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A Vehicle Assignment Problem to Improve Logistics Operations in A Mexican Freight Transport Company

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Abstract: *The purpose of this paper is to apply the vehicle assignment model to a Mexican freight transport company, whose costs elements were analyzed through factor analysis and ANOVA. Main factors identified help to minimize logistics costs, because the company can manage them, through the daily program of units. The model helps not only to assign the vehicles to one route, but to identify the movements they must do when the units are empty and they must be moved between routes, improving the assignment, maintenance, penalty, idle time, and general logistics costs. This research not only covers the mathematical problem, but also the statistical analysis carried out to obtain the main factors to be included as part of the costing model to assign units and minimize the overall costs incurred by the company.*

Keywords: *Logistics, Freight Transport, Assignment, Factor Analysis, Vehicle Assignment.*

I. Introduction

In Mexico, the road freight transport sector is of paramount economic, social, and environmental importance, since it has had an Average Annual Growth Rate (AAGR) of 3.4% in terms of its worth in Mexico's Gross Domestic Product (GDP) from 1993 to 2020, which is important for the generation of incomes, taxes, and jobs; also, 64% of exports and 51% of imports was moved through freight transport (INEGI, 2021). Importance of road freight transport GDP can be known through its percentual participation to the economy, which was about 3.3% in 2020, representing the 56.4% of the overall transport GDP (Gobierno de Mexico, 2022; INEGI, 2021).

According to the Mexican Secretaria de Economía (2023), the logistics costs for Mexican companies represents about 10.3% of sales, with 40% for transport costs and 60% for inventories, request processing, warehousing, and transport operations planning; moreover, in relation with GDP, logistics costs represent 15.3% of the overall Mexico's GDP.

In the supply chain, transport is a fundamental activity for the overall economy, moving goods form one place to another, with the 81.1% of the overall costs represented by fuel and lubricants, other expenses for goods and services, maintenance, and infrastructure and toll payments (INEGI, 2021).

Mexican transport industry is made up of several transport modes, such as road freight transport, the main activity representing more than a half of the GDP, passengers, services related, rail, courier services, air mode, pipeline, waterway, and touristic transport. In 2020, this industry has about one million of persons hired, which represents about 2.4% of the hired people in the overall economy; also, the mix is made up 72.5% of truck drivers and maintenance, and 23.8% of administrative, accountant and managerial employees (INEGI, 2023).

In Mexico, main vehicles used in road freight transport are classified according to the vehicle type as Light Truck (C), Heavy Trucks (T), Semi-Trailer Trucks (S), and Trailer Trucks (R), the combination of these vehicles with their axles (represented by a number), their load, models, and joints, give specific classification for the load capacity – for example a T2 represents a Heavy Truck with two axles (Berrones-Sanz, 2020).

Among various factors that can influence the efficiency, effectiveness of road freight transports is the truck performance, human factors, types of vehicles used, empty running, road conditions, social problems, traffic conditions (Bueno-Pascual et al., 2021; Kulovic, 2017; Velarde et al., 2019). Variables that can affect transport costs are the transportation distance, truck load capacity, time, as well as the type of materials transported (Schettino et al., 2021; Soranso et al., 2022).

Therefore, all companies need transport planning, to reduce costs and increase productivity, for which it is important to understand what the implied costs for a specific business are, according to their services, and how the factors can influence the freight transport costs.

Regarding this scenario, this study is aimed to analyse the variables that influence the logistics costs for a Mexican freight transport company and how can be used to minimize the overall operation costs, considering the main factors that affects efficiency and effectiveness in Mexico. It will be investigated through a factor analysis for the results of a survey and using the routing and assignment models' equations to estimate the value by considering the different types of vehicles used for the company to provide its services.

II. Literature Review

1.1 Freight transport costs optimization

Costs optimization is an important matter for any organization, since they have significant impact in the economic activities, and it impacts more to logistics companies, since the value added to the final customer is the delivery of products from one point to another, representing 40%-50% of overall amount of logistics costs (Thai et al., 2021). Cost reduction is one of the challenges in freight transport, since there are different levels of uncertainty in the supply chain, as well as factors affecting efficiency and productivity, which make hard to optimize operations with optimization methods due to it is required results in short computing times with high-quality solutions, for which heuristics methods are employed (Castaneda et al., 2022).

Goal of increase efficiency and effectiveness of supply chain is to optimize costs of goods distribution to some locations using available resources in the best way, normally using the Vehicle Routing Problem (VRP) models to minimize costs (Calvet et al., 2016; Gonzalez-Marin, 2014; Grasas et al., 2017; Gruler et al., 2017; Jesica, 2017; Juan et al., 2014; Quintero-Araujo, 2016; Quintero-Araujo, 2017).

1.2 Vehicle Routing Problem

Vehicle Routing Problem (VRP) is a mathematical model used to minimize the costs between multiples routes passing through all customer locations, generalizing the Travelling Salesman Problem (TSP), which is like assignment problem, with the difference that TSP deals with finding the shortest tour in a city situation in which each city is visited exactly once, minimizing the total distance travelled. The salesman problem has two extra restrictions, being the first one that it cannot be selected the element in the leading diagonal, as well as items are not produced again until all items are produced at once (Herdianti, Gunawan, and Komsiyah, 2021). The general mathematical model for the vehicle routing problem is described as follows (Munari, Dollevoet, and Spliet, 2017):

$$Min\ z = \sum \sum d_{ij} x_{ij} \tag{1}$$

Subject to:

$$\sum x_{ij} = 1 \qquad i = 1, \dots n \tag{2}$$

$$\sum x_{ijk} - \sum x_{ikj} = O \qquad k = 1, \dots n \tag{3}$$

$$x_{ioj} \leq K \qquad \forall i = 0, \forall j = 0, \tag{4}$$

$$y_j \geq y_i + q_j x_{ij} - Q(1 - x_{ij}) \qquad \forall i = 0, \dots, n+1\ ,\ \forall j = 0, \dots, n+1 \tag{5}$$

$$d_i \leq y_i \leq Q \qquad i = 0, \dots, n+1 \tag{6}$$

$$x_{ij} \in \{0,1\} \qquad \forall i = 0, \dots, n+1\ ,\ \forall j = 0, \dots, n+1 \tag{7}$$

Equation (1) is the objective function, and it imposes the total travel distance of the routes is minimized. Constraints in Equation (2) ensure all customers are visited once, (3) guarantee the correct flow of vehicles through the arcs, (4) limits the maximum number of routes to K (number of vehicles), (5) and (6) ensure that vehicle capacity is not exceeded.

1.3 Statistics analysis

It was assessed whether if freight transport costs associated with the travelling (other than fuel costs), are associated with each other regarding the increase of time to deliver the final product, increasing the overall logistics costs, for which it was used the Pearson correlation coefficient matrix using a confidence level of 95%, considering a very strong correlation when $r \geq |0.90|$, strong when $|0.70| < r \leq |0.90|$, medium when

$|0.40| \leq r < |0.70|$, low when $|0.1| \leq r < |0.40|$ and negligible when $r < |0.10|$ (Schober, Boer, and Schwarte, 2018).

In order to assess data suitability it was used the Kaiser-Meyer-Olkin (KMO) to assess the sampling adequacy, considering the factor analysis, whose values are considered very good if $0.9 \leq KMO \leq 1$, good if $0.8 \leq KMO < 0.9$, medium if $0.7 \leq KMO < 0.8$, reasoinable if values are $0.6 \leq KMO < 0.7$, $0.5 \leq KMO < 0.6$ acceptable and nor adequate or unacceptable if $KMO < 0.5$ (Reddy, and Kulshrestha, 2019; Shrestha, 2021). Regarding the Bartlett's Test of Sphericity, it was tested if variables are unrelated and unsuitable for the dependant variable, being significant if $p - value < 0.05$ (Shrestha, 2021).

III. Methodology

A Quantitative research design was used to carry out this design, for which it was used a survey to collect data and respond the main research question which is what the main variables are influencing Mexican logistics costs, for which it was selected a random sample of 184,774companies in Mexico (CANACAR, 2021), using the equation (8), in order to investigate main factors affecting their logistics processes.

$$n = \frac{z_{\frac{\alpha}{2}}^2 p(1-p)N}{\varepsilon^2(N-1)+z_{\frac{\alpha}{2}}^2 p(1-p)} \tag{8}$$

Where:

n: Sample size.
$1-\alpha$: confidence level.
p: Probability of selecting an small or medium-sized company.
N: Population size.
ε: Sampling Error.
$z_{\frac{\alpha}{2}}$: Standard random variable.

Considering the population size of $N = 184{,}774$ representing the total freight transport companies in Mexico, with a confidence level of $1 - \alpha = 95\%$ (Hazra, 2017), for which the standard value $z = 1.95996$, with a sampling error $\varepsilon = 5\%$ (Khadka, 2019). If the probability of selecting a small and medium-sized company is $p = 95\%$, the sample size $n = 73$, which is the minimum number of surveyed companies to get results that can be generalized.

With the results of the survey, factors affecting costs can be identified and used in the vehicle routing problem equations to minimize the overall costs. Hence, those factors are used considering the company operations, which has the following conditions:

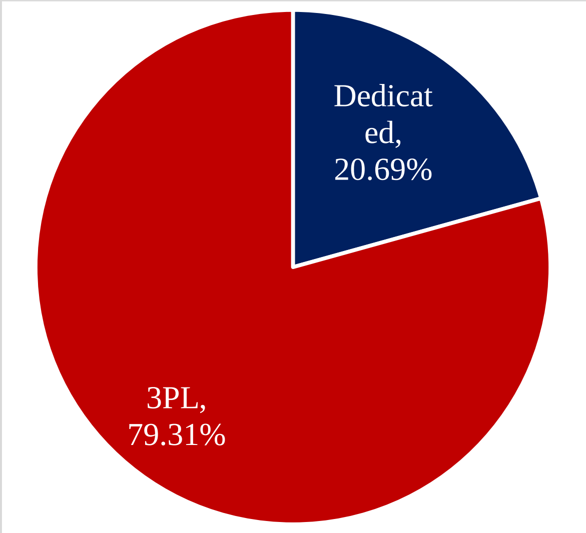
- **Products**: Company deliver 5 different products for its customers, such as sand, molasses, glass, oil, yeast, scrap metal.
- **Truck Drivers**: Drivers are classified according to the license type and productivity as A – those drivers who can transport dangerous material, as well as double-trailer freight trucks for long distances with up to 65 tons, and their productivity is high – B – they can handle dangerous material, but only one trailer freight trucks with up to 31 tons with a productivity medium to high – and C – this type can deliver products using a double-trailer freight trucks or a single one, with a low or medium productivity.
- **Trucks**: They can be classified in three types, which depends on the technical specifications such as model, year, type of road in which they can travel, and the load they can handle. So, type A are those which can be used for long distances, and they can carry a load up to 65 tons and any type of roads, type B can be used for long or short distances, they carry up to 65 tons, but only for trips in plain roads, and type C, are those that can be used only for short distances and they can handle only up to 31 tons (inside Cities or States).
- **Delivery Programmes**: Delivery programmes are provided on monthly basis for the customer. However, most of the times, customers require the movement of units from one place to another, to satisfy the demand for any destination given.
- **Deliver points**: Source and destination points are located across Mexico, which makes complex to change a truck unit from one point to another, as well as, to make changes in the programmes, which must be done in advance, otherwise the operations are impacted highly since the moving can take days or even a week.

IV. Results and Findings

1.4 Survey results

The survey was applied to 87 companies focused on logistics services, where focused mainly to provide 3PL (79.31%) services and dedicated (20.69%), as shown in Figure 1. Results of the survey with $KMO = 0.525$ indicates that values cannot be reduced, but results are acceptable, it means, all the factors impacting the costs should be used separately to calculate the total cost. The Bartlett's test of Sphericity test resulted in 0.00 – which means data structure is suitable to be analysed. Spearman's correlation index was $r = 0.528$, indicating that there is a medium correlation between the productivity of the units and the analysed factors SUCH AS maintenance of the truck, truck driver idle time, trucks documentation, trucks release in loading and unloading centers, deposits to the truck drivers related to travel expenses, external causes, and truck breakdown.

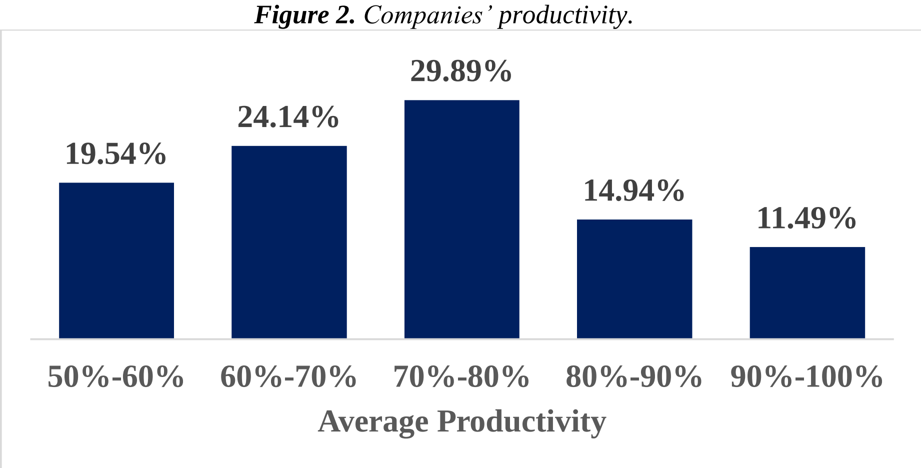
Figure 1. *Services offered by surveyed companies.*



Source: *Own development.*

Average productivity for the companies was about 72% (Figure 2), representing a high opportunity area in terms of improvement, considering the high logistics costs involved and its contribution to the economy.

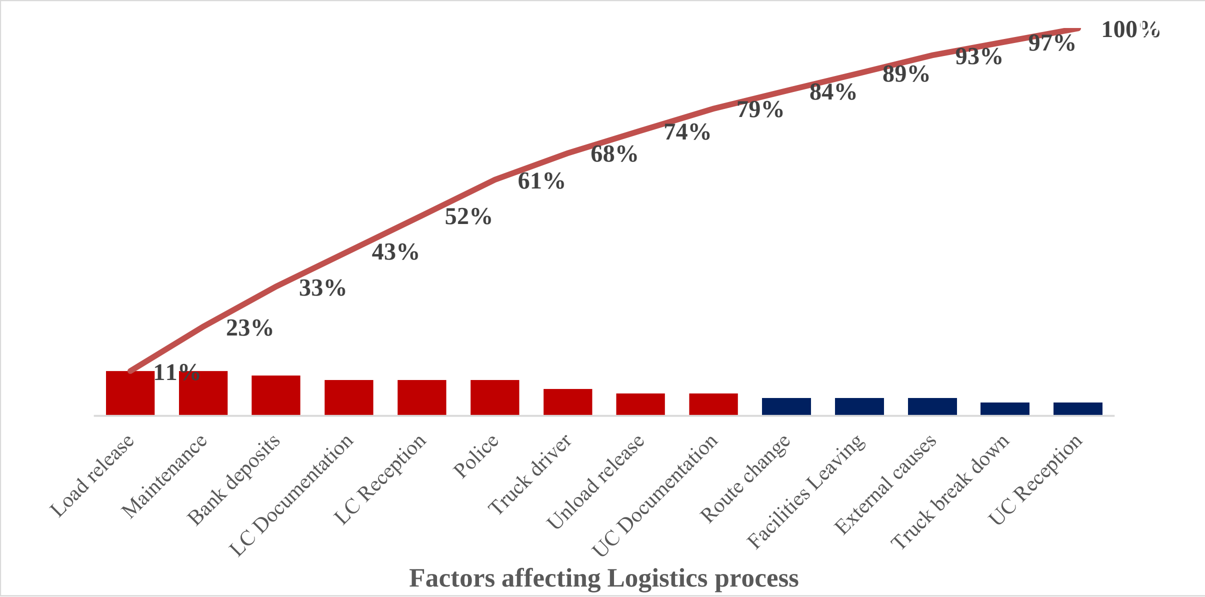
Figure 2. *Companies' productivity.*



Source: *Own development.*

Figure 3 shows main factors affecting the logistics process causing truck delays are load release (waiting time since arrival up to served), maintenance (waiting time for maintenance), bank deposits (deposits to the truck drivers for the travelling expenses), LC documentation (release of load documents to the truck driver), police (time spent when police stop the truck for inspection in compliance with laws), truck driver (different issues related to the truck driver like sleeping, idle time, etc.), unload release (waiting time from arrival to the unload centers up to the truck is served for unload), and UC documentation (waiting time to release documents related to the load received).

Figure 3. *Main factors affecting logistics process.*



Source: *Own development.*

1.5 The vehicle routing problem for the mexican company

Under the conditions for which this study was carried out, main factors affecting the overall logistics costs can be added to the VRP equation to create a minimal cost allocation model, in which the logistics challenges increasing costs will be addressed and they will be used as shown in Equation (8) to Equation (16).

$$Min\ z = \sum\sum\sum s_{ijk}c_{ijk}x_{ijk} + \sum\sum f_{ij}x_{ij} + \sum\sum o_{km}\sum\sum x_{ijkm} + \sum\sum\sum M_{ijk}x_{ijk} + \sum\sum\sum I_{ijm}x_{ijm} + \sum\sum\sum L_{ijm}x_{ijm} + A \quad (8)$$

Subject to: (9)

$$\sum\sum x_{ijk} = 1 \qquad j = 2, \dots n \quad (10)$$

$$\sum\sum x_{1jk} = 1 \qquad \forall j = 2..n, \forall k = 1, \dots n \quad (11)$$

$$\sum x_{ijk} - \sum x_{jik} = 0 \qquad \forall j = 1, \dots n, \forall k = 1, \dots n \quad (12)$$

$$\sum\sum s_j x_{ijk} \leq D_{it} \qquad \forall i = 1, \dots, n\ ,\ \forall j = 1, \dots, n \quad (13)$$

$$\sum\sum x_{km} \leq O_m \qquad \forall k = 1, \dots n, \forall m = 1, \dots n \quad (14)$$

$$x_{ijkm} \in \{0,1\} \qquad \forall i = 1, \dots, n+1\ ,\ \forall j = 1, \dots, n+1,\ \forall k = 1, \dots, n+1, \forall m = 1, \dots, n+1 \quad (16)$$

Where:

i	Departure node
j	Destination node
k	Vehicle type
m	Operator type
n	Number of trips per vehicle per day
x_{ijkm}	Number of vehicles of type k from node i to node j driven by operator m
O_m	Number of operators type m
s_{ijk}	Maximum amount of daily shipped product from node i to node j with a vehicle type k
D_i	Customer demand at node j (delivery program – tons/day)
A	Fixed Cost of trucks assignment
c_{ijkm}	Cost per ton of trip from node i to j using a k operator with a vehicle type m
f_{ij}	Fuel cost from Source i to Destination j
o_{km}	Opportunity cost of assigning$a$ k operator with a vehicle type m
M_{ijk}	Maintenance cost vehicle of type k from node i to node j

I_{ijm} Idle cost caused by the operator m from node i to node j
L_{ijm} Other Logistics cost (Like law costs) caused by the operator m from node i to node j

With equations given it was run the model considering 30 company routes, for a given month, considering the units were able to move between routes and it can be assigned just once in any given day, also by considering a given number of travels per week, which depends on the routes, the type of tuck (full = 60 tons, single = 30 tons), and a given driver, which depends on the type of license and productivity, getting as result overall costs as shown in Table .

Costs	Current (USD)	Using the Assignment Model (USD)	% Reduction
Travel cost	$4,500,000	$900,000	80.00%
Assignment	$37,500	$37,500	0.00%
Fuel	$192,000.00	$71,040	63.00%
Maintenance	$75,000	$38,250	49.00%
Idle Time	$240,000	$62,400	74.00%
Logistics	$3,232	$1,777	45.00%
TOTAL	**$5,047,732**	**$1,110,967**	**77.99%**

Table 1. Reducing Costs by Using Math Approach

V. Conclusions and Recommendations

By Using Vehicle Assignment problem it was able to be reduced the overall logistics costs, being those mainly related with the assignment of a truck to a route, which is important, because using the right unit and the right drive can help to improve business profit by reducing the costs, but not only this can be reduced, but also it can increase the incomes by increasing the customer satisfaction. Moreover, with the accurate assignment, trucks can be sent to maintenance in the right dates, reducing not only maintenance costs, but also impacting the idle times, the fuel costs, as well as idle times, produced because of sending the truck to the wrong assignment, making it less productive. Moreover, it can be also shown that the solution provided was built using the factors that are impacting many freight transport companies in Mexico, since as it was shown the human factor is one of the main concerns and it also impacts other part of the processes, causing higher costs across the supply chain.

To increase the model reliability, it can be used stochastic models to calculate probability of producing idle times, so it can create a model based on probability, which can be more accurate than using the average data of last months, but it will also require higher calculations time, so it needs to be assessed, since the current solution provides to the company high savings.

Disclosure Statement

The authors declare no conflict of interest.

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