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Optimizing Aircraft Operations in Case of Increasing Demand for Limited Airport Capacity

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Abstract

The purpose of this paper is to minimize the total difference between the requested and assigned departure time of aircraft to enhance the efficiency of using limited airport capacity. The mathematical model was formed by employing mixed integer linear programming. The parameters, decision variables, and constraints were defined to cover the problem. The baseline and alternative scenarios were compared to present the improved results. Sensitivity analysis was performed to test the ability of the model with different parameters. Also, in order to test the mathematical model, distinct from both the baseline and alternative scenarios, CHQ airport was based by using its number of parking positions and taxi-in/out durations in the sensitivity analysis. The proposed model reduced the total difference by 20.78% for 30 aircraft for 5 parking positions in the alternative scenario. The results showed that it may well serve to improve the imbalance regarding operational conditions.

1 Introduction

The demand for airline transport has been increasing exponentially for many years. Even in some crisis situations, the sector continues to grow and can reach its targets in a very short time. However, this increase in airline transport is causing problems of capacity and congestion day by day. This situation leads to the fact that today not every airline company can organize flights to every destination even to the points within the country of the flag carriers as they wish. The most important reason for this situation is that the limited airport capacity cannot be increased, or this process is very costly. For this reason, airport operators or countries regulate their limited capacity with regulations and commercial agreements. As a result of these regulations, airline companies have to perform operations at the appointed times (slots) instead of the take-off and landing times, which are strategically important for them. Although this process is tried to be improved later, current solutions remain insufficient. In this case, it is necessary to re-create the current flight plans with a more controlled way by taking into account the existing demands of the airline companies. At this point, it is necessary to realize this solution without straining the existing physical conditions of the airport capacity.

Airport capacity is often measured in relation to runway capacity. Gelhausen et al. defined the runway as a weak part of an airport in terms of capacity and stated that it has a key role in determining the capacity (Gelhausen, Berster and Wilken, 2013). However, the number of parking positions has a significant impact on airport capacity. Insufficient parking spaces or gates will be restrictive even in situations where runway capacity is available for operations. Sena et al. highlighted that this is a critical problem at many airports where the number of parking spaces is insufficient to serve all scheduled aircraft (Sena, Gzara and Stützle, 2020). In addition, Androutsopoulos and Madas stated that the intensity of delays is affected by the temporal distribution and peaks of demand (Androutsopoulos and Madas, 2019). Therefore, the most influential factor on airport capacity becomes parking spaces. The impact of this problem can be resolved by constructing new parking positions in order to increase the capacity. However, as Jacquillat and Odoni emphasized, high costs for construction must be met and there must be a new area where the airport surface can be expanded (Jacquillat and Odoni, 2018).

The problem addressed in this study is to reduce delays and make more efficient use of limited airport resources by minimizing discrepancies between requested and assigned aircraft operation times. Specifically, the problem arises due to airport capacity constraints, such as limited parking positions and runway availability, coupled with the increasing demand for air transportation. These constraints lead to congestion, preventing airlines from operating at their preferred times. The problem can be formally defined as follows: Given a set of aircraft whose operators are requesting earlier departure times and a limited number of parking positions, the objective is to assign departure times regarding these requests in a manner that minimizes the total difference between the requested and assigned departure times, while adhering to operational constraints such as turnaround time, taxi-in/out durations, and runway usage limits. The features of the problem are limited parking positions requiring efficient use by aircraft; the need to minimize the discrepancy between operational times requested by airlines and the times assigned; considering turnaround and taxi durations; the requirement to account for runway usage limitations; and the management of airlines' current operational demands.

In this study, an optimization model was developed for an airport with limited parking space by using the integer programming method. This model tries to ensure that the parking positions are used in the most efficient way with a tactical approach in airport use. As is known, tactical use is the result of a strategic planning. For this reason, the model can also be used to improve existing flight list even if planning is done. The mathematical model aims to minimize the difference between the operating times requested and assigned by the flights as regarding the features of the problem. In this way, both the operating times of the airline companies will be brought closer to the time they demand and the limited number of parking positions will be used more effectively.

The developed model directs both the carrier and the airport operator to a more effective use in airline transportation. The model can also be evaluated as a solution for air traffic flow management from a different perspective.

2 Literature review

Yan and Yang conducted a study showing the real impact of aircraft scheduling disruptions at an airport in Taiwan (Yan and Yang, 1996). Cao and Kanafani aimed to create an optimum flight list by investigating the rescheduling of aircraft (Cao and Kanafani, 2000). The study conducted by Howe et al. aimed to overcome demand/capacity imbalances with slot auctions and network simulations (Howe et al. 2003). Madas and Zografos used the slot methodology and the Analytic Hierarchy Process (AHP) to implement a related pricing strategy to this in order to achieve the most effective assignment (Madas and Zografos, 2010). Zografos et al. aimed to minimize the difference between the demanded and the allocated time (Zografos, Salouras, & Madas, 2012). Capacity deficiencies in terms of the stochastic nature of the system, latency, and assigned times were also investigated (Mukherjee and Hansen, 2007; Corolli, Lulli and Ntaimo, 2014; Corolli et al., 2017). Jacquillat and Odoni aimed to minimize congestion costs by optimizing flight plans and capacity utilization at strategic/tactical levels (Jacquillat and Odoni, 2015). Cai aimed to improve congestion and total aircraft delay simultaneously with a mathematical model (Cai et al., 2017). Controlling delays and their distribution is especially important in terms of time buffer zones. Ivanov et al. stated that these buffer times added to operational times are an opportunity for airlines to react to unexpected delays (Ivanov et al., 2017). Rodriguez-Díaz et al. aimed to minimize the delays in the planned departure and arrival times and to determine the sequence of the aircraft with constrained position shifting (Rodríguez-Díaz, Adenso-Díaz and González-Torre, 2017). Pellegrini aimed to simultaneously allocate slots at airports by taking into account turnaround time restrictions (Pellegrini et al., 2017). In a different study, algorithm-based assignment of push-back vehicles was made to reduce emissions and delay in taxi operations (Bubalo, Schulte and Voß, 2017). In order to determine the practical capacity and demand, a different study was carried out for independent parallel runways in the simulation environment (Bubalo and Daduna, 2011). Benlic's study aimed to minimize the difference between planned and demanded times to reduce the number of unallocated demands (Benlic, 2018). Fairbrother et al. studied the fair distribution of airline preferences in terms of total displacement (Fairbrother, Zografos and Glazebrook, 2020). Zografos et al. (2018) and Androutsopoulos et al. (2020) investigated the bi-objective scheduling model by considering the total and maximum allowable displacement objectives (Zografos, Androutsopoulos and Madas, 2018; Androutsopoulos, Manousakis and Madas, 2020). An integer linear programming model was created to evaluate the weight of objectives in terms of displacement and implementation difficulties in slot allocation (Ye et al., 2019). Another study was conducted in order to create an original algorithm that looks for a feasible solution within a reasonable solution time for slot allocation. The proposed algorithm was created to obtain the best solution by taking into account the airport's apron capacity and using a heuristic approach that reduces the calculation time (Ribeiro, Jacquillat and Antunes, 2019). A demand smoothing model was designed in order to create a new flight schedule. The model proposed a new schedule without any cancelled aircraft and caused a reduction in delay (Pyrgiotis and Odoni, 2016). Zografos et al's study is also important for a more detailed review of current developments and future requirements (Zografos, Madas and Androutsopoulos, 2017).

The studies that previously contributed to the topic of this work were given in this section. The studies were given as underlying some specifications such as solution approach, optimization method, focusing area. Also, the contributions and distinctive aspects of this work were presented in the following section.

3 Specificity of the study

Even though the model in this study is not aiming to allocate slots to the aircraft from scratch, it aims to improve planned flight schedules that have issued aircraft with a slot or not to have a better use of limited capacity at airports. In the current system, slot assignments are made to the carriers for the sequential and effective use of the limited capacity and the aircraft can use the airport capacity within a certain period of time. The current system, as it is, prefers a delay-based solution and assigns aircraft to certain times, which makes the system more cumbersome. This system can also ignore airline companies' new requests or changing strategies (airline preference) as it aims to have aircraft move within this time range, or it needs a cancelled flight or unassigned time for revision. However, after the strategic slot assignments are completed at the tactical stage on the day of operation, stretching this time interval backwards will both relieve the existing capacity and will consider the new strategies or unexpected changing demands of airline companies. By optimizing the schedule and stretching times backward, the model can align the operational times with the airlines' demands, reduce inefficiencies, and make more effective use of limited resources. This approach may help to ensure that the airport can handle the existing demand more efficiently without the need for costly expansions, thereby improving overall operational balance and reducing delays.

When the previous studies are analysed, it is seen that both delay and reducing the gap between the assigned and planned operation times were stated among the common objectives. According to the literature review, it is also seen that the studies have aimed to improve the existing system by reconsidering the process having been applied these days. However, Zografos et al. emphasized in their study in 2017 that the slot times made in the current system should be handled individually rather than in series (Zografos, Madas, & Androutsopoulos, 2017). Similarly, Benlic stated in her study conducted in 2018 that slot assignments are made in series and that these time-spaced assignments complicate the problem (Benlic, 2018). Thus, in this study, as stated previously, in line with the demands of the airline companies, both the determined time intervals will be stretched backwards to give a more flexible structure to the system. In addition, each operation time can be handled for each flight. To achieve this, a mathematical model was developed in order to take into account the operating times that are thought to be assigned to flights by the current system. This model will ensure that these strategically assigned times are re-determined in accordance with the operational constraints in the tactical process and in line with the demand of the airline company. This model handles the existing flight times by reallocating them individually and it aims to improve the existing flight schedule rather than starting all operations from scratch. Thus, a more flexible model is being created to meet the new requests of airline companies by making changes to the assigned times on strategic days for the desired modifications to be made on the day of operation.

Handling the operation times individually, stretching the assigned time interval backward, updating the time assignments in the strategic phase according to the demands of the airline companies, and using many operational constraints in the tactical phase (runway conflicts, parking position usage, turnaround time, taxi-in/out durations determined according to the parking position) in the mathematical model distinguish the article from the others in the literature. In the mentioned method, EUROCONTROL processes are taken as an example, albeit partially, but the purpose is to operate the limited airport capacity in the form of scheduling to an earlier time in delay-based slot process and to provide flexibility to the carriers. Additionally, operational constraints in the tactical process are used in the model to establish a connection between allocated times in the strategic planning and new requirements and unexpected changing demand in the tactical processes. In this context, the mathematical model also differentiates the problem of the article from the gate assignment problem (Bouras et al., 2014; Cecen, 2021).

In summary, this model introduces an approach that optimizes the use of limited capacity by flexibly adjusting allocated times backward in accordance with the demands of airline companies at the strategic phase. While doing so, it also considers operational constraints at the tactical phase. Moreover, it offers a more practical and flexible approach by making improvements upon them. Thus, since it is a model based on previously planned flight schedule, it will be able to work in harmony with the outputs of the existing system and to present a model that is both compatible and practical for implementation.

4 Mathematical model

Two scenarios such as basic and alternative ones were used in the study. In the basic and alternative scenarios, an airport with 5 parking positions was used. In the basic scenario, a flight list was created with a demand of 30 aircraft to the airport in 1 hour. The reason for choosing 5 parking positions is to clearly observe the difference between the assigned and demanded times due to the imbalance between the demand and the capacity. However, the model was also tested for data sets with different numbers of parking positions (10, 15) and the total numbers of aircraft (10, 15, 20, 25) under the title of "Sensitivity Analysis" in the study and the model performance was observed. In addition, CHQ (Chania Airport) was chosen because it is a Level 3 airport in the summer period, and the mathematical model was tested with a demand data having an exponential distribution based on taxi-in/out durations determined according to total number of parking spaces and parking positions. Since the basic-alternative scenarios were tested for a small airport with 5 parking spaces, the aircraft were considered as a single category, but aircraft wake-vortex categories were also added to the mathematical model for the CHQ airport application.

As a result of the intense operation demand in the base scenario, the airport capacity is exceeded. Thus, the times demanded by the airline companies are arranged with a delay at the strategic stage in order to establish the demand-capacity balance. This situation creates a difference between the demanded time and the assigned time, and this difference increases cumulatively.

In the alternative scenario, the mathematical model established for the problem is tested. In this scenario, which has the same parameters as the basic scenario, the airline companies' demand for earlier operation time and the durations regarding this demand are additionally given as parameters to the model. Although stretching the time interval backwards is a useful approach, it is important for passenger rights and comfort to have a limit for this. Therefore, it is limited to a maximum value. Additional information about this parameter for early time demand is given in the following subheading. The mathematical model used in the alternative scenario consists of parameters and constraints suitable for the purpose of the study.

4.1 Parameters and decision variables

Indices, parameters and variables used in the model are given in Table 1.

Table 1. Parameters and decision variables

Indices	Explanation
I	set of aircraft at the airport $i, i1, i2 \in I$
J	set of parking position at the airport $j \in J$
O	set of aircraft category
S	set of demand control
Parameters	**Explanation**
M	very large positive number

cat_i	wake-turbulence category for aircraft *i*
td_i	assigned departure time for aircraft *i*
trd_i	requested departure time for aircraft *i*
ta_i	arrival time for aircraft *i*
d_i	demand for early departure time
dur_s	early time duration, $s = d_i$
$sep_{o1,o2}$	separation between category *o1* and *o2* among departure aircraft
tin_j	duration of taxi-in for park position *j*
$tout_j$	duration of taxi-out from park position *j*
tat_i	duration of turnaround time for aircraft *i*
tsa	separation (2 min.) among arrival aircraft
$tsad$	separation (1 min.) between arrival and departure aircraft

Variables	Explanation
ntd_i	new departure time for aircraft *i*
nta_i	new arrival time for aircraft *i*
tpo_i	time of leaving parking position for aircraft *i*
$taxi\_in_i$	taxi-in duration for aircraft *i*
$taxi\_out_i$	taxi-out duration for aircraft *i*
t_i	time saving for aircraft *i*
$x_{i,j}$	0–1 variable that takes a value of 1 if aircraft *i* is assigned to parking position *j; otherwise, 0.*
$y_{i1,i2}$	0–1 variable that takes a value of 1 if new arrival time (nta) of aircraft *i1* is greater than the nta of aircraft *i2; otherwise, 0.*
$z_{i1,i2}$	0–1 variable that takes a value of 1 if the nta of aircraft *i1* is greater than the new departure time (ntd) of aircraft *i2; otherwise, 0.*
$p_{i1,i2}$	0–1 variable that takes a value of 1 if the ntd of aircraft *i1* is greater than the ntd of aircraft *i2; otherwise, 0.*

The early time demand parameter d_i represents four situations in the model. These situations are related to earlier departure demands such as not taking off early, taking off maximum 20 minutes earlier, taking off maximum 30 minutes earlier, and taking off maximum 40 minutes earlier (Table 2). This means that, for example, if an aircraft has demand (d_i=3), it may take a value between 0 and 30 minutes earlier. This will bring flexibility to the model to find an optimum solution.

Table 2. Corresponding values of d_i on dur_s

d_i	dur_s (minute)
1	0
2	20
3	30
4	40

Each carrier will notify the system of the relevant demand parameter and of the maximum earliest time it can achieve. Then, this parameter and operational constraints in the tactical phase are determined and placed in the model. The functions of the mathematical model and linearization of nonlinear constraints are given below.

$$min \sum_i ntd_i\text{-}trd_i \tag{1}$$

$$nta_i = ta_i\text{-}t_i \quad \forall i \tag{2}$$

$$t_i \leq dur_s \quad \forall i,s|s=d_i \tag{3}$$

$$\sum_j x_{i,j} = 1 \quad \forall i \tag{4}$$

$$taxi\_in_i = \sum_j tin_j x_{i,j} \quad \forall i \tag{5}$$

$$taxi\_out_i = \sum_j tout_j x_{i,j} \quad \forall i \tag{6}$$

$$tpo_i = nta_i + taxi\_in_i + tat_i \quad \forall i \tag{7}$$

$$trd_i \leq ntd_i \leq td_i \quad \forall i \tag{8}$$

$$ntd_i = tpo_i + taxi\_out_i \quad \forall i \tag{9}$$

$$nta_{i1} \geq tpo_{i2}\text{-}(2\text{-}x_{i1,j}\text{-}x_{i2,j})M \quad \forall i1,i2,j|i1>i2 \tag{10}$$

$$nta_{i1}\text{-}nta_{i2} \geq tsa\text{-}(1\text{-}y_{i1,i2})M \quad \forall i1,i2|i1\neq i2 \tag{11}$$

$$nta_{i2}\text{-}nta_{i1} \geq tsa\text{-}(y_{i1,i2})M \quad \forall i1,i2|i1\neq i2 \tag{11.1}$$

$$nta_{i1}\text{-}ntd_{i2} \geq tsad\text{-}(1\text{-}z_{i1,i2})M \quad \forall i1,i2|i1\neq i2 \tag{12}$$

$$ntd_{i2}\text{-}nta_{i1} \geq tsad\text{-}(z_{i1,i2})M \quad \forall i1,i2|i1\neq i2 \tag{12.1}$$

$$ntd_{i1}\text{-}ntd_{i2} \geq sep_{(o1,\ o2)}\text{-}(1\text{-}p_{i1,i2})M \quad \forall i1,i2|i1\neq i2,\ o1=cat(i1),\ o2=cat(i2) \tag{13}$$

$$ntd_{i2}\text{-}ntd_{i1} \geq sep_{(o1,\ o2)}\text{-}(p_{i1,i2})M \quad \forall i1,i2|i1\neq i2,\ o1=cat(i1),\ o2=cat(i2) \tag{13.1}$$

$$td_i\text{-}ntd_i \leq dur_s \quad \forall i,s|s=d_i \tag{14}$$

$$ntd_i \geq 0 \quad \forall i \tag{15}$$

$$nta_i \geq 0 \quad \forall i \tag{16}$$

$$tpo_i \geq 0 \quad \forall i \tag{17}$$

$$taxi\_in_i \geq 0 \text{ and integer} \quad \forall i \tag{18}$$

$$taxi\_out_i \geq 0 \text{ and integer} \quad \forall i \tag{19}$$

$$t_i \geq 0 \text{ and integer} \quad \forall i \tag{20}$$

$$x_{i,j} \in \{0,1\} \quad \forall i, \forall j \tag{21}$$

$$y_{i1,i2} \in \{0,1\} \quad \forall i1, \forall i2 \tag{22}$$

$$z_{i1,i2} \in \{0,1\} \quad \forall i1, \forall i2 \tag{23}$$

$$p_{i1,i2} \in \{0,1\} \quad \forall i1, \forall i2 \tag{24}$$

The constraint in Equation (2) calculates the new arrival time as regarding Equation (3). The constraint in Equation (3) limits the time saving with an upper boundary since any time savings must not disturb other operations and passengers at airports. In this equation, maximum level of the dur_s is chosen by aircraft operators according to the Table 2. Equation (4) ensures that each aircraft *i* is assigned to a parking position *j*. The constraints in Equations (5) and (6) calculates the taxi-in and taxi-out duration according to assigned parking position *j* of each aircraft *i*. Equation (7) calculates the time of leaving assigned parking position *j* of each aircraft *i*. Equation (8) ensures that the new departure time is greater than the requested departure time and lesser than the assigned departure time for aircraft *i*. Hence, it ensures that the new departure time cannot be early or delayed according to the requested and assigned departure time, respectively. Equation (9) calculates the new departure time according to the taxi-out duration of each aircraft *i*. Equation (10) controls conflict among aircraft *i1, i2* that are assigned to the same parking position *j*. It was a concern in the research of Sena et al. (2020) and it is a useful expression in terms of operational requirements to prevent extra waiting time for an available parking position. The constraints in Equation (11)-(13) controls conflict among aircraft on the runway. The constraint in Equation (14) limits the difference between the assigned departure time and the new departure time of aircraft *i* with dur_s. It prevents to give more earlier departure time than aircraft operator demands. The constraints in Equation (15)-(24) are sign constraints.

5 Numerical results

As mentioned in the previous section, firstly the basic scenario was determined and the results related to this scenario were obtained as in Figure 1.

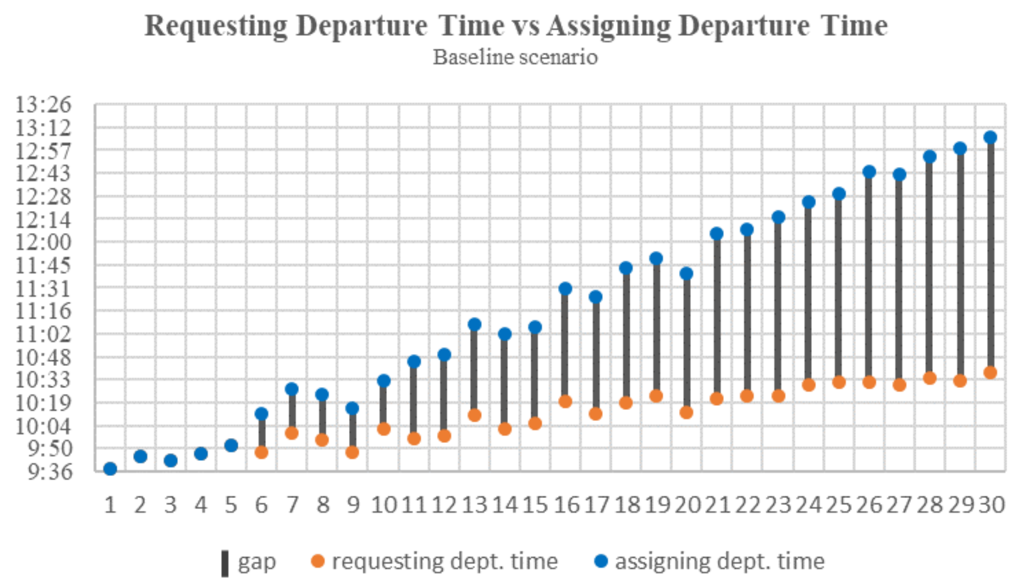

Figure 1. Baseline Scenario

While the orange dots and the blue dots in Figure 1 show the requested times and the assigned times respectively, the black bars show the difference between these two times. Because of the high demand, a difference arises between the requested time and the assigned time with the 6th flight and it increases cumulatively. This difference ensures that when the 6th aircraft lands, the required capacity is ready for it. For example, when the requested departure time of the last flight was 10:38, this could not be met. Instead, the appointed departure time was 13:06.

The alternative scenario was created to reduce this difference arising in the basic scenario. The alternative scenario was formed with the airlines' demands to minimize the difference between the requested and assigned departure times. As a result, the aircraft which have a demand for an earlier departure time receive it according to separation criteria and airport capacity. This process decreases the difference, and this saving is usable for other aircraft which also have a demand for an earlier departure time. This begins another chain reaction to reverse or at least reduce the effects of the demand/capacity imbalance. The comparison between the baseline scenario and the alternative scenario is presented in Figure 2.

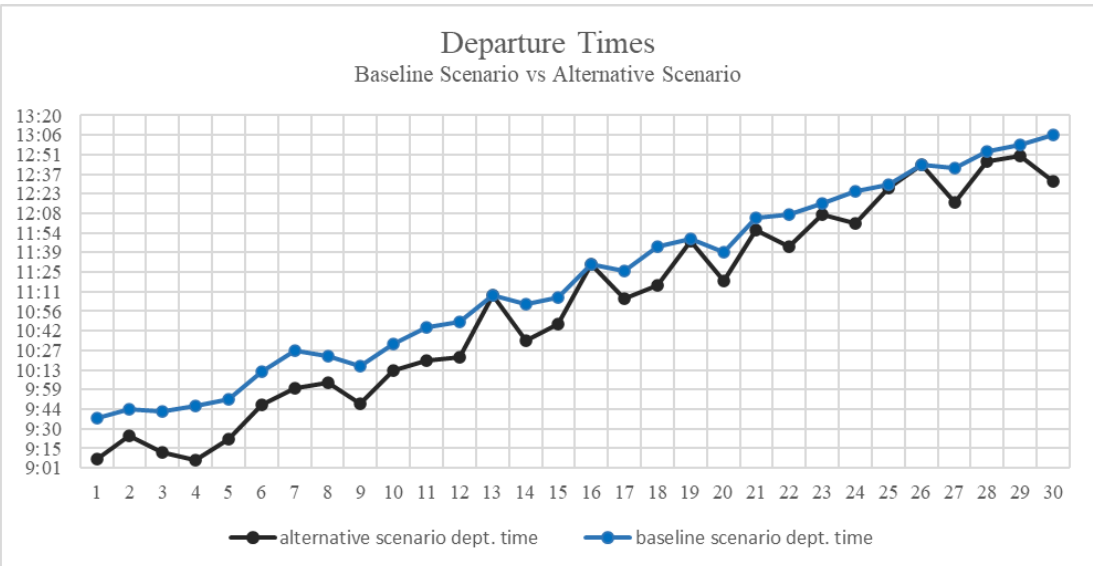

Figure 2. The comparison between the baseline and the alternative scenario

While the blue dots represent the assigned departure times for each aircraft in the basic scenario, the black dots represent the departure times suggested by the mathematical model in the alternative scenario. As can be seen from this graph, the departure times have been shifted to earlier times by the model. Thus, the difference between the requested and assigned times is reduced. However, some flights could not get an earlier time because either they did not request it or there was no suitable capacity for it.

There is a noticeable improvement in minimizing the difference when compared to the baseline scenario. The assigned departure time of the last aircraft is 13:06 pm in the baseline scenario, but this time is 12:32 pm in the alternative scenario.

Figure 3 represents the difference (gap) between the requested departure time and assigned departure time and the saving of the alternative scenario for each aircraft that has departure time different than the requested one.

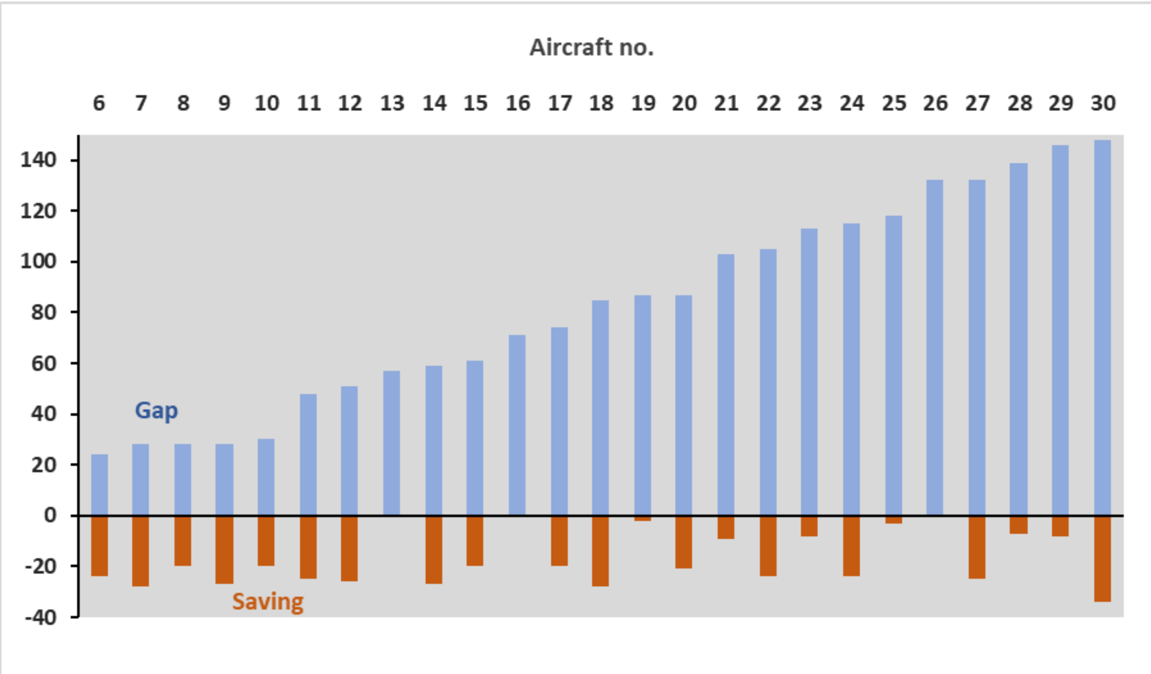

Figure 3. Gap (difference) and saving of each aircraft

The blue columns represent the gap, whereas the orange columns show the saving of each aircraft. Since the saving means decreasing the difference, it is in the negative part of the graph. Among these aircraft, aircraft 30 has the largest saving of 34 min. There is no unsatisfied demand, but two aircraft have a relatively small saving of just 2 min and 3 min as the model searches for the optimum solution for total saving.

The testing of the model with 30 aircraft at a single runway airport shows good results and the total difference between the requested departure time and assigned departure time of the aircraft is reduced by 20.78%. The computation time was 10,053 sec. for this dataset and it was within the time limitation that is 10,800 sec. The model was tested with a CPU specification of 2.6 GHz and RAM 8.00 GB, and the General Algebraic Modeling System (GAMS), which is an optimization program, was employed with CPLEX to solve the mathematical model. The computation time is sufficiently fast to seek an optimum solution strategically. The planning horizon was able to absorb this computation time; however, the metaheuristic algorithms, especially simulated annealing, would be useful to ease the computation time problem, but using these algorithms mostly means accepting a feasible solution instead of an optimum one.

To show the operation times of each aircraft in the baseline scenario and alternative scenario, the Gantt chart is given in Figure 4.

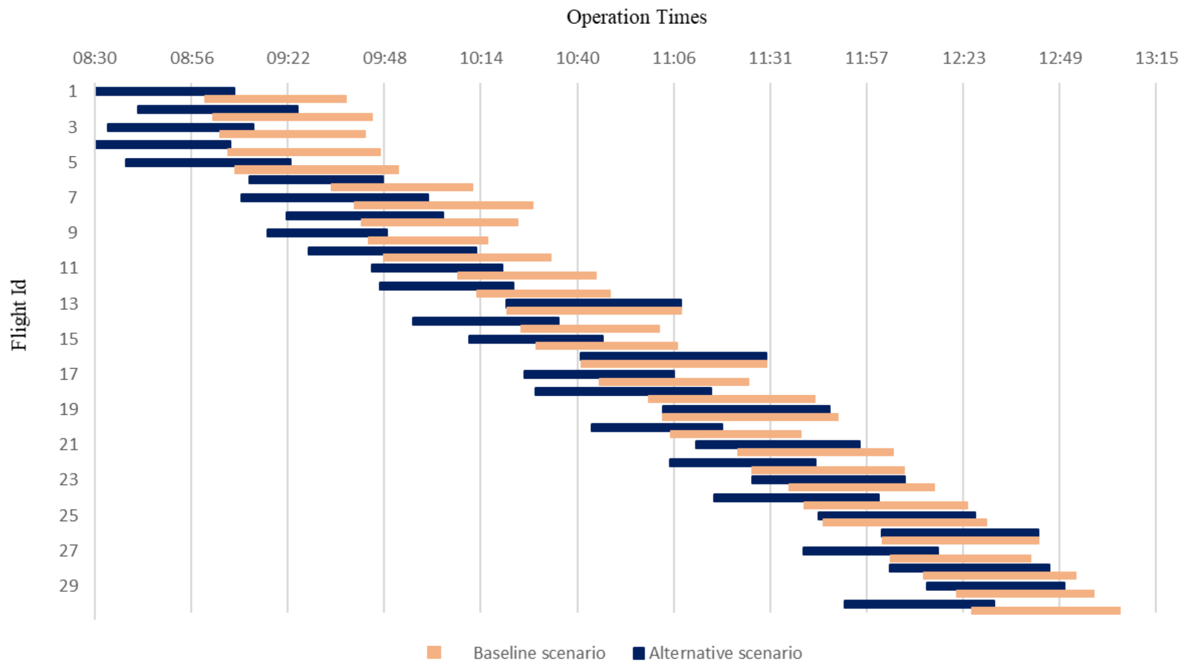

Figure 4. The Gantt chart of the aircraft operations

Each time point cannot be shown due to space requirement; however, it is clear that aircraft which have early time demand get an earlier departure time. While the salmon bars represent the aircraft operations in the baseline scenario, the blue bars represent the aircraft operations in the alternative scenario. The beginning of each bar points the arrival time of each aircraft, the length of each one shows the duration between the arrival time and the departure time and the end of each bar represents the departure time of each aircraft. As seen in Figure 4, the saving of each aircraft in the alternative scenario is at a noticeable level when compared to the baseline scenario.

6 Sensitivity analysis

Sensitivity analysis is a useful approach to understand the model's abilities with different parameters. The aim of this analysis was to test the model with a different number of aircraft and parking positions. The first sensitivity analysis aimed to test the model from less to a greater number of aircraft. Therefore, the size of the aircraft set varied between 10, 15, 20, and 25 aircraft. Each aircraft set was constituted by adding new aircraft at the end of the list to preserve the conditions of excessive demand. All sensitivity analyses in the study were tested with the same computer and software. The result of the first sensitivity analysis is shown in Table 3.

Table 3. Sensitivity analysis for varied aircraft set size

Number of aircraft	Parking Position *total*	Total Difference *min.*	Total Saving *min.*	Saving Rate *%*	Computation *sec.*
10		138	119	86.23	0
15		414	218	52.65	0
20	5	818	289	35.33	22
25		1372	363	26.45	1,080
30		2069	430	20.78	10,053

The total difference shows the total gap score between the requested and assigned departure times. Total saving represents the output of the model when it is compared to the results of the baseline scenario. The performance of the model decreases as the size of the aircraft set increases, as shown in Table 3. Additionally, the computation time of the model increases as the total saving increases; however, the rate of total saving by gap score decreases because the increase in the total saving is lower than in the total difference as the size of aircraft set increases. The result of the dataset that have 30 aircraft is given to be compared with the results of the sensitivity analysis. The computation time was 1,080 sec. for the 25-aircraft dataset and only five extra aircraft increased the computation time to 10,053 sec. for the 30-aircraft dataset.

Another sensitivity analysis aimed to reveal the performance of the model for the same size dataset of the alternative scenario but with a different number of parking positions as considering a relatively larger airport for 30-aircraft set. Table 4 shows the total saving, the difference score, and the computation time of the model.

Table 4. Sensitivity analysis for the number of the parking positions

N. of aircraft	Parking Position *total*	Total Difference *min.*	Total Saving *min.*	Saving Rate *%*	Computation *sec.*
30	10	561	234	41.71	720
	15	148	87	58.78	745

As shown in Table 4, increasing parking position capacity at the airport decreases the total difference score between the requested and assigned departure times. However, there is still a gap among these times to be optimized. Hence, the second analysis was employed to reveal the performance of the model under the conditions of relaxed capacity. The results show that the performance of the model for a different number of parking positions is at a remarkable level. The total saving decreases for each aircraft set, because the number of aircraft that have departure time different than the requested one is reducing as the capacity of parking position is increasing. When compared to the results of baseline scenario, the saving rate is 41.71% and 58.78% for 10 parking positions and 15 parking positions respectively.

7 Application

It is very difficult to access all the data necessary for testing the mathematical model due to the pandemic conditions and the protection of the data by third-party agreements. However, the mathematical model suggested in the study can be tested based on the conditions of a real airport. In this context, the chosen airport has been CHQ (Chania Airport), which serves as Level 3 in the summer period. This airport tries to respond to operational demands with a single runway and 12 parking spaces. The operation demands in the data set were created in accordance with the exponential distribution to make the model more realistic. Similarly, the Heavy category has been added to the wake-turbulence categories of the aircraft to increase the realistic nature of the model. The number of parking positions and taxi-in/out times in the mathematical model were re-determined according to the positions of the parking positions based on this airport. Thus, not only a real airport and a real-like traffic distribution were taken as a basis, but aircraft categories were also included in the calculation. The basic and alternative scenario results updated according to the situations above are given in Table 5.

Table 5. Results for airport-based conditions

Baseline scenario		Alternative scenario		
N. of aircraft	Gap score, min.	Total saving, min.	Saving rate, %	Computation, sec.
30	182	132	73	125

As can be seen in Table 5, when the operation demand for 30 aircraft, 12 parking spaces and aircraft categories (medium, heavy) are included in the model, it creates a difference score of 182 minutes in the basic scenario. The reason why this score is lower than the scenario with 5 parking positions is that the traffic with exponential distribution is less dense and the number of parking positions is higher. The mathematical model for the relevant airport (CHQ) reduced the 182-minute difference score to 50 minutes. Thus, it provided an improvement of 73% when compared to baseline scenario of this application.

8 Discussion

The model accounts for turnaround times to ensure that adjustments to operation times do not reduce the time needed for aircraft preparation and maintenance. Taxi durations and runway occupancy are considered to ensure efficient scheduling, even with adjusted times. The model limits requests for early times to a maximum value, preventing excessive changes that could disrupt operations or consume buffer times. By incorporating these factors, the model minimizes the risk of consuming essential buffer times while optimizing the scheduling of aircraft.

Since the requests for earlier operation times will be left to the airlines' discretion prior to the process, the final decision regarding the interaction with connecting flights will be made by the airlines. Although the current model does not explicitly address connected flights and this issue may be negligible for point-to-point flights, it provides indirect support by considering key operational factors such as turnaround times and taxi duration. By ensuring efficient scheduling, the model helps maintain timely arrivals and departures, thereby increasing the likelihood that connected flights will also operate on required time. Additionally, the model limits requests for early departures to a maximum value, which helps reduce the risk of operational disruptions affecting connected flights. Effective coordination and communication between airlines and ground services further assist in managing early time, ensuring that necessary adjustments are made to prevent missed connections. Future versions of the model may incorporate specific constraints and objectives related to connected flights, thereby enhancing its ability to manage early departures in alignment with connection timings. Overall, while the current model does not directly target connected flights, it manages related issues through its focus on operational efficiency and scheduling constraints, with plans for future enhancements to address these concerns more comprehensively.

9 Conclusion

A mathematical model, which minimizes the difference between the assigned and requested operation times by considering the operational times assigned in the strategic planning, the changing strategies of airline companies or the delays they will experience in tactical processes and by reupdating them, is presented in this study. The model tries to do so by offering carriers to take off earlier and it also considers the operational constraints in the tactical operation. With a systematic approach, first of all, a demand/capacity imbalance was created in a single runway airport. As a result, the relevant flight list and the difference between the assigned and requested operation times were recorded. In the alternative scenario, this flight list is taken and given to the mathematical model with the current demands of the airline companies. The difference resulting from demand/capacity imbalance of the mathematical model performance and the difference between the assigned and requested time has been reduced by 20.78% in comparison with the baseline scenario. This improvement is significant as it demonstrates the model's effectiveness in managing flight scheduling. When applied over longer periods, such as weekly, monthly, or even yearly, this reduction in discrepancy may translate into substantial operational efficiency gains and better alignment of requested and assigned operational times. Sensitivity analyses were carried out to show that the model responds positively to the change in the parking position or the number of aircraft and to test the model. As a result of these analyses, it has been observed that the performance of the model adapts to the parameter changes and produces solutions for the operations at higher capacity airports. When the solution time of the model is examined, it is observed that the optimum solution was reached in a time below the maximum time (10.800 sec.)

determined for all data sets. All of these analyses showed that the model can be applicable and compatible to work with the current system to have a better use of limited capacity at airports.

The mathematical model was updated by using the taxi-in/out times for the selected airport according to the number of parking spaces and their positions. In addition, the separation constraint in the model was arranged according to the wake-vortex turbulence separation of the take-off aircraft and the model became more realistic. In the scenario created by using the parameters of a real airport, the mathematical model provided noticeable improvements in a short time. As was stated, the main limitation of this study is reaching all the data required by the model. Although an airport was selected to use its parameters in the model and accomplished to use some of them, it is still planned to try to get more specific data. Another concern is to arrange passenger movements to aircraft have earlier departure time. Airlines, generally, advise passengers to come to the airport 1.5 - 2 hours earlier than departure time. However, the mathematical model allows a maximum of 40 minutes earlier departure. For this reason, it is thought that passengers will not be affected much by this situation.

The current framework for scheduling airport movements is based on several variables such as operation demand, airport capacity (e.g. the use of parking positions), turnaround durations etc. These variables are managed by controlling aircraft movements within specific time slots. This approach involves assigning delays to aircraft operating at airports experiencing bottlenecks, making this framework a delay-based solution. Conversely, if an airline wishes to change its operational time due to strategic reasons, the Network Manager handles this request for related flight. In our model, all requests are tried to be examined one by one then they are optimized collectively through the objective by the model. As a result, it provides an integrated flight list that better responds to airlines' new requests for time changes for their flights, if such requests exist.

Airlines and airports could leverage the model to test their operational time change and its effects. Incorporating the model into capacity replanning tools would improve the overall utilization of airport resources. The model is scalable, and its constraints and objective function is adaptable to various airport sizes and conditions. Furthermore, the model can work with the results of the current system to produce an improved schedule, demonstrating that the model can work in harmony with the current system. Hence, the model promises substantial efficiency gains, improved decision-making, and better utilization of airport resources, making it a valuable addition to the current framework.

In order to be able to update the times allocated in the strategic planning in the model upon the demands of the airline companies, not only the suitability of the operation and turnaround times were checked, but also the constraints in tactical operation such as the suitability of the parking position, runway conflicts and tracking of the taxi-in/out times for the relevant parking positions were also taken into account. This allowed the model to gain a more general structure and made it testable for different scenarios under different airport capacity conditions or under additional constraints. The time improvements realized within the scope of the model and the created scenarios will contribute to the efficiency and profitability focus of today's airline companies. As a result of the study, it is possible to use the available capacity of an airport more efficiently instead of adding a parking space to the airport. Optionally, the results can be observed by adding parking spaces to the model and changing the parameters. Further improvements (such as the application of all necessary data, a greater focus on connecting flights, metaheuristic algorithms, simulation analyse) are planned and it is predicted that their results will pave the way for the model to be used in real traffic operations.

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Conflict Of Interest (COI)

There are no conflict of interest.

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