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GBRC
ISBN 978.605.82617.5.4

PressAcademia Procedia
YEAR 2019 VOLUME 9

Global Business Research Congress, May 30-31, 2019, Istanbul, Turkey.

BASIC APPROACHES TO AIR TRAFFIC AND AIRPORT SLOTS ALLOCATION

DOI: 10.17261/Pressacademia.2019.1079
PAP-V.9-2019(26)-p.120-125

Savas S. Ates[2], Mhd Noor Hayek[2]
[1]Eskisehir Technical University, Faculty of Aeronautics and Astronautics, Eskisehir, Turkey
ssates@eskisehir.edu.tr, ORCID: 0000-0003-2462-0039
[2]Anadolu University, Graduate School of Social Sciences, Eskisehir, Turkey
mnh@anadolu.edu.tr, ORCID: 0000-0003-2462-0039

To cite this document
Ates S.S., Hayek, M.N., (2019). Basic approaches to air traffic and airport slots allocation. PressAcademia Procedia (PAP), V.9, p.120-125
Permemant link to this document: http://doi.org/10.17261/Pressacademia.2019.1079

ABSTRACT
Purpose- The purpose of the study is to determine the basic approaches to air traffic and airport slots allocation. It has been admitted that demand on aviation has been doubled many times in the last years. This has necessitated creating new models and strategies to tackle the problems of congested airports/airspace.
Methodology- Literature review method was used. In this review article, some theoretical and practical studies to overcome this problem have been presented. In addition, new models and simulations have been analyzed.
Findings- Many problems have been made. Some researchers have applied analytical algorithms; In addition, others have used integer algorithms. However, while researching the literature, the airspace congestion studies are all about the airspace.
Conclusion- A review of the literature. The different methods, algorithms, approaches. In addition, the airport congestion was at. Moreover, it was a comprehensive comparison of all presented.

Keywords: Airport congestion, airport slot allocation, air traffic capacity, air traffic flow management, fast time simulation.
JEL Codes: L91, L93, L98

1. INTRODUCTION

Over the last years, the growth of air traffic has exponentially increased. This has created some issues related to the airport/airspace capacity. Nearly all the biggest airports around the world are congested and some of them are even over congested. To overcome this problem, many studies and research have been conducted and all of them have presented reasonable solutions to this problem.

2. LITERATURE REVIEW

For the performance side, (Picard, Tampieri and Wan, 2018) have suggested using a congested pricing strategy to be applied at airports where passengers have preference for departing on peak times. (Çınar and Demirel, 2017) have presented a new approach to slot allocation based on calculating aircrafts' take off times. (Özdemir, Çetek and Usanmaz, 2018) have suggested building end-around taxiways network of the airside to reduce delays and congestions at busy airports.

Many analytical studies have been conducted, too (Madas and Zografos, 2006) have presented the instruments and strategies that had been used in airport slot allocation. In addition, (Ribeiro, Jacquillat, Antunes, Odoni and Pita, 2018) have presented an optimized approach for airport slot allocation under IATA guidelines. Finally, (Pellegrini, Bolic, Castelli and Pesenti, 2017) have presented a model for the simultaneous optimization of airport slot allocation.

Considering air space capacity, (Özdemir and Usanmaz, 2017) have investigated the impact of the air traffic route configurations on sector capacity. In addition, (Çeçen and Çetek, 2017) have analyzed the en-route airspace effect on air space capacity using genetic algorithms.

Over the last years, air traffic demand has grown in an exponential rate. The annual growth rate is believed to be 4.7-5.1% until 2030 (Çeçen and Çetek, 2017). In Turkey, air traffic has steadily increased by 15-20% annually since 2003 (Yıldırım, 2013). This increase has imposed many problems on both airport and airspace capacities utilization.

In order to tackle this problem, IATA (International Air Transport Association) and has regulated this business through regulating what is called "Slots". There are two different categories of slots; airport slots and airspace slots. Airport slot is defined as the permission to use the full range of an airport's infrastructure to perform aircraft arrivals or departures on a specific day and at a specific time (Ribeiro, Jacquillat, Antunes, Odoni and Pita, 2018). Airspace slot can also be defined as the permission to use a specific space of the earth's atmosphere to be used by an aircraft during a determined time and identified entry/exit points (Çınar and Demirel, 2017).

Airports/Airspace slots are allocated on a semi-annual basis through a meeting of slot coordinators at IATA's headquarter in Montreal, Canada (Daniel, 2014). Slots may be traded, returned, but never sold. Generally, there are four different types of slots rights; they are: Historic Slots; Change-To-Historic Slots; New Entrant Slots; and Remaining Slots (Ribeiro, Jacquillat, Antunes, Odoni and Pita, 2018).

- ✓ **Historic Slots –** They are the type of slots that are issued for a user if it operated the corresponding slot at least 80% of the times in the preceding equivalent season. This kind of slot has a 50% share of the slot market.
- ✓ **Change-To-Historic Slots –** There are two different types of them; CR and CL. The difference between the two types of change-to-historic requests is that, when an airline submits a CR code, it is willing to accept any slot between the requested and historic slot times whenever the requested slot is not available while, when an airline submits a CL code, it is only willing to accept the historic slot time when the requested slot is not available.
- ✓ **New Entrants Slots –** They are the type of slots that are issued to operators who will operate flights to new destinations. According to the IATA guidelines, after allocating historic slots and change-to-historic slots, 50% of the remaining slots must be allocated to new entrants, unless the number of requests from new entrants falls below that percentage.
- ✓ **Remaining Slots –** They are the kind of slots that do not lie in any of the previous types of slots.

2.1. Research Considering Airport Capacity

2.1.1. Slot Allocation Strategies

In order to tackle the problems arising from airport congestion, many strategies have been presented to deal with this matter. Here, a multi-strategy research that has focused on the operational objectives of slot allocation (Madas and Zografos, 2006) and a bottleneck pricing model of slots (Daniel, 2014) will be examined.

Madas and Zografos (2006) have presented alternative airport slot allocation strategies as candidate strategic options for practical implementation. The applies strategies have been identified as: 1) the *enhanced status quo* strategy; 2) the *gradual* strategy; 3) the *controlled trading* strategy; 4) a *congestion pricing* strategy; 5) the *big bang* strategy.

The *enhanced status quo* strategy maintains the overriding principle of historic slot holdings based on grandfather rights and the rationale of administrative coordination of slot allocation in conjunction with primary slot trading. The *gradual* strategy involves a conservative approach albeit with a clearer orientation towards market mechanisms and a slightly more drastic revision of the status quo. The *controlled trading* strategy essentially combines conservative and innovative elements in one strategy. The *congestion pricing* strategy represents a more direct use of fiscal instruments to address the mismatch of supply and demand for airport operations. The *big bang* strategy involves abandoning grandfather rights entirely.

Daniel (2014) have investigated the principle of slot pricing and auctioning on the slot allocation process. He has suggested that airports have to abandon all the "traditional" types of slot rights and admit a new system where slots are auctioned based on the congestion times. A bottleneck model has been developed to enable airports to choose the timing and quantity of their slot-constraint in order to minimize queuing-delay and early or late time costs.

Results have shown that this strategy would be able to decrease the congestion presented at major airports in case it was applied. However, this might adversely affect the airport social welfare especially in cases that there are long-term issued slots to loyal airlines.

2.1.2. Take-off Slots Approach

In order to maximize both the airports revenues and social welfare, some research has investigated the aircraft take-off slot allocation process. Here, a mathematical model to increase the slot allocation efficiency (Picard, Tampieri and Wan, 2018) and an alternative approach to allocate take-off slots (Çınar and Demirel, 2017) will be presented.

Picard, Tampieri and Wan (2018) have studied the impact of constrained available peak-time slot on the allocating process when passengers have preference to depart in peak times. They have investigated both private and public airports. An integer mathematical model based on the logical values of [0,1] with a cumulative distribution function was used to analyze the airline's market equilibrium and slot market to provide solutions to this problem.

It has been found that private airports have incentives to grant slots so that airlines competing in the same destination market fly in different time periods. They may also keep some peak slots unused in the destination markets with competing airlines. By contrast, monopoly airlines operating alone in an airport-pair market prefer to operate one flight to each destination. However, and for public airports, monopolies market patterns have to be followed in order to maximize an airport's social welfare.

Çınar and Demirel (2017) have presented an alternative Approach for Calculated Take Off Times ACTOT to make new departure time offers to the airline operators. This is to give a better solution for narrow airport capacity. Many strategies were made by the researchers in the form of different scenarios as a way to overcome this problem.

The applied methodology has provided many advantages to solve the congestion problem. It provides flexibility to pre-planned flights and slots. In addition, it leads steps which increase the existing capacity of landing fields. Moreover, it will be possible to add additional trips to influential take off airports for different companies that accept ACTOTs as chain reaction. Finally, it will increase the landing airport capacity. It will have a great importance in terms of charge policy of new flight plans.

2.1.3. Slot Allocation Optimization

In order to optimize the slot allocation process, many models have been made. Here, a novel multi-objective Priority- based Slot Allocation Model (PSAM) and an effective model for the Simultaneous Optimization of airport SloT Allocation (SOSTA) will be investigated.

The Priority- based Slot Allocation Model (PSAM) utilizes a model where all slots are allocated based on a determined level of priority. In addition, this model takes into consideration the IATA priority constraints -different types of slots-. An integer programming methodology was used to provide optimal slot allocation solutions at airports where demand is greater than their capacity (Ribeiro, Jacquillat, Antunes, Odoni and Pita, 2018).

The Priority-based Slot Allocation Model (PSAM) has resulted in that the capacity at the examined airports has never exceeded over the day after the slot allocation. In addition, there has been a significant reduction of slot displacements. Moreover, the distribution of average daily displacement has been reduced making schedule more accurate. Finally, the tail of the displacement distribution across slots has been reduced, thus alleviating the costs associated with the largest displacements.

Simultaneous Optimization of airport SloT Allocation (SOSTA) has been an integer linear programming model used to optimize the airport slot allocation process on the European scale. It also considers aircraft rotations through the turnaround time constraints, which is another novel contribution to the slot allocation process (Pellegrini, Bolic, Castelli and Pesenti, 2017).

Simultaneous Optimization of airport SloT Allocation (SOSTA) has resulted in significantly decreasing the number of missed allocations and displacement cost when capacity is reduced, maximum displacement is increased, or additional block time is also increased. In addition, it can assess the number of missed allocation and displacement cost when grandfather rights are either flexible or rigid. Moreover, it can estimate the total and maximum number of missed allocations for all different objective functions of the capacity reduction.

The Priority-based Slot Allocation Model (PSAM) has been found to minimize the displacement of the airlines' slot requests, while fully complying with the "primary criteria" of the IATA guidelines and with airport declared capacities. Simultaneous Optimization of airport SloT Allocation (SOSTA) has been found to decrease the number of missed slot allocations and cost displacement when airport capacity is decreased.

2.2. Research Considering Airspace Capacity

In this section, the literature of air space / sector capacity will be investigated. Some research has considered the air traffic route configuration on capacity (Özdemir and Usanmaz, 2017), However, others have considered the impact of increasing the entry/exit point on capacity (Çeçen and Çetek, 2017).

In their research, (Özdemir and Usanmaz, 2017), have investigated the impact that the modification of an air traffic route configuration might have on sector capacity. They have focused on the intersection angle that aircraft might have while passing a determined air route. They have also implemented different models where different types of aircrafts having different weights flying at different speeds might follow the same route. A fast time simulation was used in analyzing the different models and scenarios they have tested.

The simulation has shown that the increasing of intersection angle between air routes reduces the average delay time and sector occupancy, thus enhances capacity. Based on the investigated scenarios, the intersection angle of 60° of a route intersecting at three points provides much better results in terms of airspace efficiency and sector capacity.

In their research, (Çeçen and Çetek, 2017) have presented a multiple entry point assignment model based on a genetic algorithm to minimize delays and increase throughput of a generic high-altitude en-route sector. They have investigated a 1) Baseline Scenario of a Single Entry Point, 2) An Alternative Scenario 1 of Multiple Entry Points, and 3) An Alternative Scenario 2 of Multiple Input Points with Different Spacing.

2.3. Research Considering Airspace Capacity

2.3.1. Airport Congestion in Turkey

It has been admitted that Ataturk Airport of Istanbul has been classified as one of the most congested airports in Europe (Özdemir, Çetek and Usanmaz, 2018). This has always pushed the airport to its maximum capacity. To investigate Turkey's airports congestion problem, an airport master planning in Turkey have been presented by (Yıldırım, 2013).

Özdemir, Çetek and Usanmaz (2018) have suggested building both End-Around Taxiways "EAT" and Rapid-Exit Taxiways "RET" to overcome the congestion problem at Ataturk Airport. They have used a fast-time simulation and tested many scenarios through it.

It has been found that building an end around taxiway that is located at landing runaway's (23) section; EAT-1, can reduce the average delay time and taxi time by about 73% and 37%, respectively. However, building another runway that is located at landing runway's (05) section; EAT-2, reduces the average delay and taxi time by about 78% and 52%, respectively. It has been found that EAT-2 can provide better results compared to EAT-1 due to shorter taxi distance. Besides, it also improves the capacity by 1.43%.

It also has been found that building a rapid exit taxiway that is located at landing runaway's (23) section; RET-1, reduces average runway occupancy time by 10.6%. However, building a rapid exit taxiway that is located at the far end of the landing runway's (05) section; RET-2, on runway 05 has not made a significant change.

3. FINDINGS AND DISCUSSIONS

Considering the airport congestion problem, many studies have been made. Some researchers have applied analytical algorithms; in addition, others have used integer algorithms to find solutions to the issued problem using the available infrastructure of airports. Other researchers have suggested building new infrastructures to be used to tackle this problem (Çınar and Demirel, 2017), (Özdemir, Çetek, and Usanmaz, 2018), (Ribeiro, Jacquillat, Antunes, Odoni and Pita, 2018), and (Pellegrini, Bolic, Castelli and Pesenti, 2017). However, while investigating the literature of the airspace congestion studies, all of it is 5 concerned about changing the geometric shape of used airspace (Özdemir and Usanmaz, 2017) and (Çeçen and Çetek, 2017).

In the first scenario, it has been found that when an increasing percentage of wide-body aircrafts exceeds the critical value of (60%), they get a higher probability of the initial separation distance between them, thus the throughput increases by 4-6%. However, in the second scenario, the throughput has been increased by 10% compared to base line scenario leading to less average delays than the single entry point scenario. Moreover, in the third scenario, the average delays were nearly educed to half compared to the baseline scenario. See table-1 for a summary of the methodologies followed, suggestions, and results.

Table 1: A Comparison of the Different Approaches and Methodologies of Airport / Airspace Slot Allocations

<table>
<tr><th>Res. Area</th><th>Slot Category</th><th>Researchers</th><th>Approach</th><th>Methodology</th><th>Results</th></tr>
<tr><td rowspan="6">Airport Capacity</td><td rowspan="2">Slot Allocation Strategies</td><td>Madas and Zografos (2006)</td><td>Operational Objectives of Slot Allocations</td><td>Alternative Airport Slot Allocation Strategies</td><td rowspan="2">Decreased Congestion at Major Airports around the World</td></tr>
<tr><td>Daniel (2014)</td><td>Pricing and Auctioning on Slot Allocation Process</td><td>Bottleneck Pricing Model of Slots</td></tr>
<tr><td rowspan="2">Take-Off Slots Approach</td><td>Picard, Tampieri and Wan (2018)</td><td>Constrained Available Peak-Time Slot Allocation</td><td rowspan="2">An Integer Mathematical Logical Model</td><td>Increased Number of Slot Allocation at Only Private Airports</td></tr>
<tr><td>Çınar and Demirel (2017)</td><td>Approach for Calculated Take-Off Times (ACTOT)</td><td>Increased Landing Capacity</td></tr>
<tr><td rowspan="2">Slot Allocation Optimization</td><td>Ribeiro, Jacquelin, Antunes, Odone and Pita (2018)</td><td>Priority- Based Slot Allocation Model (PSAM)</td><td rowspan="2">An Integer Programming Methodology</td><td>Significant Reduction of Slot Displacements and Reduced Distribution of Average Daily Displacement</td></tr>
<tr><td>Pellegrini, Bolic, Castelli and Pesenti (2017)</td><td>Simultaneous Optimization of Airport Slot Allocation (SOSTA)</td><td>Significant Decreased of No. of Missed Allocations and Displacement Cost</td></tr>
<tr><td rowspan="2">Airspace Capacity</td><td>Air Traffic Route Configuration</td><td>Özdemir And Usanmaz (2017)</td><td>Modification of Configuration of Air Traffic Route</td><td rowspan="2">A Fast-Time Simulation</td><td>Reduced Average Delay Time and Sector Occupancy</td></tr>
<tr><td>Entry/Exit Points of Air Traffic Route</td><td>Çeçen And Çetek (2017)</td><td>Multiple Entry Point Assignment Model</td><td>Less Average Delays</td></tr>
<tr><td rowspan="2">Airport Amendment</td><td>End-Around Taxiway (EAT)</td><td rowspan="2">Özdemir, Çetek And Usanmaz (2018)</td><td>End-Around Taxiway (EAT)</td><td rowspan="2">A Fast-Time Simulation</td><td>Reduced Average Delay Time and Taxi Time</td></tr>
<tr><td>Rapid-Exit Taxiway (RET)</td><td>Rapid-Exit Taxiway (Ret)</td><td>Reduces Average Runway Occupancy</td></tr>
</table>

4. CONCLUSION

In this article, the congestion problem of both airports and airspace has been investigated. It has been shown that airports / airspace have been exposed to many approaches to overcome this problem.

A review of the literature on slot allocation has been made through this article. The different methodologies, algorithms, approaches and their results were investigated. In addition, the airport congestion issue at Turkey's biggest airports was also look into. Moreover, a comprehensive comparison of all presented approaches was made.

It has been shown that adopting different slot allocation strategies considering the operational objectives and pricing and auctioning on slot allocations have decreased airport congestion at major airports around the world. In addition, using new approaches to take-off slot allocations have resulted in increased number of allocated slots specially the landing ones. Moreover, choosing to optimize slot allocations have resulted in significant of slot displacement and decreased number of slot allocations.

Airspace congestion problem has been tackled in this article, too. It has been shown that modifying air traffic route configuration in addition to increasing the number of entry / exit points of air traffic routes have significantly reduced average delay time and sector occupancy.

Finally, it has been shown that building End-Around Taxiways (EAT) and Rapid-Exit Taxiways (RET) at Ataturk Airport of Istanbul would significantly reduce average delay time, taxi time, and runway occupancy.

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