SIMULATION AND OPTIMIZATION WITH GRASP IN SUPPLY FUEL IN THE NORTH OF MEXICO CITY

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ABSTRACT
In this paper, the fuel distribution network from fuel farms to a set of filling stations in the North of Mexico City is simulated and optimized. At present, the company supplies the fuel with a homogenous fleet and it is interested in including a heterogeneous fleet seeking to minimize the ordering, holding, and transportation costs, within constraints of inventory in filling stations, as well as the truck capacity. Data collection, demand analysis, and inventory and transport cost calculations are proposed for the simulation in the network; we propose a mathematical model with metaheuristics Greedy Randomized Adaptive Search Procedure (GRASP), with elements of linear programming. Finally, the results are analyzed getting 44.8 per cent in savings when compared with the current situation

Keywords: Mathematical model; metaheuristics; GRASP; inventory; transports; supply chain managements; fuels.

1. INTRODUCTION

Fuel supply has been studied since 1959, when Dantzig and Ramser, evaluated the optimization of gasoline-transporting vehicle routing from a terminal to different fuel stations.

Since then, a variety of bibliographical material on optimization and simulation of fuel supply has been published, most of them on optimization of the distribution from production sites to refineries, as well as from refineries to mayor storage terminals, mostly by pipelines.

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Nowadays, the Supply Chain Management of petroleum fuel is very important for the development of human life in each community of the planet. Mexico City is one of the most populous cities in Latin America and the world; the supply of fuel in all of boroughs is not easily achieved. The goal of this work was to obtain a mathematical optimization of the quantity of each fuel station and the minimization inventory and transport costs.

2. PROBLEM STATEMENT

Mexico City has four fuel farms, that supply with three types of fuel: Fuel A (FA), Fuel B (FB) and Diesel (D) to 371 Filling Station (FS) in 16 boroughs and some suburban towns within the metropolitan area. The fuel farm has a homogenous fleet for supply with fuel to each FS.
In the FS, a continuous review and control inventory system and a weekly demand forecasting and scheduling method have been implemented, because it is necessary to have a good service level for the costumer.
Currently the company supplies the fuel from the fuel farm to the FS with a homogenous fleet of trucks with capacity of 20,000 cubic meters. The enterprise is interested in knowing if a heterogeneous fleet and their scheduling is convenient for the supply in the borough of Azcapotzalco in the North of Mexico City in order to minimize the inventory and transport costs. The studied region is shown in the Figure 1.

Figure 1: Study region and FS localization.
Source: Adapted of http://www.ubicalas.com

Now we will present a supply and management inventory proposal where we hope to decrease the inventory and transport cost, furthermore to determine the optimal type of truck for the supply. To validate this information the research of other authors like Coelho, Cordeau y Laporte (2012) was used as a reference, where they make a mathematical model that minimized inventory and transport cost of the vehicle fleet; Kasthuri y Seshaiah (2013) presented an inventory model with a lot of product with dependent demand; and Genedi y Zaki (2011) proposed a model for quality control in the inventories.

3. MATERIALS AND METHODS

3.1. Data collection

There is only data of monthly demand of FS1 and FS6 (between January 2014 and October 2015). To get the demand data of 16 FS, a geometric structure called the Voronoi Diagram (Guth & Klingel, 2012) was used to limit the supply area (Okabe, Boots & Sugihara 1992) of each FS and to get the estimated demand in relation to population. This data was obtained with tools like AutoCAD and the database of The National Insitute of Statistics and Geography (http://www.inegi.org.mx/).

3.2. Demand behavior

The analysis of demand behavior of fuel was made with a Coefficient of Variation (CV) developed with Peterson & Silver (1987); this is used to know if the demand is deterministic or probabilistic (Andrade et al., 2014). If the CV is less or equal to 0.2, the data is poorly dispersed in relation with the mean, because the demand is considered deterministic. The CV is the ratio between the variance and the mean squared like is in the Equation 1.

$$CV = \frac{\sigma^2}{DM^2} \tag{1}$$

3.3. Transport and inventory costs

The transport cost is calculated for the three types of different trucks; it is classified according to its capacity: 10, 20 and 60 cubic meters. This cost is proportional to distance between the fuel farm and the FS, the performance and the efficiency by type of fuel, and the cost per liter of fuel.

Table 1. Holding cost

	Holding Cost [$/m³/month]		
FS	**FA**	**FB**	**Diesel**
1	$0.09	$0.32	$0.15
2	$0.04	$0.12	$0.06
3	$0.08	$0.26	There is not
4	$0.04	$0.13	There is not
5	$0.04	$0.13	There is not
6	$0.05	$0.16	$0.08
7	$0.13	$0.41	There is not
8	$0.03	$0.09	$0.04
9	$0.02	$0.06	There is not
10	$0.06	$0.21	$0.10
11	$0.01	$0.05	$0.02
12	$0.02	$0.06	$0.03
13	$0.05	$0.18	$0.09
14	$0.04	$0.13	There is not
15	$0.03	$0.10	There is not
16	$0.04	$0.14	$0.07
17	$0.05	$0.16	$0.23
18	$0.09	$0.31	$0.15

Source: Elaborated by the author

The inventory cost is composed with the order and holding (Mora, 2008). The holding cost consider the series to storage fees with relation value of the land, opportunity cost, workforce, insurance, and energy consumption (Benítez, 2012). The order costs are the fixed costs involved in making the fuel order. In Table 1 the values of the cost are described.

Table 2. Transport cost

	Transport Cost [$/truck]		
FS	**Truck 10 m³**	**Truck 20 m³**	**Truck 40 m³**
1	$3.95	$4.18	$6.13
2	$4.58	$4.85	$7.10
3	$2.33	$2.47	$3.62
4	$3.05	$3.23	$4.73
5	$3.47	$3.68	$5.38
6	$4.55	$4.82	$7.05
7	$2.57	$2.73	$3.99
8	$4.82	$5.10	$7.47
9	$5.15	$5.45	$7.98
10	$3.17	$3.36	$4.92
11	$1.29	$1.36	$2.00
12	$2.99	$3.17	$4.64
13	$2.81	$2.98	$4.36
14	$2.27	$2.41	$3.53
15	$1.77	$1.87	$2.74
16	$2.69	$2.85	$4.18
17	$3.83	$4.06	$5.94
18	$5.12	$5.42	$7.94

Source: Elaborated by the author

3.4. Mathematical Model

Table 3: Parameters, index and decision variables.

Item		Descriptions
Index	I	A set of fuel, i = FA, FB, D
	J	A set of truck, j = Truck 10 m^3, Truck 20 m^3, Truck 40 m^3,
	K	A set of FS, k = FS1, FS2, …, FS18
Parameters	D_{ik}	Demand of fuel i in the FS k [m^3/month].
	Ch_{ik}	Holding cost fuel i in the FS k [\$/m^3/month].
	Co_{ik}	Order cost fuel i in the FS k [\$/order].
	Ct_{jk}	Transport cost truck j in to supply fuel in the FS k [\$/ truck].
	Ctr_j	Capacity truck j [m^3].
	Ces_{ik}	Capacity FS [m^3].
Decision variables	Q_{ijk}	Quantity fuel i to order with truck j in the FS k [m^3].
	T_{ijk}	Numbers trucks j to supply fuel i in the FS k [numbers].

Source: Elaborated by the author

The variables involved in the design of the network of fuel distribution in Azcapotzalco is related with customer needs and the networks costs (Chopra, 2001). The index, parameters and decision variables are shown in Table 3.

For the mathematical formulation, a nonlinear programing mixed integer was developed, where the objective function is nonlinear and the constraints are linear. Equation 2 is the objective function that minimizes the holding, order and transport costs. Equation 3 says that the order quantity cannot exceed the inventory capacity in the FS; Equations 4 and 5 are the contrast about filling the truck between 90 and 95 per cent of its capacity; finally, Equation 6 is related with nature of variables like non-negative and the number of truck like integer.

$$Min\ CT = \sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{18} Ch_{jk}\cdot Q_{ijk} + \sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{18} Co_{ik}\cdot\frac{D_{ik}}{Q_{ijk}} + \sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{18} Ct_{jk}\cdot T_{ijk} \qquad (2)$$

$$\sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{18} Q_{ijk} \le Ces_{ik} \qquad \forall i,k \qquad (3)$$

$$Q_{ijk} \ge 90\% \cdot Ctr_j \cdot T_{ijk} \qquad \forall i,j,k \qquad (4)$$

$$Q_{ijk} \le 95\% \cdot Ctr_j \cdot T_{ijk} \qquad \forall i,j,k \qquad (5)$$

$$Q_{ijk} \ge 0, \quad T_{ijk} \ge 0 \qquad T_{ijk} \in \mathbb{Z} \qquad \forall i,j,k \qquad (6)$$

3.5. Simulation developed with GRASP Algorithm

The simulation model was based on imitation, with a mathematical model, a real situation, the study of the properties and operative characteristics (Heizer, 2008).

This model was developed using the metaheuristic GRASP; the search algorithm has two phases: building a feasible solution and a local search with iterations in the neighborhood where the solutions are found (Festa, 2009).

The building solution is developed in Microsoft Excel 2016 where 48 different feasible combinatories were found for transporting fuel from fuel farms to FS. Two variables were defined: α_{ijk} y $ß_{ijk.}$

Table 4. Variables α_{ijk} y $ß_{ijk.}$

Variables	Description
$\boldsymbol{\alpha_{ijk}}$	Alternative to supply fuel for fuel i, truck j and FS k. This variable is associated with T_{ijk} (numbers trucks).
$\boldsymbol{ß_{ijk.}}$	Percentage filling truck. It takes the values 90, 91, …, 95 per cent. It is defined to supply fuel for fuel i, truck j and FS k.

Source: Elaborated by the author

The variables α_{ijk} y $ß_{ijk}$ are necessary for the formation with variable Q_{ijk} (order quantity) represented in Equation 7 and then in Equation 8 that represented the total cost supply (CT_{ijk}). These variables are simulated in each iteration, while the better solution is found.

$$Q_{ijk} = T_{ijk}(\alpha_{ijk}) \cdot \beta_{ijk} \cdot Ctr_j \qquad \forall\, i,j,k \qquad (7)$$

$$CT_{ijk} = Ch_{jk} \cdot Q_{ijk} + Co_{ik} \cdot \frac{D_{ik}}{Q_{ijk}} + Ct_{jk} \cdot T_{ijk} \qquad (8)$$

The description about algorithm is explain below:

Algorithm

1: Set high value to variable CT_{ijk}*
2: *while* iterations < total iterations {
set α_{ijk} y $ß_{ijk}$
if ($CT_{ijk}' \le CT_{ijk}$* & CT_{ijk} !=0) {
CT_{ijk}* = CT_{ijk}'
else
CT_{ijk}* = CT_{ijk}*
}
}

3: $Min = \sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{18} Y_{ijk} CT_{ijk}^{*}$

$\sum_{j=1}^{3} Y_{ijk} \ge 1$

$\sum_{j=1}^{3} Y_{3jk} = 0 \qquad \forall\, k = 3,4,5,7,9,14,15.$

$Y_{ijk} \in \{0,1\}$

4: END

The first step is the initialization phase, where variable CTijk setting value 999,999. The second stage is the local search when it stops the total iterations defined by the user.

In each iteration there are setting random variables permitted for αijk y ßijk with the proposal the to building a set of solutions CTijk'. If CTijk' is less than to CTijk* and non-equal to zero, this variable is saved like the new CTijk*, otherwise CTijk* is the same value.

When the iteration stops, it is applying a linear binary programming: the objective function minimizes the inventory and transport cost for to supply fuel i, truck j and FS k. The first constrains assures the supply fuel to everything all the FS. The second constrains says the FS is not suppliedy with Diesel. And Then the last constrains is are about the binary nature binary of decision variables.

4. RESULTS

The developmented of the model was compiled in Dev-C++ with language programming C++ making 100 million iterations in Windows 10, using an Intel Core i3 processor, Intel Core i3 CPU 2.40 GHz CPU for the stages 1 and 2. SThe stage 3 was run in Solver of Microsoft Excel 2016. The results are available in the Tables 5 and 6.

Table 5. Quantity of gas by FS.

FS	FA [m^3]	FB [m^3]	Diesel [m^3]
1	76	38	76
2	95	76	76
3	95	38	0
4	95	76	0
5	95	76	0
6	76	76	76
7	76	38	0
8	95	76	76
9	95	76	0
10	95	76	76
11	95	95	95
12	95	76	95
13	95	76	76
14	95	76	0
15	95	76	0
16	95	76	76
17	95	76	38
18	76	38	76
Average	90.8	68.6	46.4

Source: Elaborated by the author

Table 6. Number of truck and capacity [m^3].

FS	N° Truck FA/ Cap [m^3]		N° Truck FB/ Cap [m^3]		N° Truck Diesel/ Cap [m^3]	
1	2	40	1	40	2	40
2	5	20	2	40	2	40
3	5	20	1	40	0	0
4	5	20	2	40	0	0
5	5	20	2	40	0	0
6	2	40	2	40	2	40
7	2	40	1	40	0	0
8	5	20	2	40	2	40
9	5	20	2	40	0	0
10	5	20	2	40	2	40
11	5	20	5	20	5	20
12	5	20	2	40	5	20
13	5	20	2	40	2	40
14	5	20	2	40	0	0
15	5	20	2	40	0	0
16	5	20	2	40	2	40
17	5	20	2	40	1	40
18	2	40	1	40	2	40

Source: Elaborated by the author

In Table 7 it is shown that the saving holding costs and transport costs are increased on average 69.8 and 118.6 per cent respectively, while the order costs are reduced on average in 59.8 per cent. A relevant aspect to consider is that the increase in holding and transport costs are not as significant as the the order costs, mainly because the holding cost is cheaper than the order cost. In general, the total saving is 44.8 per cent, equivalent to $1,980 each month.

Finally, the saving total in a year is $23,770.61, in Figure 2 a graph of the current and the proposed costs is shown.

Table 7. Current situation versus proposal situation

	Actual situation monthly			Proposal situation monthly		
FS	**Hold Cost.**	**Order Cost**	**Trans Cost**	**Hold. Cost.**	**Order Cost**	**Trans Cost**
1	$9.9	$182.1	$12.5	$15.4	$51.8	$30.6
2	$5.0	$289.1	$24.2	$8.2	$112.6	$52.6
3	$5.6	$159.9	$4.95	$8.6	$41.3	$15.9
4	$3.2	$195.9	$9.7	$6.7	$68.8	$25.6
5	$3.6	$145.9	$14.7	$6.9	$66.1	$29.1
6	$5.5	$256.6	$19.2	$11.0	$89.7	$42.3
7	$8.9	$102.1	$5.45	$12.6	$30.5	$11.9

8	$4.4	$272.0	$35.7	$6.4	$141.3	$55.4
9	$2.1	$245.1	$32.7	$3.2	$144.6	$43.2
10	$6.9	$203.6	$13.4	$14.4	$63.0	$36.4
11	$3.3	$389.6	$13.6	$4.1	$240.0	$20.4
12	$3.8	$341.5	$25.3	$4.9	$187.2	$40.9
13	$6.0	$234.9	$11.9	$12.6	$72.8	$32.3
14	$3.5	$149.5	$9.6	$6.7	$67.7	$19.1
15	$3.0	$171.3	$9.3	$5.2	$90.7	$14.8
16	$4.6	$308.6	$11.4	$9.6	$95.6	$30.9
17	$8.2	$194.6	$16.2	$12.6	$73.6	$38.1
18	$9.5	$189.8	$16.2	$14.9	$53.9	$39.6
Avg	$5.4	$224.0	$15.9	$9.1	$94.0	$32.2

Source: Elaborated by the author

5. CONCLUSIONS

According to the response of GRASP algorithm there is a monthly saving of 44.8 per cent in cost, using a heterogeneous fleet. The company needs to implement a new system of supply fuel.

The GRASP is a metaheuristic technique, when it is possible to find a better solution in this problem with another algorithm.

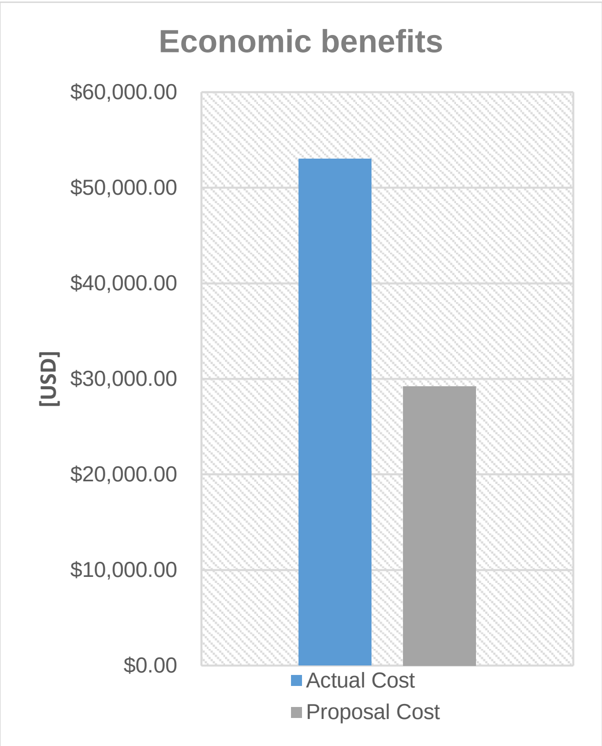

Figure 2: Economic benefits
Source: Elaborated by the author

REFERENCES

Andrade C., Tello D. & Romero O. 2014. Modelo matemático para la administración de inventario en una microempresa del rubro alimenticio. Caso de aplicación. En: VII Simposio Internacional de Ingeniería Industrial: Actualidad y Nuevas Tendencias Lima, Perú. 448p, 2014.

Benítez R. 2012. Influencia de los costos de mantenimiento en la toma de decisiones. La Habana: Centro de Inmunología Molecular.

Chopra S. 2001. Designing the Distribution Network in Supply Chain. Kellogg School of Management, Northwestern University. 1-10.

Coelho L., Cordeau, J. & Laporte, G. 2012. The inventory-routing problem with transshipment. Computers & Operation Research. 39 (2012) 2537-2548, 2012.

Dantzig, G., Ramser J. (1959). The Truck Dispatching Problem. Management Science, Vol. 6 No. 1, pp 80-91.

Dev-C++. Web site. Consulted in 2016. https://sourceforge.net/projects/orwelldevcpp/

Festa P. and Resende, M. 2009. An annotated bibliography of GRASP – Part I: Algorithms. International Transactions in Operational Research. N°. 16, pp 1-24.

Guth N., and Klingel, P. 2012. Demand Allocation in Water Distribution Network Modelling – A GIS-Based Approach Using Voronoi Diagrams with Constraints. Application of Geographic Information Systems, Dr. Bhuiyan Monwar Alam (Ed.), ISBN: 978-953-51-0824-5, InTech, DOI: 10.5772/50014.

Heizer J., Render, B., 2008. Dirección de la producción y operaciones. 8ª ed. Madrid, Pearson Education pp. 458-459.

INEGI: Instituto Nacional de Estadística y Geografía (INEGI). Web site: www.inegi.org.mx.

Kasthuri R., and Seshaiah C. 2013 Multi-item EOQ model with demand dependent on unit price. Applied and Computational Mathematics. Vol. 2, N°. 6, pp. 149-151.

Kotb K., Genedi H. & Zaki S. 2011. Quality Control for Probabilistic Single-Item EOQ Model with Zero Lead Time under Two Restriction: A Geometric Programming Approach. International Journal of Mathematical Archive, Mar -2011, pp. 335-338

Microsoft Excel 2016. Web site: https://www.office.com/.

Mora L. 2008. Gestión Logística Integral. Ecoe Ediciones. Bogotá.

Okabe A., Boots B. & Sugihara K. Spatial tessellations: concepts and applications of Voronoi diagrams. Willey New York.

Peterson, R. and Silver, E. 1985. Decision systems for inventory management and production planning. Willey New York.

Ubicalas.com. Web site. http://www.ubicalas.com/.

Winston W. 2004. Investigación de operaciones: Aplicaciones y algoritmos (4ª ed.). Thompson. México D. F.

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