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REDUCTION OF TAXI-RELATED AIRPORT EMISSIONS WITH DISRUPTION-AWARE STAND ASSIGNMENT: CASE OF MEXICO CITY INTERNATIONAL AIRPORT

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ABSTRACT

Airport management is often challenged by the task of managing aircraft parking positions most efficiently while complying with environmental regulations and capacity restrictions. Frequently this task is additionally affected by various perturbations, affecting punctuality of airport operations. This paper presents an innovative approach for obtaining an efficient stand assignment considering the stochastic nature of the airport environment and emissions reduction target of the modern air transportation industry. Furthermore, the presented methodology demonstrates how the same procedure of creating a stand assignment can help to identify an emissions mitigation potential. This paper illustrates the application of the presented methodology combined with simulation and demonstrates the impact of the application of Bayesian modeling and metaheuristic optimization for reduction of taxi-related emissions.

1 INTRODUCTION

Modern airports are facing a global challenge of significant reduction of pollutant emissions and moving towards carbon-neutral operations while coping with rapid air traffic growth and maintaining the required level of service (ICAO 2019a). Emissions produced by airport activities influence local air quality at and around airports. One of the most important sources of emissions at the airport is aircraft operations, such as landing, taxiing, and take-off (ICAO 2019b). Thus, in addition to technological innovations and switching to sustainable aviation fuels, improvement in the efficiency of these operations is considered in the scope of global air industry measures (ATAG 2020).

The level of emissions produced during taxiing in the airport depends on the amount of fuel burnt and the time for which an aircraft has to move between its assigned parking position (stand) and runway entrance/exit points. In general, over a third of total aircraft emissions outside of the cruise phase can be generated during taxiing (Fleuti and Maraini 2017). Therefore, there is a need to allocate aircraft in such a way that taxiing distance and time are minimized, ensuring the reduction of fuel consumption and related emissions.

A stand assignment schedule can often be disrupted by last-minute changes in the flight schedule during the day. Such changes may lead to longer turnaround times and deteriorating airport performance. As a result, some aircraft might have to wait on the ground and some might have to wait in the air in the airport TMA, which culminates in higher fuel consumption and additional emissions.

Ineffective management of terminal facilities can create a propagation of schedule disruptions to the successive flights and connected airports, also affecting the level of emissions. Therefore, it is necessary to efficiently manage terminal facilities, such as stands, to mitigate the impact of scheduled perturbations and reduce the level of pollutant emissions, created during taxi, at the same time.

The stand allocation problem (also known as the stand assignment problem), tackled in this paper, was previously approached by many researchers. However, only some of them considered the stochasticity of airport operations in their methodology. Quite often to decrease the number of stand allocation conflicts and related aircraft waiting times, a stand has a certain idle time between two consecutive flights assigned to it. This idle time is called buffer time and has been proven as the best working measure for flight deviations up to 30 minutes (Hassounah and Steuart 1993; Yan and Chang 1998; Yan and Huo 2001; Yan et al. 2002). Nonetheless, such action can significantly reduce airport terminal capacity and therefore, should be avoided in modern congested airports.

Idle waiting and taxiing are estimated to contribute the most to the aircraft fuel consumption and airport emissions (Nikoleris et al. 2011). Therefore, the goals of idle waiting reduction and taxiing footprint optimization were approached by many researchers. Duinkerken et al. (2013), Li and Zhang (2017) estimated that using a single-engine approach, external electric engine, and towing sources for taxiing can significantly reduce emissions. Tsao et al. (2009) demonstrated that aircraft idle waiting time on the ground can be reduced by optimization of taxi-out and take-off sequences. Applications of pushback control, gate holding, and departure sequence optimization (Simaiakis and Balakrishnan 2016) applied by Khadilkar and Balakrishnan (2012), Simaiakis et al. (2014), and Ashok et al. (2017) showed a significant reduction of emissions related to taxiway and runway congestions.

Although the aforementioned methods proved to reduce environmental footprint, some of them also led to increasing stand occupancy times, thereby significantly reducing airport capacity which can become problematic in congested airports. Furthermore, these works have considered neither flight arrival time perturbations, nor taxiing from the runway to the stands (the taxi-in phase) that can substantially impact the taxiing time and related emissions (Hao et al. 2016). To fill the gap in this area and provide air transport management with a methodology to improve both efficiency and environmental impact of stand assignment operations, this paper presents how these two objectives can be combined in the stand assignment and demonstrates their achievement using simulation techniques.

This paper presents a bi-objective application of a stand assignment approach, that was previously introduced by Bagamanova and Mujica Mota (2020), for evaluating various stand assignment policies in terms of their sensitivity to schedule perturbations and environmental footprint. The presented methodology combines the benefits of data-mining and evolutionary optimization for generating a stand assignment that minimizes emissions and, by using simulation, the efficiency against possible schedule deviations and related emissions reduction is proved. The presented approach learns probabilities of schedule deviations depending on characteristics of the scheduled flights using Bayesian multilevel modeling (Bürkner 2017) from historical airport performance data. These probabilities are then used to calculate the most probable level of deviation for each flight in the target flight schedule. The calculated deviations are then considered in the generation of stand assignment, which is optimized to meet the goal of minimization of emissions generated during the taxi of an aircraft.

This paper continues as follows. Section 2 outlines the stand assignment methodology. Section 3 presents a case study and simulation experiments results. Conclusions and further research are presented in Section 4.

2 METHODOLOGY

The stand assignment method presented in this paper is composed of the two-module approach and experiments in a simulation model. The two-module approach generates optimized stand allocations based on the target flight schedule, historical data about schedule disruptions for the previous period, and user-defined assignment policies and optimization goals. After that, the obtained allocations are estimated in the simulation model that allows evaluating the environmental footprint quality of stand assignments generated in the two-module approach under the stochasticity of a real-life airport system.

2.1 Algorithm Description

This section gives a short description of the two-module approach that generates optimized stand assignments. A more general description can be found at Bagamanova and Mujica Mota (2020).

The two-module approach is composed of two elements. Module I takes care of estimating probabilities of schedule deviations from the airport historical data. These probabilities are expressed in the form of Bayesian distributional models and describe a likelihood of certain levels of schedule deviations for various flight characteristics available in the historical data (e.g. such as airline name, scheduled time of arrival, and day of the week). By considering probable disruptions in the assignment planning, it is intended to reduce the idle time that aircraft might have to spend waiting for the planned stand availability and related emissions.

Module II assigns the target flight schedule to the available stands, respecting user-defined assignment policy and restrictions, considering most probable or user-defined probability level schedule disruptions in the stand occupancy times. Then the generated assignment is optimized with a genetic algorithm according to user-specified optimization goals. The result of such optimization is not necessarily an optimal solution, however, randomness used in the genetic algorithm in the form of crossover and mutation operators allows us to obtain a good quality solution in a reasonable time (Bagamanova and Mujica Mota 2020). The resulting stand assignment considers the stochasticity in the form of stand occupancy times deviations generated from the schedule deviations distributional models.

2.2 Optimization Objective

To increase stand assignment efficiency and mitigate pollutant footprint, produced by aircraft movement on the ground and aircraft idle waiting for stand availability, the following bi-objective optimization goal function has been implemented in the optimization component of Module II of the two-module approach:

$$min(w_1 * O_{taxi} + w_2 * O_{hold}) \tag{1}$$

The objective function (1) consists of the following individual objectives:

1. Minimize taxi distance to and from the parking positions and therefore the related emissions:

$$O_{taxi} = \overline{d_{sched.taxi}} / Max\ d_{airport}$$

2. Minimize the number of aircraft waiting for stand availability and, therefore, the idle use of engines:

$$O_{hold} = \sum fl.hold \ / \sum fl.$$

Where:

- $\overline{d_{sched.taxi}}$ – the average taxi distance to and from the stand in the allocated schedule;
- $Max\ d_{airport}$ – the maximum possible taxi distance at the airport for considered runway configuration;
- $\sum fl.hold$ - the number of aircraft that must wait for the stand availability;
- $\sum fl.$ - the total number of aircraft in the schedule to allocate;
- w_n – priority weight for the corresponding objective. In the scope of this paper, all the weights are equal to 1 to obtain a stand assignment equally balanced for both considered objectives. For practical use, different stakeholders of the airport can decide the weights based on their preferences.

In the original implementation of the two-module approach by Bagamanova and Mujica Mota (2020), the optimization objective function in Module II also included maximization of the use of contact stands. This is a general preference for many airports as it allows to fully benefit from terminal building in terms of providing passenger experience and reduces the number of ground service vehicles moving on the apron. Yet, for the scope of this paper, such an objective was excluded as the primary goal is to generate a stand assignment with minimized emissions. Nevertheless, it might be interesting to investigate the environmental cost of prioritizing contact stand use in the optimization component in future work.

3 CASE STUDY: MEXICO CITY INTERNATIONAL AIRPORT

This section discusses the application of the two-module approach for encountering more environmentally efficient stand assignment policies for a case study airport.

3.1 General Information

Mexico City International Airport (IATA code: MEX) is the main airport in Mexico with approximately 450 thousand landings and take-offs annually. There are two terminal buildings, separated by two parallel runways. These runways are never operated simultaneously due to proximity to each other. Such layout restricts MEX capacity and since 2017 it has been officially limited to 61 movements per hour with a maximum of 40 landings (SCT 2017).

In the scope of this paper, it is considered that 26 airlines are operating in two terminals in MEX, performing both international and domestic flights. From the total 91 stands available at MEX, only 84 were considered in this paper, as the rest is not used for passenger flights. Hence, Terminal 1 is represented by 11 open stands and 33 contact stands, among which 16 stands are dedicated to domestic flights and 17 to international. Terminal 2 is represented by 17 open stands and 23 contact stands, where 13 are used for domestic flights, 10 – for international.

3.2 Schedule Disruptions and Emissions

On a global level, in 2018 Mexico generated approximately 1.5% of global air passenger transport-related emissions (Graver et al. 2019). MEX is located in the direct proximity of the urban zones of Mexico City, which makes the airport significantly affect air quality and noise levels of the city. According to SEDEMA (2018), MEX produces around 15% of the total pollutant emissions of Mexico city.

In 2017 Mexico has officially joined a global initiative for carbon-neutral air transport operations (ICAO 2020), which implies that all country airports have to follow ICAO emission reduction policies and standards. Despite these facts, up to the date of writing this paper official MEX website did not publish any official estimations of airport emissions level nor disclosed any measures to reduce the environmental footprint of its operations.

MEX frequently suffers from punctuality problems. In 2018 only 67% of all flights were performed on time (SCT 2019) with more than 20% of departing flights being delayed by 46 min on average (Flightstats 2018). Considering such a high level of perturbations and recent engagement in global pollutant footprint reduction initiative, MEX becomes a good target for application of the two-module approach to discover the hidden potential for emissions reduction related to stand assignment planning.

3.3 Implementation of the Two-Module Approach

As input data for this study, we used an official performance report for a period from 28.05.2018 to 03.06.2018, retrieved from International Airport of Mexico City (2018). This report consisted of more than 8,000 flights with actual and scheduled arrival times, flight numbers, airline names, and type of aircraft used. In the chosen week approximately 7% of arriving flights deviated for more than one hour from their schedule. More than 53% of scheduled arrivals suffered from a substantial delay of more than 15 min, which is a significant perturbation for a congested airport.

Due to the unavailability of actual data on turnaround times and arrival-departure aircraft correspondence, it was assumed to use only arriving passenger flights from the obtained report and define 60 minutes turnaround time for all flights in the performed experiments. Such limitations reduced the number of flights to 3,914 arrivals, where 31.7% were international flights and 68.3% - domestic.

The selected data of 3,914 flights have been processed in Module I and the Bayesian models for arriving time deviations were built, assuming the correlation of deviations with airline name and hour of scheduled arrival. The detailed description of the resulting parameters of regression models, composing the summative Bayesian model, and output of Module I can be found at Bagamanova and Mujica Mota (2020).

Lastly, Module II created an assignment, considering most probable scheduled deviations, assignment policy restrictions, and optimized it according to the objective function (1). As the two-module approach is considered to be a more effective replacement to traditionally used buffer times, for the generation of stand assignment in Module II no buffer times were intentionally added between consecutive flights assigned to the same stand. The resulting assignment statistics are shown in Figure 1.

Every airport has its own stand assignment policy restrictions, which implies certain use of the stands. The following are the restrictions considered in the presented algorithm:

- Domestic and international flights must be assigned to the specific stands in the designated zones. These are internal specifications of the airport e.g. international flights are assigned to stands that have access to the designated border control areas;
- Flight delays must be considered in the assignment (according to conditional probability distributions from Module I). In this paper, only arrival delays are considered due to unavailability of ground handling data and correspondence of arriving aircraft to departing aircraft;
- An assigned stand must correspond to the size of an aircraft (large aircraft require extra space due to larger wingspan). This is implemented through the identification of allowed stands for each flight on the stage of processing the input data in Module II.

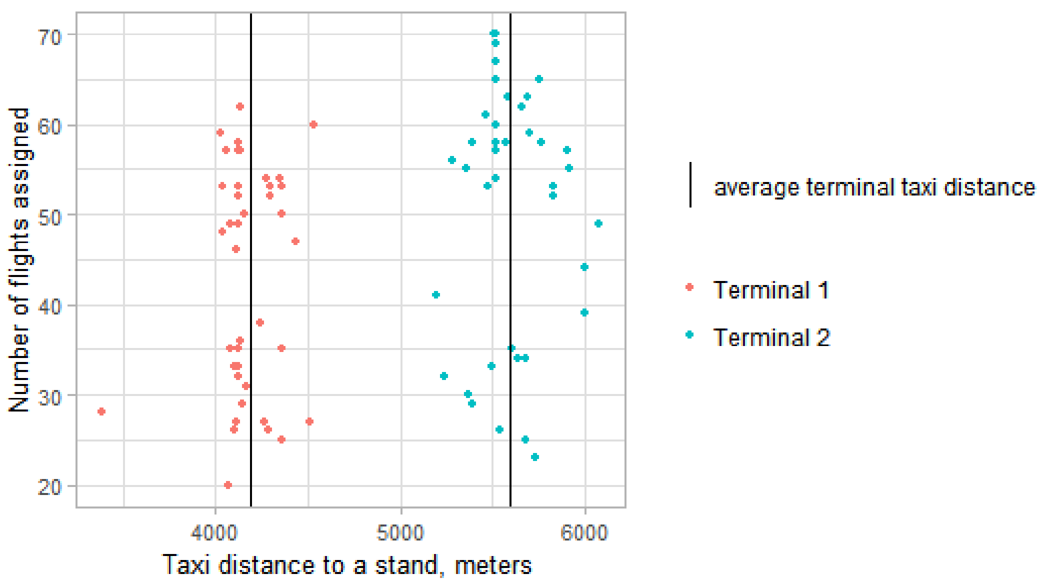

Figure 1: Assignment statistics for Module II generated stand allocation.

As can be observed from Figure 1, most of the flights were assigned to stands located not too far from the runways. In Terminal 1 approximately 61.1% of scheduled flights were assigned to a stand located closer than Terminal 1 average taxi distance of 4.2 km from the runway; for Terminal 2 - 61.3% of flights were assigned to the stands with less than average Terminal 2 taxi distance of 5.6 km. Naturally, some of the flights had to be assigned to further located stands due to assignment policy constraints, designated border control zones, and unavailability of closer located stands. Nevertheless, Figure 1 demonstrates the algorithm's success with the minimization of taxi distance.

One of the limitations of the data used for this study is the unavailability of actual historical MEX stand assignments. Therefore, for the moment, it is impossible to compare the quality of the two-module approach results with actual MEX stand assignments. Thus, to evaluate the quality of the obtained assignment and owing to the absence of actual historical stand assignments at MEX, the two-module approach assignment was tested in the environment of the MEX simulation model, as described in the next section. The detailed description and validation of this simulation model can be found at Mujica Mota and Flores (2019).

3.4 Simulation Experiments

The principal objective of using a simulation model in this study is to evaluate the effects of consideration of schedule deviations in the stand assignment on the taxi-related emissions in close-to-reality conditions and encounter ways to improve airport performance and emissions level. The simulation model used in this study allows us to incorporate stochastic elements (such as stop-go situations, waiting for push-back at the gate) that were not considered in the assignment generation, but do influence aircraft movements on the ground in the real life.

For each simulation replication the following performance indicators were tracked:

- total taxi distance for all aircraft of the allocated schedule: $d_{total\ taxi} = \sum_{i=1}^{N}(d_{in\ i} + d_{out\ i})$;
- total taxi time for all aircraft of the allocated schedule: $t_{total\ taxi} = \sum_{i=1}^{N}(t_{in\ i} + t_{out\ i} + t_{wait\ i})$;
- total amount of taxi-related pollutant emissions $e_{total\ taxi} = t_{total\ taxi} * F_{NO} + t_{total\ taxi} * F_{CO}$;

where:

- $d_{in\ i}$ – distance traveled by aircraft *i* from runway exit to a stand;
- $d_{out\ i}$ – distance traveled by aircraft *i* from a stand to runway entry point;
- $t_{in\ i}$ – time traveled by aircraft *i* from runway exit to a stand;
- $t_{out\ i}$ – time traveled by aircraft *i* from a stand to runway entry point;
- $t_{wait\ i}$ - time spent by aircraft *i* waiting for stand availability;
- F_{NO} and F_{CO} – emission factors for NOx and CO_2 respectively;
- $i \ldots N$ – number of aircraft.

Emission factors depend on the engine characteristics, type of fuel used, and aircraft weight among others (ICAO 2019b). Due to the unavailability of any actual data about engine specifications and aircraft weight for the studied flight schedule, the amount of total emissions $e_{total\ taxi}$ was calculated assuming constant taxi speed and the taxi emissions reference for Airbus A320 (engine CFM56) (European Environment Agency 2016). This aircraft type was chosen as it was used in 55% of the studied flights. Less than 1% of the studied flights were performed with a large type of aircraft and the rest of the flights were represented mostly by regional class. The adapted emission factors per minute of taxiing are shown in Table 1.

Table 1: Emissions factors per minute of taxiing.

Type	Factor, kg/min
Fuel consumption	14.52
NOx emission per min, F_{NO}	0.065196
CO_2 emission per min, F_{CO}	1.7604

Assuming certain emission factors in this paper is made to get a general estimation of the two-module approach application impact on airport emissions. Nevertheless, it is considered to perform a more detailed calculation in the future, accounting for different emission factors for all present types of aircraft, when more actual data on aircraft specifications become available.

At the time of performing this study, there was no information available about exact or historical stand assignments in MEX. Therefore, the two-module approach generated assignments were compared to a random last-minute assignment, generated directly during every simulation run. A random last-minute assignment allocates a flight during simulation to any suitable stand available at the moment of aircraft starting landing approach. That means that any suitable stand not occupied at the decision moment can be chosen regardless of its taxi distance to the runway. As the choice is made randomly, every simulation run results in different usage of stands. As there is no preliminary planned assignment in such last-minute allocation, it is considered that the effects of schedule disruptions on stand usage are minimized and there is less possibility for assignment conflicts. Although, it is not estimated at what environmental cost these effects are minimized. In this section, the effects of such last-minute random allocation on the taxi-related emissions are estimated and compared to a proactive allocation planning, performed by the two-module approach. Additionally, to trace the effects of schedule deviations on taxi-related emissions, simulation scenarios containing both on-time and disrupted arrivals were included in this study.

An overview of the defined stand assignment scenarios is presented in Table 2. These scenarios can be described as follows:

1. *Scenario A*. Base case. It represents an ideal situation with all flights arriving on time, stand assignment generated only with the use of Module II (i.e. optimized allocation without considering deviations).
2. *Scenario B*. Stand assignment generated only with the use of Module II (i.e. optimized allocation without considering deviations). The flights arrived with arrival time deviations, generated based on arrival time deviation distributions learned in Module I.
3. *Scenario C*. Stand assignment generated considering the expected delay with the use of both Module I and Module II. Flights arrived with arrival time deviations, generated based on arrival time deviation distributions learned in Module I.
4. *Scenario D*. Arriving flights are assigned to stands using last-minute random allocation. Flights arrived on time, according to the schedule.
   Scenario E. Arriving flights are assigned to stands using last-minute random allocation. Flights arrived with arrival time deviations, generated based on arrival time deviation distributions learned in Module I.

Table 2: Stand assignment scenarios.

Scenario name	Schedule disruptions	Schedule disruptions considered	Assignment optimization	Assignment generation
A	-	-	Yes	Module II
B	Yes	-	Yes	Module II
C	Yes	Yes	Yes	Two-module
D	-	-	-	Random last-minute
E	Yes	-	-	Random last-minute

The objective of this paper is to discover the hidden potential for the reduction of taxi-related emissions through stand assignment optimization. And as has been observed in the analysis of the generated assignment in section 3.3, the current distribution of domestic and international areas in the terminals has a considerable influence on the assignment results and therefore on the level of taxi-related emissions. Therefore, the relaxation of some restrictions of MEX was considered to verify if such action can bring any benefit to the environmental footprint of real-life stand assignment operations. Therefore, it has been decided to manipulate some of the available assignment restrictions and therefore come up with new assignment policies, that would not require major airport facilities reconstruction. The only requirement remaining strict for all simulated assignment policies is the requirement of assignment of large aircraft only to the specially equipped stands. The new assignment policies were compared to the original policy, which contains strict assignment constraints, through the series of experiments, simulating scenarios A-E under each of the defined policies. In such a way for every assignment policy, the performance of the two-module approach under on-time and disrupted arrivals were evaluated and compared to the random last-minute allocation. The defined assignment policies include the following:

1. *Group I* – base case experiments. Stand assignment generated according to the original set of assignment restrictions with strict adherence to the designated terminal and international/domestic zone.
2. *Group II* – aircraft are allocated to any available stand in the originally planned terminal. This means that both international and domestic flights can be allocated to the same stand.
3. *Group III* – aircraft may choose stands in any terminal but must obey the designated zone policy. This means that a domestic flight must be assigned to the domestic zone but can be assigned to the domestic zone of any terminal.
4. *Group IV* – aircraft can be assigned to any zone of any terminal. This is a layout restrictions-free assignment policy that allows getting closer to the minimum possible taxi distance and taxi-related emissions for the studied flight schedule.
5. *Group V* – Terminal 1 is fully designated for domestic flights. This means that even if a flight was originally planned to Terminal 2, in case if it is domestic it will be assigned to Terminal 1.
6. *Group VI* - Terminal 1 is fully designated for international flights. This means that even if a flight was originally planned to Terminal 2 if it is international it will be assigned to Terminal 1.

Using the same data to learn Bayesian distributional models for schedule disruptions and to generate simulation experiments stochasticity can be considered as a limitation of this paper. Nevertheless, the main goal of the proposed approach is to mitigate the negative impact of schedule disruptions on the airport environment, not to predict the exact delay or early arrival time for the scheduled flights. By considering a certain probability interval in the assignment planning, we intend to provide a tool for influencing stand allocation robustness. With a bigger probability interval, more perturbations can be considered; however, it might reduce stand resources capacity and thus, can be seen as a limitation for some congested airports. Smaller probability intervals would result in smaller stand blocking times but might increase the number of aircraft that might wait for the stand availability. This trade-off is not discussed in this paper, although will be explored in future research.

For each assignment policy, experiments A-E were executed with 30 replications each. Each replication had a duration of 7 days plus extra hours for arrival schedule deviations. The next section presents and discusses the results of the performed experiments.

3.5 Experiments Results

The performed experiments results were compared across scenarios to identify an assignment policy that allows to significantly reduce the emissions. The comparative statistics for the tracked indicators for experiments in Groups I – VI are presented in Figure 2 - Figure 4.

As can be seen in Figure 2, scenarios A and B have similar taxi distance values, as they used the same stand assignment; scenario B differs from scenario A only in presence of stochastic arrival time deviations. Scenarios D and E generally resulted in higher taxi distance value, as they did not optimize the assignment to minimize the taxi time. The lowest taxi distance was achieved in Group V, which corresponds to the assignment policy with Terminal 1 being fully dedicated to the domestic flights and Terminal 2 – to international. Under this policy, both the two-module approach and random last-minute allocation generated close values with a 0.2% difference. The lowest taxi distance corresponds to scenario E in Group V, which is 4.2% lower than in assignment generated by the two-module approach under original assignment policy in scenario C Group I. In these experiments, random last-minute allocation outperforming an optimized stand assignment can be explained by the fact that last-minute allocation in scenarios D and E was allowing overlapping assignments to the same stand if all other suitable stands already had been occupied. Overall, results demonstrated in Figure 2, reveal that by reorganizing the use of MEX terminal buildings and dedicating Terminal 1 entirely to domestic flights it is possible to reduce taxiing distance by 4.2% weekly.

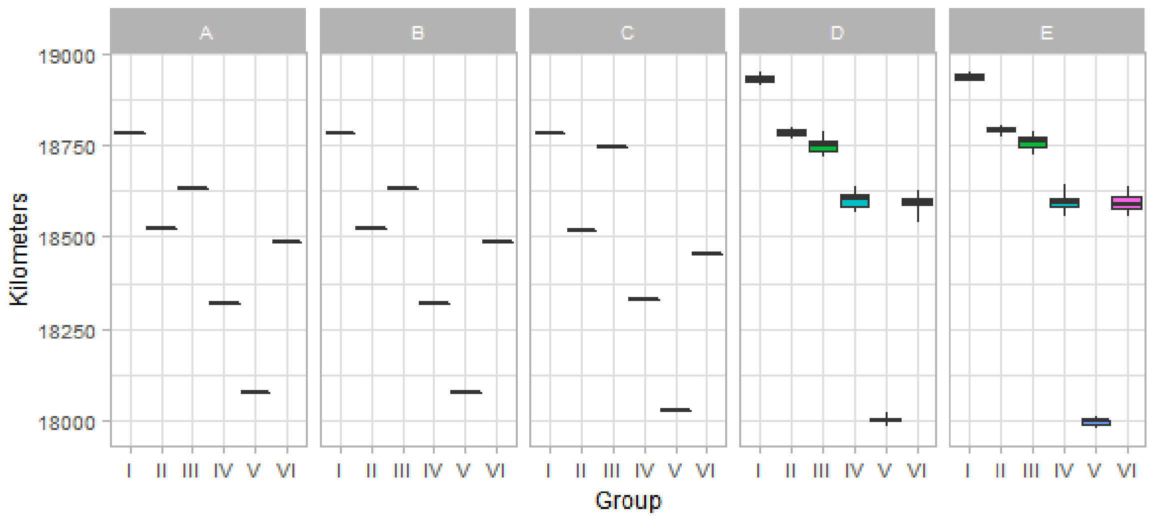

Figure 2: Comparison of total taxi distance for scenarios A - E through the groups of experiments.

When talking about total taxi time, shown in Figure 3, it can be noticed that scenario B shows more variability and higher mean values than scenario A due to the presence of stochastic deviations and aircraft waiting times. The lowest taxi time value corresponds to scenario C in Group V, which is the allocation generated by the two-module approach. The total taxi time obtained in this scenario is 9% lower than in scenario C of Group I.

Remarkably, the taxi time in scenario C through all the groups is always lower than in scenarios with random last-minute allocation and schedule disruptions not considered in the allocation (B, D, and E). Such observation allows concluding, that consideration of expected schedule deviations in the stand assignment is beneficial for airport operations as it results in shorter taxi times owing to decreased stand availability waiting times.

When the amount of total pollutant emissions is compared, the lowest value again corresponds to Group V for Scenarios C (see Figure 4). The amount of emissions in scenario C Group V is approximately 9% less than the amount produced under original assignment policy of Group I. Random last-minute allocation in scenario E in Group V, interestingly, resulted only in 3.8% higher emissions than in scenario C. However, such a random allocation demonstrated quite a high variability under all assignment policies.

It can be noticed that Figure 3 and Figure 4 have similar values, which could be explained by the assumption of uniform emissions factors for the entire study. Nevertheless, it could be interesting to repeat the experiments in the future with more specific emission factors, e.g. adapted from BADA (EUROCONTROL 2020), and analyze the correlation between total emissions and total taxi time for a purpose of combining them into a single optimization objective.

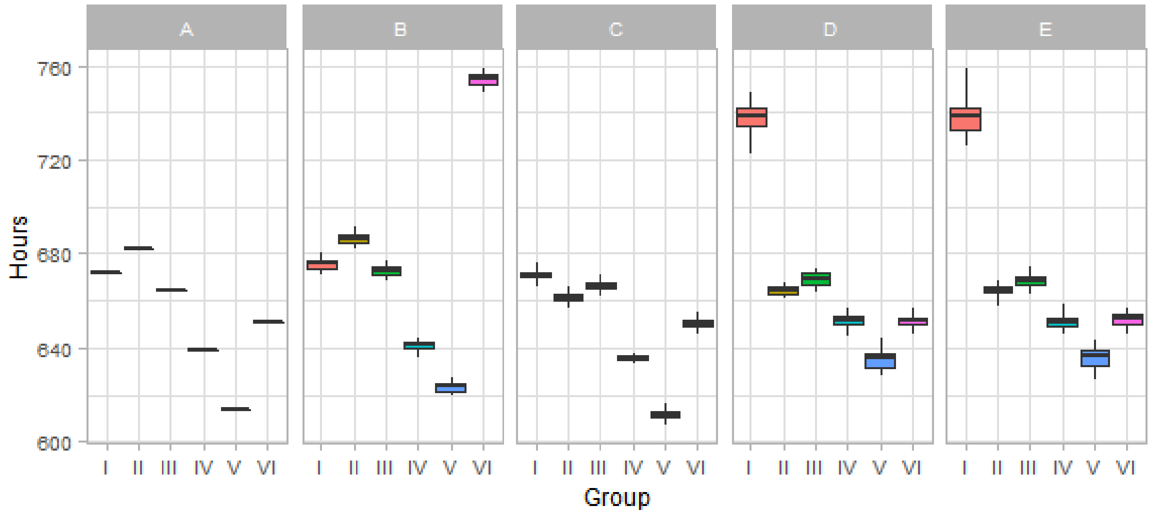

Figure 3: Comparison of total taxi time for scenarios A - E through the groups of experiments.

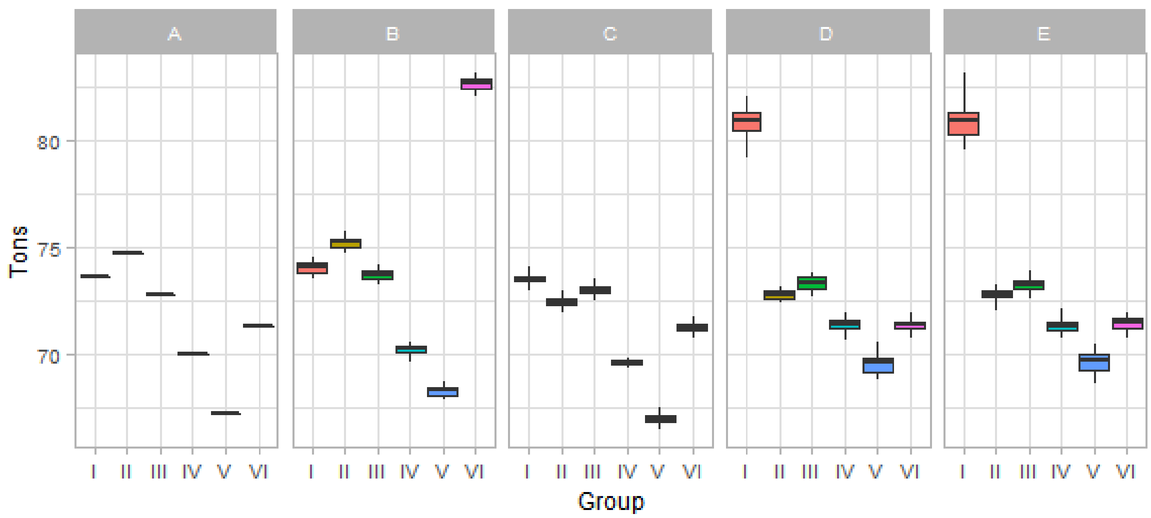

Figure 4: Comparison of total CO_2 + NOx emissions for scenarios A - E through the groups of experiments.

Summarizing the results, it can be concluded that the most beneficial stand assignment policy in terms of related emissions is the one in Group V. This means that rearranging the use of terminal buildings and dedicating Terminal 1 to domestic flights, can save MEX around 9% of total pollutant emissions weekly compared to existing terminal buildings designation under the operational conditions considered in the experiments.

4 CONCLUSIONS AND FUTURE RESEARCH

This paper presents an application of an innovative approach that combines Bayesian methods and a bi-objective heuristic optimization for solving the stand allocation problem in airports from the perspective of minimization of related emissions. To validate the impact of the presented approach on airport environmental footprint, the simulation was included in the methodology to introduce the effects of the stochastic nature of the real-life system. In the case presented, the methodology showed a clear benefit of consideration of possible schedule disruptions in the stand assignment planning for emissions mitigation. Furthermore, the application of the two-module approach with the relaxation of assignment restrictions revealed a hidden potential of mitigation of taxi-related pollutant emissions. For the case of Mexico City International Airport, the best-obtained results correspond to the dedication of entire Terminal 1 to domestic flights and Terminal 2 – to international flights Such rearrangement of terminal buildings could decrease taxi-related pollutant emissions by approximately 9% weekly, compared to the present use of terminals.

As future work, other variables, such as actual turnaround times and departure time deviations, and more historical performance data would be considered in Module I for providing more accuracy on the expected perturbations. When more historical data become available, it would also be beneficial to use different but comparable sets of data to learn the deviation models and perform the simulation experiments to better estimate the accuracy of the obtained deviation models. Enhancement of the two-module approach optimization component and simulation study with aircraft emissions specifications is also considered for a more precise estimation of emissions and their impact on the stand allocation.

Furthermore, it would be interesting to compare the quality of the two-module generated stand assignments with the historical (actual) stand assignments for the same airport and test the presented approach on other airport configurations and stand assignments policies. Additionally, it can be investigated if taxi distance reduction and emission reduction objectives can be combined into a single optimization objective and what would be the impact on emissions level if aircraft waiting times are considered instead of the number of waiting aircraft. Moreover, the use of information obtained from the simulation model will be incorporated into the optimization loop to provide even more qualitative solutions.

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