	77893	77875	77857
Public Vehicles	66546	0	-	-	-	-	-	-	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
Private Vehicles' Starting Point	66546	-	0	-	-	-	-	-	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66546	-	-	0	-	-	-	-	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66546	-	-	-	0	-	-	-	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66546	-	-	-	-	0	-	-	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66546	-	-	-	-	-	0	-	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66546	-	-	-	-	-	-	0	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66546	-	-	-	-	-	-	-	0	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
Shelter	66546	-	-	-	-	-	-	-	-	0	19	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66789	-	-	-	-	-	-	-	-	20	0	22	22	21	20	21	22	22	18	22	21	19	19	20	18	20	20
Supermarket	77968	-	-	-	-	-	-	-	-	12	22	0	2	2	2	1	1	3	8	1	3	5	12	11	10	5	5
	77581	-	-	-	-	-	-	-	-	12	22	2	0	5	7	3	3	5	10	1	3	4	12	11	10	5	5
	77152	-	-	-	-	-	-	-	-	11	21	2	5	0	2	3	4	1	9	2	3	3	11	10	9	4	4
	77496	-	-	-	-	-	-	-	-	10	20	2	6	2	0	4	5	2	8	2	3	2	10	9	8	3	3
	77814	-	-	-	-	-	-	-	-	11	21	1	2	3	4	0	1	2	9	2	2	3	11	10	9	4	4
	77896	-	-	-	-	-	-	-	-	11	21	1	2	4	5	1	0	3	9	1	2	3	11	10	9	4	4
	77638	-	-	-	-	-	-	-	-	12	21	3	4	1	2	2	3	0	9	3	3	4	11	10	10	4	5
	77574	-	-	-	-	-	-	-	-	8	16	8	9	8	7	8	9	8	0	8	8	7	7	2	1	7	7
	77856	-	-	-	-	-	-	-	-	11	21	1	1	2	2	2	1	3	9	0	3	3	11	10	9	4	4
	77491	-	-	-	-	-	-	-	-	11	20	3	3	3	3	2	2	3	8	3	0	3	10	9	9	3	4
	77821	-	-	-	-	-	-	-	-	10	17	3	4	3	2	3	4	3	6	4	4	0	9	7	7	2	3
	77984	-	-	-	-	-	-	-	-	2	19	11	12	13	10	11	11	13	9	11	11	11	0	9	8	12	9
	77851	-	-	-	-	-	-	-	-	9	19	11	12	10	9	10	11	11	5	11	11	9	8	0	5	9	9
	77893	-	-	-	-	-	-	-	-	9	19	9	10	9	8	9	10	10	1	10	9	7	8	4	0	8	8
	77875	-	-	-	-	-	-	-	-	10	19	3	3	2	1	2	2	3	7	2	2	2	9	8	8	0	3
	77857	-	-	-	-	-	-	-	-	10	20	4	5	4	3	4	4	4	8	4	4	2	9	8	8	2	0

5. Public Vehicles

Table III.5, presents the fleet of public vehicles that are available for the transportation of commodities from the aforementioned supermarkets to the two (2) shelters. As it can be seen, only one vehicle with hydraulic door is available. The table provides the capacity of the vehicle (in m^3) as well as the information about the starting point (depot) of the vehicle.

Table III.5. *Public vehicles for supply transportation*

Type of Vehicle	ID	Number of Each Type of Vehicle	Capacity (in m^3)	Model	Technical Characteristics	Hydraulic Door	Starting Point					Coordinates	
							Company Name	Address	ID	Number	City	Latitude	Longitude
Truck	9930	1	7.68	-	-	Yes	Diputación de Teruel	Polígono La Paz, Calle Berlín	66546	N/A	Teruel	40.33302	-1.08217

6. Private Vehicles

Table III.6, presents the fleet of private vehicles that are available for the transportation of commodities from the aforementioned supermarkets to the two (2) shelters. As it can be seen, seven (7) trucks with hydraulic doors are available. The table provides the capacity of the vehicles (in m^3) as well as the information about the starting point (depot) of the vehicle.

Table III.6. *Private vehicles for supply transportation*

Type of Vehicle	ID	Number of Each Type of Vehicle	Capacity (in m^3)	Model	Technical Characteristics	Hydraulic Door	Starting Point					Coordinates	
							Company Name	Address	ID	Number	City	Latitude	Longitude
Truck	8845	1	7.68	Iveco Eurocargo	Refrigerator Reinforced Isothermal	Yes	Alvimar SCL. Don Jate S.A.	Polígono La Paz, Berlín	66546	128	Teruel	40.33302	-1.08217
Truck	8875	1	11.52	Iveco Eurocargo		Yes	Alvimar SCL. Don Jate S.A.	Polígono La Paz, Berlín	66546	128	Teruel	40.33302	-1.08217
Truck	8861	1	5.76	Ebro L80	Refrigerator - Isothermal	Yes	Frigorificos La Perla S.L.	Polígono La Paz, Colonia. Parcela 62	66546	16	Teruel	40.33302	-1.08217
Truck	8891	1	5.76	Nissan Cabstar	Isothermal	Yes	Frigorificos Cervera SL	Polígono La Paz, Génova. Parcela 139	66546	-	Teruel	40.33302	-1.08217
Truck	8837	1	5.76	Mercedes Benz	Isothermal	Yes	Frigorificos Cervera SL	Polígono La Paz, Génova. Parcela 139	66546	-	Teruel	40.33302	-1.08217
Truck	8847	1	5.76	-	-	Yes	Bebinter SA	Polígono La Paz, Estocolmo	66546	55	Teruel	40.33302	-1.08217
Truck	8829	1	5.76	Nissan Trade	-	Yes	Bebinter SA	Polígono La Paz, Estocolmo	66546	55	Teruel	40.33302	-1.08217

Appendix IV: ESHFP: Input Data for the case study of daily supply (7-days)

Necessary data for ESHFP for the scenario of daily supply

The following tables present the necessary data in terms of a) type of commodities that will be provided to the evacuees and the intervention groups, b) the available supermarkets that will supply the commodities (same for all days), c) the shelters that will be used by the evacuees and the intervnetion groups per day, d) the transportation network that links the supermarkets with the shelters, e) the private and public fleet of vehicles available for the transportation of goods, for the ESHFP (same for all days). Futher details about the input data are given in the following sections.

1. Commodities

Table IV.1, presents the type of commodities, characterized by an ID number, that will be provided to the evacuees and the intervention groups per day. It also presents their characteristics (e.g. storage unit, number of items per storage unit, etc).

Table IV.1. *Type of commodities and unit characteristics*

Type		Dimensions (m) per item (commodity)			Storage unit (item, carton, pallet)	Number of items (commodity) per storage unit	Volume (in m^3 and in *lt*) per storage unit	Number of storage units per europallet
	Commodity 's ID	Length	Width	Height				
1. Agua mineral (1,5lt)	**334**	0.0650	0.0700	0.3400	carton (plastic stretch film)	6	0.009 *(9)*	84
2. Dairy products. juices	**339**	0.0900	0.0600	0.2100	carton (plastic stretch film)	6	0.007 *(7)*	125
3. Fruits (oranges, apples)	**336**	0.1000	0.1000	0.1000	Wooden or cardboard Fruit Box	6	0.006 *(6)*	40
4. Sandwiches	**338**	0.3000	0.0700	0.0600	cardboard box	15	0.019 *(19)*	40
5. Hygiene kits	**335**	0.2000	0.1800	0.0500	Box	18	0.032 *(32)*	52
6. Mattress or landing mat	**331**	1.8000	0.6000	0.0500	Warp plastic	2	0.108 *(108)*	48

2. Supermarkets

Table IV.2, presents the exact location of each supermarket (i.e. address and coordinates) that will supply both the evacuees and the intervention groups along with their corresponding IDs. Furthermore, the daily stock per commodity in units is also presented.

Table IV.2. *Location of supermarkets and daily stock per commodity (in units)*

Supermarket's ID	Detailed Address	Coordinates		Supplies (Stock in Units) Per Commodities' ID					
		Latitude	Longitude	334	339	336	338	335	331
77968	Alvimar SCL. Don Jate SA. Polígono La Paz, Calle Berlín, 128. 44195 Teruel	40.3617	-1.1521	1260	1725	2400	0	0	0
77581	Amela y Martín, SL. Polígono La Paz, Calle Irún, Parcela 177 Izq. 44195 Teruel	40.3634	-1.15536	13306	1200	0	0	0	0
77152	Bebinter SA. Polígono La Paz, Calle Estocolmo, 55. 44195 Teruel	40.3589	-1.14533	12096	0	0	0	0	0
77496	Coaliment Aragón SAU. Polígono La Paz, Calle Berlín-Dublín, 42. 44195 Teruel	40.3578	-1.14294	2318	375	2400	0	0	0
77814	Conpol SL. Polígono La Paz, Calle Berlín, 81. 44195 Teruel	40.3609	-1.14923	0	3075	0	0	0	0
77896	Frigoríficos Cervera SL. Polígono La Paz, Calle Génova, Parcela 139. 44195 Teruel	40.3628	-1.15156	29736	7125	0	0	0	0
77638	Frigoríficos La Perla, SL. Polígono La Paz, Calle Colonia, Parcela 62. 44195 Teruel	40.3588	-1.14684	0	26925	0	0	0	0
77574	Horno Paco Sanz SL. Carretera de Cubla, 4. Puerta 5. 44001 Teruel	40.3344	-1.11112	0	75	0	0	0	0
77856	José Galo SL. Polígono La Paz, Calle Génova, 142. 44195 Teruel	40.3639	-1.15116	0	0	0	0	0	0
77491	Logística Terdibe SL. Polígono La Paz, Parcela 246. 44195 Teruel	40.3679	-1.15295	655	1725	0	0	0	0
77821	Distribuciones Manuel Borque SL. Parque Industrial Carretera de San Blas, 10. 44195 Teruel	40.3545	-1.13249	7812	1725	0	0	0	0
77984	Hipermercado Simply. Avenida de Sagunto, s/n. 44002 Teruel	40.3338	-1.08859	958	900	2400	0	0	0
77851	Juancivi SL. Hotel Isabel de Segura. Ronda del Turia, 2. 44002 Teruel	40.3339	-1.10787	0	0	0	600	0	0
77893	Taller Cocina de Teruel SL. Carretera de Cubla, 4. 44001 Teruel	40.335	-1.1108	0	0	0	600	0	0
77875	Asociados Hosteleros de Teruel SL. Carretera Sagunto-Burgos, km 123. 44195 Teruel	40.3591	-1.13831	0	0	0	600	0	0
77857	Cruz Roja Teruel. Polígono Industrial La Paz. 162A. 44195 Teruel	40.3577	-1.13463	0	0	0	0	187	100

3. Shelters

Table IV.3, presents the exact location of each shelter as well as the demand per commodity per person for the first day and its ID.

Table IV.3. *Location of shelter and daily demand per commodity per person*

Location	ID	Coordinates		Total Demand (units) Per Commodities' ID					
		Latitude	Longitude	334	339	336	338	335	331
Day 1									
Teruel	66546	40.33302	-1.08217	480	192	288	288	96	96
Mas De la Cabrera	66782	40.1553	-1.2428	513	0	171	171	0	0
Villel	66789	40.23628	-1.19423	1370	0	548	274	0	0
Day 2									
Teruel	66546	40.33302	-1.08217	288	96	192	192	0	0
Villel	66789	40.23628	-1.19423	915	0	366	183	0	0
Days 3 & 4 (per day)									
San Blas	66501	40.35815	-1.17850	915	0	366	183	0	0
Days 5, 6 & 7 (per day)									
San Blas	66501	40.35815	-1.17850	705	0	282	141	0	0

Table IV.4, presents the daily number of the staff of the intervention groups (Shelters Mas de la Cabrera, Ville and, San Blass) that will be served.

Table IV.4. *Total staff of intervention groups per shelter (in daily basis)*

Day	People/Day	Mas de la Cabrera	Villel	San Blas	Total people/day
1st	139	341	-	-	432
1st	202		-	-	
1st	91	-	274	-	
2nd	183	-		-	183
3rd	183	-	-	789	183
4th	183	-	-		183
5th	141	-	-		141
6th	141	-	-		141
7th	141	-	-		141

4. Network

Table IV.5, presents the transport network (arcs) that connect the shelters with the supermarkets and the supermarkets themselves.

Table IV.5. *Travel times between shelters and supermarkets*

From	To	Network (min)																											
		Public Vehicles’ Starting Point	Private Vehicles' Starting Point							Shelter				Supermarket															
	IDs	66546	66546	66546	66546	66546	66546	66546	66546	66546	66782	66789	66501	77968	77581	77152	77496	77814	77896	77638	77574	77856	77491	77821	77984	77851	77893	77875	77857
Public Vehicles’	66546	0	-	-	-	-	-	-	-	-	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
Private Vehicles' Starting Point	66546	-	0	-	-	-	-	-	-	-	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66546	-	-	0	-	-	-	-	-	-	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66546	-	-	-	0	-	-	-	-	-	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66546	-	-	-	-	0	-	-	-	-	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66546	-	-	-	-	-	0	-	-	-	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66546	-	-	-	-	-	-	0	-	-	-	-	-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66546	-	-	-	-	-	-	-	0	-	-		-	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
Shelter	66546	-	-	-	-	-	-	-	-	0	32	19	11	13	12	13	12	13	11	13	8	11	11	11	2	9	8	11	9
	66782									33	0	19	35	35	35	34	33	34	35	35	31	35	35	33	32	33	31	33	33
	66789	-	-	-	-	-	-	-	-	20	19	0	21	22	22	21	20	21	22	22	18	22	21	19	19	20	18	20	20
	66501	-	-	-	-	-	-	-	-	11	34	20	0	5	4	6	5	6	5	6	9	5	4	5	11	10	9	5	6
Supermarket	77968	-	-	-	-	-	-	-	-	12	35	22	6	0	2	2	2	1	1	3	8	1	3	5	12	11	10	5	5
	77581	-	-	-	-	-	-	-	-	12	35	22	5	2	0	5	7	3	3	5	10	1	3	4	12	11	10	5	5
	77152	-	-	-	-	-	-	-	-	11	34	21	6	2	5	0	2	3	4	1	9	2	3	3	11	10	9	4	4
	77496	-	-	-	-	-	-	-	-	10	33	20	5	2	6	2	0	4	5	2	8	2	3	2	10	9	8	3	3
	77814	-	-	-	-	-	-	-	-	11	34	21	6	1	2	3	4	0	1	2	9	2	2	3	11	10	9	4	4
	77896	-	-	-	-	-	-	-	-	11	34	21	5	1	2	4	5	1	0	3	9	1	2	3	11	10	9	4	4
	77638	-	-	-	-	-	-	-	-	12	34	21	6	3	4	1	2	2	3	0	9	3	3	4	11	10	10	4	5
	77574	-	-	-	-	-	-	-	-	8	29	16	9	8	9	8	7	8	9	8	0	8	8	7	7	2	1	7	7
	77856	-	-	-	-	-	-	-	-	11	34	21	5	1	1	2	2	2	1	3	9	0	3	3	11	10	9	4	4
	77491	-	-	-	-	-	-	-	-	11	33	20	5	3	3	3	3	2	2	3	8	3	0	3	10	9	9	3	4
	77821	-	-	-	-	-	-	-	-	10	30	17	4	3	4	3	2	3	4	3	6	4	4	0	9	7	7	2	3
	77984	-	-	-	-	-	-	-	-	2	32	19	12	11	12	13	10	11	11	13	9	11	11	11	0	9	8	12	9
	77851	-	-	-	-	-	-	-	-	9	32	19	11	11	12	10	9	10	11	11	5	11	11	9	8	0	5	9	9
	77893	-	-	-	-	-	-	-	-	9	30	19	10	9	10	9	8	9	10	10	1	10	9	7	8	4	0	8	8
	77875	-	-	-	-	-	-	-	-	10	32	19	6	3	3	2	1	2	2	3	7	2	2	2	9	8	8	0	3
	77857	-	-	-	-	-	-	-	-	10	32	20	5	4	5	4	3	4	4	4	8	4	4	2	9	8	8	2	0

5. Public Vehicles

Table IV.6, presents the fleet of public vehicles that are available for the transportation of commodities from the aforementioned supermarkets to the two (2) shelters. As it can be seen, only one vehicle with hydraulic door is available. The table provides the capacity of the vehicle (in m^3) as well as the information about the starting point (depot) of the vehicle.

Table IV.6. *Public vehicles for supply transportation*

Type of Vehicle	ID	Number of Each Type of Vehicle	Capacity (in m^3)	Model	Technical Characteristics	Hydraulic Door	Starting Point					Coordinates	
							Company Name	Address	ID	Number	City	Latitude	Longitude
Truck	9930	1	7.68	-	-	Yes	Diputación de Teruel	Polígono La Paz, Calle Berlín	66546	N/A	Teruel	40,33302	-1,08217

6. Private Vehicles

Table IV.7, presents the fleet of private vehicles that are available for the transportation of commodities from the aforementioned supermarkets to the two (2) shelters. As it can be seen, seven (7) trucks with hydraulic doors are available. The table provides the capacity of the vehicles (in m^3) as well as the information about the starting point (depot) of the vehicle.

Table IV.7. *Private vehicles for supply transportation*

Type of Vehicle	ID	Number of Each Type of Vehicle	Capacity (in m^3)	Model	Technical Characteristics	Hydraulic Door	Starting Point					Coordinates	
							Company Name	Address	ID	Number	City	Latitude	Longitude
Truck	8845	1	7.68	Iveco Eurocargo	Refrigerator Reinforced Isothermal	Yes	Alvimar SCL. Don Jate S.A.	Polígono La Paz, Berlín	66546	128	Teruel	40.33302	-1.08217
Truck	8875	1	11.52	Iveco Eurocargo		Yes	Alvimar SCL. Don Jate S.A.	Polígono La Paz, Berlín	66546	128	Teruel	40.33302	-1.08217
Truck	8861	1	5.76	Ebro L80	Refrigerator - Isothermal	Yes	Frigorificos La Perla S.L.	Polígono La Paz, Colonia. Parcela 62	66546	16	Teruel	40.33302	-1.08217
Truck	8891	1	5.76	Nissan Cabstar	Isothermal	Yes	Frigorificos Cervera SL	Polígono La Paz, Génova. Parcela 139	66546	-	Teruel	40.33302	-1.08217
Truck	8837	1	5.76	Mercedes Benz	Isothermal	Yes	Frigorificos Cervera SL	Polígono La Paz, Génova. Parcela 139	66546	-	Teruel	40.33302	-1.08217
Truck	8847	1	5.76	-	-	Yes	Bebinter SA	Polígono La Paz, Estocolmo	66546	55	Teruel	40.33302	-1.08217
Truck	8829	1	5.76	Nissan Trade	-	Yes	Bebinter SA	Polígono La Paz, Estocolmo	66546	55	Teruel	40.33302	-1.08217

Appendix V: Output Data for the case study of daily supply (7-days)

The following tables present the solution including the provisions supply schedule for ESHFP for Scenario B which was presented in Chapter 5.2. More specifically, the provisions supply plan for Day 2 is shown in Table V.1., the provisions supply plan for the day 3 & 4 is shown in Table V.2. Note that the demand at the accommodation sites of the intervention groups for Days 3 and 4 is exactly the same, and, thus, the same supply plan will be adopted for these two days. This is also the case for days 5, 6 and 7 which provisions supply plan, is shown in Table V.3.

Table V.1. *Provisions supply plan for Day 2*

Number of Route	1			1		
Vehicle ID	9930 (PB)			8875 (PR)		
Route Starting Time	0			0		
Ending Time	56			49		
	ID of Supermarket / Shelter	**Commodity ID**	**Quantity (into cubic meters)**	**ID of Supermarket / Shelter**	**Commodity ID**	**Quantity (into cubic meters)**
Supermarkets	77984	334	1,416	77875	334	0
		339	0		339	0
		336	0,366		336	0
		338	0		338	0,242
		335	0		335	0
		331	0		331	0
	77893	334	0	77496	334	0,446
		339	0		339	0,109
		336	0		336	0,192
		338	0,231		338	0
		335	0		335	0
		331	0		331	0
Shelters	66789 Villel	334	1,416	66546 Teruel	334	0,446
		339	0		339	0,109
		336	0,366		336	0,192
		338	0,231		338	0.242
		335	0		335	0
		331	0		331	0

Cluster	**Shelter ID**	**Shelter Service Time (in min)**	**Total Supply Time**
1	66546	49	**56**
2	66789	56	

*PB = Public Vehicle
*PR = Private Vehicle

Table V.2. *Provisions supply plan for Days 3 & 4*

Number of Route	1		
Vehicle ID	9930 (PB)		
Route Starting Time	0		
Ending Time	47		
	ID of Supermarket / Shelter	**Commodity ID**	**Quantity (into cubic meters)**
Supermarkets	77984	334	1,416
		339	0
		336	0,366
		338	0
		335	0
		331	0
	77893	334	0
		339	0
		336	0
		338	0,231
		335	0
		331	0
Shelters	66501 San Blas	334	1,416
		339	0
		336	0,366
		338	0,231
		335	0
		331	0
Cluster	**Shelter ID**	**Shelter Service Time (in min)**	**Total Supply Time**
1	66501	47	**47**

*PB = Public Vehicle
*PR = Private Vehicle

Table V.3. *Provisions supply plan for Days 5, 6 & 7*

Number of Route	1		
Vehicle ID	9930 (PB)		
Route Starting Time	0		
Ending Time	47		
	ID of Supermarket / Shelter	**Commodity ID**	**Quantity (into cubic meters)**
Supermarkets	77984	334	1,091
		339	0
		336	0,282
		338	0
		335	0
		331	0
	77893	334	0
		339	0
		336	0
		338	0,178
		335	0
		331	0
Shelters	66501 San Blas	334	1,091
		339	0
		336	0,282
		338	0,178
		335	0
		331	0
Cluster	**Shelter ID**	**Shelter Service Time (in min)**	**Total Supply Time**
1	66501	47	**47**

***PB = Public Vehicle**
***PR = Private Vehicle**