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Mexico City Flight Route Optimization: Operations Management Challenge

Optimización de rutas de vuelo de la ciudad de México: Desafío de la Administración de Operaciones

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ABSTRACT

We live in a globalized and competitive world where cities face serious mobility problems. The objective of this article proposes a flight route optimization model at Mexico City International Airport. The optimization process is carried out by means of Dijkstra's algorithm and graph theory. With the obtained data, the graphs are generated by means of a simulation process and development of the operations management giving positive results in the research.

Keywords: Optimization, operations management, graph theory

RESUMEN

Vivimos en un mundo globalizado y competitivo donde las ciudades enfrentan serios problemas de movilidad. El objetivo del presente artículo propone un modelo de optimización de rutas de vuelo en el Aeropuerto Internacional de la Ciudad de México. El proceso de optimización se lleva a cabo mediante el algoritmo de Dijkstra y teoría de grafos, con los datos obtenidos se generan los grafos representados mediante un proceso de simulación y desarrollo de la administración de operaciones dando resultados positivos en la investigación.

Palabras clave: Optimización, administración de operaciones, teoría de grafos.

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INTRODUCTION

Nowadays one of the problems that afflict every society has to do with the amount of time it takes for individuals to move from one destination to another. Currently the International Airport of Mexico City, is exceeded by the demand for flights and lack of infrastructure, just to mention a few causes. This article proposes to generate an optimal route, as well as the re-planning of the same flight routes, since every society faces serious mobility problems, so intelligent air traffic control is important. In the last decades the development of computer tools or operations research methods for the resolution of real problems in the design of transport routes has increased, based on conceptual models such as artificial intelligence or neural networks among others, which are programmed and incorporate different algorithms depending on the complexity of the same.

The Industrial Revolution 4.0 (IR 4.0) era has become a reference for several countries in technological, economic, social, cultural, defense and security development. Indonesia also needs to implement this, if it wants to be highly competitive (Tosida, 2020, pp. 160-170) and so, is important to apply intelligent algorithms to complex problems in big cities.

To this end, it is proposed to respond to air traffic by means of a model that allows the optimization of the flight system at Mexico City's international airport through the modeling of the Dijkstra algorithm. In this paper some works related to the proposed research are presented, after that, methodology and the solution procedure are described. Introduces to the theorical concepts about computational complexity and graphs theory, the encoding and results are shown and makes an analysis of them. Finally, the conclusions obtained from this research work is shown.

RELATED WORKS

Some works on the subject of mobility propose unmanned aerial vehicles (Unmanned Aerial Vehicles), which turn out to be precisely the generation of trajectories in hostile environments, considering static and dynamic environments, which are characterized because the elements involved (obstacles and threats) are known at the time of the generation of the trajectory and there are no modifications during the flight (Pajares :2008, pp. 83-92).

> (Rodríguez: 2017, pp. 288-298) Describes their methodology, School Bus Routing Problem, consists of finding an efficient sequence of routes for a fleet of school buses that pick up students at various stops satisfying various restrictions such as the maximum capacity of the bus, such as the maximum time and time limit to reach the destination.

(Jungnickel: 2008, pp 17-20) mentions in his work A real-time replanning algorithm based on a lyapunov stability index for subway lines the use of different methodologies seeks to respond to the conflict of land or air mobility. The present work defines the variables that must be taken into account to have a better air control, using different software to model the data, the routes of transfer in kilometers are determined analyzing the information to determine the graph that will allow to generate the mathematical model that will have different variables one of them the distance and that when being solved through the modeling, it will determine the points of arrival to different tourist places reducing times and optimizing the resources.

Some methodologies were applied for the Designation of the New Aviation Routes such as the methodology of Edsger DIJKSTRA, which refers to the Dijkstra algorithm, Leonhard Euler's Methodology that refers to the Theory of networks to make the Shortest Route, with the different distances from node to node resulting in the minimization of such Routes, which may occur in the process and delays. In conclusion, the present work allows to know in advance the short routes by means of the proposed mathematical model, the long aerial lapses will be able to be eliminated, allowing a control on the air traffic.

Some investigations related to giving immediate response to air traffic, seek to optimize times and routes transfer. As mentioned in his work (Romero: 2017, pp 161-168). The genetic algorithms for optimization and study of transport trips, through the use of artificial intelligence, shows the implementation of a genetic algorithm (GA) as a tool to plan and optimize transport routes, with the aim of finding the best route destinations.

Many optimization problems require a better order to perform a given set of operations (Held: 2015, pp. 196-210).

(Espinal: 2011, pp. 28-32) Mentions in his article, an application of a computer tool based on the theory of graphs which deals with analyzing and solving (Capacitated Vehicle Routing Problem, CVRP), His study analyzed a fleet of 13 vehicles with the same specifications, the result was a saving of 21.9% in resources used since the routes can be covered using 2 fewer vehicles.

The present work proposes the generation of a new trajectory, as well as the re-planning of the same flight routes, since it faces serious mobility problems, so intelligent air traffic control is important. As mentioned in (Goncalo: 2018, pp. 1-19), proposes a new technique for searching new routes and paths called xTrenk the main idea is to find new routes through navigation search engines in many areas besides video games, namely communication network routing, robotic route planning and global positioning through system navigation systems just to mention some applications.

METHODS

The country must have adequate airport capacity for its development, as airports serve both passenger and freight transport. The capacity of an airport is determined from two perspectives, called "air" capacity and "ground" capacity. It is determined by various factors, such as the number of runways, the type of aircraft and the distance to be kept between them for safety reasons. The ground capacity refers to the number of passengers it can receive and is related to the capacity of the terminal and its services. The International Airport is saturated as it carries out more operations per hour than the limit set by the national aviation authority, which is reflected in sub-optimal services. It is estimated that from 75% of the use of the maximum capacity, the cost per operation increases. The current airport operates at more than 85% of its maximum capacity. In 2017 it received around 45 million passengers, which represents an increase of 7.2% with respect to the previous year. Due to the urban density of the area, it does not have space to expand (Ocampo: 2018).

Therefore, the Mexico City International Airport presents several problems, some of them are Installed capacity, infrastructure and above all, optimal and efficient air traffic control. This paper emphasizes the need to generate new aviation routes that will allow for the improvement of air traffic. To do this, we propose to respond to this problem by analyzing Dijkstra's algorithm with which we will give a new proposal to the problem of air traffic, using an analysis based on the theory of graphs (Jungnickel: 2008, pp. 17-20).

Professor Leonard Euler, Swiss mathematician (1807 - 1783) one of his most important works focused on the field of pure mathematics. Thus, he simplified the city plan by considering four points (vertices) joined by 7 roads (edges).

The problem was to see if it was possible to go through the diagram without lifting the pencil from the paper, going through all the points once and returning to the starting point. Euler demonstrated that such a route was impossible, since, if such a path existed, the number of edges in any vertex of the graph should be even (for each edge that carries a vertex there should be another one that comes out).

> In the situations proposed by Leonard Euler, it is to get to symbolize the concrete problem with the use of a graphic scheme or graph formed by vertices and lines, which join those same vertices, from it, a possible solution to the initial problem posed will be studied through a reflection on the associated graphic scheme (Bondy: 1982).

COMPUTATIONAL COMPLEXITY

There is a scale to measure complexity, which includes, among others: P, Time-soluble polynomial; P-complete, the most difficult problems in P. NP problems with positive answers verifiable in polynomial time and NP-complete, the most difficult problems of NP. Many of these classes have a co-class that contains problems complementary to those of the original class. The problems that have a solution with order of linear complexity are the problems that are resolved in a time that relates linearly with its size. Although currently most of the algorithms solved by the machines have at most one complexity or polynomial computational cost, i.e. the ratio of the size of the problem to its execution is polynomial. These are problems grouped in class P (Cortés: 2004, pp.102-105).

Graph Theory

The graphs can be considered formally as diagrams or drawings (diagrammatic representation), or algebraically as a pair of sets (algebraic representation). Networks are represented in the form of graphs or matrices, the latter being the form that allows us to easily carry out an analysis of the formal characteristics of the network (Wasserman: 1994), (Stanley: 1994).

The geometrical definition tells us that a G graph is a set of points in space, some of which are connected to each other by lines. (See fig. 1) We show an example of a network (Menéndez: 1998).

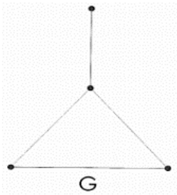


Figure 1. Geometric representation of Graph G.

The networks presented in the following paper are defined as a simple network G as the pair (V(G), E(G)), in which V(G) is a non-empty finite set of elements called vertices (or nodes, or points), and E(G) is a finite set of non-ordered pairs of elements of V(G) called edges (or lines); sometimes we will call the set of vertices and the set of edges from G to V(G) and E(G), respectively. For example, Figure 2 represents the simple graph G whose set of vertices V(G) is the set {u, v, w, z}, and whose set of edges E(G) is made up of the labels of the axes of the figures are often sources of confusion.

The pairs {u, v}, {v, w}, {u, w} and {w, z}. It is said that {v, w} is the edge which joins the vertices v and w and is designated in abbreviated form vw. Note that since E(G) is a set rather than a family, there can never be more than one edge joining a given pair of vertices in a single graph. (We use the word "family" to denote a collection of elements, some of which may appear several times; for example, (a, b, c) is a set, but (a, a, a, b, c) is a family (Calderero: 2003).

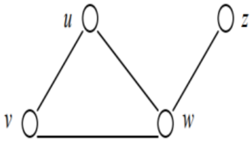


Figure 2. Geometric representation of Graph G.

Happens that many of the demonstrable results for simple graphs can be extended without difficulty to more general objects where two vertices may have more than one edge. Furthermore, it may often be desirable to lift the restriction that each edge must join two different vertices, and to allow for the existence of loops, i.e., edges that join a vertex to itself. The resulting object, which can have multiple loops and edges, is a general network, or simply a network. That according to that in which each vertex is once adjacent to all the others, so it can say that all the elements are related to each other (García: 2002).

A C graph is, in a more rigorous definition, a pair (V(G), E(G)), where V(G) is a non-empty finite set of elements called vertices, and E(G) is a finite family of non-ordered pairs of elements (not essentially different) from V(G) called edges; note that the use of the word "family" allows for multiple edges. We will call V(G) and E(G) a set of vertices and a family of edges of G, respectively. Thus, in the Fig. 2, V(G) is the set {u, v, w, z} and E(G) is the family composed of the edges {u, v}, {v, v}. {v. v}, {v. w}. {v, w}. {v. w}. "u. w, u. w, and w. z.".

> One issue related to graph theory is the study of digraphs (often called oriented graphs or networks, although we will use the word 'network' in a somewhat different sense). A D digraph is defined as a pair (V(D), A(D)), where V(D) is a non-empty finite set of elements called vertices, and A(D) is a finite family of ordered pairs of V(D) elements called arcs (or oriented edges, or di-arists) (Wilson: 1972).

Graph theory has also served as an inspiration for the social sciences, especially for developing a non-metaphorical concept of social network that substitutes the nodes for the social actors and verifies the position, centrality and importance of each actor within the network. This measure allows the quantification and abstraction of relationships (Taha: 2004).

Dijkstra's algorithm (minimum route)

The problem of the shortest route can be solved using linear programming; however, because the simplex method is of exponential complexity, it is preferred to use algorithms that take advantage of the structure in network that one has for these problems. To do this, the algorithm maintains an S set of nodes whose minimum path end weights from the source node have already been determined (Espinal: 2011, pp. 28-32).

Applying the DIJKSTRA algorithm methodology

Objective: To find optimal routes from one vertex of the network that we will call origin to all other vertices of the network. Dijkstra's algorithm will allow us to find one or several optimal routes between the origin node and all the other nodes of the network.

Dijkstra's algorithm. If ij is the shortest distance from source node 1 to node i, and dij (0) is defined as the distance in kilometres of the arc (i, j). Then the algorithm defines the node next to, or after, j as [uj, i] = [ui + dij, i], dij 0

The start node is [0, - -], which indicates that the node has no predecessor.

The nodes in Dijkstra's algorithm are of two classes: temporary and permanent. It is called temporary if it is changed or if a shorter path to a node can be found. When it is seen that no better path can be found, the state changes from temporary to permanent.

Steps:

a) Label the source node (node 1) with the permanent label [0, - -]. Match i =1. Step i.

b) Calculate the temporary ones [ui + dij, i] for each node j that can be reached from node i, if j does not have a permanent label. If node j is already with [uj, k] by another node k, and if ui + dij uj, substitute [uj, k] by [uj + dij, i].

c) If all the nodes are permanent, you must stop. Otherwise, select [ur, s] which has the shortest distance (=ur) between all temporary ones (ties are arbitrarily broken). Make i =r and repeat step i. (Taha: 2004).

LINGO SOFTWARE MATHEMATICAL MODELING

The modeling made with the lingo program, allows to obtain the optimal routes for the different tourist sites. To avoid redundancy in the data, the programming code modelled in lingo from the starting point, which is the AICM, to the destination Manzanillo is presented as an example.

Program code

First Solution:

First AICM Modeled Network - MANZANILLO Min=1052.13*xA1 (N.AICM-Culiacán) +1008.42*xA2 (Culiacán-Ixtapan) +1170.31*xA3 (Ixtapan-La Paz)+221.74*XA4 (La Paz-L. Mochis) +863.77*xA5 (L. Mochis Manzanillo)+500.17*XB1 (N. AICM-Huatulco) +1115.97*xB2 (Huatulco-Cozumel)+1628.74*xB3 (Cozumel-L. Cárdenas) +276.30*xB4 (L. Cárdenas-Manzanillo) +485.50*xC1 (N.AICM-Colima) +689.55*xC2 (Colima-C. Victoria)+396. 58*xC3 (C. Victoria-León) +1408.79*xC4 (León-Chetumal) +1709.65*xC5 (Chetumal-Manzanillo) +1540.41*xA11 (Culiacán-Huatulco) +1557.22*xA12 (Ixtapan-Cozumel) +1082.37*xA13 (La Paz-L. Cárdenas) +811.74*xA31 (La Paz-Manzanillo) +866.71*xC21 (Colima-Huatulco) +1285.09*xC22 (C. Victoria-Cozumel)+341.59*xC23 (León-L. Cárdenas)+381.49*xC32 (León-Manzanillo);

Restrictions

![ROUTE A]! 1052.13*xA1+1008.42*xA2+1170.31*xA3+221.74*XA4+863.77*xA5;

![ROUTE B]! 500.17*XB1+1115.97*xB2+1628.74*xB3+276.30*xB4;

![ROUTE C]! 485.50*xC1+689.55*xC2+396.58*xC3+1408.79*xC4+1709.65*xC5;

![POSSIBLE ROUTE 1A THROUGH B]!
1540.41*xA11+500.17*XB1 1+1115.97*xB2+1628.74*xB3+276.30*xB4;

![POSSIBLE ROUTE 12A THROUGH B]!
1557.22*xA12+1115.97*xB2+1628.74*xB3+276.30*xB4;

![POSSIBLE ROUTE 13A THROUGH B]! 1082.37*xA13+1628.74*xB3+276.30*xB4;[possible route 13a through b]! 811.74*xA31+1628.74*xB3+276.30*xB4;

![POSSIBLE ROUTE 21C GOING THROUGH B]!
866.71*xC21+500.17*XB1+1115.97*xB2+1628.74*xB3+276.30*xB4;

![POSSIBLE ROUTE 22C THROUGH B]!
1285.09*xC22+1115.97*xB2+1628.74*xB3+276.30*xB4;

![POSSIBLE ROUTE 23C THROUGH B]! 341.59*xC23+1628.74*xB3+276.30*xB4;

![POSSIBLE ROUTE 23C THROUGH B]! 381.49*xC32+1628.74*xB3+276.30*xB4;

After Mathematical Modeling, there is only one optimal route from the New AICM to Manzanillo by this method: N. AICM COLIMA C. VICTORIA LEON MANZANILLO. As seen in Fig. 3.

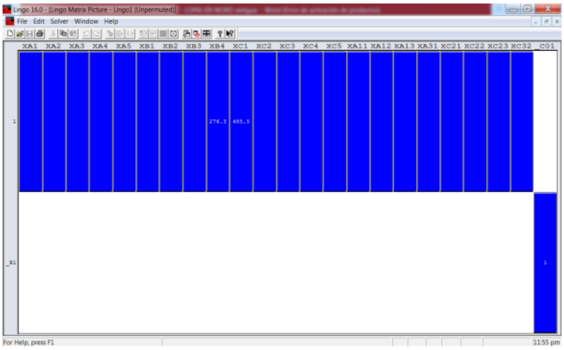


Figure 3. Optimal Solution Chart.

RESULTS

In the present investigation, risks are detected in the transfer times from one destination to another in the international airport of Mexico City, as well as the current routes present delays and setbacks that affect the end user. The route proposed to optimize the problem of arrivals at the AICM was determined by measuring the new routes at the New Mexico City international airport using the Google Maps tool. This measurement is based (in kilometers) and will be used in the modeling of the network.

In Fig. 4. the Google Maps tool is used to measure the point of origin with its respective location and the destination zone where the different international airports are located.

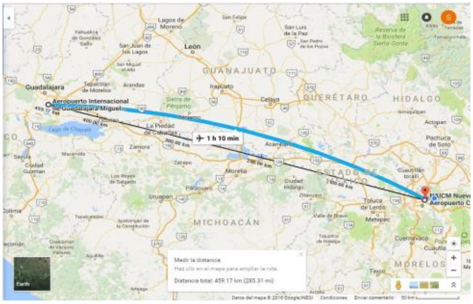


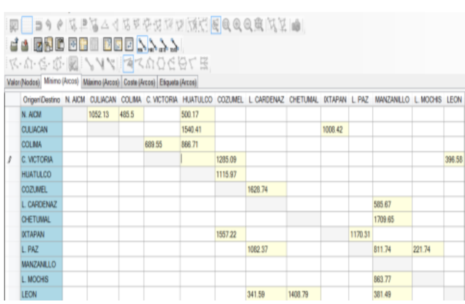
Figure 4. Graphical representation of national flights.

As shown in Fig. 4, the distances in kilometers of the different domestic flights were determined and are shown in Table 1. Same as used to generate the networks and the simulation using Dijkstra's algorithm, the distances with the shortest route optimizing the arrival times of the domestic flights.

Table 1. Calculation of the different flight destinations from the Mexico City International Airport in Kilometers for the problem resolution using Dijkstra's algorithm.

N°	Punto de partida	Destinos	Kilómetros
1	AICM	Miguel hidalgo, Guadalajara	459.17 km
2	AICM	General Ignacio Pesquería, Hermosillo	1,615.77 km
3	AICM	Francisco Sarabia, Durango	774.01 km
4	AICM	Ciudad Obregón	1,409.38 km
5	AICM	Ciudad Juárez	1,551.57 km
6	AICM	Ciudad del Carmen	762.96 km
7	AICM	Acapulco	316.56 km
8	AICM	Aguascalientes	425.25 km
9	AICM	Campeche	890.17 km
10	AICM	Cancún	1,274.97 km
11	AICM	Chetumal	1,127.67 km
12	AICM	Ciudad Victoria	474.82 km
13	AICM	Colima	485.50 km
14	AICM	Cozumel	1,265.34 km
15	AICM	Culiacán	1,052.13 km
16	AICM	Huatulco	500.17 km
17	AICM	Ixtapan – Zihuatanejo	334.19 km
18	AICM	La paz	1,284.24 km
19	AICM	Lázaro Cárdenas	377.61 km
20	AICM	León – El Bajío	314.18 km

Below is the proposal of the new network Modeled using the Graph Software the data obtained from Table 1, in which the distances from the International Airport of Mexico City to the different National Airports were determined, the network is built, hoping to find an optimal route proposal which will reduce the arrival times to the different destination points, being the new AICM the point of origin, consequently the blue arc shape shown in figure 3 represents the distance from one airport to another, each node is connected from one point to another and both form a network that will be modeled as shown in Fig. 5.



Origen\Destino	N. AICM	CULIACAN	COLIMA	C. VICTORIA	HUATULCO	COZUMEL	L. CARDENAZ	CHETUMAL	IXTAPAN	L. PAZ	MANZANILLO	L. MOCHIS	LEON
N. AICM		1052.13	485.5		500.17								
CULIACAN					1540.41				1008.42				
COLIMA				689.55	866.71								
C. VICTORIA						1285.09							396.58
HUATULCO						1115.97							
COZUMEL							1628.74						
L. CARDENAZ											585.67		
CHETUMAL											1709.65		
IXTAPAN						1557.22				1170.31			
L. PAZ							1082.37				811.74	221.74	
MANZANILLO													
L. MOCHIS											863.77		
LEON							341.59	1408.79			381.49		

Figure 5. Graphs of domestic flights to find the Minimum Route.

A network of 15 connected nodes will be generated which will generate new AICM starting points towards the various national destinations, but always with the starting point of the modelled network being the AICM point of origin consequently the arcs are the distances from one airport to another thus building a network that is related from one point to another that will later have to be modeled to find the shortest route as can be seen in Fig. 6.

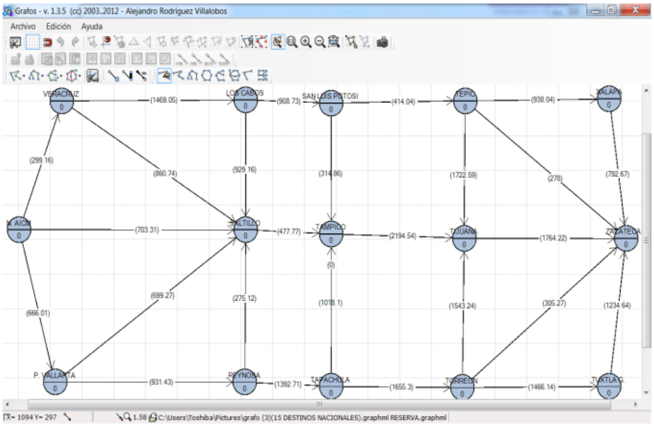


Figure 6. Graphs of national flights to find the optimal route for the model.

CONCLUSIONS

In this work a new strategy is presented that addresses the search and response on the problem of air traffic, since the allocation is often not correct, the research presents a proposal to optimize flight times from a point (n) to a point (m), gives optimal way. We especially emphasize on the markets of the United States and Europe.

Currently the company is evaluating new routes for better air control in order to minimize their routes for operational staff and achieve the goal of reducing time and costs, by discharging the new routes can be achieved great changes such as generating greater awareness in terms of optimization, will have new guidelines that will generate added value to the department of Civil Aviation and Air Control. Once authorized, it can be implemented in other airports in Mexico.

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