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MODELLING THE GROUND CONNECTION BETWEEN TWO AIRPORTS IN A MULTI-AIRPORT SYSTEM: CASE SANTA LUCIA-MEXICO CITY

Miguel Mujica Mota[(a)], Paolo Scala[(b)], Danny Spit[(c)], Reyhan Tasdelen[(d)]

[(a),(c),(d)]Aviation Academy, Amsterdam University of Applied Sciences
[(b)]Amsterdam School of International Business, Amsterdam University of Applied Sciences

[(a)]m.mujica.mota@hva.nl, [(d)]p.m.scala@hva.nl,[(b)]danny.spit@hva.nl, [(c)]reyhan.tasdelen@hva.nl

ABSTRACT
This study presents a model-based analysis of the ground connectivity performance of the future Santa Lucia-Mexico City multi-airport system. The plan of the current government is to connect the two airports by a dedicated line, either by bus or other transport so that passengers and airlines can get the benefit of a coordinated operation. Performance indicators such as minimum connecting time, vehicle utilization and passenger waiting time are used to evaluate the future performance. Results reveal that when all passengers are allowed to use the connection, a big number of vehicles are required for providing a good level of service while in the case of a restricted use to only transfer passengers the operation with Bus would have a good performance.

Keywords: multi-airport system, connectivity, congestion, AIMC, transport

1. INTRODUCTION
Benito Juárez International Airport, better known as Mexico City International Airport, has faced rapid growth of air traffic in the last decade, witnessing a passenger growth of 61% in a decade, going from 25.8 million in 2007 to 41.7 million in 2016 (AICM 2019).
On the other hand, the infrastructures at Mexico City airport have not seen any major upgrade/expansion in recent years, with the consequence of saturation and congestion. One of the main indicators of congestion is represented by the high number of delayed flights, which in turn affects airport operations and, above all, the level of service to the passengers.
In order to cope with this problem, the first action taken by the airport authority was to set a limit to the hourly operations (landings and take offs), to a maximum of 61Atm/hr (DOF 2014). Although, this solution restricted the traffic to the airport, the system operated in most part of the day at the edge of its capacity with some periods of the day exceeding his declared capacity (see Figure 1).
Recently, the government authority of Mexico proposed to develop a Mexico City multi-airport system. This multi-airport system, composed by three airports, Mexico City (MEX), Toluca (TLC), and Santa Lucia (NLU), should relieve Mexico City airport from congestion by sharing the air traffic demand amongst the three airports. Toluca and Santa Lucia airports, are located around 100 and 40 km from Mexico City airport, respectively. Toluca airport is currently operating commercial traffic, while Santa Lucia airport is currently operating only military operations.

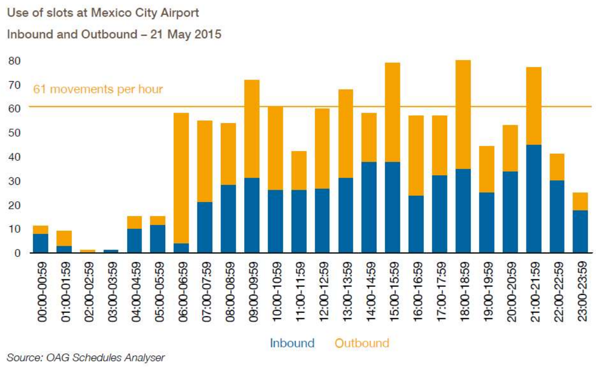

Figure 1: Daily trend of the air traffic at Mexico City airport (AOG 2019)

The proposal of the government is to upgrade and expand the facilities at Santa Lucia airport for accommodating commercial traffic. To this end, the investment in Santa Lucia airport will clearly bring the needed extra capacity to the Mexico City catchment area.
This work, is part of a study performed by the authors which focuses on the feasibility of the multi-airport system Santa Lucia-Mexico City, the current paper focuses only on the connectivity of the two airports.
Multi-airport systems (MAS) are comprised by a number of airports that provide service to metropolitan areas, where secondary airports give support to a main airport and altogether satisfy the air traffic demand. Two typical cases of MAS are New York City, where three principal airports give service to the NYC metropolitan area, composed by John F. Kennedy Airport, Newark and LaGuardia, or London whose MAS is composed by 5 airports.
The management of MASs presents a variety of operational difficulties, irrespective of political, technical and economic difficulties (de Neufville 1995). For instance, estimating the maximum and operating capacity of a MAS could be more complicated than estimating the capacity of a single airport, which is already a demanding task (Gilbo 1993), because the interactions between the operations at different airports could make it infeasible to concurrently operate all the airports at their operating capacity (Ramanujam and Balakrishnan 2009). A crucial aspect when developing a multi-airport system is to consider the connectivity between the airports and the region to be served as it was suggested by Fasone et al. (2012) and Yang et al. (2016). The current aim of the authorities who are working on the development of the multi-airport system Santa Lucia-

Mexico City, is to develop a flexible environment where passengers that arrive at one of the two airports can be transferred to the other airport with a minimum (acceptable) connecting time.
Due to the big investments at stake for the development of Santa Lucia airport and its connectivity with Mexico city airport, it is important to properly design the infrastructures. In this context, it becomes critical the use of the right tools for evaluating the performance of the system, so that infrastructures can be designed in the most optimal way. Modeling and simulation techniques have been widely used for planning activities in various fields, from logistics to manufacturing (Banks 1998; Brunner et al. 1998; Negahban and Smith 2014), and lately some authors have also used them for airport planning purposes (Mujica et al. 2018; Mujica and Scala 2019).
Considering the previously issues regarding the multi-airport planning and design, the aim of this study is to identify and understand the limitations and impact of the connecting infrastructure in the performance of the system Santa Lucia-Mexico City. Moreover, this study will give an indication of the resources needed for the smooth connectivity operations between the two airports.
The remaining of the paper is as follows. In the next section a literature review about multi-airport system is presented. In section 3, the methodology employed in this study is described while at section 4, experiments are conducted and results shown. Lastly in the final section, conclusions are drawn.

2. LITERATURE REVIEW

Scientific community has paid attention to multi-airport systems since they are a valid alternative for absorbing the demand as current facilities are not able to cope with the growing rates of traffic.
As defined by de Neufville and Odoni (2013): “a multi-airport system is the set of significant airports that serve commercial transport in a metropolitan region, without regard to ownership or political control of the individual airports”. All multi-airport systems have a primary airport with one or more secondary airports which have less traffic than the primary airport.
The topic of MASs has been gaining some attention the last few years as many issues regarding complex airport systems have been studied. For example, the subject of the main factors involved in airport selection among customers has been extensively studied using statistical methods (Hess and Polak, 2005; Loo 2008; Ishii et al. 2009; Marcucci and Gatta 2011; de Luca 2012; Fuellhart et al. 2013; Nesset and Helgesen 2014). 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 travelers than for leisure travelers. In contrast, leisure travelers were found to be more sensitive to price changes than business travelers.
The seminal paper of De Neufville (1995) introduced the analysis of the viability of MASs by identifying that air traffic of a metropolitan area should exceed 10 million originating passengers per year to make a MAS economical and operationally viable. The previous value has changed with time, and De Neufville and Odoni (2013) updated it as 15 million passengers per year. They also mentioned that this is not the only necessary condition to make a MAS economical and operationally viable, since customer and airline preferences for a primary airport is difficult to change and this might cause an underutilization of secondary airports. Furthermore, Fasone et al. (2012) and Yang et al. (2016) suggest 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 primary airport.
To the knowledge of the authors, none of the previous studies have analyzed the operational viability of a system using a model-based approach. In the current work this gap is partially fulfilled by simulating the connection transport line between the two airports and evaluating its performance in terms of connecting time, and other indicators related to passengers’ level of service.

3. METHODOLOGY

The methodology followed in this work, is the one presented by Mujica et al. (2018) 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 (Figure 2). By using this methodology an integral model of the multi-airport is developed considering all the different components such as: terminal facilities of the two airports and the connection between them. Moreover, the different components were modeled by applying different level of abstractions, the airports were modeled in low-detailed version, while the connection between the two airports was modeled in a high-detailed version. The approach allows identifying potential problems of the future system as well as increasing the situational awareness during the planning process of the airport facilities. A more detailed description of the methodology can be found in the paper of Mujica et al. (2018).

3.1. The simulation model

The model created for this study is an extension of the model created by the group of Mujica et al. (2019). In the existing model, the two airports under study are connected to each other by a transport line (following the plan of the current

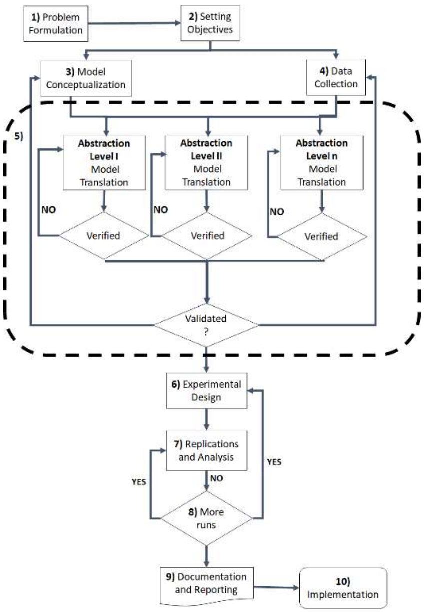

Figure 2: n-model simulation methodology

government) allowing passengers move between the two airports. The model was built considering public information from the government. Key elements were included and some assumptions were made for developing the conceptual model of the system. In addition, the boundaries of the model were set; in this case the complete airport operations were not considered, only some important processes like check-in and security in both airports were modeled as high-level models leaving some particularities out of scope. A network model was developed for simulating the flow of entities in the correspondent network. One set of entities represented passengers, another set was representing luggage while other entities represented vehicles that transport passengers and bags. It is worth to note that there can be different types of passengers making use of the connection: passengers that can check-in in one airport and then depart from the other one; passengers that arrive at one of the two airports and then transfer to the other airport in order to catch a connecting flight. These characteristics raise questions like how to handle different types of passengers and also the impact of restricting the utilization of connection only to transfer passengers. These scenarios are considered in the experimental design. Table 1 presents some of the assumptions made for the current approach. A commercial simulation software was used for translating the methodology into an integral model. Figure 3 illustrates the model developed.

Several scenarios were developed in which different options were compared, considering different demand levels, types of vehicles, share of traffic between the two airports and also the amount of bags the passengers are carrying among others.

Some of the elements that have been considered for this model are:

- Arrival and departure flights to and from Mexico City International Airport
- Arrival and departure flights to and from Santa Lucia Airport
- Transfer passengers between Mexico City and Santa Lucia airports
- A highway that connects the two airports
- Alternative vehicles for passengers transportation between the two airports
- Current and Future demand

Table 1: Model assumptions

Assumption	Value
Speed of baggage system within airport	15km/h
Distance between check-in and bus/rail station NLU	450m
Distance between check in and bus/rail station MEX	1050m
Number of active check-in desks MEX/NLU	100/100
Number of active security gates MEX/NLU	30/30
Duration of security process	Random Triangular(3,4,7) min
Vehicle boarding time per passenger	1.15 sec
Vehicle deboarding time per passenger	1 sec

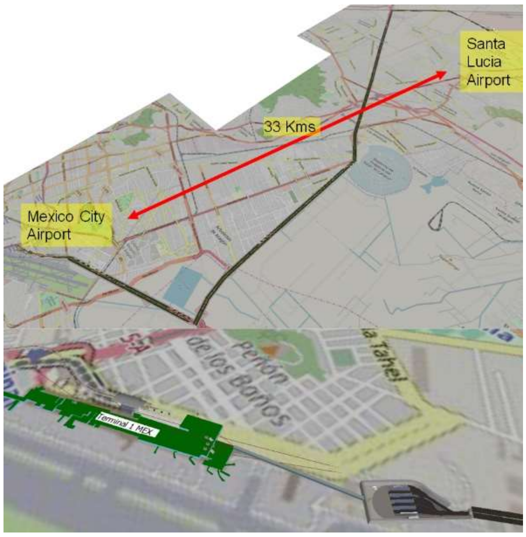

Figure 3: Simulation model snapshot for the connection

4. EXPERIMENTS AND RESULTS

In order to evaluate the performance of the multi-airport system we have constructed different scenarios and measured specific performance indicators. The scenarios were based on the following factors:

- Passengers configuration. Two configurations were considered. One where all passengers are allowed to use connection between the two airports; and a second one where only transfer passengers are allowed to use the connection.

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- Traffic scenario. Two different traffic scenarios were analyzed; short term traffic development (10% traffic increase, Scenario 2021) and medium term traffic development (60% traffic increase, Scenario 2030). The traffic increase was based on the assumption that traffic would have increased with a constant growth rate per year of 5.4% since 2014.
- Vehicle used for transporting passengers. Three different types of vehicle were tested. The first one represents a regular Bus (capacity 95 seats) (Volvo 2019a), the second one represents a BRT biarticulated bus (capacity 240 seats) (Volvo 2019b), and the last one represents an innovative mode of transport, a tram that does not require a track for moving (capacity 300 seats) (Lipeng 2018). In Table 2 the main characteristics of these transport modes are described.

Table 2: Characteristics of the vehicles utilized

Vehicle	Speed	Capacity
Bus	80 Km/h	95 pax
BRT	72 Km/h	240 pax
Trackless tram	70 Km/h	300 pax

- Number of vehicles used. For each transport mode, three different options in terms of number of vehicles were evaluated. For the scenarios where all passengers are allowed to connect between the two airports we considered the following ones:
    - Bus: [35, 40, 45]
    - BRT:[24,27, 30]
    - Tram [21,24, 27]

For the scenarios where only transfer passengers are allowed:

- Bus: [4, 8, 12]
- BRT, Tram:[3, 6, 9]

In total 36 different scenarios were evaluated for each of the two passengers configurations. The PIs measured were: minimum connecting time (MCT); vehicle utilization (VU); and passengers waiting time (WT) at the stations. MCT is the most important and representative of the multi-airport connectivity performance. It represents an indicator of the travel efficiency between the two airports and is key for the airlines to decide whether to operate in one airport or another. VU tells how efficiently the vehicles are utilized given the traffic configuration and it is directly related to the cost of operation. The WT tells how long passengers need to wait before getting to the vehicles that take them to the other terminal. It impacts directly in the level of service of passengers.

Simulations were run for a period of one day for each scenario, 50 replications were conducted in order to obtain accurate results. The PIs consider the 95 percentile of the observations.

4.1. Non restricted Scenarios

In this section, results are shown by analyzing each PI and evaluating different transport modes. This scenarios assume passengers can use the connecting vehicles indistinctly no matter if they are flying from MEX or NLU.

4.1.1. Scenario 2021

This scenario represents a short-term prediction of the future air traffic growth at Santa Lucia-Mexico City multi airport system. The main assumption behind this scenario is that the traffic will be increased by 10% compared to the current year. MCT is calculated from gate to gate between the two airports, therefore, it becomes relevant to specify from which terminal the passengers are transferring, since Mexico City has two terminals. Figure 4 and 5 are graphs of MCT versus VU for the case where passengers are transferring from Mexico City to Santa Lucia, and vice versa. Each graph shows the results according to the different options in terms of type of vehicle and number of vehicles utilized. The bars in the graph represent MCT, while the lines represent the VU. As the blue and orange bars show, the use of Busses generate a big MCT when compared to other transport mode, regardless the direction of transfer.

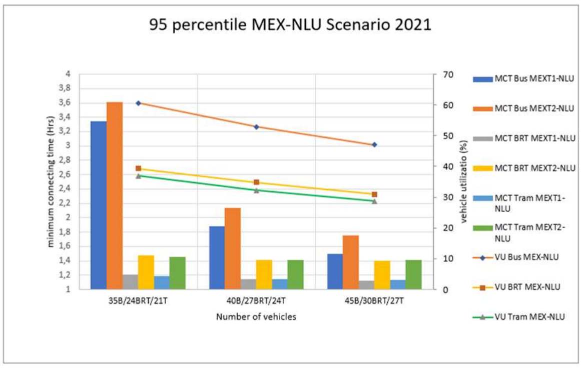

Figure 4: 95 percentile MCT vs VU from MEX to NLU for scenario 2021

We notice that for any of the options, MCT for Mexico City Airport terminal 2 are higher than Mexico city airport terminal 1, this is because terminal 2 is located in a more remote location compared to terminal1.

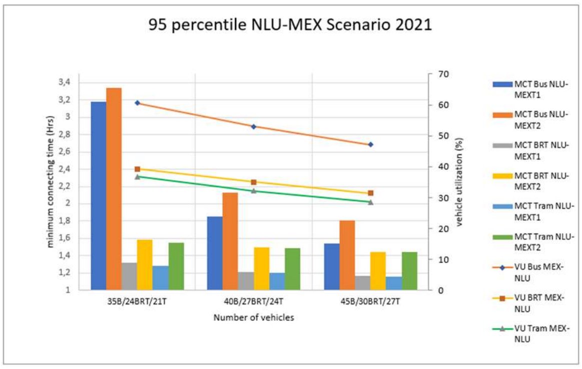

Figure 5: 95 percentile MCT vs VU from NLU to MEX for scenario 2021

The highest MCT for Buses is around 3.6 hours and it relates to the case from Mexico City airport to Santa Lucia airport with 35 vehicles utilized. The lowest MCT for the Buses was found in the scenario with 45 vehicles utilized with value of 1.5 hours, for both transfer directions. BRT and Tram show similar results, ranging from 1.4 to 1.2 hours when passengers transfer from Mexico City airport, and from 1.6 to 1.2 hours for passengers that transfer from Santa Lucia airport. Increasing the number of vehicles has a small impact of the MCT for BRT and Tram. The dependency on Buses numbers is stronger as it can be seen from the previous figures.

VU is higher for the Buses compared to BRT and Tram. It ranges between 60% and 45% for Buses, between 40% and 30% for BRT and between 35% and 28% for Tram. These results suggest that BRT and Tram provide a good level of service, however, they might be underutilized in times of the day.

Figure 6, shows the passengers WT at the stations of Mexico City and Santa Lucia for this scenario.

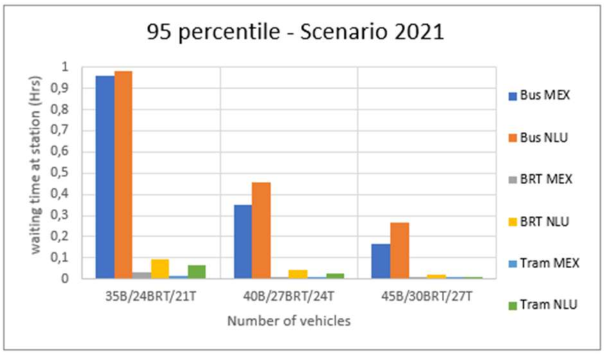

Figure 6: 95 percentile WT at station for scenario 2021

Buses have the longest WT, which is almost one hour in the worst situation. BRT and Tram show very short WT in both stations under the current numbers of vehicles, with highest values of 0,1 hours (6 minutes). Regarding Buses, they present a negative correlation with waiting times of passengers. In the best scenarios, using 45 Buses, passengers are expected to wait 0,15 hours (9 minutes) for Mexico City and 0,25 hours (15 minutes) for Santa Lucia.

4.1.2. Scenario 2030

This scenario represents a medium-term analysis of the future air traffic. The assumption is that the traffic will be increased by 60% compared to 2019. Figure 7 and 8, plot MCT versus VU for the case where passengers are transferring from Mexico City airport to Santa Lucia airport, and vice versa. In this scenario, it can be noted that in all of the scenarios analyzed, the utilization of only Buses is prohibitive, since MCT would be of several hours.

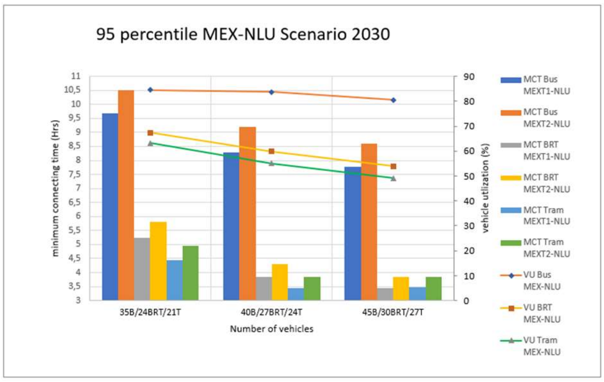

Figure 7: 95 percentile MCT vs VU from MEX to NLU for scenario 2030

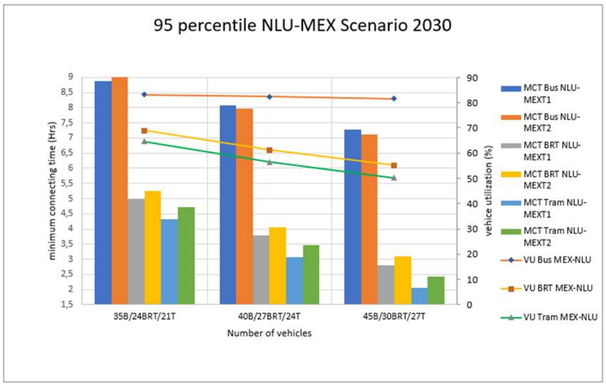

Figure 8: 95 percentile MCT vs VU from NLU to MEX for scenario 2030

For the other vehicles the amount of hours for MCT make them also unfeasible. This is an indication that other scenarios with a bigger amount of vehicles should be evaluated for the long term and also the impact of other elements in the system like security filters or check-in desks.

Regarding the scenario with the biggest amount of vehicles, Tram presents the best performance.

Regarding the WT, as Figure 9 shows, the Buses have the highest value, with peak of almost around 7 hours when 35 vehicles are utilized, and the lower value of 4 hours when 45 vehicles are utilized.

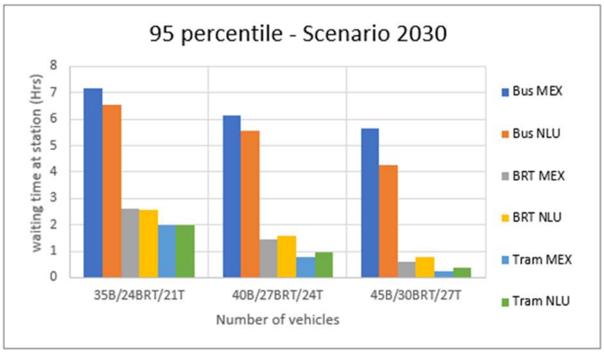

Figure 9: 95 percentile WT at station for scenario 2030

Tram show the lowest WT in both stations compared with Buses and BRT Buses, with values of 0,1 hours (6 minutes) and 0,18 hours (10,8 minutes) for Mexico City airport station and Santa Lucia airport station, respectively.

4.2. Restricted Scenarios

In these additional scenarios, only transfer passengers will use the connection between the two airports. The authors assumed that around 4% of passengers will transfer from one airport to the other. Due to the lower amount of transfer passengers considered in these scenarios, we have analyzed the scenarios considering an small amount of vehicles.

As with the previous scenarios, we evaluated the two traffic scenarios, short-term (2021) and medium-term traffic (2030).

4.2.1. Scenario 2021

Figure 10 and 11, present MCT versus VU for the case where passengers are transferring from Mexico City airport to Santa Lucia airport, and vice versa.

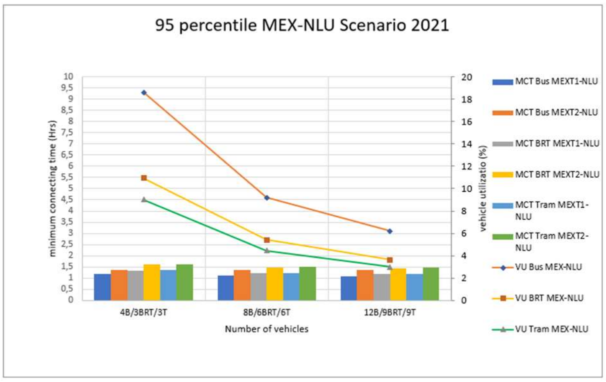

Figure 10: 95 percentile MCT vs VU from MEX to NLU, Scenario 2021 (transfer passengers)

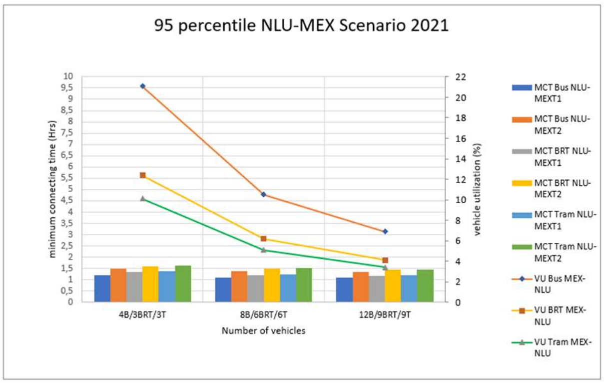

Figure 11: 95 percentile MCT vs VU from NLU to MEX, Scenario 2021 (transfer passengers)

As in the previous scenarios, the bars in the graph represent MCT, while the lines represent the VU. We notice that the use of Buses slightly outperforms the other two transportation modes. However, all of them have similar MCTs, ranging between 1.2 and 1.5 hours. Same results are obtained regardless the direction of the passengers. VU in this scenario is low, with maximum values obtained by Bus with 21% when using 4 vehicles. The use of BRT and Tram generate low vehicle utilization, almost the half compared to Buses, having 12% and 10% for BRT and Tram, respectively. These values suggest that the situation of only transfer passengers is prone to optimization of the amount of vehicles used.

As it can be noted, as the number of vehicles are increased, the vehicle utilization decreases for all the different transportation modes, while connecting times stay steady. Under this circumstance, the best scenarios would be with the operation using a minimum amount of vehicles.

Figure 12, shows passengers' WT at the stations of Mexico City and Santa Lucia. Even by testing the lowest amount of vehicles for the different transport modes, waiting times are not high, as they range between 0.18 hours (10.8 minutes), 0.9 hours (5.4 minutes). The lowest values have been found in the scenario where 12 Bus vehicles were tested, obtaining values under 0,02 hours (1,2 minutes) in both stations. However, these values do not significantly differ from the ones obtained by using less vehicles, as 0.1 hours (6 minutes) were obtained when 4 Bus vehicles were evaluated.

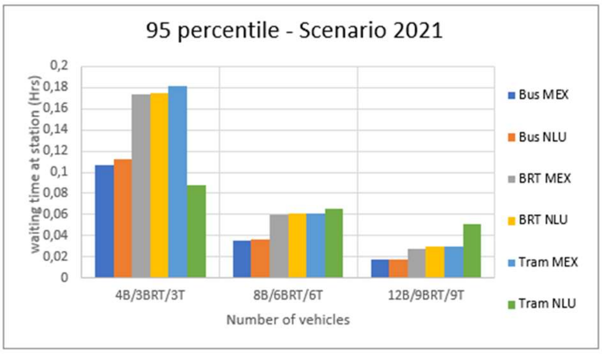

Figure 12: 95 percentile WT, Scenario 2021 (transfer passengers)

4.2.2. Scenario 2030

Figure 13 and 14, present MCT versus VU for the scenario with high demand and where only transfer passengers are allowed to use the connection between the two airports. The results obtained show similar values for the short-term scenario (low traffic amount), with values between 1.2 and 1.5 hours of connecting times regardless of the transport mode, number of vehicle utilized, and direction. In Figure 13, it can be seen that VU, show values up to 28% for Buses, 16% for BRT, and 13% for Tram. Figure 14, which represents values of passengers flow from Santa Lucia airport to Mexico City airport, show higher values of VU, with a peak, found for scenario using 4 Buses, of 38%. BRT and Tram have their peak of VU when 3 vehicles are utilized, obtaining 22% and 18%, respectively.

Figure 15 shows the values of WT at the station, where it can be noticed that similarly as the previous scenario depicted in Figure 12, values of waiting time do not vary significantly between the different use of transport mode and the amount of vehicles. Maximum values are obtained when the minimum number of vehicles is utilized, with a high peak of almost 0.27 hours (16.2 minutes) and a low peak of 0.13 hours (7,8 minutes). Minimum values of WT are obtained when the maximum number of vehicle is utilized, with a high peak of almost 0.03 hours (1.8 minutes) and a low peak of 0.02 hours (1.2 minutes).

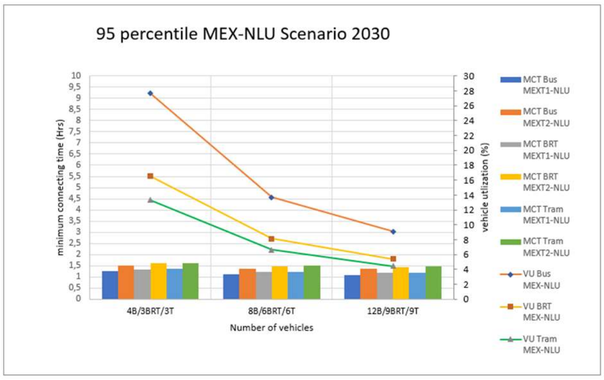

Figure 13: 95 percentile MCT vs VU from MEX to NLU, Scenario 2030 (only transfer passengers)

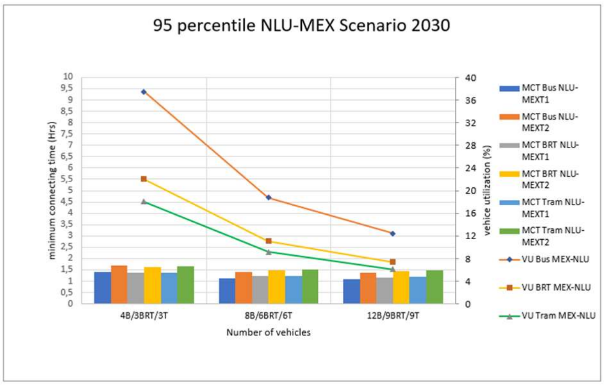

Figure 14: 95 percentile MCT vs VU from NLU to MEX, Scenario 2030 (transfer passengers)

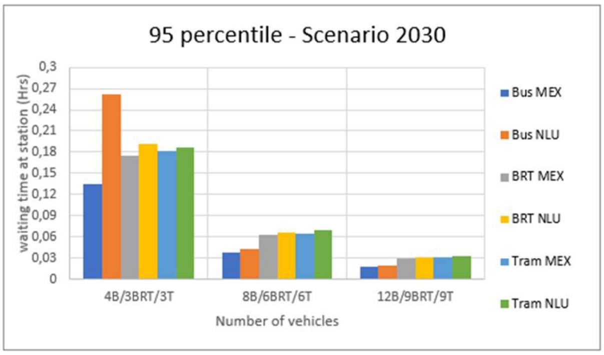

Figure 15: 95 percentile WT at station for scenario 2030 (only transfer passengers)

5. CONCLUSIONS

In this study, a simulation-based analysis has been conducted to evaluate the passenger ground connectivity between Santa Lucia and Mexico City airports which will be part of the Multi-airport system of Mexico. Different transportation vehicles were evaluated such as Bus, BRT and Tram considering minimum connecting time, vehicle utilization and passenger waiting time as the main performance indicators. Different sets of vehicles were considered for different time horizons and restrictions of use. Regarding the non-restricted scenario, the expected minimum connecting times and the amount of vehicles required to provide good service is big and highly dependent on demand. On regard to a scenario restricted to use by only transfer/transit passengers, the results clearly show that the amount of required vehicles are much less than the one of the previous scenario. For this scenario, all the performance indicators show good values with an expected MCT around 1.5 hrs in most of the cases.

It is important to remark that the study revealed that the non-restricted use of the transport connection by passengers might lead to a rapid saturation of the system when more passengers use it in the future. On the other hand, a restricted use to only transfer or transit passengers will keep the system operating at good levels even under scenarios of high demand.

Apart from the potential problems identified, it was possible to have an initial estimation of the performance of the system once it is up and running with real demand, revealing the importance of using simulation techniques.

As future work, the analysis will be further extended by considering other amounts of vehicles to find the optimal set under a multi-objective approach for balancing indicators like efficiency, service, cost and eventually environmental aspects.

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