An Efficient Landing Route Structure to Enhance Airport capacity

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Abstract: Due to the air traffic growth tendencies around the world, capacity problems have been emerging among different elements within the system, but perhaps one of the most visible and expensive is the air traffic congestion. Therefore, innovative methodologies to tackle it have been developing. Special attention has been centering at the terminal maneuvering area which is perhaps one of the most complex types of airspace. In this work, a simulation-optimization modeling technique is presented to tackle the air traffic congestion by building an optimal landing sequences to feed optimally the runway. Therefore, different Terminal Maneouver Area route structures have been designed and tested to analyze its benefits. In a first approach, Queretaro (Mexico) airspace is used as a case study. Following this, the merging and sequencing problem is addressed by means of genetic algorithms aiming to minimize conflicts between arrivals; and in a third stage, a discrete simulation approach is used to introduced the stochastic aspects of the problem such as arrival speed profiles, delays, and wind interaction, among others.

Keywords: merging and sequencing problem, terminal maneuvering air traffic management, optimization, discrete event simulation.

1. INTRODUCTION

Nowadays, Air Transport System plays a major role in the global economy. It connects businesses to global markets; it is a major tourist's transportation, more than half of the world's tourist travel by air; it also enables worldwide access to time-sensitive products, from fresh products to emergency aid. In the past 20 years, air travel has grown at an average of 1.8 times as fast as global Gross Domestic Product (GDP) even though there have been substantial yearly crisis such as Gulf crisis, 9/11 attacks or 2008 financial crisis, to mention some.

Passenger traffic grew 5.3% expressed in Revenue Passenger Kilometers (RPK) in 2012, moving around 2.9 billion passengers and $5.3 trillion USD worth of cargo. This growth has supported the employment of 56.6 million people (directly and indirectly) and contributed over $2.2 trillion USD to global GDP [1].

Traffic distribution of the largest markets during 2012 place North American, Europe and Asia-Pacific with the 83% of the total global traffic. The Asia-Pacific region has been delivering the highest margins (around the 31% of the traffic) and largest profits followed by North American, with almost the same amount of traffic load. Latin America moved 4% of the worldwide traffic load but its tendency previews an economic growth of 4% per year [2].

In Latin America region, two different situations can be pointed out in two largest markets: Brazil and Mexico. A deceleration process was particularly pronounced in Brazil meanwhile the Mexican economy strengthened as increased business and consumer confidence sustained domestic demand [1].

Traffic growth tendencies bring a lot of benefits but also disadvantages, perhaps one of the most prominent is related to system capacity. It has been predicted an expansion of passenger and cargo traffic and greater aviation connectivity, but with its corresponding increase in workload to airport services and air traffic control activities, among other elements of the system.

Helping to make best use of the available capacity at an airport combined with a more efficient, and predictable, arrival sequence can enhance the airport and air traffic management system capacity. Furthermore, this approach leads to a reduction in tactical intervention by the Air traffic controllers, but also leading to lower fuel consumption, less noise and pollution around the airport.

The present work aims to deal with capacity problem from the air side point of view by analyzing the Terminal Maneouver Area (TMA) route configuration. The proposed approach uses Genetic Algorithms to tackle the merging and sequencing problem to find a conflict free set of landing routes; and a discrete event simulation model to deal with the stochastic parameters of the system. The overall objective is to build a robust modeling technique which exploits the advantages of both optimization and simulation techniques to solve a complex problem as the merging and sequencing at TMA.

The reminder of this works is as follows; Section 2 provides an overview of the most prominent solutions to enhance capacity making emphasis in the airside solutions. In Section 3, it is presented the current and proposed route structure for Queretaro TMA. Following this, the proposed approach to solve the merging and sequencing problem is presented and explain in detail in Section 4. Section 5 contains some preliminary results. Finally, conclusions and future works are discussed at the end of the paper.

2. TRAFFIC GROWTH PROMINENT SOLUTIONS

To overcome the problems generated by the continuous growth of commercial aviation, a revisit or development of diverse philosophies is crucial. Airports, Air Navigation Service Provider (ANSP), and airlines among other stakeholders, share challenges and opportunities to develop or enhance their capacity. The most common ones include, in its pillars a collaborative decision making activity among all stake holders.

Approaches to alleviate air traffic congestion in dense regions (normally, metropolitan regions) include the development of an efficient Metropolitan Airport System (MAS). In the United States, the concept of an airport system was envisioned more than 50 years ago. According to [10], the basic guiding principles are: Airports should be safe, efficient, affordable to both users and government, they should be flexible and expandable to accommodate the increasing demand and be able to handle new aircraft and traffic types, they should be also compatible with the surrounding communities' needs, and they should contribute to the development of the region and national economy.

Airlines have implemented diverse approaches to meet traffic growth in an efficient manner and at a profitable cost. They have had to seek commercial partners to help them provide the network and service coverage required. Therefore, since 1990, alliances between airlines on international markets have become a dominant feature of the airline industry. One of the most important reasons is that alliances also allowed airlines to expand route systems with high quality standards without duplicating services that would add congestion.

Since the 70's, economists have tackle airport congestion by calling for the use of a price regulation mechanism. As a result, the airport *peak load* congestion pricing mechanism is proposed, which involves charging different landing fees at different times: during peak hours, flights are charged higher rates than during off-peak hours.

Regarding the airside, diverse modernization projects such as The Single European Sky ATM Research (SESAR) launched by the European Community and the Next Generation Air Transportation System (NextGen) launched by US government, among others, are aimed to ensure the safety and fluidity of Air Transport over the next thirty years. These projects are revisiting some key aspects to overhaul airspace systems. They are developing new philosophies and a variety of airspace concepts to satisfy strategic objectives such as increase safety, capacity and flight efficiency, i.e. reduce congestion, increasing operational efficiency in both air and land side, augment flight efficiency and mitigate environmental impact.

Airspace Concepts include details of the practical organization of the airspace and its operations as well as the CNS/ATM assumptions in which they are based. Practical organization of the airspace includes revisiting the ATS route structure, separation minima, route spacing, sector configuration and obstacle clearance. In the capacity and airspace utilization planning, the traffic flows demand plays an essential role in an efficient organization of airspace volumes which could increase the airspace capacity if properly addressed. At the same time, airspace control management must be undertaken to minimize the risk of potential conflicts while maximizing users' initial business interests' choices as often as possible [8].

At major airports, airspace congestion has become a severe problem, especially at international hub or multi-airport systems serving major cities and tourist destinations. The need for integrating related operations of areas with a high density of traffic like the TMA, is a primary concern to alleviate air traffic congestion while maintaining safe operations.

To optimize the structure of flows involved in localized congested areas, the change in their associated topology in terms of 4D Trajectories is proposed (trajectories defined in the three spatial dimensions together with a time-stamp) as one of the bases, including adherence to an agreed upon or constrained time of arrival and the improvement of spacing, sequencing and merging accuracy with the use of an adapted ground system automation support toolset.

Diverse approaches, both exact and heuristic, have been proposed to deal with the merging and sequencing problem in TMA but recently the approximate algorithms gained importance in the literature.

It was introduced a decision methodology called Constrained Position Shifting (CPS) [7] and [3] presented a CPS heuristic for the static and dynamic case of the Aircraft Landing Problem (ALP). The ALP aims at deciding a landing time for each aircraft such that each one lands within predetermined time window and that separation standards are respected. Different approaches for the ALP have been studied, some implement the CPS method and some others develop their own heuristics. For example, a Dynamic-Programming-based approach which used a method called Constrained Position Shifting (CPS) as in [3] and [4], it is a class of algorithms that is able to handle commonly-encountered operational constraints for the sequence problem. In [5] another approach which is based on Linear Programming solves the static case presenting a mixed-integer zero-one formulation of the problem together with a population heuristic algorithm. The CPS idea has been previously addressed by the authors in [13] using it to merge and sequence aircraft with a causal modeling approach.

In most European and North America TMAs, Arrival tools such as Arrival Manager (AMANs) systems or Final Approach Spacing Tool (FAST) have been developed to provide automated sequencing support for the ATC handling traffic arriving to an airport, continuously building arrival sequences and times for flights, taking into account the locally defined landing rate, the required spacing for flights arriving to the runway and other criteria. Unfortunately, when relying on open-loop vectoring techniques, the sequence manager is not fully aware of controllers' intentions and hence its purpose of building an efficient sequence is not achieved, besides, holding patterns may result when TMA capacity is exceeded at peak periods [8].

Other proposals deal with the design of RNAV routes and terminal procedures, including departure procedures (DPs) and standard terminal arrivals (STARs). RNAV is a method of navigation that permits aircraft operation on any desired flight path within the coverage of ground or space based navigation aids or within the limits of the capability of self-contained aids, or a combination of these. Arrival RNAV & P-RNAV procedures have been defined in some TMAs with the aiming at airspace capacity, workload, efficiency, predictability and environmental benefits procedures.

Approaches such as the method called "Point Merge technique" presented by [6] and [9] aims to merge arrival flows of aircraft of traffic into a safe and efficient sequence without relying on open-loop vectors. Its objective is to achieve the aircraft sequence on a point with conventional direct-to instructions, using predefined legs at iso-distance to this point for path shortening or stretching. In [14] a topology structure similar to the Point merge approach has been proposed to deal with the CD\&CR in both, En-Route and TMA using a causal approach. The main difference corresponds to the pre-defined topology used to expedite or delay aircraft and the use of path and speed regulation. In [15] an evolutionary algorithm has been developed to merge and sequence aircraft in TMA using two different topologies structures; it aims at optimizing the distance and therefore the delay introduced. Unfortunately, these procedures are not applied worldwide and when they are applied is mainly under low or medium traffic loads but not when high traffic loads are arising, and therefore, their major benefits have not been exploited.

3. CASE STUDY ROUTE STRUCTURE

In the last decade, the total passenger traffic has been growing at an average of 4.6% (RPK). According to [11], in 2014, the total number of operations reached more than 1 million from which 800 000 of the total correspond to domestic flights. Mexico transported over 65 million passengers through almost 750 regular routes, 53% of them were international and heading to United States. The domestic airline sector has been growing faster than the international one, it were transported 40.6 million passengers (62.5% of the total) while the international only increased a 7% moving 24.4 million passengers.

Mexico moved 617 500 tons of cargo in 2012, which represent a 5.6% increase in comparison with 2013. As for passengers, the international cargo volume grow at a faster rate than the domestic sector, it increased in 7.9% over the previous year transporting 56.9% of the total.

Mexico counts with 76 airports, 63 of them are international airports and 13 domestic, in addition there are 1431 aerodromes register in the country. This places Mexico as one of the countries in Latin America with the biggest airport network. The busiest airport in Mexico is called Mexico City International Airport (ICAO code: MMMX), which also conforms, since 2003 the pillar of the Metropolitan Airport System (MAS), together with 4 international airports: Toluca (ICAO CODE: MMTO); Queretaro (ICAO code: MMQT); Puebla (ICAO code: MMPB); Cuernavaca (ICAO code: MMCB) [12].

From the total passenger movements in 2014, the Metropolitan Airport System has moved around 31 million which represent 54% of the total passenger transported. The cargo sector moved around 70% of the volume.

As part of the MAS, and due to the nature of the industrial region in Queretaro, airport and government authorities have boost the airport cargo services. Queretaro International Airport contributes with around 4% of total cargo in the country. However, in recent years, Queretaro International Airport have observed an amazing growing rate of 17.5% and 1.7% in international and domestic cargo, respectively.

Furthermore, in the last years, Queretaro City and its suburbs have been developing a strong aeronautical industrial region as an initiative of Mexican Government. Nowadays, it can be found enterprises such as General Electric, Bombardier, Grupo Safran, ITR, Scema, among others. It also hosts one of the biggest heavy maintenance facility, (Maintenance, Repair and Overhaul, MRO), leaded by Grupo Aeroméxico and Delta Air Lines.

Queretaro International Airport has being hosting DHL hub operations since 2010. Its infrastructure was designed to process 40 tons daily. However, since September 2014, cargo operations are held in an area of 10 000 m^2 that has the capacity to move around 140 tons per day, which translates in an increment of 45%. Nowadays, DHL operates 12 daily flights in addition to 15 ground routes, connecting Queretaro to sites such as Ciudad Juarez, Chihuahua, Monterrey, Hermosillo, Ciudad Obregon, Mazatlan, Villahermosa, Culiacan, La Paz, Cabo San Lucas, Cancun, Merida and Mexico City, among others [12].

Due to the increasing demand within Queretaro International Airport, it is needed an efficient use of airspace, which includes predictable and efficient landing and departing operations. Therefore, a review of landing and departure operations, procedures and airspace configuration is needed to enhance airspace and airport capacity.

3.1. Landing route configuration

Fig. 1 shows Queretaro TMA chart, it can be found in it, information regarding minimum speeds and altitudes, airspace classification and main VORs and entry routes, among other important information. Fig. 2 depict the landing route structure for runway 27L/09R and 09L/27R, respectively.

In arrivals using runway 09L/27R, eight landing routes fuse into one single route towards the final approach (runway 09L/27R) by merging in one waypoint called *D12.0* and following a final sequence denoted by *D8.0*, *D6.0*, *D4.0* and *D7.0* waypoint until threshold. In the arrival using runway 27L/09R six routes fuse into one single route towards the final approach (runway 09L/27R) by merging in one waypoint called *D12.0* and following a final sequence denoted by *D9.0*, *D6.0*, *D1.4* and *D7.0* waypoint.

The proposed landing route configuration is designed using a radius of 50NM center at the airport to define TMA in accordance to [12]. When designing an alternative route configuration, it is needed to clarify some concepts such as alternative route and links. The *alternative routes* aim to deviate aircraft to solve potential conflicts detected between TMA entry points until final approach meanwhile an optimized sequence is built. An alternative route is conformed by diverse numbers of *links* which join an Entry point to runway. A link is defined as a portion of a route which connects two waypoints (or nodes).

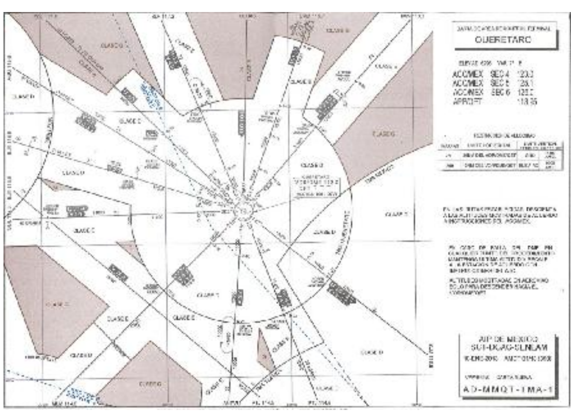

Figure 1 Queretaro air space configuration

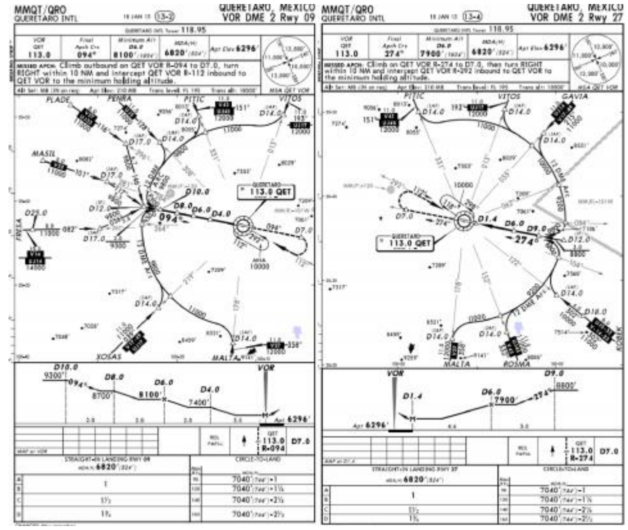

Figure 2 Queretaro arrival routes layout

In previous works of the authors [13] and [14], different route configuration and modeling approaches have been developed using Gran Canaria, Spain TMA. The different route configuration aims to avoid conflicts among aircraft by absorbing delays by a route change maneouver. Each alternative route conserves its Flight level constraints and lateral separation minima (based on ICAO document DOC-4444), as well as other airspace considerations such as avoid restricted, prohibited or any other areas not allowed for commercial flights.

Landing route configuration is designed to cope with the routes more congested. According to [12], the most congested routes are 2 international and 3 national: *Queretaro-Houston, Queretaro-Monterrey, Queretaro-Dallas, Queretaro-Cancun and Queretaro-Mexico.* Three routes (Houston, Monterrey & Dallas), normally enter by the norther waypoints: *VITOS*, *PITIC*, *PENRA*, or *PLADE*. The other two routes (Cancun & Mexico) enter by the south *KOBEK*, *ROSMA* or *MALTA*.

Fig. 3 (upper part) presents the proposed arrival route structure for runway 09L\/27R. There are eight entry points and one main merging point (20 18 20N 100 13 38W.

All routes have been designed to maintain a minimum altitude, as dictated by Mexican government authority. As an example, see the bottom of Fig. 3 and which introduces route MALTA-N26-N22-N21-N17-N15-N14-RWY. This route has its maximum elevation of 2569 MSL at the first link (between MALTA and N26). All proposed routes were subjected to a review of its elevation constraints, some of them were discarded and some of them modified as needed.

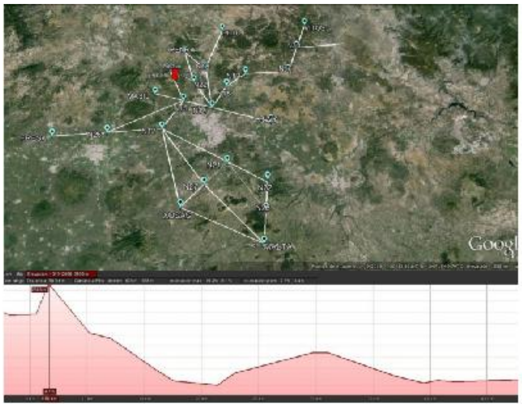

Figure 3 Synthetic arrival routes, runway 09L/27R

3.2. Scenario

Table 1 shows Queretaro scenario used within the case study. The scenario investigated test 38 aircraft on 1 hour period. As input for the model, the entry point, aircraft type, entry time and speed are donated. For the optimization model, the average entry speed has been used meanwhile, for the simulation tests, a triangular distribution has been employed to introduce stochasticity within the aircraft speed.

The results have proved to find optimal solutions for both topology structures, the current one and the one proposed within section 3.1 and depicted in Fig. 3.

4. PROPOSED METODOLOGY

4.1. Optimization model

To test the benefits of the proposed landing structure, a genetic algorithm has been employed to schedule a set of landing aircraft. The objective of scheduling a set of landing aircraft is to determine the landing times and sequence of a set of landing aircraft in a particular runway so as to increase the runway throughput while satisfying diverse operational and safety constraints. The mathematical formulation has been previously presented in [15] and it has proved to give good results in other scenarios.

The TMA has been modeled by a graph:

$$G = N, A \tag{1}$$

Where: N, represent the set of nodes and, A, represent the set of links.

For each route r_j, it is defined a set of alternative routes, noted as $alt(r_j)$. These alternative routes are noted as:

$$\sum_{k=1}^{k=L(r_j)} r_j \tag{2}$$

Where: $L(r_j)$ is the number of links of route r_j, having alternatives choices.

Table 1. Margins and Column Width

Entry point	Aircraft type	Entry time [h]	Entry speed [km/h]
Vitos	Light	0.014722222	Triangular(516.708,574.12,631.532)
Masil	Medium	0.050833333	Triangular(466.704,518.56,570.416)
Plade	Medium	0.1125	Triangular(516.708,574.12,631.532)
Fresa	Medium	0.278333333	Triangular(516.708,574.12,631.532)
Pitic	Light	0.328333333	Triangular(466.704,518.56,570.416)
Vitos	Light	0.417222222	Triangular(516.708,574.12,631.532)
Masil	Medium	0.470555556	Triangular(466.704,518.56,570.416)
Penra	Light	0.528888889	Triangular(516.708,574.12,631.532)
Xosas	Light	0.5975	Triangular(466.704,518.56,570.416)
Fresa	Heavy	0.668055556	Triangular(466.704,518.56,570.416)
Penra	Light	0.723333333	Triangular(516.708,574.12,631.532)
Xosas	Medium	0.783888889	Triangular(466.704,518.56,570.416)
Vitos	Light	0.861944444	Triangular(516.708,574.12,631.532)
Masil	Light	0.9175	Triangular(466.704,518.56,570.416)
Masil	Medium	0.073333333	Triangular(483.372,537.08,590.788)
Plade	Light	0.074166667	Triangular(483.372,537.08,590.788)
Pitic	Heavy	0.074444444	Triangular(483.372,537.08,590.788)
Fresa	Light	0.132777778	Triangular(516.708,574.12,631.532)
Vitos	Light	0.222777778	Triangular(483.372,537.08,590.788)
Masil	Heavy	0.276388889	Triangular(516.708,574.12,631.532)
Plade	Medium	0.3075	Triangular(483.372,537.08,590.788)
Fresa	Medium	0.358611111	Triangular(516.708,574.12,631.532)
Malta	Light	0.473055556	Triangular(516.708,574.12,631.532)
Penra	Medium	0.530277778	Triangular(483.372,537.08,590.788)
Vitos	Light	0.611666667	Triangular(516.708,574.12,631.532)
Plade	Heavy	0.672777778	Triangular(483.372,537.08,590.788)
Fresa	Medium	0.736666667	Triangular(483.372,537.08,590.788)
Pitic	Light	0.806111111	Triangular(516.708,574.12,631.532)
Penra	Light	0.919166667	Triangular(483.372,537.08,590.788)
Vitos	Light	1.001388889	Triangular(516.708,574.12,631.532)
Masil	Medium	0.073333333	Triangular(483.372,537.08,590.788)
Malta	Light	0.242222222	Triangular(483.372,537.08,590.788)
Xosas	Light	0.398333333	Triangular(483.372,537.08,590.788)
Vitos	Medium	0.501666667	Triangular(483.372,537.08,590.788)
Pitic	Heavy	0.573333333	Triangular(483.372,537.08,590.788)
Fresa	Light	0.796666667	Triangular(483.372,537.08,590.788)
Malta	Medium	0.960277778	Triangular(483.372,537.08,590.788)
Xosas	Light	1.042777778	Triangular(483.372,537.08,590.788)

The mathematical formulation requires the following parameters:

f_i: the flight planned to land in a given time horizon $[0,T_{max}]$, $f_i = \{1, \dots, n\}$,

e_i: the entry point of flight f_i in the TMA $i \in f_i$,

t_i: the time of flight f_i at entry point $i \in f_i$,

y_i: the speed of aircraft (f_i) $i \in f_i$,

r_j: the original route of aircraft (f_i) $i \in f_i$,

wt_i: the wake turbulence category (heavy, medium, light)

mss_{ik}: the required minimum safe separation between aircraft i and k if i lands before k, $mss_{ij} \geq 0 \forall\ i, k \in f_i$ due to their wake vortex constraint.

$d(f_i, f_j)$: the distance separating aircraft i and k if i lands before k.

The modeling approach considers two kinds of conflicts: Node conflict and Link conflict. A *Link conflict* is predicted if aircraft flying on the same link have lost the minimum safe separation (mss_{ik}) between aircraft i and k depending on the aircraft's wake turbulence category, i.e. $mss_{ij} \geq d(f_i, f_j)\ \forall\ t \in [0,T]\ \ d(f_i, f_j)$, if i lands before k, $mss_{ij} \geq d(f_i, f_j)\ \forall\ i, k \in f_i$). A *Node conflict* is predicted when an aircraft f_i is flying over a node n_k, other aircraft have to be 5NM away from the node. The optimization process is subject to speed constraint $mss_{ij}\ \forall\ \ f_i \in F\ v_i \in [v_{imin}, v_{imax}]$

4.2. Simulation model

The simulation model has been developed using a general purpose simulation software called SIMIO (SIMIOweb, 2015). Fig. 4 depicts the simulation model introduced in section 3.1.

For the conflict detection it has been implemented the logic: a conflict is detected if a pair of aircraft flying in the same route have lost it separation minima (based on ICAO document DOC-4444). In case a conflict is detected, a delay is induced to the following aircraft by amending its speed and route. Fig. 5 top shows the coding wake vortex separation in SIMIO comparing the leading and the following aircraft separation.

Route selection depends on the delay required. As for the merging point technique [9], it is proposed an enveloped of predefined routes which are easy to select by controllers (see Fig. 6). Speed changes are employed to couple the speeds for leading and following aircraft to avoid catch up encounters. Fig. 5 bottom shows the coding for speed and route selection. All speed and route changes are performed when entering a link segment of the route. In addition, a reduction of 10% of its current speed is performed to slow down the aircraft for landing.

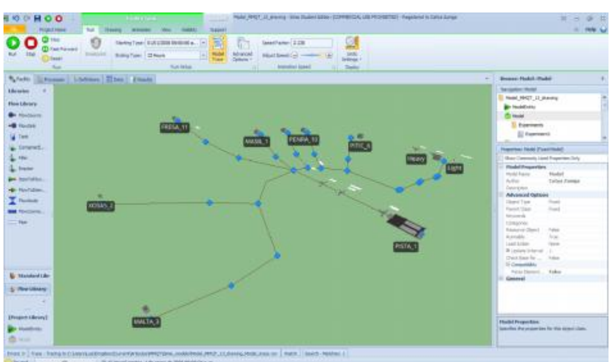

Figure 4 Simulation model

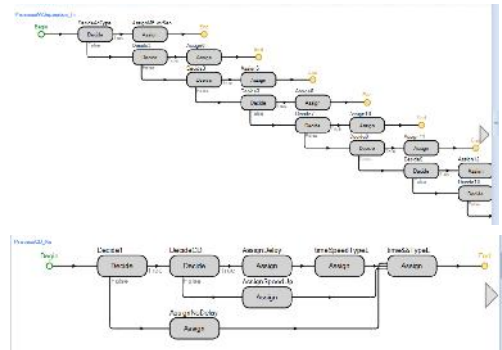

Figure 5 Simulation model

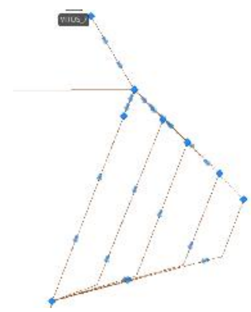

Figure 6 Simulation model

4.3. Results

The genetic algorithm parameters used for the genetic algorithm are presented in Table 2.

Fig. 7 and 8 represent the evolution of the fitness features with generation for the 38 aircraft scenario. The evolution of the fitness features is summarized for which the fitness of the best individual, the average fitness on population and the standard deviation are plot with generations.

The simulation report can be used to investigate the a wide variety of parameters such as time of an aircraft within the route, average, maximum and minim speed, number of conflicts encountered, number of speed and route changes, average number of aircraft in a link or route, among others.

Table 2. GA parameters

	38 aircraft scenario parameters
Number of generation	100
Pop size	100
Probability of Crossover	0,3
Probability of Mutation	0,3

Fig. 9 introduces some of the possible results for the simulation model in a 100 run experiment when investigating each aircraft type statistics. Fig. 10 shows an example of link statistics, where the number of aircraft in the link together with is spent time in it can be noticed. Finally, Fig. 11 presents statistics about runway such as utilization and average processing time per aircraft, among others.

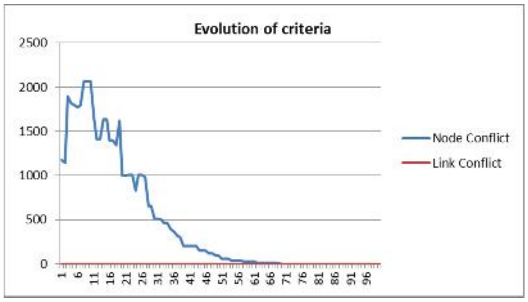

Figure 7 Evolution of the fitness for Queretaro, Mexico TMA

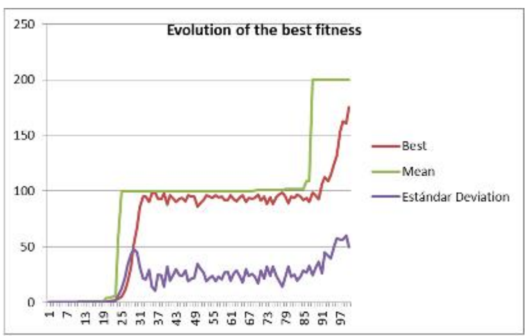

Figure 8 Evolution of the best fitness

Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average	Minimum	Maximum	Half Width
ModelEntity	Heavy	[Population]	Content	NumberInSystem	Average	0.0579	0.0542	0.0621	0.0004
					Maximum	2.1200	2.0000	3.0000	0.0656
			FlowTime	TimeInSystem	Average (Ho...	0.1391	0.1301	0.1490	0.0009
					Maximum (H...	0.2173	0.1936	0.2177	0.0022
					Minimum (Ho...	0.1038	0.0888	0.1205	0.0014
			Throughput	NumberCreated	Total	5.0000	5.0000	5.0000	0.0000
				NumberDestroyed	Total	5.0000	5.0000	5.0000	0.0000
	Light	[Population]	Content	NumberInSystem	Average	0.2700	0.2590	0.2930	0.0011
					Maximum	7.0300	7.0000	8.0000	0.0345
			FlowTime	TimeInSystem	Average (Ho...	0.1656	0.1599	0.1758	0.0007
					Maximum (H...	0.2245	0.2024	0.2579	0.0019
					Minimum (Ho...	0.1041	0.0967	0.1181	0.0009
			Throughput	NumberCreated	Total	20.0000	20.0000	20.0000	0.0000
				NumberDestroyed	Total	20.0000	20.0000	20.0000	0.0000
	Medium	[Population]	Content	NumberInSystem	Average	0.1654	0.1571	0.1719	0.0007
					Maximum	4.0000	4.0000	4.0000	0.0000
			FlowTime	TimeInSystem	Average (Ho...	0.1526	0.1450	0.1587	0.0006
					Maximum (H...	0.2203	0.1997	0.2521	0.0020
					Minimum (Ho...	0.1010	0.0952	0.1106	0.0006
			Throughput	NumberCreated	Total	13.0000	13.0000	13.0000	0.0000
				NumberDestroyed	Total	13.0000	13.0000	13.0000	0.0000

Figure 9 Simulation statistics for aircraft type

Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average	Minimum	Maximum	Half Width
Path	Path77	[Travelers]	Content	NumberOnLink	Maximum	0.7500	0.0000	1.0000	0.0875
			FlowTime	TimeOnLink	Average (Ho...	0.0000	0.0000	0.0000	0.0000
					Maximum (H...	0.0000	0.0000	0.0000	0.0000
					Minimum (Ho...	0.0000	0.0000	0.0000	0.0000
			Throughput	NumberEntered	Total	1.2800	0.0000	4.0000	0.2130
				NumberExited	Total	1.2800	0.0000	4.0000	0.2139
	Path78	[Travelers]	Content	NumberOnLink	Average	0.0000	0.0000	0.0000	0.0000
					Maximum	0.8200	0.0000	1.0000	0.0776
			FlowTime	TimeOnLink	Average (Ho...	0.0000	0.0000	0.0000	0.0000
					Maximum (H...	0.0000	0.0000	0.0000	0.0000
					Minimum (Ho...	0.0000	0.0000	0.0000	0.0000
			Throughput	NumberEntered	Total	1.5500	0.0000	5.0000	0.2220
				NumberExited	Total	1.5500	0.0000	5.0000	0.2220

Figure 10 Example of simulation statistics for links

Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average	Minimum	Maximum	Half Width
Path	Path5	[Travelers]	Throughput	NumberExited	Total	3.1000	3.0000	3.0000	0.3000
Server	PISTA_1	[Resource]	Capacity	ScheduledUtilization	Percent	1.5606	1.5264	1.6806	0.3062
				UnitsAllocated	Total	38.0000	38.0000	38.0000	0.0000
				UnitsScheduled	Average	1.0000	1.0000	1.0000	0.0000
					Maximum	1.0000	1.0000	1.0000	0.0000
				UnitsUtilized	Average	0.0159	0.0153	0.0168	0.0001
					Maximum	1.0000	1.0000	1.0000	0.0000
			ResourceState	ProcessingTime	Average (Ho...	0.0053	0.0050	0.0080	0.0001
					Occurrences	30.4000	24.0000	35.0000	0.4006
					Percent	1.5606	1.5264	1.6806	0.3062
					Total (Hours)	0.1909	0.1832	0.2017	0.0007
				StarvedTime	Average (Ho...	0.3783	0.3278	0.4726	0.0059
					Occurrences	31.4000	25.0000	36.0000	0.4806
					Percent	98.4094	98.3194	98.4736	0.0062
					Total (Hours)	11.8091	11.7983	11.8168	0.0007
		InputBuffer	Content	NumberInStation	Average	0.0026	0.0010	0.0061	0.0002
					Maximum	1.7600	1.0000	4.0000	0.1281
			HoldingTime	TimeInStation	Average (Ho...	0.0008	0.0000	0.0019	0.0001
					Maximum (H...	0.0046	0.0008	0.0171	0.0005
					Minimum (Ho...	0.0000	0.0000	0.0000	0.0000
			Throughput	NumberEntered	Total	38.0000	38.0000	38.0000	0.0000
				NumberExited	Total	38.0000	38.0000	38.0000	0.0000
		OutputBuffer	Throughput	NumberEntered	Total	38.0000	38.0000	38.0000	0.0000
				NumberExited	Total	38.0000	38.0000	38.0000	0.0000
		Processing	Content	NumberInStation	Average	0.0159	0.0153	0.0168	0.0001
					Maximum	1.0000	1.0000	1.0000	0.0000
			HoldingTime	TimeInStation	Average (Ho...	0.0050	0.0046	0.0053	0.0000
					Maximum (H...	0.0064	0.0060	0.0067	0.0000
					Minimum (Ho...	0.0037	0.0034	0.0041	0.0000
			Throughput	NumberEntered	Total	38.0000	38.0000	38.0000	0.0000
				NumberExited	Total	38.0000	38.0000	38.0000	0.0000

Figure 11 Example of simulation statistics for links

5. Conclusions

The present work introduces a new methodology that combines an optimization technique, such as genetic algorithms with discrete event simulation to perform the merging and sequencing problem at TMA. One, and perhaps the most valuable benefit of the proposed methodology relies on the ability to deal with both deterministic and stochastic characteristics of real problems resulting in a more robust and reliable solution.

ACKNOWLEDGMENTS

The authors acknowledge all the support provided by the National Council of Science and Technology of México (CONACYT).

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