HAZARDOUS MATERIALS TRANSPORTATION IN BOGOTA, COLOMBIA: An optimization approach.

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RESUMEN: El transporte de sustancias peligrosas puede tener varios impactos cuando ocurre un accidente, entre ellos, impacto social, ambiental y económico. Por lo anterior, los planeadores de ruta se enfrentan a un gran problema al diseñar las rutas de los vehículos en las grandes ciudades. Este artículo está enfocado en el desarrollo de una herramienta para la toma de decisiones basada en técnicas de optimización para el diseño de rutas que minimice la distancia total recorrida , la población afectada y la infraestructura que se puede ver afectada. El problema es modelado con un grafo dirigido compuesto por un nodo depósito, nodos de demanda y nodos de tránsito. Para satisfacer la demanda se utiliza una flota de vehículos heterogénea. El algoritmo propuesto se probó en dos instancias, la primera es una instancia generada aleatoriamente y la segunda es un caso real en la Localidad de Puente Aranda.

ABSTRACT: The transport of Hazardous Materials transportation has several impacts: social, environmental, and economic; that might appear when an accident occurs. This is the reason because the route planners faced a big issue designing routes for tank trucks into big cities. This paper is focused in developing a decision support tool based on optimization techniques to design the distribution routes to transport HazMats that minimize total travel distance, affected population and infrastructure. The problem is modeled as a directed graph composed of a depot node, demand nodes and transit nodes. To satisfy the demand are used vehicles with a specific cost and capacity. This problem could be classified as a heterogeneous fleet vehicle routing problem (HFVRP) with multiple objectives. The proposed algorithm is tested on two set of instances, the first one randomly generated and the second from Bogotá Geographic Information System .

1 INTRODUCTION

Hazardous Materials (HazMats) are considered all materials that during their manufacturing, manipulation, transportation and/or storage could affects the health of the population, material and/or environmental damages due to release liquids, gases, flammable, explosive, toxic steams or other. The United Nations sorts HazMats into nine classes according to their physical, chemical, and nuclear properties. For example, biological wastes are classified as class 6 and these wastes are collected at many hospitals and shipped to a special waste management facility for safe disposal.

According to the Office of Hazardous Materials Safety (OHMS), the number of HazMats shipments in United States at more than 800.000 per day, of which 62% involve chemical and allied products, 37% involve petroleum products and the remaining 1% involves waste hazardous materials, medical wastes, among others. Otherwise, the total tons shipped exceed 3.1 billion per year. The high amount of HazMats shipments requires attention from governments until general population.

The transportation of HazMats can be classified according to the mode of transport, namely: road, rail, water, air and pipeline. Some shipments are intermodal. In relation with the OHMS information, the transportation modes used in the total shipments to road (94%), air (5.35%), rail (0.53%), pipelines (0.11%) and water (0.04%).

HazMats transportation involves multiple players such as shippers, carriers, packaging manufacturers, insurers, governments, and emergency responders; each has a different role in safely moving HazMats from their origins to their destinations [1]. The HazMats transport is not the unique problem with the HazMats. The waste facilities and team respondents locations in emergency case are other problems related with HazMats.

The number of players determines the number of objectives, too. So, the HazMats transportation is a typical multiobjective problem with multiple stakeholders.

In Bogota, HazMats storage and transportation are controlled by laws and guides elaborated by the government and experts of the topic. The minimization of risk associated with the HazMats transportation can be achieved with driver training and regular vehicle maintenance, but a large part of risk minimization should be done using Operation Research Techniques.

The aim of this paper is provide distribution routes by roads from a dispatch terminal (Node 0) to customers (demand nodes) using the Bogota road network. These distribution routes must guarantee the minimum distance traveled by vehicles, the minimum population and infrastructure affectation, in case of, an accident occur during the transportation activity. The distribution of HazMats is done using heterogeneous fleet of vehicles that means with different capacities, fixed and variable costs.

A decision support tool for the route planners in the transportation companies is one of the results of this research.

The reminder of this paper is organized as follow. In section 2 is presented related literature review. The problem description and the model used are explained in section 3. In section 4 is presented a heuristic method description and the proposed algorithms. The algorithms were proved on two instances and the descriptions and results of them are showed in section 5. Finally, in section 6 are presented the conclusions of this research and their contributions in the practice.

2 LITERATURE REVIEW

Given that distribution of HazMats involves trucks of different characteristics; this problem is considered as a Heterogeneous Fleet Vehicle Routing Problem (HFVRP). Golden et al. [2] in 1984 were first introduced to this problem. They proposed an algorithm based on Clarke & Wright [3] saving algorithm with two implementations to a VRP giant tour searching minimize the total travel distance by the vehicles with a unit cost, satisfying the customer demands. Renaud and Boctor [4], by the same way, proposed a greedy algorithm with improvement procedure.

Due to complexity of VRP and its variants, metaheuristics methods were proposed by some authors; Osman and Salhi [5] were the first to propose the Tabu Search, followed by Gendreau et al. [6], Wassan and Osman [7] and Prins [8]. The latter solves a lot of variants of the problem, taking into account, a fixed and variable cost per vehicle type and without it.

The needs to find “good” solutions to this type of problems have led to better solutions have been found. Tarantilis et al. [9] proposed a list-based threshold accepting metaheuristic that was improved by Li et al. [10] Their method was based on a variant of the threshold accepting algorithm for the Heterogeneous Fixed Fleet Vehicle Routing Problem (HFFVRP). Gendreau et al. [6], Wassan and Osman [7] reported some of the best solutions for the problem, but Lima et al. [11] improved them proposing a memetic algorithm.

The large size of the real case problems is a factor to take into account into the solution method, by this reason Taillard [12] developed hybrid column generation methods that use Tabu Search to find “good” columns and Yaman [13] found some lower bounds, improved in 2007 by Choi y Tcha [14] using column generation with a branch & bound algorithm. Nevertheless for this problem (HFVRP), the optimal never was proved.

Now, considering the specific problem of this research: HazMats transportation; this problem has been studied since 70´s according to List et al. [15] and multiobjective approaches have been identified. Some of the objectives studied are minimization of cost, risk, total travel distance, emergency time response and equitative risk in a specific region. However most of the researches consider a weighted function of different type of risk and their damages.

At the beginning of the HazMats transportation studies Abkowitz and Cheng [16] proposed a methodology into a framework for optimizing the routing of truck movements of HazMats. Later, the minimization of cost and risk are main objectives in HazMats transportation problem. Kara and Verter [17] proposed a bi-level programming; Mohaymany and Khodadadiyan [18] proposed route design methodologies that minimize the risk in a network. Giannikos [19] use constraint programming for minimize cost and risk looking for equitative risk distribution in region. Erkut and Alp [20] developed an integer programming problem and a pathaddition heuristic to design HazMats routes in and through a major population center and recently, Androutsopoulos and Zografos [21] proposed a k-shortest path algorithm using an additional objective function based on cost and risk.

In parallel to methodologies and the best ways to construct routes that minimize the cost and risk in HazMats transportation appears other applicability approaches as wastes management and disposal of HazMats and location-allocation emergency units minimizing responses times, total travel distances, risk and material damages. Among authors that work in those approaches can be found Zografos & Davis [22], Alidi [23], List and Turnquist [24], Zografos and Androutsopoulos [25].

Zografos & Davis [22] used goal programming approach in a noncapacity and capacity network; Alidi [23] used constraint programming including transport cost, wastes treatment and disposal; List and Turnquist [24] designed a radioactive waste routing system and location of emergency response teams; Zografos and Androutsopoulos [25] proposed a heuristic to solve the problem and Alumur and Kara [26] proposed a mathematical model.

In fact that HazMats problems are multiobjectives and the existence of trade-offs between the considered objectives was the need to present the different solutions on a decision support tool; Nema and Gupta [27] proposed an improved formulation based on multiobjective integer programming approach for the optimal configuration of Regional Hazardous Waste Management System (RHWMS); Zografos and Androutsopoulos [28] presented a decision support system for assessing alternative distribution routes in terms of travel time, risk and evacuation implications; Sadjadi [29] used a nonlinear cost function for determine routes and proposed solutions based on quadratic programming and Dell'Olmo et al. [30] proposed a shortest path multicriterion algorithm based on greedy heuristic finding non-dominated solutions minimizing risk and equitative distribution of it.

3 PROBLEM STATEMENT

In order to describe the problem, a directed graph $G= \{N, E\}$ representing the network road is employed. Let $N= \{N_T, N_D\}$ be the set of nodes and E be the set of arcs. The two subsets N_T and N_D represent transit nodes and demand nodes, respectively. Each node $i \in N_D$ has a demand (d_{is}) of the HazMat s $\in S$, where $S= \{1 \ldots m\}$ is the set of HazMats. Each arc $\{(i, j) \in E | \ i, j \in N\}$ is characterized by a length (l_{ij}), an accident probability (p_{ij}) per kilometer, a population density (dp_{ij}) and area of infrastructure (h_{ij}). $V= \{1 \ldots c\}$ is the set of types of vehicles used for HazMats transportation. Each type of vehicle $v \in V$ has maximal capacity (q_v) for any HazMats.

$$Min\ FO1: \sum_{v \in V} \sum_{(i,j) \in E} (l_{ij} * X_{ijv}) \qquad (1)$$

$$Min\ FO2: \quad \sum_{v \in V} \sum_{s \in S} \sum_{(i,j) \in E} (p_{ij} * l_{ij} * dp_{ij}) * X_{ijv} \qquad (2)$$

$$Min\ FO3: \sum_{v \in V} \sum_{s \in S} \sum_{(i,j) \in E} (p_{ij} * l_{ij} * h_{ij}) * X_{ijv} \qquad (3)$$

The purpose is to design routes that minimizing the total travel distance, population and infrastructure risk represented by equation (1-3); guaranteeing that each node $i \in N_D$ should be supplied by only one vehicle and once and respecting the capacity of each type of vehicle.

The decisions to take are:

- Which vehicle will satisfy the demand of material $s \in S$ of the node $i \in N_D$
- Which arcs will be used by the vehicle $v \in V$
- The quantity of material $s \in S$ in the vehicle $v \in V$ when this use *the arc* $(i, j) \in E$.
- Which transit nodes visit. It is important to notice that in the problem is not necessary to visit all nodes as in the traditional VRP or HFVRP.

As this problem is a variation of the VRP is considered as NP-Hard problem [31], the HFVRP with multiple objectives is NP-Hard too. For this reason, it is proposed heuristic method to find good solutions in polynomial time. Furthermore, it is necessary proposed a method that takes into account several objective functions.

```
1: //Initialization
2: Select the set of neighborhood structures Nk, k=1,...,kmax that will be used in the search.
3: Find initial solution x.
4: //Main step
5: While k<= kmax
6:    Generate a point x' at random from the kth neighborhood of x ( x' ε Nk (x));
7:    Apply some local search method with x' as the initial solution;
8:    Denote with x" the obtained local optimum;
9:    if x" is better than the incumbent do
10:      x:=x";
11:      Continue the search with N1 (k:=1);
12:   else
13:      k:=k+1;
14:      end-if
15: end-While
```

Figure 1 : VNS pseudocode.

4 MULTIOBJECTIVE VARIABLE NEIGHBORHOOD SEARCH (MO-VNS)

This method is based on *Variable Neighborhood Search (VNS),* which consists of systematic neighborhood changes during local search [32]. The first to use this method was Geiger [33]. An adaptation of VNS to a multiobjective approach is presented on Figure 1. Line 1-3 Initialize algorithm defining a set of neighborhood structure k (k=1…k_{max}) to use and an initial solution x. Lines 4-12 describe the main algorithm loop where a solution is improved thanks to a neighborhood structure (lines 6-8). When solution x is improve, the new solution x" is kept and go to line 6 restarting otherwise, other neighborhood is tested. This procedure is repeated until stop conditions are satisfied.

In our proposal, a solution is composed by a set of cluster (routes); each cluster is an array of nodes, including transit and clients nodes.

In order to manage the transit nodes, a preprocessing information procedure is proposed. Using the Floyd-Warshall algorithm that computes the shortest path between all pair of nodes, a O-D matrix including only demand nodes and the base, that allow us to solve a HFVRP visiting all nodes.

The Floyd-Warshall algorithm is turned using each optimization criteria producing:

- Shortest path matrix: contain the shortest path between all pair of nodes (demand and transit nodes).
- Demand nodes matrix: this matrix is a reduction of the previous one, taking into account, only the demand nodes and node 0.
- Path matrix: this matrix saves the path between all pair of demand nodes.

4.1 *Algorithm components*

Solution strategy

Two strategies are proposed to solve the problem. The first one is based on route first cluster second and the second on cluster first route second.

- The Route first-Cluster second consists on solves a traveling salesman problem (TSP) for all nodes generating a giant tour, relaxing some constraints, i.e.: capacity. The MO-VNS works on the giant tour and when the algorithm finish, the final tour is cutting using the *split method* [34] including the whole problem constraints. This strategy is called *MO-VNS1*.
- On the other hand Cluster first- Route second generate initial clusters of clients by solution using the *split method* and The MO-VNS works on this clusters. This strategy is called *MO-VNS2*.

Split Method

The Split method presented by Beasley [34] and base on the Bellman´s Algorithm was modified in order to consider an unlimited heterogeneous fleet. Starting with a giant tour, each node is labeled with a cumulative cost of routes until it, cost node precedence identification and an assigned type of vehicle. The pseudocode is shown in Figure 2. Line 1-6 initialize for each node on the permutation is labeled with infinite cumulative cost (M), the cost node precedence identification of base (P) is zero and assigned type of vehicle(C) to base is zero. Lines 7-13 calculate the distance from base to current node and the demands of the visited nodes are saved. Lines 14-20 assigned a type of vehicle checking the capacity feasibility. If neither fulfills the capacity, go to Line 5. Lines 23-27 update the labels at each iteration with a less cumulative costs, node cost precedence identification and assigned type of vehicle. The capacity of the vehicles is evaluated and the cost of the vehicle assigned is calculated (Lines 15-21). Lines 22-30 kept the best label for the current node.

To evaluate the different objectives Eq. (2) and Eq. (3) are modified in the following way:

$$Min\ FO2: \quad \sum_{v \in V} \sum_{s \in S} \sum_{(i,j) \in E} \left(p_{ij} * l_{ij} * dp_{ij}\right) * r * X_{ijv} \quad (15)$$

$$Min\ FO3: \sum_{v \in V} \sum_{s \in S} \sum_{(i,j) \in E} \left(p_{ij} * l_{ij} * h_{ij}\right) * r * X_{ijv} \quad (16)$$

Where,

$$r = \begin{cases} 0.1\ km \quad Si\ \ 0 \leq Z_{svij} \leq Lim1 \ \ \forall\, s \in S;\ \forall\, v \in V \\ 0.3\ km\ \ Si\ Lim1 < Z_{svij} \leq Lim2 \ \ \forall\, s \in S;\ \forall\, v \in V \\ 0.5\ km \qquad Si\ \ Lim2 \leq Z_{svij} \ \ \forall\, s \in S;\ \forall\, v \in V \end{cases} \quad (17)$$

r represents damage ratio depending on the HazMat amount transported by a type of vehicle.

Initial solutions set (D)

Depending of strategy solution, the initial solutions are added to set D and generated using the following methods:

- Nearest neighborhood: at each iteration a node is added to the current solution. The selection of the node to insert is the closer one according to: 1) Euclidian distance, 2) less risky node following the shortest path matrix and 3) following the Floyd-Warshall matrix.
- Sweep: starting with base at each iteration a node is inserted. The node is selected according its XY coordinates. A counterclockwise "sweep" begins to add the first demand node found.
- Random: the node to be inserted is randomly selected. Each solution has for each objective a value.

Set of neighborhood structures

In the proposed MO-VNS, the neighborhood structures presented by Prins [35] are used. Let *u* and *v* can be demand nodes or depot node and belong to the same cluster (or giant tour) or to distinct cluster. For each pair (*u*, *v*), the following neighborhood structures are tested(*x* is the successor of *u* and *y* the successor of *v* along their respective cluster):

- If u is a demand node, move *u* after *v*.
- If *u* and *x* are demand nodes and v is in the same cluster, move (*u*, *x*) after *v*.

```
1: M(0):=0,  P(0):=0, C(0):=0
2: For i = 1 to numNodes do
3:       M(i)= infinite
4: end-For
5: For i = 1 to numNodes do
6:     j:=i , load:=0, isFull:=false
7:     While j<numNodes && isFull==false do
8:           load:= load + d_j
9:            If i==j then
10:                dist:=dist_{0,j} + dist_{j,0}
11:           else
12:                dist:=dist – dist_{j-1,0} + dist_{j-1,j} + dist_{j,0}
13:           end-if
14:           v:=1
15:           While isFull==false && v<=numTypesVehicles do
16:                If load<=q_v Then
17:                    isFull:=true
18:                else
19:                    v:=v+1
20:                end-If
21:            end-While
22:            If isFull==true Then
23:                If [M(i-1) + cf_v + (co_v * dist)]<M(j) Then
24:                    M(j) :=M(i-1) + cf_v + (co_v * dist)
25:                  P(j):=i-1 , C(j)=v
26:                end-If
27:               isFull:=false
28:             else
29:                isFull:=true
30:             end-If
31:             j:=j+1
32:        end-While
33: end-For
```

Figure 2 : *Split Method* pseudocode.

- If *u*, *x* are in distinct cluster of *v*, permute (*u*, *x)* with *v*.
- If *u*, *x* are demand nodes and v is in the same cluster, move (*x*, *u*) after *v*.
- If (*u*, *x*) and (*v*, *y*) are in distinct cluster, permute (*u*, *x*) and (*v*, *y*).
- If *u* and *v* are demand nodes in the same cluster, permute *u* and *v*.
- If *u*, *x* and *v* are in the same cluster, permute (*u*, *x)* with *v*.
- If (*u*, *x*) and (*v*, *y*) are in the same cluster, permute (*u*, *x*) and (*v*, *y*).

All the previous neighborhood structures are implemented in MO-VNS of both strategies (*MO-VNS1* and *MO-VNS2*) according with the case.

Adaptation to multiobjective problem

Multiobjective problems must satisfy the following:

$$MOP = \begin{cases} Min\ F(x) = \left(f_1(x), f_2(x), \ldots, f_n(x)\right) \\ s.a. \quad x \in S \end{cases}$$

Where n is the number of objective functions ($n \geq 2$); x is the decision variables vector $(x_1, x_2, \dots x_r)$; S is the feasible solutions space and $F(x)$ is the objective functions vector.

Given the fact that the problem has three objectives, it is solved doing comparison between objective pairs (total travel distance vs. population risk, total travel distance vs. infrastructure risk and population risk vs. infrastructure risk). Additionally, other multiobjective adaptation was done in Line 9 of Figure 1, when the comparison between a modified solution (x'') and the incumbent is made using *Pareto Dominance.*

Definition. A solution $y = (y_1, y_2, \dots, y_n)$ dominates (denoted by $\prec$) to solution $z = (z_1, z_2, \dots, z_n)$ if and only if $\forall\, i \in \{1 \dots n\}$, $y_i \leq z_i$ and $\exists\, i \in \{1 \dots n\}, y_i < z_i$.

In both strategies, when the neighborhood structures are tested in each iteration, no-dominated solution found is added to set *D*. This process is done until fulfill a stopping criterion.

4.2 FAST NON DOMINATED SORT

It is a sorting method used on multiobjective problems known in the literature as *Fast Nondominated Sorting* [36]. This method sorts the nondominated solutions in set D forming the *Pareto Frontier* and sorts the solutions in different levels of nondominance.

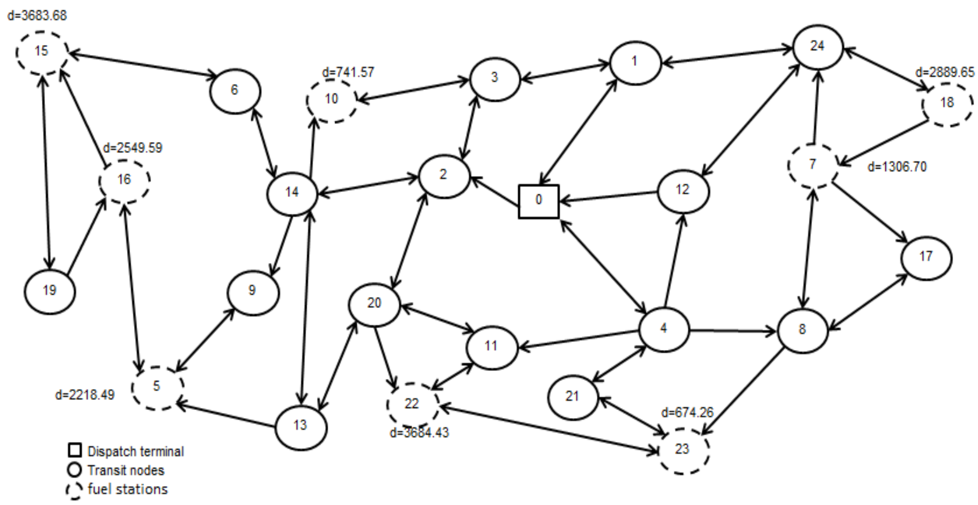

Figure 3 : Random instance graph.

5 COMPUTATIONAL EXPERIMENTS

The solution method was proved in two instances. The first one was randomly generated and the second one is a real case in the Localidad Puente Aranda in Bogotá, Colombia. In both cases, the hazardous material to transport is gasoline. There are three vehicle types with capacity of 3300, 6500 and 10000 gallons; fixed costs of USD$1685, USD$3371 and USD$4494; variable costs of USD$0.11/km., USD$0.22/km. and USD$0.28/km., respectively. The limits to damage ratio are *Lim1*=2000 gals. And *Lim2*=5000 gals.

5.1 *Random instance*

This instance has 8 fuel stations (demand nodes), 16 transit nodes, a dispatch terminal (node 0) and 63 arcs. Each node has XY coordinates distributed U[-75, 75], a demand distributed U[500, 5000] gallons. Each arc has number of people distributed U[77, 2830], square kilometers of infrastructure U[0.062, 0.130] and the accident probability U[10^{-8}, 10^{-6}]. The accident probability range is used in several papers [25]. Figure 3 represents directed graph of the instance.

MO-VNS1 Strategy

The effect of the MO-VNS method in the *MO-VNS1* strategy is showed in Figure 4. The improvement of the initial solutions using the MO-VNS is a good measure of the results obtained with this strategy.

MO-VNS2 Strategy

The effect of the MO-VNS method in the *MO-VNS2* strategy is showed in Figure 5. The improvement in this approach is not enough, but the number of nondominated solutions found is most than *MO-VNS1* approach.

The representation of minimum distance, population-risk and infrastructure-risk routes found are shown in Figure 8, Figure 12 and Figure 15, respectively.

Comparison between both strategies

Only one objective pair is used to look the Pareto Frontier *MO-VNS2* found the best distance and population-risk. The *MO-VNS2* presents non dominated solutions with respect to *MO-VNS1* Pareto Frontier.

On the other hand, the number of solutions in *MO-VNS1* Frontier is higher than *MO-VNS2*. The number of solutions could be a measure to determine which strategy is better.

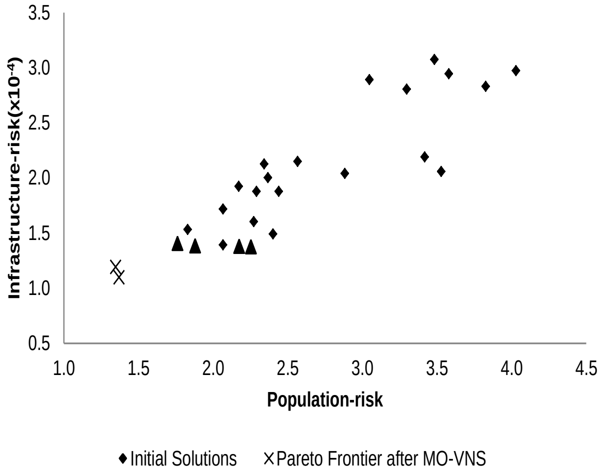

Figure 4 : Pareto Frontier of the initial solutions and Pareto Frontier after MO-VNS in *MO-VNS1*.

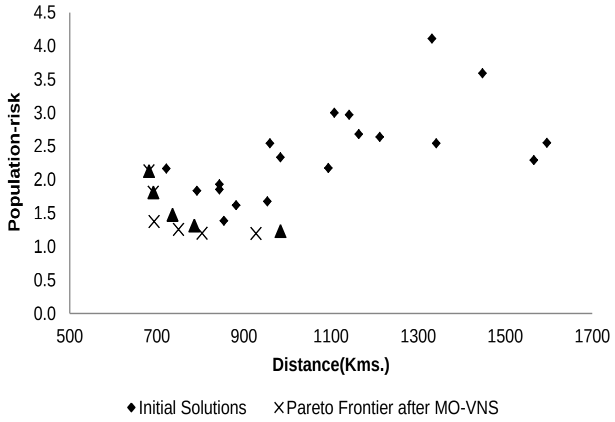

Figure 5 : Pareto Frontier of the initial solutions and Pareto Frontier after MO-VNS in *MO-VNS2*.

5.2 *Real case (Localidad Puente Aranda in Bogotá)*

This instance has 31 fuel stations (represented as triangles), 66 transit nodes (represented as points), a dispatch terminal (represented as a rectangle) and 260 arcs.

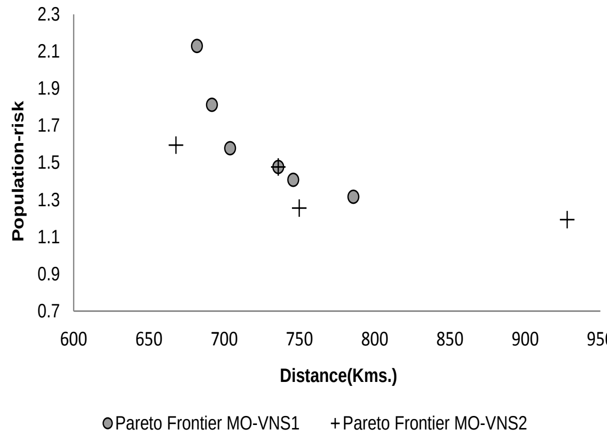

Figure 6 : Comparison between both Pareto Frontiers.

Figure 7 represents graph of Localidad Puente Aranda in Bogotá, Colombia. The distance and the accident probabilities of the arcs were taken of research project called "Mapas de Riesgo" that is making Germán Bravo, their colleagues in the Universidad de los Andes and Colombian entity related with the road prevention called Fondo de Prevención Vial (FPV) using ArcGIS software.

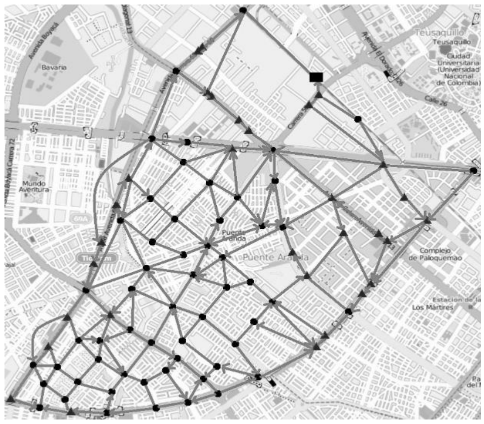

Figure 7 : Real Case Graph *MO-VNS2* Approach.

This project has been ongoing since 2011, and then used the information for the year 2010. The square kilometers of infrastructure were taken of research [37] realized in 2009 by governmental entity called Secretaria Distrital de Planeación. The gasoline demand in fuel stations was randomly generated with uniform distribution U [500, 5000] gallons.

MO-VNS1 Strategy

Figure 9 present the behavior of MO-VNS method in real instance with respect of the initial solutions. The construction of Pareto Frontier using MO-VNS is evident with the Pareto Frontier after MO-VNS representation.

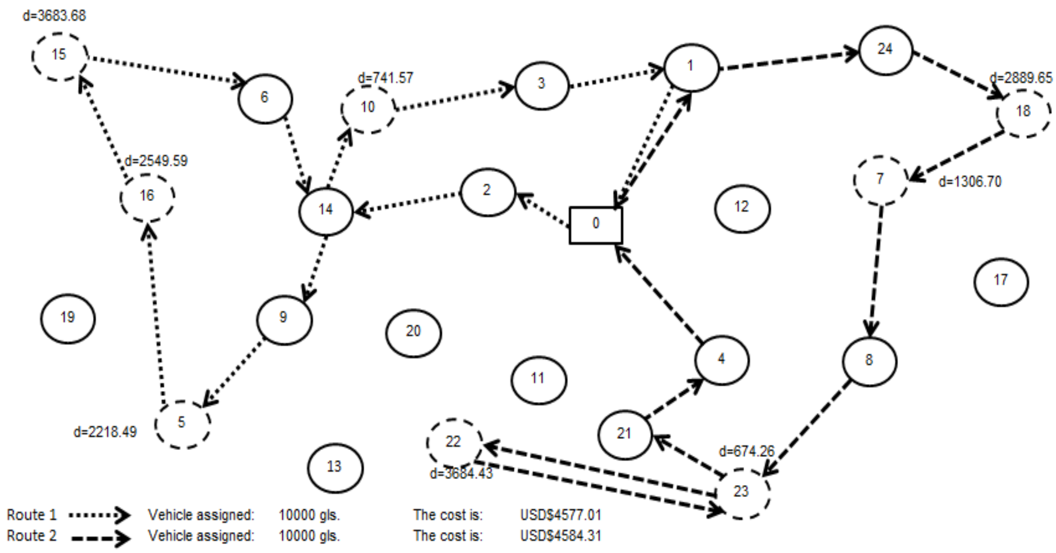

Figure 8: Minimum distance found.

MO-VNS2 Strategy

In relation with Figure 9, the improvement is best in *MO-VNS2* than *MO-VNS1*. This is shown in Figure 10.

Comparison between both strategies

In this case, the Figure 11 shows the *MO-VNS1* solutions are most dominant than *MO-VNS2*, but the number of solutions in Pareto Frontier is higher in *MO-VNS2* than *MO-VNS1*.

The Figure 13 and Figure 14 represent 2 of 9 routes of a solution that minimize total travel distance. The solutions that minimize population-risk and infrastructure-risk were plotted too. The fuel stations served by the vehicle assigned are circled.

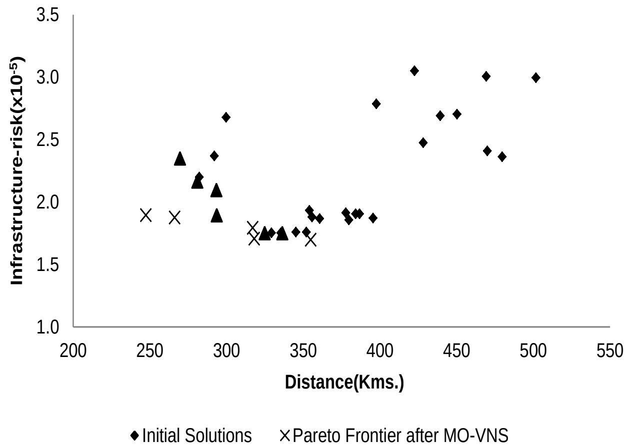

Figure 10 : Pareto Frontier of the initial solutions and Pareto Frontier after MO-VNS *in MO-VNS2*.

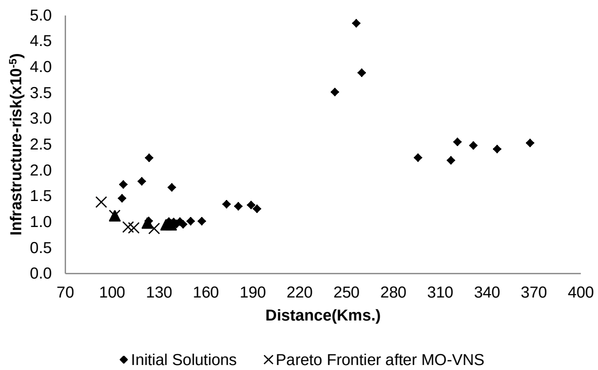

Figure 9 : Pareto Frontier of the initial solutions and Pareto Frontier after MO-VNS in *MO-VNS1*.

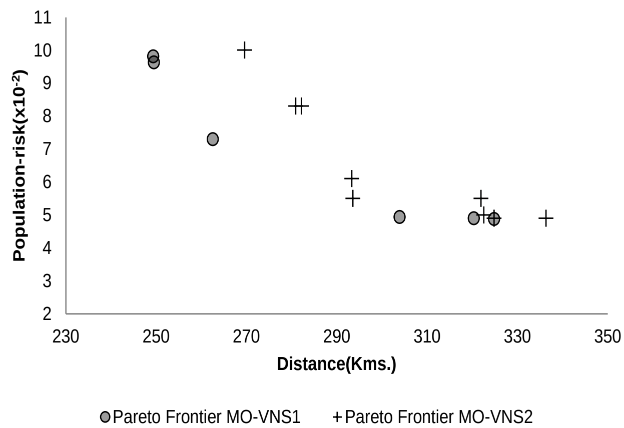

Figure 11 : Comparison between both Pareto Frontiers.

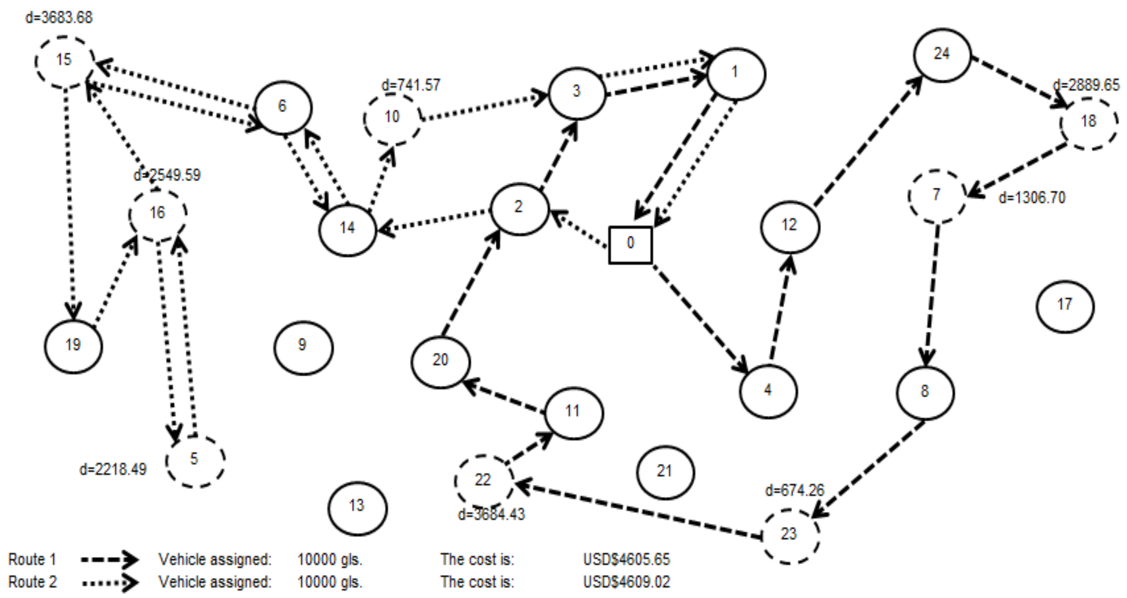

Figure 12 : Minimum population-risk found.

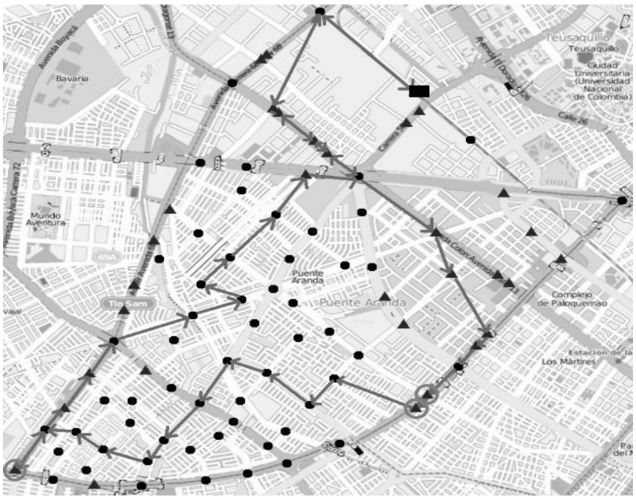

Figure 13 : Vehicle assigned : 10000 gals.- The cost is: USD$4503.46.

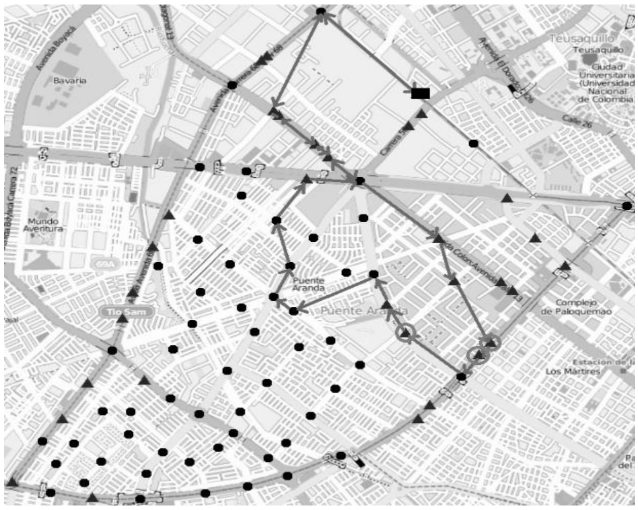

Figure 14 : Vehicle assigned : 6500 gals. – The cost is: USD$3375.88

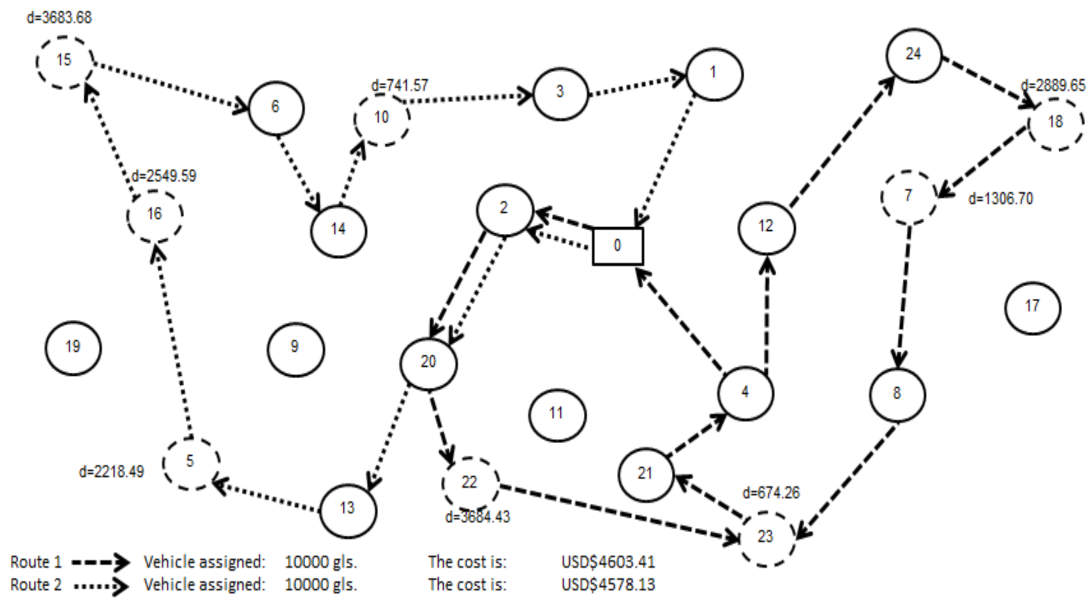

Figure 15 : Minimum infrastructure-risk found.

Table 1 : Comparison of *MO-VNS1* and *MO-VNS2* approaches.

		MO-VNS 1				***MO-VNS 2***		
	Objective functions	Initial Solution	*MO-VNS* Solution	End Solution	Improve (%)	Initial Solution	End Solution	Improve (%)
Random instance	Distance(Kms.)	572	512	622	10.48	682	664	2.63
	Population-risk	2.174	1.370	1.110	36.98	1.232	1.141	7.38
	Infrastructure-risk ($x10^{-4}$)	1.376	1.097	1.013	20.27	1.075	1.013	5.76
Real Case	Distance(Kms.)	101.65	88.81	249.32	12.62	269.60	247.45	8.21
	Population-risk ($x10^{-2}$)	2.3	2.1	4.85	8.69	4.9	4.8	2.04
	Infrastructure-risk	$9.46x10^{-6}$	$8.7x10^{-6}$	$1.60x10^{-5}$	8.03	$1.75x10^{-5}$	$1.66x10^{-5}$	5.14

5.3 *Comparison of MO-VNS1 and MO-VNS2*

The Table 1 shows the best results by approach for each of the objective functions in set *D* for each instance. Initial solution is the best into the initial individuals generated with the initialization methods. In case of *MO-VNS1,* the best solution after applied *neighborhood structures* (MO-VNS) and before of *Split Method* is showed in *MO-VNS Solution* column. *MO-VNS Solution* column is useful for look the effect of the MO-VNS into the strategies like is shown in Figure 4, Figure 5, Figure 9 and Figure 10. *End Solution* is the best solution found by the strategy and *Improve (%)* refers to improvement of the best initial solution and MO-VNS solution. It is important looks that each objective function value in Table 1 belongs to the different routes.

The *MO-VNS1* has the higher improvements than *MO-VNS2* in both instances. In the random instance the best distance and population-risk were found with *MO-VNS1,* but the same results are found for infrastructure-risk with both strategies. Nevertheless, *MO-VNS2* found the best distance and population-risk in real case.

6 CONCLUSIONS

The *MO-VNS1* strategy has a good behaviour, because in all cases neighborhood structures are feasible movements, while the *MO-VNS2* was applied to clusters, then it could be exists two types of infeasible movements. The first is related with the length of the selected clusters and the other is the capacity of the vehicle assigned to each cluster, previously. Therefore, the *MO-VNS1* is most useful than *MO-VNS2* when the problem size is small related with the length of the cluster after Split Method.

But if the problem size is large, the *MO-VNS2* might be find better solutions.

The decision making tool is a result of the research. *MO-VNS2* approach generated most feasible solutions than *MO-VNS1*. The feasible solutions are a set of possible routes that can take the vehicles to distribute the HazMats and its objective functions. This shows to the decision makers the routes impact.

The solution method proposed is novel in the literature of HazMats transportation problem. Each step of the approaches contributed in the good results. From initialization methods to build the initial solutions as Nearest Neighborhood following the Floyd-Warshall matrix that always solutions appears in the *Pareto Frontier* of the initial solutions to *Split Method* where a good individual is divided in optimal cluster based on vehicle capacities and its costs. Furthermore, the XY comparison between objective functions could be useful to visualize the different solutions and its impacts related with some objective.

Finally, this research explore a new method to determine routes for HazMats transportation in the practical environment taking into account the importance of making good planning of these

7 FUTURE WORK

The importance of this research and their applicability on the practical environmental implies test by different ways the proposed strategies. The following step is identifying some multiobjective measure metrics for proved the strategies efficiency. Later, the comparison with related literature problems and more random instances generated with the aim of improve the strategies in a better and justified way.

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