Methodology for analysing Multi-Airport System Capacity: SBPL-MMMX System Case

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SIMULATION-BASED ANALYSIS OF CAPACITY FOR A MULTI-AIRPORT SYSTEM: MEXICO CITY CASE STUDY

Introduction

Mexico City airport is the main gateway to the country since years ago. However, its growth has been hampered by the saturation of the airport which in most slots of the day it is impossible to accommodate more traffic. The latter can be only achieved by performing three activities: infrastructure expansion, optimization of the current resources or by managing the system under a different paradigm such as the multi-airport system approach.
The previous government in Mexico decided for the first choice by constructing a new infrastructure in an old lake which made the project a risky business with uncertain outcomes. For the previous reasons and other consequences mainly environmental [1] the new government (by late 2018) decided to cancel the project and betted for a less risky approach by expanding an old military facility and changing the approach to a multi-airport system which will be composed by Santa Lucia Airport, Mexico City Airport and eventually Toluca which is also in the vicinity of Mexico City.
The opposition to this solution claim that the multi-airport system approach will not be able to solve the original problem of saturation in Mexico city airport while at the same time maintaining a steady traffic growth and also that the multi-airport system will not be equivalent in capacity to the previous option of a completely new airport.
The present study aims at answering some of the questions raised by the critics to the project, in particular, it will answer the questions of whether this proposal is able to cope with the expected demand in the coming years and if it is also able to solve the congestion problems in the current airport of Mexico city. In addition, this study will provide some light in the expected performance indicators of the new facilities and the limitations that will be faced once the expected traffic becomes a reality.
The present analysis involves the following aircraft fields

• Benito Juárez International Airport of Mexico City (MEX) which is the main airport for Mexico City
• Military Base "General Alfredo Lezama Álvarez" of Santa Lucia (NLU) which is currently a military base, but it will be upgraded to attract commercial traffic.

STATE OF THE ART IN MULTI-AIRPORT SYSTEMS

The topic of Multi-Airport Systems (MAS) has been gaining some attention the last few years as many issues regarding complex airport systems have been studied. The concept of a MAS is defined as one main airport with another or more secondary airports that together serve a metropolitan region and it has diverse issues that require attention, such as capacity, coordination, selection, sustainability and feasibility among others.
Regarding the definition and feasibility, the seminal paper of de Neufville [2] introduced the analysis of the viability of MAS by defining that the air traffic of a metropolitan area should exceed 10 million originating passengers per year so that a MAS could be economically and operationally viable, however this number has increased up to 15 million in some cases.

On the other hand, the paper of Martin and Voltes-Dorta [3] provides some caution for the development and use of MAS. They suggest, considering a financial approach, that some MAS worldwide are operating inefficiently and that the consolidation of air traffic of the whole MAS into one airport could provide a better performance regarding operating costs. However, their conclusions did not consider that, as the utilization of any capacity-constrained resource increases in a stochastic environment, the service levels of the system rapidly deteriorate with a non-linear function [4].

Furthermore, Fasone et al. [5] and Yang et al. [6] suggested that the viability of a MAS is intertwined with the development of other transport infrastructure, such as, railways, roads and bus services, that connects customers and cargo with the various airports in the system so that customers of the MAS could have accessible options to use any of the airports in the system and change their initial preference regarding the principal airport.

As mentioned, de Neufville and Odoni [7] state the viability threshold, which in 2013 they calculated was 15 million passengers per year for originating passengers, discarding the transfer ones.

Regarding the issue of airport selection, the subject of the main factors involved influencing selection among customers has been extensively studied using statistical methods ([8], [9], [10], [11], [12], [13], [14]. These papers found that air fare, access time, flight frequency, the number of airlines and the availability of particular airport–airline combinations were statistically significant factors in customer choice of airport. Interestingly, airport access time was found to be more important for business travellers than for leisure travellers. In contrast, leisure travellers were found to be more sensitive to price changes than business travellers.

The specific issue of multi-airport capacity has only been studied by Ramanujam and Balakrishnan [15]. The study by Ramanujam and Balakrishnan [15] focuses on the definition of capacity envelopes for the MAS of NYC, based on Gilbo [16] proposal. Using quantile regression and historical data, they modelled the relation between arrival and departure rates at singular airports considering the arrival rate as the independent variable, as arrivals are given priority over departures at singular airports. In addition, they also modelled the relation between arrival and departure rates of different airports, because the (airspace) approach and departure paths of different airports in MAS could interfere with each other. They found that the visibility factor is significant for arrivals but not for departures and that the capacity envelope area is increased when using one runway for arrivals and a different runway for departures, instead of a mixed use of runway for arrivals and departures. They also found that airside capacity is more significant for defining airport capacity than airspace as approach path overlap factor was not found to be statistically significant for capacity envelope definition.

Regarding Operational capacity of an airport, there are diverse studies attempting to estimate it for a singular airport resource, such as, runway capacity ([16], [17], [18], [19], [20]), and terminal capacity ([21], [22], [23]). In addition, there are few attempts to model the actual capacity of the whole airside operations of a singular airport, i.e., runways, taxiways and apron operations. Modelling the complete set of capacity-constrained resources of an airport could provide practitioners and researchers with better decision tools for design and management of the complete airside facilities of an airport as the interactions among different serialized queues could create different behaviour patterns than singular resources. In literature, only the work of Mujica et al. [24] present this approach. The paper by Mujica et al. [24] analyses, using Discrete Simulation, the capacity and performance of Lelystad Airport assuming that some traffic will be diverted from the highly utilized Schiphol Airport in Amsterdam. They modelled the capacity of Lelystad Airport considering historic data of wind visibility and airport traffic and considering various operative restrictions, such as, the separation criteria between aircraft operations, weather conditions, mix of aircrafts and type of taxiways. They found that the use of rapid exit taxiways could increase the throughput of a singular airport.

Thus, this literature review shows that regarding airport systems some studies have covered different aspects of single airports and by using some mathematical techniques some aspects of the MAS, but no authors have modelled a Multi-Airport System considering an integral approach (two or three airport operations together with airspace and/or different elements of the airport). This type of study could provide great insight in understanding the consequences and potential problems that might appear once the system of airports is operational. Consequently, the objective of the paper is to address this gap as it will be focused on studying a twin system that will be operational in the near future in Mexico considering the current Mexico City International Airport and the future Santa Lucia Airport.

METHODOLOGY

The study considers the two airports in their current phase and the expected developments for the short, medium and long term horizons.

Figure 1 illustrates the geographical location of NLU and MEX.

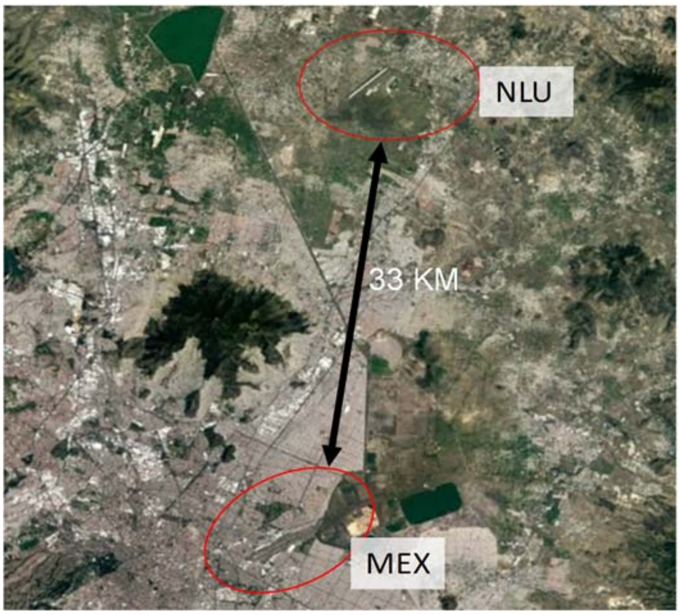

Figure 1. Aerial view of system NLU-MEX

The methodology followed in this work, is the one presented by Mujica et al. [25] for developing a multi model system in which a combination of models are developed in order to create one that minimizes the uncertainty associated with the modelling process (Fig.2).
The developed model considers the following elements:
• Benito Juárez International Airport (IATA Code: MEX). For the modelling of this airport, we used a high-detailed model developed by the authors for diverse studies [26].
• Santa Lucia Airport (IATA Code: NLU). For this airport the airport model considers the characteristics reported in public documents of the Mexican government and the development project of the airport. A macro model of this airport is developed.
• Current aeronautical routes. For the traffic approaching to the two airports, the current aeronautical routes have been considered and once NLU is operational, a modification based on the expertise and experience of the authors, has been proposed.
• Current capacities of MEX runway system regarding runway, taxiways and terminal stands.
• Capacities of NLU airport regarding runway and stands for the macro model.

The analysis is performed by developing different scenarios considering different assumptions and taking the expected demand of traffic as an input for the model together with current restrictions and traffic mix. All the technical restrictions that correspond to airspace and ground operations of the airports under study have been considered.
In the first instance, Scenario 0 is analyzed, This scenario represents the baseline for comparison of the following 6 scenarios that are used for characterizing the capacity of the aeronautical operation. This scenario is the current situation of the airport system of Mexico City.

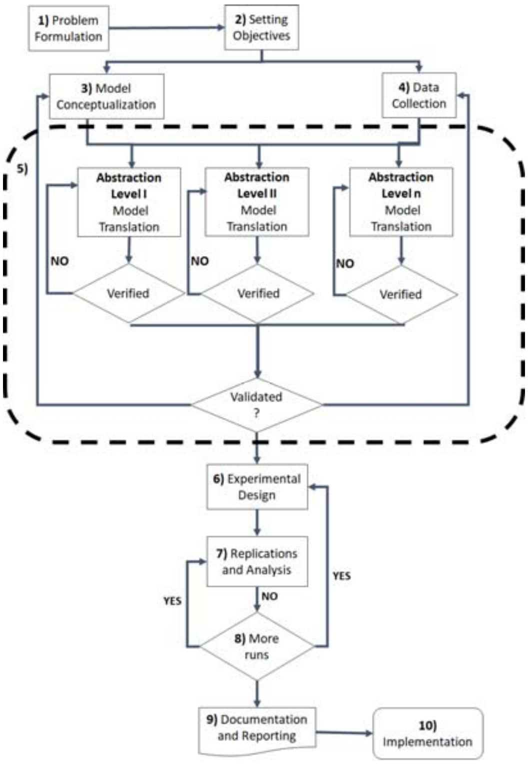

Figure 2. Methodology of the n-model virtual cycle approach for airport capacity
Source: [25]

Boundary Conditions and Analysis Criteria

The analysis is carried out considering the following operational assumptions:
• Current MEX airport layout.
• Sequential configuration of runways, taxiways and platforms for NLU.
• Current traffic mix for MEX airport.
• Current airspace based on Mexico AIP will be considered for the base case scenario.
• A feasible redesign of airspace to allow operation of NLU and MEX together is proposed.

The analysis is also made based on the following general considerations:

• The mix indexes% (C + 3D) of the AICM are maintained.
• 44,320,000 Pax / year is adopted as the current passenger level in Mexico City.
• 414,000 Movements / year is adopted. Starting with 590 arrivals/day.
• 18 hours of operation and 120 Pax / Average aircraft for both airports is assumed
• An annual operation is assumed for both airports
• The slot management model is maintained.
• The parking spaces available at MEX are maintained at 103
• 33 Parking places available in NLU are assumed from scenario 0 to 5a
• The considerations for the aeronautical capacity and associated airspace are conceptual.
All the simulations carried out consisted of simulations of 30 hours of operation and for each scenario 30 replications were made for obtaining the statistical indicators.

SCENARIO ANALYSIS AND RESULTS

The following section presents the different scenarios evaluated for the current study, starting with a base-case scenario and progressively modifying it for evaluating different situations.

Scenario 0

This scenario serves as the base case and represents the current situation of the airport in Mexico City. It makes use of a low-level simulation model, based on MEX's AIP, as well as using current air traffic values to compare the operational results with the subsequent scenarios.

The model includes the following elements:

- MEX Air Space
- Runway system 05R-23L and 05L-23R
- Terminal 1 and Terminal 2 with 103 aircraft parking positions in total
- Taxiway system with speed restrictions
- Flight plan for an average day of operation
- Traffic mix that includes low cost airlines (LCCs) and full service airlines (FSCs) and different aircraft equipment

For modelling the complete system, a simulation model of the current airspace together with the model of MEX were used. Figure 3 illustrates the airspace of the MEX model. The current routes reported in the AIP of Mexico [27] are used.

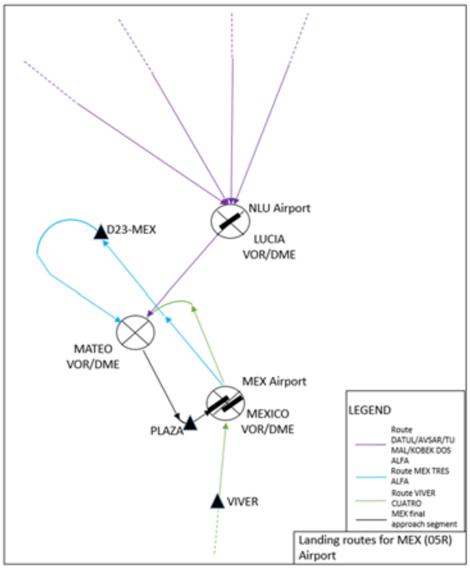

Figure 3. Elements of the airspace model

Figure 4 illustrates the low-level operating model implemented in MEX. With this model, all the emergent dynamics can be identified, as well as conflict situations that limit the capacity of the system like runway occupancy times, runway crossings, delays, congestion among others.
By running experiments with this model, we obtained performance indicators for the system, and we validated them statistically comparing them with historical data. Figure 5 presents the evolution of traffic during the day for the airport where clearly it can be seen that the levels of congestion are reached from 10 am until late at night (such as the real situation).
Regarding the remaining performance indicators for the elements that compose the system, Table 1 present different values obtained with the experiments.
It can be seen that the maximum value of ATM/HR corresponds to the declared limitation of the airport by the government. In addition, it can also be perceived that the remaining elements of the system are not fully congested during the day, only during peak times, revealing the effect of the business models of the companies that operate in the airport. From the analysis, it can also be perceived that the runway is the bottleneck of the system as it has been known for years now in Mexico.

Figure 4. Airside model of Mexico City Airport

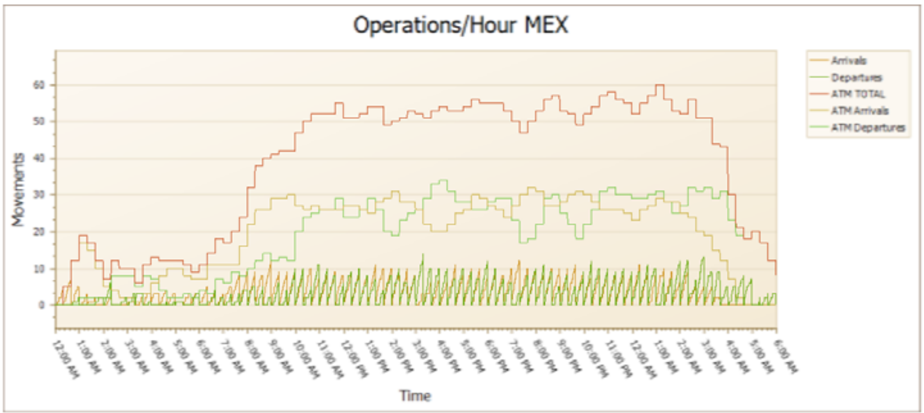

Figure 5. ATM evolution during the day

Table 1. Performance indicators of MEX

	MEX	
	Avg Value	Max Value
ATM/Hr	38.6	62
Gate Occupancy	55%	78%
Aircraft Waiting Runway	6	15
Aircraft Waiting Gate	0	6
Total Annual Passengers	30.4 MILL	48 MILL

Scenario 1

For this scenario, a redesign of the air routes that respect the operational restrictions was made, so that aircraft can fly from north and south to both airports without infringing safety restrictions.

It is assumed that low cost airlines LCCs transfer their operation to NLU and the Hub operation of legacy carriers is kept in MEX. The same airspace design was maintained for later scenarios. Figure 6 illustrates the simulated airspace as well as the location of the two airports under study.

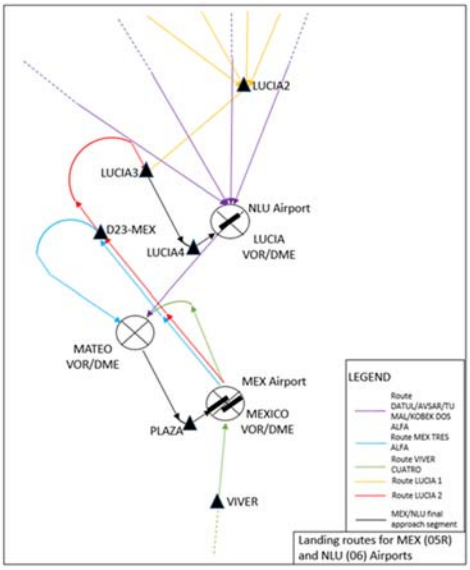

Figure 6. Air routes re-design for the system NLU-MEX

Table 2 shows the values of the air routes used for the study.

Table 2. Description of the landing routes for the MEX and NLU airports

Destination airport	Route	Waypoint	Altitude [ft]	Speed [kts]
MEX	DATUL/AVSAR/TUMAL/KOBEK/ DOS ALFA	LUCIA	12.000	220
		MATEO (IAF)	12.000	220
		PLAZA (FAF)	8.800	130
MEX	MEX TRES ALFA	MEX	FL 240*	250
		D23-MEX	18.000	250
		MATEO (IAF)	12.000	220
		PLAZA (FAF)	8.800	130
MEX	VIVER CUATRO	VIVER	12.000	250
		MEX	12.000	220
		MATEO (IAF)	12.000	220
		PLAZA (FAF)	8.800	130
NLU	Route LUCIA 1	LUCIA2	12.000	220
		LUCIA3	12.000	220
		LUCIA4 (FAF)	8.800	130
NLU	Route LUCIA 2	MEX	FL 240*	250
		D23-MEX	18.000	250
		LUCIA3	12.000	220
		LUCIA4 (FAF)	8.800	130

This scenario would correspond to a stage prior to the construction of the two runways referred in [28]. This scenario would also free up MEX capacity without affecting traffic growth. In addition, the function of the hub of MEX (in which full-service airlines operate) is not affected, and the growing demand of the low-cost airlines that service domestic demand is not hampered by this strategy. This scenario assumes that some LCC companies and charter ones will operate in NLU like the following: Magnicharter, Viva Aerobus, Interjet and Volaris; even some LCCs from the US could operate in this airport like Southwest or JetBlue. The same premise is maintained for subsequent scenarios in which we increase the volume of traffic.

As it can be seen in Table 3, once the airports are operating independently, the saturation of MEX is solved as in the worst situations the number of ATMs are 45 ATM/hr. Under the mentioned assumptions, the demand is shared by the two systems, and the maximum expected traffic with the type of equipment assumed would imply a maximum of 34 million of passengers for MEX and 30.7 million for NLU, making a total of almost 65 million passengers for the combined system.

Table 3. Performance indicators for Scenario 1

	MEX		NLU	
	AVG Value	MAX Value.	AVG Value	MAX Value
Traffic Share	57%		43%	
ATM/Hr	23	44	17	41
Gate Occupancy	47%	59%	48%	100%
Aircraft Waiting Runway	1	6	0	0
Aircraft Waiting Gate	0	0	0	8
Total Annual Passengers	18 MILL	34.7 MILL	13.4 MILL	30.7 MILL

Scenario 2

This scenario would correspond to the time-horizon when two runways have been completed in NLU, and the HUB operation of FSC would move to NLU while the LCCs would move to MEX. In this scenario, a simultaneous operation of landings and takeoffs in NLU will be possible (due to the two runways), and MEX would have enough room to absorb the growth of low-cost airlines as it is seen in the results of the simulations.

In this scenario, MEX remains as an airport for low cost airlines (LCCs); Table 4 shows the main performance indicators, as it can be seen that MEX is totally decongested, since the maximum number of movements would be 37 ATM / Hr or 60% of its capacity. On the other hand, NLU would have two tracks and operate at the time of maximum demand at 47 ATM / hr which suggests that it would not be even close to the current situation of MEX. 67 million passengers could be moved annually between the two airports with very reasonable operational indicators as Table 4 suggests.

Table 4. Performance indicators for Scenario 2

	MEX		NLU	
	AVG Value	MAX Value.	AVG Value	MAX Value
Traffic Share	43%		57%	
ATM/Hr	14	37	25	47
Gate Occupancy	19%	44%	70%	100%
Aircraft Waiting Runway	0	4	0	1
Aircraft Waiting Gate	0	0	5	23
Total Annual Passengers	11 MILL	29 MILL	19.7 MILL	37 MILL

It is important to note that it is perceived that the first bottleneck for NLU will be the aircraft parking spaces, since it is observed that there would be an average value of 5 cases of aircraft that do not have a gate when landing. Furthermore, in times of high demand this number can go up to 23 aircraft.

Scenario 3 and the following ones are designed to determine the growth limits and the elements that would restrict growth due to operational and capacity constraints.

Scenario 3

In this scenario, the same proportion of traffic mix between FSCs and LCCs is maintained, the variation of traffic consists of an increase of 10% in the demand for LCCs and FSC for both MEX and NLU. This scenario would correspond to a mid-term scenario assuming the current traffic growth trend.

In the case of NLU, the number of operations increases to a max of 50 ATM / hr at times of maximum demand, although on the other hand to avoid problems of reactive or induced delays it will be necessary to implement remote stands or add more gates to the infrastructure since the problems of aircraft without gate is evident (Table 5). 70 million passengers could be expected under this scenario(60% more than what MEX alone is currently receiving).

In this situation the problem of lacking gates for NLU is evident as the results illustrate. During peak hour, the problems could be severe (45 Aircraft waiting) which might be translated in delays for the flights at certain moments of the day.

Table 5. Performance indicators for Scenario 3

	MEX		NLU	
	AVG Value	MAX Value.	AVG Value	MAX Value
Traffic Share	43%		57%	
ATM/Hr	15.5	40	27.5	49.6
Gate Occupancy	19%	44%	75.8%	100%
Aircraft Waiting Runway	0	3	0	1
Aircraft Waiting Gate	1	1	14.4	45
Total Annual Passengers	12.2 MILL	31.5 MILL	21.7 MILL	39 MILL

Scenario 4

The increase in air traffic corresponds to 30% of LCCs and 30% of FSCs in MEX and NLU respectively. As previously mentioned, LCCs traffic can grow in MEX and FSC in NLU with a Hub-Spoke business model. This scenario would correspond to a medium-term horizon as well.
It can be realized that MEX does not present major problems, since it would be operating at a daily average of 18 ATM / Hr with peaks of 45 ATM/hr. However, in the case of NLU, it is already clear that in terms of runways there would be no problems, but it would be necessary to find a solution to the lack of Gates as Table 6 illustrates.

Table 6. Performance indicators for Scenario 4

	MEX		NLU	
	AVG Value	MAX Value.	AVG Value	MAX Value
Traffic Share	43%		57%	
ATM/Hr	17.7	45	31	65
Gate Occupancy	25%	49%	83%	100%
Aircraft Waiting Runway	0	3.6	0	2
Aircraft Waiting Gate	0	1	44	119
Total Annual Passengers	14 MILL	35.5 MILL	24.4 MILL	51 MILL

Scenario 5a and 5b

In scenario 5a and 5b air traffic increases by 70% in MEX and NLU respectively. This scenario would correspond to the assumption that traffic would grow as predicted in the next 50 years. This would be a long-term scenario, and would allow to evaluate the operation and limitations to absorb the expected traffic.

Scenario 5a

MEX reveals that under this configuration, it could grow without major problems for the next 50 years, however, NLU would have severe problems in case no gates expansion is performed as Table 7 illustrates.
Under the expected traffic, NLU gate infrastructure would be severely limited, for this reason, an alternative scenario (5b) is proposed which contemplates an expansion of the parking positions for aircraft and terminal building. In 5b, the number of parking spaces is doubled (66 Gates).

Table 7. Performance indicators for Scenario 5a

	MEX		NLU	
	AVG Value	MAX Value.	AVG Value	MAX Value
Traffic Share	43%		57%	
ATM/Hr	24	49.5	36	89
Gate Occupancy	28%	70%	85%	100%
Aircraft Waiting Runway	0.7	8	0	2.8
Aircraft Waiting Gate	0	1	112	256
Total Annual Passengers	19 MILL	39 MILL	28.4 MILL	70 MILL

Scenario 5b

The problem of lack of gates is partially solved but not completely. From Table 8 it can be noticed that there are still some problems during some days, as still some aircraft do not find a gate. The latter suggests that the double of gates is not enough for the operation, instead it is necessary to invest in more than 33 gates.
Table 8 presents the complementary indicators for the long-term scenario. As it can be seen, MEX reveals the limitation of the Runway as some aircraft will be limited by the runway, however, with a proper management of the sequence of the expected traffic mix, this can be minimized. In the case of NLU, the gates are the limiting factor for growth. The complete system would be expected to absorb a maximum of 120 mill of passengers.

Table 8. Performance indicators for Scenario 5b

	MEX		NLU	
	AVG Value	MAX Value.	AVG Value	MAX Value
Traffic Share	43%		57%	
ATM/Hr	24	50	42	105
Gate Occupancy	28%	70%	57%	100%
Aircraft Waiting Runway	0.7	8	0	4
Aircraft Waiting Gate	0	1	8	50
Total Annual Passengers	19 MILL	39.5 MILL	33 MILL	82.7 MILL

DISCUSSION AND CONCLUSION

The study presented for the first time a methodology for performing a simulation-based analysis of a Multi-airport system. We presented the case of Santa Lucia and Mexico City Airport which has become a key development for the country. The study consisted in different scenarios based on public information and governmental plans using three models: one for Mexico City airport, another for Santa Lucia and another one for the airspace that connects both airports. The experiments with the different scenarios gave light to some important issues regarding the development of the facilities such as the capacities of the system and the limitations that will appear when the growth in traffic takes place in the airport system. Some important results about the scenarios are discussed.
Regarding Scenario 0, we could identify that the main bottleneck is the runway, which coincides with what has been discussed publicly in the media. Depending on the time of the day, the effect of the runway is more or less severe. In addition, we could also identify that the limit of the capacity of 61ATM/hr can be reached sometimes. Assuming these operating levels, it can be estimated that this airport could absorb a capacity of 48 million passengers assuming the average aircraft type with an occupancy of 120 passengers, maintaining continuously 61 ATM / Hr, which is currently unfeasible.
Scenario 1 gives light on the operational levels of the system NLU-MEX system with one runway in NLU. Under the assumptions presented, NLU can operate with values of 41 ATM / Hr without major problem (using only one runway). In the case of MEX, it can be seen that the congestion problem is solved as it operates with an average of 40 ATM / hr, or what is the same at 65% of its current capacity. With the release of capacity, it would be expected that the problems of flight delays would be drastically reduced, and in addition to that, it would also be expected that the Mexican national airport network would operate without major setbacks with the consequence of deactivating the Ground Delay Program (GDP) which is currently active due to congestion [28] (Mujica and Romero, 2018).
With the following scenario where the traffic is increased (Scenario 3 to 5) they reveal that NLU will suffer from a lack of gate capacity, with the consequence of flights waiting for a parking position, inducing delays to the airlines and the national network. Scenario 5b reveals that the investment in the medium term in more gate capacity would alleviate partially the limitation, but it would suggest that the double of gates would not be sufficient for solving the problem. The different scenarios reveal that by implementing the system NLU-MEX and with the proper

timely investments, the growth in the metropolitan region of Mexico City is unleashed and it has potential to grow up to a three digit level in terms of passengers.
The study presented, revealed the different capacities the system will have at different time horizons; the short term that consists of the current situation and some 5 years more, medium term for approximately 30 yrs and a long term scenario of 50+ years in which we can identify the amount of passengers, number of movements and potential problems that will arise during the operational life of the system. The analysis provides enough information for giving light about the potential areas of improvement and requirements of expansion in the coming years. This could not be achieved without the use of simulation technology; for this reason, the authors strongly encourage the use of this methods and technology during the planning phase of any critical infrastructure.

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References

[1] Reuters. Building of New Mexico City Airport suspended, but some works continue. https://www.reuters.com/article/us-mexico-airport/building-of-new-mexico-city-airport-suspended-but-some-works-continue-idUSKCN1OX153 (03/01/2019)
[2] de Neufville, R.: "Management of multi-airport systems". Journal of Air Transport Management, Vol. 2 Issue 2 (1995), doi:http://dx.doi.org/10.1016/0969-6997(95)00035-6, pp. 99-110.
[3] Martin, J.C., Voltes-Dorta, A.: "The dilemma between capacity expansions and multi-airport systems: Empirical evidence from the industry's cost function", Transportation Research Part E: Logistics and Transportation Review, Vol. 47 Issue 3 (2011), doi: http://dx.doi.org/10.1016/j.tre.2010.11.009, pp. 382-389.
[4] Hopp, W., Spearman, M. Factory Physics. Second edn, McGraw-Hill. Longe Growe, Illinois, USA, 2000.
[5] Fasone, V., Giuffre, T., Maggiore, P.: "Multi-Airport System as a Way of Sustainability for Airport Development: Evidence from an Italian Case Study", Procedia – Social and Behavioral Sciences, Vol. 53 (2012), doi: https://doi.org/10.1016/j.sbspro.2012.09.863, pp. 95-105.
[6] Yang, Z., Yu, S., Notteboom, T.: "Airport location in multiple airport regions (MARs): The role of land and airside accessibility", Journal of Transport Geography, Vol. 52 (2016), doi: http://dx.doi.org/10.1016/j.jtrangeo.2016.03.007, pp. 98-110.
[7] de Neufville, R., Odoni, A.R. Airport Systems: Planning, Design, and Management. 2nd eds, McGraw-Hill Education, New York, USA, 2016.
[8] Hess, S., Polak, J.W.: "Mixed logit modelling of airport choice in multi-airport regions", Journal of Air Transport Management, Vol. 11 no. 2 (2005), doi: http://dx.doi.org/10.1016/j.jairtraman.2004.09.001, pp. 59-68.
[9] Loo, B.P.Y.: "Passengers' airport choice within multi-airport regions (MARs): some insights from a stated preference survey at Hong Kong International Airport", Journal of Transport Geography, Vol. 16 no. 2 (2008), doi: http://dx.doi.org/10.1016/j.jtrangeo.2007.05.003, pp. 117-125.
[10] Ishii, J., Jun, S., Van Dender, K.: "Air travel choices in multi-airport markets", Journal of Urban Economics, Vol. 65 Issue 2 (2009), doi:http://dx.doi.org/10.1016/j.jue.2008.12.001, pp.216-227.

[11] Marcucci, E., Gatta, V.: "Regional airport choice: Consumer behaviour and policy implications", Journal of Transport Geography, Vol. 19 Issue 1 (2011), doi: http://dx.doi.org/10.1016/j.jtrangeo.2009.10.001, pp. 70-84.
[12] de Luca, S.: "Modelling airport choice behaviour for direct flights, connecting flights and different travel plans", Journal of Transport Geography, Vol. 22 (2012), doi: http://dx.doi.org/10.1016/j.jtrangeo.2011.12.006, pp. 148-163.
[13] Fuellhart, K., O'Connor, K., Woltemade, C.: "Route-level passenger variation within three multi-airport regions in the USA", Journal of Transport Geography, Vol. 31 (2013), doi: http://dx.doi.org/10.1016/j.jtrangeo.2013.06.012, pp. 171-180.
[14] Nesset, E., Helgesen, Ø.: "Effects of switching costs on customer attitude loyalty to an airport in a multi-airport region", Transportation Research Part A: Policy and Practice, Vol. 67 (2014), doi: http://dx.doi.org/10.1016/j.tra.2014.07.003, pp. 240-253.
[15] Ramanujam, H. Balakrishnan. Estimation of arrival-departure capacity tradeoffs in multi-airport systems. Proceedings of the 48h IEEE Conference on Decision and Control (CDC) held jointly with 2009 28th Chinese Control Conference, Shanghai, Cina, January 2009. doi: 10.1109/CDC.2009.5400462.
[16] Gilbo, E. P.: "Airport capacity: representation, estimation, optimization", IEEE Transactions on Control Systems Technology, Vol. 1 Issue 3 (1993), doi: 10.1109/87.251882, pp. 144-154.
[17] Hockaday, S.L.M., Kanafani, A.K.: "Developments in airport capacity analysis", Transportation Research, Vol. 8 Issue 3 (1974), doi:http://dx.doi.org/10.1016/0041-1647(74)90004-5, pp. 171-180.
[18] Bäuerle, N., Engelhardt-Funke, O., Kolonko, M.: "On the waiting time of arriving aircrafts and the caapcity of airports with one or two runways", European Journal of Operational Research, Vol. 177 Issue 2 (2007), doi: https://doi.org/10.1016/j.ejor.2006.01.002, pp. 1180-1196.
[19] Janic, M.: "Modelling the capacity of closely-spaced parallel runways using innovative approach procedures", Transportation Research Part C: Emerging Technologies, Vol. 16 Issue 6 (2008), doi: http://dx.doi.org/10.1016/j.trc.2008.01.003, pp. 704-730.
[20] Janic, M.: "Modeling effects of different air traffic control operational procedures, separation rules, and service disciplines on runway landing capacity", Journal of Advanced Transportation, Vol. 48, Issue 6 (2014), doi: 10.1002/atr.1208, pp. 556-574.
[21] Janić, M., Tošić, V.: "Terminal airspace capacity model", Transportation Research Part A: General, Vol 16 Issue 4 (1982), doi:http://dx.doi.org/10.1016/0191-2607(82)90052-8, pp. 253-260.
[22] Solak, S., Clarke, J.B., Johnson, E.L.: "Airport terminal capacity planning", Transportation Research Part B: Methodological, Vol. 43, Issue 6 (2009), doi: http://dx.doi.org/10.1016/j.trb.2009.01.002, pp. 659-676.
[23] Mujica Mota, M.: "Check-in allocation improvements through the use of a simulation-optimization approach", Transportation Research Part A: Policy and Practice, Vol. 77 (2015), doi: http://dx.doi.org/10.1016/j.tra.2015.04.016, pp. 320-335.
[24] Mujica Mota, M., P. Scala, G. Boosten. Simulation-based capacity analysis for a future airport. 2014 Asia-Pacific Conference on Computer Aided System Engineering (APCASE),South Kuta, Indonesia, February 2014. doi: 10.1109/APCASE.2014.6924479.
[25] Mujica Mota, Di Bernardi A., Scala P., Ramirez-Diaz G.: "Simulation-based Virtual Cycle for Multi-level Airport Analysis", Aerospace Vol 5 No. 2 (2018), pp. 1-18.
[26] Mujica Mota, M., Romero R. Analysing the Decision-Rules for a Ground Delay Program: Mexican Airport Network. In Proc. of Int. Conf. of Research in Air Transport 2018, Castelldefels, Spain, June 2018.
[27] SENEAM, MEXICO CITY AIP. https://www.aicm.com.mx/en/government-entities/seneam (03/01/2019)
[28] Grupo Rioboo. Ante Programa de Obra, Ante Presupuesto, Ante Proyecto Arquitectónico. https://lopezobrador.org.mx/wp-content/uploads/2018/08/AISL_P05-11X17_ALL-04.pdf (03/01/2019)