UNIVERSIDAD AUTÓNOMA DE BAJA CALIFORNIA

LATIN AMERICAN JOURNAL OF APPLIED ENGINEERING

Design of a Genetic Algorithm with Hybrid Initialization for the 2E-LRP Solution Considering Heterogeneous Fleet

Diseño de un Algoritmo Genético con Inicialización Híbrida para la Solución 2E-LRP Considerando Flota Heterogénea

Andrés Guillermo Angarita Monroy
Faculty of physical-mechanical Engineering, School of Industrial and Business Studies
Industrial University of Santander
**Corresponding author: andres2198626@correo.uis.edu.co*

Abstract— Humanitarian logistics is one of the main means to face the negative effects of adverse events that put at risk the integrity or life of human beings. In this sense, the present work addresses the problem of localization and multi-scale routing, in order to design a computational tool, which allows to achieve a timely delivery of the necessary resources to meet such emergencies. The problem is formulated as a mixed integer linear programming model, taking into account the objective of minimizing the total cost and considering heterogeneous fleet. As a solution method, a genetic algorithm is developed and a new solution coding is proposed. Numerical experiments show that, for instances up to 600 customers, adequate solutions are obtained in a reasonable computation time. Finally, the statistical analysis allows inferring that the genetic components: population size, number of generations and crossover probability, have a great impact on the quality and performance of the proposed algorithm.

***Keywords*—**Genetic algorithm, location, multi-echelon, routing.

***Resumen*—** La logística humanitaria es uno de los principales medios para afrontar los efectos negativos de eventos adversos que ponen en riesgo la integridad o la vida propia del ser humano. En este sentido, el presente trabajo aborda el problema de localización y ruteo multi-escalón, con el fin de diseñar una herramienta computacional, que permita lograr una entrega oportuna de los recursos necesarios para atender dichas emergencias. El problema es formulado como un modelo de programación lineal entera mixta, teniendo en cuenta el objetivo de minimizar el costo total y considerando flota heterogénea. Como método de solución, se desarrolla un algoritmo genético y se propone una nueva codificación de la solución. Los experimentos numéricos muestran que, para instancias hasta de 600 clientes, se obtienen soluciones adecuadas en un tiempo de cómputo razonable. Finalmente, el análisis estadístico permite inferir que los componentes genéticos: tamaño de la población, número de generaciones y probabilidad de cruce, tienen una gran incidencia en la calidad y rendimiento del algoritmo propuesto.

***Palabras Claves*—**Algoritmo genético, localización, multi-escalón, ruteo.

I. INTRODUCTION

THE occurrence of natural disasters and their devastating consequences are a reality experienced year after year around the world. Approximately 75% of the world's population lives in regions affected at least once between 1980 and 2015 by an earthquake, hurricane, flood or drought. As a consequence of these phenomena, more than 184 people die every day in different parts of the world, resulting in the destruction of fixed assets and physical capital, the interruption of production and trade, and a decrease in public and private savings and investments, which put an end to progress in economic development [1]. This problem has attracted the attention of various actors in society, especially academics and government leaders, who have been concerned with seeking and establishing the necessary mechanisms to improve the response to emergency situations, thus giving rise to the emergence of humanitarian logistics as a means of dealing with the negative effects of adverse events that jeopardize the integrity or life of human beings. On the other hand, the relationship between humanitarian supply chain management and the Two Echelon Location Routing Problem (2E-LRP) is very close, because as different scenarios of natural disasters occur, humanitarian aid becomes a pressing need, and the response time, obtained from an adequate design of the logistics network (location of facilities and route planning), plays an extremely important role and implies a series of challenges, which must be overcome in order to achieve timely attention and delivery of the necessary resources to the affected population. It is also important to mention that location and routing decisions have generally been studied independently; this fact can be explained by the fact that location is a strategic decision, which is taken over a long period of time, while routing is an operational decision that is dynamically modified over a short period of time. However, these decisions are closely related, considering that the decision to locate a warehouse is often influenced by transportation costs and vice versa [2], besides playing a very important role in the overall reduction of costs necessary to build the logistics supply chain.

II. JUSTIFICATION

Currently, disasters, regardless of their origin (whether natural or human), are considered social phenomena whose damages could be prevented and mitigated to reduce or at least control their effects [3]. Thus, the incorporation of risk management for disaster attention takes on great importance, as it is the means with the greatest effectiveness to reverse the negative impacts caused by these types of events in the affected regions. Therefore, it is at this point where humanitarian logistics plays one of the most important roles, since it is responsible for planning, implementing and controlling the efficiency, cost-effectiveness, flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption, crucial for the effectiveness and speed in response activities [4].

The variety of logistics operations in disaster relief is so extensive that humanitarian logistics becomes the most expensive part of disaster relief operations, representing approximately 80% of the total costs [5]; that is why the studies and constant efforts in this area are mainly focused on the development of tools that allow to make the best use of available resources to face future threats. In view of the above, there is a need to create a model capable of providing sufficient information to the person in charge of the logistics network to make the best decisions related to the location and distribution of humanitarian resources, in order to guarantee the timely delivery of supplies to the affected regions at the lowest possible cost and time, thus minimizing the negative economic and social impacts.

III. LITERATURE REVIEW

The first research on 2E-LRP was conducted by [6], who carried out a comparative study of heuristics for the two-level location and routing problem, based on a real case: the newspaper distribution process. Taking the case study as a reference, [7] publishes an article in which he analyzes, presents and develops some solution methods for the multilevel routing and location problem, taking into account realistic dimensions (4500 customers).

On the other hand, the most outstanding literature shows that [8] propose a mathematical formulation for a set of dynamic scenarios based on the general multilevel routing and location problem (N-Echelon Location Routing Problem, NE-LRP). The computational tests are limited to the location of facilities, transshipment points and the assignment of large customers and zones to distribution centers, thus presenting the first echelons towards the study of network design problems for distribution. Furthermore, [9] conceptualizes and designs a general notation for the n-echelon location and routing problem in tactical and operational planning. The research is illustrated through six real cases: postal and parcel systems, newspaper delivery companies, logistics systems for urban goods delivery, multimodal transportation, grocery distribution, home delivery services, and e-commerce trends. It is also important to highlight the research of [10], who build a tabu search (Tabu Search, TS) algorithm to provide a solution to the two-echelon vehicle location and routing problem (2E-LRP). A year later, [11] present a detailed study of routing models for two-echelon routing in distribution systems (2E-LRMFDSD). The problem arises when considering within the same decision process the location of facilities in two adjacent tiers, together with routing plans. The study concludes by highlighting the great use and applicability of 2E-LRP systems in the solution of real problems and the potential source of research that the subject presents.

Continuing the review, [12] develop a hybrid algorithm, composed of a Greedy Randomized Adaptive Search Procedure (GRASP) completed by a Learning Process (LP) and Path Relinking (PR), in order to provide a solution to the two-step location-routing problem. Reference [13] present research based on incorporating location, routing and inventory related decisions in multi-objective problems for supply chain design. The mathematical model considers risk pooling, the existence of inventory at distribution centers (DCs) with uncertain demand, various alternatives for transporting product between facilities, and routing from DCs to the customer, under a simultaneous multilevel stochastic supply chain approach. In addition, [14] propose a Two-Echelon Multi-Products Location-Routing Problem with Pickup and Delivery (LRP-MPPD-2E) location-routing model using Mixed Integer Linear Programming (MILP), which includes constraints not considered in previous VRP research, such as: pickup and delivery on the same route, use of one or more intermediate processing centers on the same route, and demand for multiple products. Authors in [15] conduct a study focused on the Multi-objective Inventory Location Routing Problem with Fuzzy Demands (MO-ILRPFD). The model considers multiple periods and multiple products with heterogeneous fleets, in a double tier distribution network, fulfilling two conflicting objectives: minimizing the total cost (vehicle usage, inventory, transportation and distribution center location), and minimizing the product shortage for each customer.

Unlike previous studies, [16] create a model for multi-level location, routing and inventory with stochastic demand. To provide a solution to the studied problem, a genetic algorithm (GA) is constructed, which presents a non-binary encoding; in addition, the authors present a new approach for the application and interpretation of crossover and mutation operators. Also, [17] design a hybrid algorithm (genetic algorithm and simulated annealing) to provide a solution to the two-echelon location-routing problem with simultaneous pickup and delivery, considering fuzzy demand. The results obtained by solving the problem for different sizes, allow verifying that the algorithm outperforms other solution methods with respect to computational time, in a reasonable amount of time; furthermore, [18] build a multi-echelon model for the humanitarian supply chain, which considers the location of central warehouses, manages the inventory of perishable products in the pre-disaster phase and sets the routing plans. The authors propose two solution methods, the non-dominated sorting genetic algorithm II (NSGA-II) and the Pareto frontier for benchmark-based non-dominated sorting genetic algorithm II (RPBNSGA-II). Through analysis of variance, they conclude that NSGA-II offers better performance than RPBNSGA-II for small instances, but if one wants to tackle robust problems, RPBNSGA-II is superior to NSGA-II with respect to execution time. In contrast, [19] propose a multi-objective, multi-period, multi-product model for two-stage location, routing, and inventory in humanitarian logistics network design under uncertainty (2S- MOLRIU). They present two solution methods, NSGA-II and the multi-objective particle swarm optimization (MOPSO) algorithm. Statistical comparison under certainty conditions allowed concluding that MOPSO is more efficient in all criteria, but if uncertain conditions are established, NSGA-II generates better results with respect to the diversity criterion. Finally, [20] address the multi-level location and routing problem. The main product of this research is to develop a two-stage method based on an improved Clarke and Wright sparing algorithm for two-, three-, and four-level LRP, minimizing the total cost. Test instances show that, compared with other methods, the proposed method can obtain the solution to 2E-LRP in a shorter time.

So far, the most relevant works associated with 2E-LRP models and their applications in various real-world contexts, including humanitarian logistics, have been presented. As a final step, Table I and Table II are presented to summarize the most important features that have been addressed throughout the review.

Table I. Characteristics associated with the 2E-LRP.

Convention	**Interpretation**
1	Application
2	Mathematical formulation
3a	Mono-objective
3b	Multi-objective
4a	Multi-period
4b	Multi-product
5a	Deterministic parameters
5b	Stochastic parameters
6	Method / Solution algorithm

Table II. Classification of studies related to 2E-LRP.

Author	1	2*	3		4		5		6*
			a	b	a	b	a	b	
[6]	Newspaper distribution	ILP	x				x		Heuristics: Path construction+ Allocation method+ Saving procedure
[7]	Newspaper distribution	ILP	x				x		Heuristics: Location procedure + Saving technique for assignment and routing
[8]	Supply network design	MILP	x				x		CPLEX
[9]	Postal and package systems	ILP	x				x		GAMS
[10]	General	MILP	x				x		TS
[11]	Distribution systems with adjacent installations	MILP	x				x		GAMS
[12]	General	MILP	x				x		GRASP+LP +PR
[13]	Supply chains with inventory	SINLP		x				x	LINGO
[14]	Supply networks with pickup and delivery	MILP	x				x		NNH
[15]	General	MILP		x	x	x		x	GAMS/ CPLEX
[16]	Design of systems that consider inventory	MILP	x			x		x	GA
[17]	Pickup and delivery systems	MILP	x					x	GA+SA
[18]	Humanitarian logistics	MILP		x		x			NSGA-II/ RPBNSGA-II
[19]	Humanitarian network design	MILP		x	x	x	x		MOPSO
[20]	General	MILP	x				x		CW

**Note:* ILP= Integer Linear Programming; MILP= Mixed Integer Linear Programming; SINLP= Sthocastic Integer Non-Linear Programming; TS= Tabu Search; GRASP= Greedy Randomized Adaptive Search Procedure; LP= Learning Process; PR= Path Relinking; NNH= Nearest Neighbor *Heuristic*; GA= Genetic Algorithm; SA= Simulated Annealing; NSGA-II= Non-dominated Sorting Genetic Algorithm II; RPBNSGA-II= Reference Point Based Non-dominated Sorting Genetic

Algorithm II; MOPSO= Multi-Objective Particle Swarm Optimization; CW= Clarke and Wright.

IV. DESCRIPTION AND MATHEMATICAL FORMULATION OF THE PROBLEM

A schematic interpretation of the problem under study is presented below (see Fig. 1).

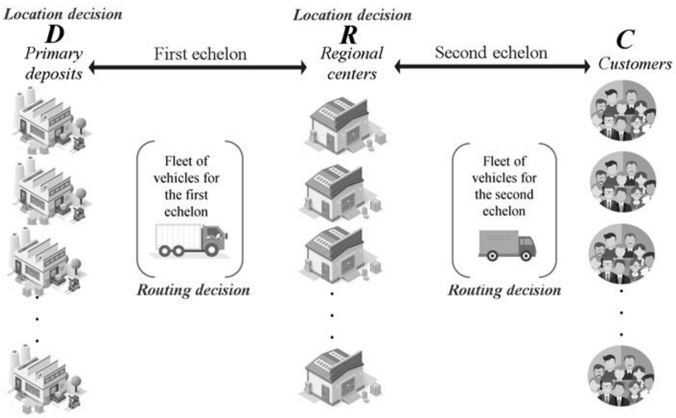

Fig. 1. Representation of the mathematical model for the 2E-LRP.

According to the specifications proposed by [21], the problem under study can be represented as a complete graph $G=(N,A)$, where N represents the set of nodes and A the set of directed edges, moreover, $N=\ D\ U\ R\ U\ C$, where D refers to the set of primary depots (PD), R is associated with the set of regional centers (RC) and C represents the set of customers, on the other hand, $A=E_1 U\ E_2$, where E_1 represents the set of directed edges connecting a primary reservoir $d\in D$ with a regional center $r\in R$ (first echelon), excluding any connection between primary reservoirs, i.e., $E_1=\{\ (i,j): i,j\ \in\ D\ U\ R\ \hat{}\ (i,j)\notin DUD\}$, and similarly, E_2 is the set of directed edges connecting a regional center $r\in R$ with a customer $c\in C$ (second echelon), excluding possible connections between regional centers, i.e., $E_2=\{\ (i,j): i,j\ \in\ R\ U\ C\ \hat{}\ (i,j)\notin RUR\}$.

Based on the formulation presented by [20] and taking into account the researcher's specifications, the mathematical model is developed as presented below:

A. Sets

D = Set of possible primary deposits
R = Set of possible regional centers
C = Set of customers
V = Set of vehicles for first level routes
W = Set of vehicles for second level routes

B. Indexes

d = Index for possible primary deposits
r = Index for possible regional centers
c = Index for customers
v = Index for first level vehicles
w = Index for the second level vehicles

C. Parameters

K_i = Capacity of facility i, $i\in D\ U\ R$
H_i = Capacity of vehicle i, $i\in W\ U\ V$
F_i = Cost of opening facility i, $i\in D\ U\ R$
G_i = Cost of using vehicle i, $i\in W\ U\ V$
D_c = Demand of customer c, $c\ \in C$
S_{ij} = Cost of traveling between node i and node j for the first echelon
T_{ij} = Cost of traveling between node i and node j for the second echelon

D. Decision variables

y_i = 1, if the facility is open at node i, with $i\in D\ U\ R$ and 0 otherwise
m_{ij}^{v} = 1, if the vehicle $v\in V$ travels from node i to node j on the first-level route, with $i\in D\ U\ R\ \hat{}\ j\ \in D\ U\ R$ and 0 otherwise
n_{ij}^{w} =1, if vehicle $w\in W$ travels from node i to node j on the second-level route, with $i\in R\ U\ C\ \hat{}\ j\ \in R\ U\ C$ and 0 otherwise
L_{dr} = 1, if the regional center $r\in R$ is assigned to the primary depot $d\in D$ and 0 otherwise
P_{rc} = 1, if customer $c\in C$ is assigned to regional center $r\in R$ and 0 otherwise
q_i = 1, if vehicle i is used on a route, with $i\ \in W\ U\ V$
F_{dr}^{v} = Flow from primary depot $d\in D$ to regional center $r\in R$ in vehicle $v\in V$
Z = Total cost

E. Objective function

$$\textbf{Minimize } \boldsymbol{Z} = \sum_{r\in R} F_r * y_r + \sum_{d\in D} F_d * y_d + \sum_{w\in W} G_w * q_w + \sum_{v\in V} G_v * q_v + \sum_{w\in W}\sum_{i\in RUC}\sum_{j\in RUC} T_{ij} * n_{ij}^{w} + + \sum_{v\in V}\sum_{i\in DUR}\sum_{j\in DUR} S_{ij} * m_{ij}^{v} \quad (1)$$

F. Restrictions

Subject to:

Second echelon

$$\sum_{r\in R} P_{rc} = 1 \quad \forall\, c\in C \quad (2)$$

$$\sum_{c\in C} D_c * P_{rc} \le K_r * y_r \quad \forall r\in R \quad (3)$$

$$\sum_{w\in W}\sum_{i\in RUC} n_{ic}^{w} = 1 \qquad \begin{matrix}\forall\, c \in C\\ i \neq c\end{matrix} \tag{4}$$

$$\sum_{i\in RUC} n_{ij}^{w} - \sum_{i\in RUC} n_{ji}^{w} = 0 \qquad \begin{matrix}\forall\, w \in W\\ \forall\, j \in R\ U\ C\\ i \neq j\end{matrix} \tag{5}$$

$$\sum_{i\in S'}\sum_{j\in S'} n_{ij}^{w} \leq |S'| - 1 \qquad \begin{matrix}\forall\, w \in W\\ S' \subseteq S\\ |S'| \geq 2\\ i \neq j\end{matrix} \tag{6}$$

$$\sum_{i\in R}\sum_{j\in C} n_{ij}^{w} \leq 1 \quad \forall\, w \in W \tag{7}$$

$$\sum_{w\in W}\sum_{j\in C} n_{rj}^{w} \leq 1 \quad \forall\, r \in R \tag{8}$$

$$\sum_{j\in RUC} n_{rj}^{w} + \sum_{j\in RUC} n_{cj}^{w} - P_{rc} \leq 1 \qquad \begin{matrix}\forall\, r \in R\\ \forall\, c \in C\\ \forall w \in W\\ r \neq j\\ c \neq j\end{matrix} \tag{9}$$

$$\sum_{c\in C}\sum_{i\in RUC} D_c * n_{ic}^{w} \leq H_w * q_w \qquad \begin{matrix}\forall w \in W\\ i \neq c\end{matrix} \tag{10}$$

First echelon

$$\sum_{d\in D} L_{dr} = 1 \quad \forall\, r \in R \tag{11}$$

$$K_d * y_d \geq \sum_{r} K_r * L_{dr} \qquad \forall d \in D \tag{12}$$

$$\sum_{i\in DUR} m_{ij}^{v} - \sum_{i\in DUR} m_{ji}^{v} = 0 \qquad \begin{matrix}\forall\, v \in V\\ \forall\, j \in D\ U\ R\\ i \neq j\end{matrix} \tag{13}$$

$$\sum_{i\in R'}\sum_{j\in R'} m_{ij}^{v} \leq |R'| - 1 \qquad \begin{matrix}\forall\, v \in V\\ R' \subseteq R\\ |R'| \geq 2\\ i \neq j\end{matrix} \tag{14}$$

$$\sum_{i\in D}\sum_{j\in R} m_{ij}^{v} \leq 1 \qquad \forall\, v \in V \tag{15}$$

$$\sum_{v\in V}\sum_{j\in R} m_{dj}^{v} \leq 1 \qquad \forall\, d \in D \tag{16}$$

$$\sum_{j\in DUR} m_{dj}^{v} + \sum_{j\in DUR} m_{rj}^{v} - L_{dr} \leq 1 \qquad \begin{matrix}\forall\, d \in D\\ \forall\, r \in R\\ \forall v \in V\\ d \neq j\\ r \neq j\end{matrix} \tag{17}$$

$$\sum_{v\in V}\sum_{d\in D} F_{dr}^{v} = \sum_{c\in C} D_c * P_{rc} \qquad \forall r \in R \tag{18}$$

$$H_v * \sum_{j\in DUR} m_{dj}^{v} - F_{dr}^{v} \geq 0 \qquad \begin{matrix}\forall\, v \in V\\ \forall\, d \in D\\ \forall r \in R\\ d \neq j\end{matrix} \tag{19}$$

$$H_v * \sum_{j\in DUR} m_{rj}^{v} - F_{dr}^{v} \geq 0 \qquad \begin{matrix}\forall\, v \in V\\ \forall\, d \in D\\ \forall\, r \in R\\ r \neq j\end{matrix} \tag{20}$$

$$\sum_{d\in D}\sum_{r\in R} F_{dr}^{v} \leq H_v * q_v \qquad \forall\, v \in V \tag{21}$$

Integrality

$$n_{ij}^{w} \in \{0,1\}, i \in RUC, j \in RUC \wedge w \in W \tag{22}$$
$$m_{ij}^{v} \in \{0,1\}, i \in DUR, j \in DUR \wedge v \in V \tag{23}$$
$$y_r \in \{0,1\}, r \in R \tag{24}$$
$$y_d \in \{0,1\}, d \in D \tag{25}$$
$$P_{rc} \in \{0,1\}, r \in R \wedge c \in C \tag{26}$$
$$L_{dr} \in \{0,1\}, d \in D \wedge r \in R \tag{27}$$
$$q_w \in \{0,1\}, w \in W \tag{28}$$
$$q_v \in \{0,1\}, v \in V \tag{29}$$
$$F_{dr}^{v} \in \mathbb{Z}^{+}, v \in V, d \in D \wedge r \in R \tag{30}$$

V. INTERPRETATION

Equation (1) is associated with the objective function, which aims to minimize the costs related to the opening of regional centers and primary depots, the cost of using both first and second level vehicles, and the costs generated by routing in each of these. On the other hand, eq. (2) guarantees the assignment of each customer to a single regional center; eq. (3) ensures that the demand of the customers assigned to a regional center does not exceed the capacity of that facility; eq. (4) imposes that each customer must be served by exactly one second-level vehicle; eq. (5) allows each vehicle to return to the same regional center from which it departed. In addition, eq. (6) prevents the formation of sub-tours or illegal routes in the second level; eq. (7) ensures the unique assignment of a vehicle to a specific regional center, if it is enabled; eq. (8) is associated with the use of only one vehicle for each open regional center; eq. (9) is associated with the use of only one vehicle for each open regional center; also, eq. (9) ensures that regional center r serves customer c, if there is a vehicle w leaving r and arriving at c; eq. (10) allows that the demand satisfied by a vehicle does not exceed its capacity, if it is used. Even more, eq. (11) imposes the assignment of each regional center to a single primary depot; eq. (12) refers to the capacity restriction in the primary depots, since, as indicated by this restriction, the capacity of an authorized primary depot must be greater than or equal to the capacity of the regional center assigned to it; eq. (13) guarantees the return to the same primary depot of vehicle v assigned to it. Equation (14) prevents the formation of sub-tours or illegal routes in the first echelon; eq. (15) allows a vehicle to be associated with at most one primary depot if it is open; eq. (16) restricts the use of only one vehicle per primary depot; eq. (17) ensures that primary depot d serves regional center r, if there is a vehicle v leaving d and arriving at r; eq. (18) is related to the conservation of the flow in regional center r, taking into account that the quantity entering the regional center must be equal to the total demand of the assigned customers. Equations (19)-(20) guarantee that the amount of flow in a vehicle v, from a primary depot d to a regional center r is positive, if and only if both the primary depot and the regional center are visited by the same vehicle v and eq. (21) is related to the capacity limitation for a vehicle v (the flow transported in a vehicle v from a primary depot d to a regional center r, must be less than or equal to the capacity of that vehicle). Finally, eq. (22)-(30) establish the nature of the decision variables considered in the model.

VI. APPLICATION OF THE GENETIC ALGORITHM TO THE 2E-LRP

A. Representation of the solution

Each member (solution to the problem) of the population is composed of 6 sub-chains as shown in Fig. 2-7.

First echelon

Sub-chain of CR assignment to enabled PD	1	2	…	R	RC
	6	4		D	PD open

Fig. 2. Sub-chain of RC assignment to enabled PD.

Sub-chain for the assignment of vehicles to enabled PD	6	4	…	D	PD open
	3	9		V	Vehicles

Fig. 3. Sub-chain for the assignment of vehicles to enabled PD.

Sub-chain of routes (first echelon)		
PD_6	…	PD_M
0		0
1		R
8		9
4		0
0		12
-1		0
0		-1
5		0
0		3
		0

Fig. 4. Sub-chain of PD-RC routes for the first echelon.

Second echelon

Sub-chain for assigning clients to enabled RC	1	2	…	C	Customers
	3	4		R	RCopen

Fig.5. Sub-chain for assigning clients to enabled RC.

Sub-chain of assignment of vehicles to enabled CR	3	4	…	R	RC
	7	2		W	Vehicles

Fig. 6. Sub-chain for the assignment of vehicles to enabled RC.

Sub-chain of routes (second echelon)		
RC_3	…	RC_K
0		0
1		C
2		6
4		0
0		-1
-1		0
0		8
7		1
0		0

Fig. 7. Sub-chain of RC-C routes for the second echelon.

According to the evolutionary methodology, the following fundamental sub-processes can be evidenced:

S1. Creation of the initial population: Three techniques are used, the first related to a *saving method*, the second is known as *nearest neighbor* and the third is a *random method*. The percentage participation of each method in the creation of individuals is equal to 30% for the first two procedures and 40% for the last one, taking as a basis for calculation the size *N* of the population.

Saving method: It basically consists of ordering from smallest to largest, the distances or the cost of traveling to a set of points P_k, taking as reference an origin node N_i, to then form according to this sequential order the route *R* that should visit those points.

Nearest neighbor method: This heuristic is based on the idea of moving from one city to the next, in such a way that, of all the options, the city chosen is the closest to where the traveler, i.e., selecting low-cost edges.

Random method: This method consists of the arbitrary design of routes that allow visiting a set of nodes N_i starting from a point P_0.

Once the initial population has been constructed, the development of the temporary population begins, using the genetic operators.

S2. Selection operator (Deterministic + Random tournament): Randomly choose two members of the population, compare their fitness and select the one with the best fitness, that is, the one with the lowest measure of adjustment, thus obtaining parent 1, after this, an individual is randomly chosen again from the population and is defined as parent 2.

S3. Crossover operator (Uniform crossover, with $P_C = 0.9$): When selecting the parents, the algorithm proceeds to generate a random number N_A and verify if the crossover "$N_A < P_C$" is performed. If the answer is positive, it must create a mask of size equivalent to the sub-chain: assignment of clients to the enabled CRs, and apply the logical operation that gives rise to child 1 and child 2.

S4. Mutation operator (Point mutation, with $P_M = 0.025$): Once the population size is met, the algorithm labels each member created with a random number N_A and verifies whether or not the mutation is performed, which consists of randomly exchanging two genes of the sub-chain: assignment of customers to enabled CR; this process is repeated twice.

VII. EXPERIMENTATION

With the development of the framework (computational tool) for the metaheuristic "Genetic Algorithm" in Matlab R2018a software, the next phase is the validation; as the formulated model presents particular study assumptions, its functionality and consistency are checked using numerical experiments. In order to create coherent scenarios that allow an adequate evaluation of the algorithm, in terms of quality (Objective Function, O.F) and performance (Computational Time, C.T), a set of test instances for the 2E-LRP obtained from [22] is taken as a reference and the configurations shown in Table III are developed.

Table III. Test instances for the 2E-LRP.

Number	Instance type
1	50C-10R-7D-16W-10V
2	240C-25R-15D-30W-20V
3	600C-30R-20D-35W-25V

Note: C = Customers, R = Regional Centers, D = Primary depots, W = Second tier vehicles and V = First tier vehicles.

A. *Results*

To solve each proposed instance (see Table III) using the developed framework, the initialization parameters shown in Table IV are used.

Table IV. Parameters of the genetic algorithm.

Parameter	Level
TP	30
NG	35
PC	0,9
PM	0,025

Note: TP = Initial population size, NG = Number of generations or iterations, PC = Probability of crossover and PM = Probability of mutation.

It is important to mention that:

1. The value of the O.F is given in pesos ($) and the C.T in seconds (s).
2. The results shown below are obtained using an iMac computer with an Intel Core i5-5200 2.7 GHZ processor.

Table V. Results instance 1.

I: 50C-10R-7D-16W-10V		
Replica	O.F	C.T
R1	$ 124.529	538,7
R2	$ 143.830	527,3
Average	$ 134.180	533,00

Table VI. Results instance 2.

I: 240C-25R-15D-30W-20V		
Replica	O.F	C.T
R1	$ 2'319.018	734,64
R2	$ 2'299.014	732,31
Average	$ 2'309.016	733,48

Table VII. Results instance 3.

I: 600C-30R-20D-35W-25V		
Replica	O.F	C.T
R1	$ 2'202.110	958,6
R2	$ 2'111.705	977,89
Average	$ 2'156.908	968,25

Table VIII. Genetic algorithm factorial design.

	Level	
Factors	Low (-1)	High (+1)
TP	10	30
NG	15	35
PC	0,9	1
PM	0,025	0,1

According to the results obtained (see Table V, Table VI and Table VII), it is possible to show that for instance 1, the value of the target O.F takes an average value of $134.180 with a C.T of 533 seconds or 8,89 minutes. For instance 2, the average O.F value is equal to $2'309.016 with a C.T equivalent to 733,48 seconds or 12,22 minutes; while for instance 3, the average O.F value is $2'156.908 and the C.T is equal to 968,25 seconds or 16,14 minutes. Therefore, it can be stated that, for several instances, the applied metaheuristic generates good solutions in a reasonable computation time (less than 30 minutes).

VIII. STATISTICAL ANALYSIS

Once the validation stage is over, it is interesting to identify the set of factors that significantly intervene in the performance of the algorithm. Therefore, a 2^k factorial design is performed, with the purpose of achieving a formal understanding of those factors that significantly influence the variables: objective function (O.F) and computational time (C.T). After analyzing the conceptual structure of the metaheuristic, the main factors to be analyzed are defined as: population size (TP), number of generations (NG), crossover probability (PC) and mutation probability (PM), thus obtaining a factorial design of the form 2^4 . The configuration of the factorial design for the proposed instances (see Table III) is presented in Table VIII; in addition, the results are consolidated taking the main effects plot as a reference (see Fig. 8-13).

A. Instance 50C-10R-7D-16W-10V

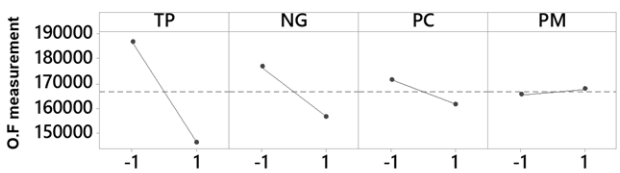

Fig. 8. Main effects plot for the O.F (I_1)

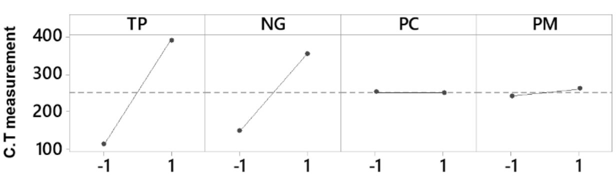

Fig. 9. Main effects plot for C.T (I_1)

B. Instance 240C-25R-15D-30W-20V

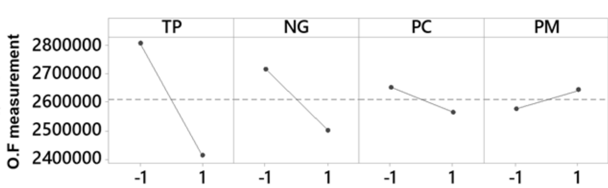

Fig. 10. Main effects plot for the O.F (I_2)

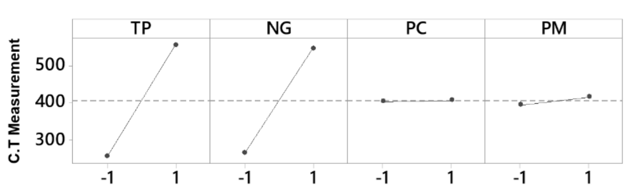

Fig. 11. Main effects plot for C.T (I_2)

C. Instance 600C-30R-20D-35W-25V

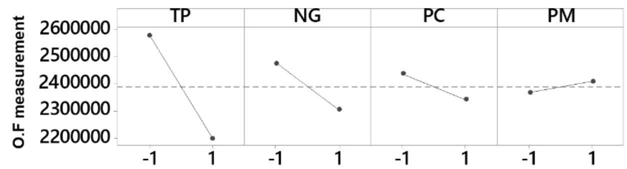

Fig.12. Main effects plot for the O.F (I_3)

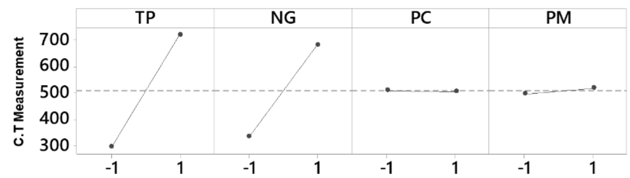

Fig. 13. Main effects plot for C.T (I_3)

IX. CONCLUSIONS

According to the literature review, few authors have addressed the problem of location and routing of multi-level vehicles considering heterogeneous trained fleet, therefore, this study can be considered as a reference for future research in the area of humanitarian logistics and commercial logistics, given that the multidisciplinary approach with which the model was formulated and the framework, allow to adapt it without any inconvenience. In addition, it is important to mention that the considerations presented in the model, together with the new solution method developed, contribute significantly to the work done by [20] since they provide a much more realistic and applicative view of the problem.

The representation of the solution and the logical procedure proposed in the different phases (initialization, selection, crossover and mutation) of the genetic algorithm, greatly facilitate the various algorithmic processes that must be carried out to obtain a feasible solution to the problem under study; as can be seen in the experimentation, the computational time required to solve an instance composed of 600 clients is approximately 17 minutes, which is a reasonable time given the complexity involved in the multi-scale location and distribution system.

The implementation of a hybrid initialization technique for the construction of the population made it possible to limit the search space to the best feasible areas of the problem, thus reducing the loss of time by the algorithm in unnecessary regions, thanks to the nature of the methods (nearest neighbor and saving) implemented. However, it is important to clarify that the application of these heuristic procedures was done under a participation percentage equivalent to 30% for each one and 40% for the random approach, because although it is important to avoid infeasible regions and reduce the search space to the best solutions, it is also vital to maintain diversity in the members created, so the highest percentage of participation in the creation of individuals is assigned to the random procedure, thus avoiding a premature convergence of the algorithm to local optimum.

According to the statistical analysis, it is possible to infer with 95% confidence that the main factors affecting the quality of the solution obtained with the genetic algorithm metaheuristic are: population size (TP), number of generations (NG) and crossover probability (PC); on the other hand, the factors that have a statistically significant effect on the performance (computational time, C.T) of the genetic algorithm are: population size (TP), number of generations (NG) and crossover probability (PM): Population size (TP), number of generations (NG) and mutation probability (PM). Now, if the desired objective is to obtain the lowest possible cost regardless of the computational time required (desired objective in this research), then the high levels (+1) of TP, NG and PC should be chosen, but if the purpose is to achieve good feasible solutions in the shortest possible time, then the low levels (-1) corresponding to TP, NG and PM should be chosen.

Although the proposed solution method was not compared with other metaheuristic or hybrid algorithms presented in the literature, due to the additional considerations that were taken into account when building the model and a basic existence of the test instances for the 2E-LRP found to date of the research, it can be affirmed, based on numerical experiments and experimental design, that the genetic approach developed in the present investigative work has great competitiveness (performance) when facing various scenarios, since that when executing this methodology to solve complex instances in the humanitarian context, they demand a low computational time.

X. FOR FUTURE RESEARCH

From the present research, it is suggested to make some study assumptions more flexible, for example, allowing transshipment between facilities of the same echelon, considering multiple products, dividing the demand of a customer or the load of an enabled regional center and the assignment of multiple vehicles to the same facility; this with the objective of minimizing costs, achieving greater flexibility in the routes, expanding the scope and application that 2E-LRP has in global logistics (humanitarian, commercial and urban).

On the other hand, although uncertainty will make the models more complex, uncertain demand is more realistic, therefore, it would be interesting to consider dynamic, stochastic or fuzzy factors in the behavior of customer demand. It would also be important to include difficult time windows, since in many cases time restrictions to serve a customer or set of customers become a major drawback when obtaining coherent solutions that fit with the reality of the problem. In addition, enabling multi-period planning along with inventory control, which involves decisions about the replenishment cycle and quantity required, will contribute to the development of a much more useful and robust model for supply chain management.

Finally, it is suggested to implement new solution techniques with the purpose of improving the quality of the answers obtained, according to the desired objective (maximizing benefits or minimizing costs) and at the same time, achieving a reduction of the required computational cost; therefore, it would be interesting to experiment with hybrid algorithms or parallel programming techniques.

REFERENCES

[1] United Nations Development Programme; “Informe Mundial: La Reducción de Riesgos de Desastres. Un desafío para el Desarrollo.” [online], 2011, 2010 [date of reference July 13 th of 2018]. https://www.undp.org/content/undp/es/home/librarypage/crisis-prevention-and-recovery/reduction_risques_catastrophes.html

[2] Rand, G.K.; “Methodological choices in depot location studies.” Journal of the Operational Research Society, Vol. 27, no 1, pp 241-249, 1976.

[3] Cecchini, S., Sunkel, G., and Barrantes, A., “Protección social de la infancia frente a los desastres.” [Online], CEPAL, 2017, 2010 [date of reference October 18 th of 2019] https://www.cepal.org/es/enfoques/proteccion-social-la-infancia-frente-desastres

[4] [4] Thomas, A.S. and Kopczak, L.R.; “From logistics to supply chain management: the Path forward in the humanitarian sector” Fritz Institute, Vol. 15, pp 1-15, 2005. http://www.fritzinstitute.org/PDFs/WhitePaper/FromLogisticsto.pdf

[5] Tomasini, R., and Wassenhove, L. V., “Humanitarian Logistics” [online], Naples: Springer, Basingstoke, Hampshire: Palgrave Macmillan UK. 2009 [date of reference August 19 th of 2019]. doi:10.1057/9780230233485

[6] Jacobsen, S. and Madsen, O.; “A comparative study of heuristics for a two-level routing-location problem.” European Journal of Operational Research, Vol. 5, no 6, pp378-87, 1980. doi:10.1016/0377-2217(80)90124-1

[7] Madesen, O.B.; “Methods for solving combined two level location-routing problems of realistic dimensions.” European Journal of Operational Research, Vol 12, no 3, pp 295-301, 1983. doi:10.1016/0377-2217(83)90199-6

[8] Ambrosino, D., y Scutellà, M.; “Distribution network design: New problems and related models.” European Journal of Operational Research, Vol. 165, no 3, pp 610-624, 2005. doi:10.1016/j.ejor.2003.04.009

[9] Gonzalez-Feliu, J.; “The multi-echelon location-routing problem: concepts and methods for tactical and operational planning.” ResearchGate, Version 1, pp 1-11, 2009. https://www.researchgate.net/publication/39064434_The_N-echelon_Location_routing_problem_concepts_and_methods_for_tactical_and_operational_planning

[10] Boccia, M., Crainic, T. G., Sforza, A., and Sterle, C. “International Symposium on Experimental Algorithms.” [online], Naples: Springer, 2010 [date of reference August 16 th of 2019], A Metaheuristic for a Two Echelon Location-Routing Problem at doi:10.1007/978-3-642-13193-6_25

[11] Boccia, M., Crainic, T. G., Sforza, A., y Sterle, C.; "Location-Routing Models for Designing a Two-Echelon Freight Distribution System." CIRRELT, pp 1-26, 2011. https://www.cirrelt.ca/DocumentsTravail/CIRRELT-2011-06.pdf

[12] Nguyen, V.-P., Prins, C., and Prodhon, C.; "Solving the two-echelon location routing problem by a GRASP reinforced by a learning process and path relinking." European Journal of Operational Research, Vol 216, no 6, pp 113-126, 2012. doi: 10.1016/j.ejor.2011.07.030

[13] Tavakkoli-Moghaddam, R., Forouzanfar, F., and Ebrahimnejad, S.; "Incorporating location, routing, and inventory decisions in a bi-objective supply chain design problem with risk-pooling." Journal of Industrial Engineering International, Vol. 9, no 1, 2013. doi:10.1186/2251-712X-9-19

[14] Rahmani, Y., Cherif-Khetta, W., and Oulamara, A.; "The Two-Echelon Multi-products Location-Routing problem with Pickup and Delivery: Formulation and heuristic approaches." International Journal of Production Research, Vol 54, no 4, pp 999-1019, 2014. doi:10.1080/00207543.2015.1040127

[15] Tavakkoli-Moghaddam, R., and Raziei, Z.; "A New Bi-Objective Location-Routing-Inventory Problem with Fuzzy Demands." IFAC-PapersOnLine, Vol. 49, no 12, pp 1116-1121, 2016. doi:10.1016/j.ifacol.2016.07.646

[16] Nakhjirkan, S., and Rafiei, F. M.; "An Integrated Multi-Echelon Supply Chain Network Design Considering Stochastic Demand: A Genetic Algorithm Based Solution." Promet - Traffic & Transportation, Vol. 29, no 4, pp 391-400, 2017. doi:10.7307/ptt.v29i4.2193

[17] Samani, M. G., and Hosseini-Motlagh, S.-M.; "A Hybrid Algorithm for a Two-Echelon Location-Routing Problem with Simultaneous Pickup and Delivery under Fuzzy Demand." International Journal of Transportation Engineering, Vol 5, no. 1, pp 59-85, 2017. doi:10.22119/IJTE.2017.45837

[18] Tavana, M., Abtahi, A.-R., Di Caprio, D., Hashemi, R., and Yousefi-Zenouz, R.; "An integrated location-inventory-routing humanitarian supply chain network with pre- and post-disaster management considerations." Socio-Economic Planning Sciences, Vol. 64, pp 21-37, 2018. doi.org/10.1016/j.seps.2017.12.004

[19] Vahdani, B., Veysmoradi, D., Noori, F., and Mansour, F.; "Two-stage multi-objective location-routing-inventory model for humanitarian logistics network design under uncertainty." International Journal of Disaster Risk Reduction, Vol. 27, pp 290-306, 2018. doi:10.1016/j.ijdrr.2017.10.015

[20] Dai, Z., Aqlan, F., Gao, K., and Zhou, Y.; "A two-phase method for multi-echelon location-routing problems in supply chains." Expert Systems With Applications, Vol. 115, pp 618-634, 2018. doi:10.1016/j.eswa.2018.06.050

[21] Cuda, R., Guastaroba, G., and Speranza, M.; "A survey on two-echelon routing problems." Computers & Operations Research, Vol. 55, pp 185-199, 2015. doi:10.1016/j.cor.2014.06.008

[22] Prodhon, C.; "Instances du LRP-2E." [online], 2010. http://prodhonc.free.fr/Instances/instancesLRP2E_fr.htm

Este estudio fue financiado por los autores. Los autores declaran no tener ningún conflicto de interés.