International Journal of Applied Mathematics, Electronics and Computers 9(3): 043-051, 2021

e-ISSN: 2147-8228

INTERNATIONAL JOURNAL OF APPLIED MATHEMATICS ELECTRONICS AND COMPUTERS

www.dergipark.org.tr/ijamec

International Open Access

Volume 09
Issue 03

September, 2021

Research Article

Departure Passenger Flow Simulation: Case Study on Izmir Adnan Menderes Airport Pre and Post COVID-19

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ARTICLE INFO

Article history:
Received 27 April 2021
Accepted 13 September 2021

Keywords:
Arrival pattern,
Covid-19 effect,
Crowd analysis,
Passenger flow,
Passenger density,
Simulation,

ABSTRACT

The flow of departing passengers from the airport inside the terminal is affected by strategic and tactical decisions of airport operation teams. The decisions made by the managers regarding opening and closing times of check-in, boarding, and gates are critical to optimize the performance of the terminal operation. In this research, Izmir Adnan Menderes Airport was taken as a use case.

Departure terminal building of check-in, security control, and boarding gates was taken as the focus entities.

The simulation passenger input data were produced for check-in, security, and boarding gates using different distribution probability methodologies to match the actual data. Three days of data (300 flights, 3 thousand passengers) has been derived with the help of a custom generator. A unique simulation tool called Departure Passenger Flow Simulator (DPFs) has been developed for research. Due to manage passenger flow pre and post COVID-19, the opening and closing times of assets (check-in and gates) were simulated in 6 iterations in DPFs in 3 different scenarios. As a result of the research, it was understood that the resources for Izmir Adnan Menderes Airport were sufficient, considering the COVID-19 measures published by the European Aviation Safety Agency (EASA) and the General Directorate of Civil Aviation.

1. Introduction

Capacity can generally be defined as a measure of flow or system capability and many factors are taken into account in the calculation of airport capacity at service level. Some of these are airline strategy, traffic estimates and preliminary forecasts, planning of peak demand and planning charts, etc. These calculations are essential for airport facility requirements and service level assessments, balancing capacity, and evaluating airport concepts [1]. Determining airport capacity is also vital in terms of design, land use planning, and master planning.

Airport terminal buildings are very complex systems. There are two airline passenger flows in the terminal buildings: departure passenger flow and arrival passenger flow. The time passengers spend in the check-in queue during the departure process constitutes 61% of the total departure travel time [2]. The time spent for security checks, boarding and other procedures also constitutes 39% of the total departure travel time.

In the airport terminal design, the passenger flow volume is determined by considering the various characteristics of the users (passengers to be processed). Designing by considering the service level in passenger flows is one of the essential elements. Passenger flow forecasts are vital to optimizing the performance of the terminal operation, as they will affect the strategic and tactical planning of terminal capacity.

A passenger terminal capacity and service level survey typically includes the following systems: [1],

- Check-in,
- Passport control,

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DOI: 10.18100/ijamec.928696

- Security control,
- Other departure facilities, including doors and waiting rooms.
- Arrival facilities including immigration, customs, baggage collection, and a farewell/greeters lounge.
- Transit and transfer facilities.
- Air bridge and open parking position ground handling operations.
- Baggage handling operations.
- Vaccine control procedures can also be done in the future
- Test of Covid-19 procedures.
- Others.

When passengers arrive at the terminal building for a departure or arrival, a massive human wave is created into the subsystems. As long as the arrival rate of passengers does not exceed the dynamic capacity of the various elements, there will be a minimal delay and queuing. However, bottlenecks and disruptions occur when the crowd is systematically more than sustainable capacity. In this case, the complex dynamic overflow (saturation) interaction computation cannot be calculated only with mathematical models. Saturation points are reflected as closely as possible by predictive tools such as simulation. In addition, problems experienced at other airports may also contribute to this calculation.

Airport passenger flow processes have been reshaped due to the social distance and hygiene rules implemented within the scope of combating the Covid-19 epidemic that emerged at the beginning of 2020. Many airports worldwide have adopted different practices, and the time spent by the passengers in the airport has been prolonged. There have been unforeseen changes in the flow rate and density of passengers in the terminal buildings.

In this research, designed data sets are used to simulate passenger flow in departing passenger terminal buildings. Data that will form iterations with different distribution methods for passenger flow simulations are presented in the research. Within the scope of the research, the change in passenger flow pre and post Covid-19 was analyzed with the simulation model created for Izmir Adnan Menderes Airport. To manage the pre-post COVID-19 passenger flow, the opening and closing times of assets (counters and gates) were simulated with different scenarios. The motivation of this research is to organize passenger flows in the operation of airport terminals according to different scenarios. The results obtained show passenger flow fluctuations according to different statistical distribution methods in today's social distance rules. The contribution of the results of the article to the literature and also to the aviation industry can be to prevent idle capacity, develop operational techniques, ensure biosecurity and reduce costs by airport terminal operators.

2. Literature Review

2.1. Check-in

Check-in is the process of taking the baggage and preparing the boarding pass for the passengers with flight tickets to be admitted to the flight under the determined rules. There are studies with optimization and simulation and hybrid studies that use both approaches for the check-in process in the literature.

In one of the studies that Takakuwa ve Oyama (2003) simulated the international departure passenger flow, it was observed that the passengers spent 25% of the time they spend at the airports while waiting, and 80% of this waiting time occurred at check-in counters [3].

Joustra and Dijk (2001) developed a case study and simulation approach for Schiphol airport to show why simulation is necessary to evaluate check-in operations and simulate check-in counters. With the research, suggestions were made regarding the growth capacity in Schiphol [4].

Chun and Mak (1999) developed an intelligent resource simulation system (IRSS) to estimate the resource requirements of an international airport [5]. They obtained the data by entering the statistical check-in information they obtained into this system, and later made it easier to decide on the most appropriate counter number and when to open with the check-in counter assignment system (CCAS) they developed. They have observed that up to 40% of the resources are saved thanks to the systems used.

Another research is a linear mathematical model proposal for the correct use of resources in traditional check-in services. The model developed by Bruno et al. (2019) was established to minimize the waiting time depending on the incoming flight and aircraft capacity [6]. As a result of the implementation of the model, the service levels of the check-in counters were prevented from remaining idle, and the most appropriate personnel programming was provided.

Galanda et al. (2019) developed a simulation model to determine the number of check-in desks at the airport. To simulate the airport check-in process, they evaluated the software and made their applications with the help of a simulation package software [7]. The time spent by the passengers during the check-in period was obtained from a manufacturer they created via programming.

Rolim et al. (2020) studied operating procedures and how demand growth affects the level of check-in service [8]. São Paulo/Guarulhos airport developed 273 scenarios for international departures check-in desks. As a result of the study, they found that the most important factors are the counter processing time, the number of counters per airline, self-service technologies, and the opening time of the check-in desks, respectively.

2.2. Security Check

The purpose of security measures at an airport is to determine whether there is a prohibited item on passengers and staff or in baggage and prevent illegal activities [9]. In the past two decades, aviation security has become a high priority of national interest and concern. The September 11 events led to many fundamental operational and aviation security policies at all commercial airports [10]. Skorupski ve Uchronski (2016) stated that the transportation systems, which are considered critical infrastructure parts, are constantly at risk of terrorist attacks and that although the airport terminals are well protected, they are a frequent target for these attacks [11]. The development of the civil aviation network has made air transport the primary target for terrorist activities [12].

Airports are required to take necessary security measures within the framework of ICAO and ECAC rules. Security guards must adequately inspect restricted parts of passengers and public areas to protect against illegal activities. The large and too many of physical areas to be protected affect the flow of passengers within the terminal and may cause congestion from time to time [13]. Also, planning and sustaining of the passenger security control is very costly for terminal operations. Other disadvantages are the density at the control points and the delays caused by the queues [14].

Pendergraft et al. (2004) mentioned the necessity of a sufficient number of personnel and control point equipment such as X-ray devices to carry out standard procedures at control points to prevent density and malfunctions [15]. He stated that the intensity of the busiest times and the importance of the additional staff required to distribute the queue, and the waiting time at the check-in counters affect the time and waiting time at the security checkpoints.

2.3. Boarding

Boarding refers to the final check made before boarding the plane. Sometimes before the plane's departure time, the passengers take turns passing through the final checkpoint and board the plane after being directed by the attendant.

Bachmat et al. (2009) modeled the boarding process and performed boarding analysis. As a result of the model, they developed an estimation for the boarding process. They used a method based on discrete event simulations in their calculations [16]

Notomista et al. (2016) developed a fast boarding strategy using online seat assignment based on passenger classification in their research onboarding processes. Using optical sensors, they obtained sample data for their calculations by assigning each person a measure of agility and a measure to characterize the size of hand luggage. They prepared comprehensive simulations with the data obtained. As a result of the research, they achieved an average speed increase of approximately 15% with the strategy they developed [17]. Another study, calibrated using video data obtained from the observations of eight thousand passengers at Zurich airport, was conducted by Steiner and Philipp (2009). In the research, the effects of various factors onboarding times were investigated. Based on the results of the simulations, it was determined that it was possible to speed up 4 minutes the process of the pre-boarding area with less hand luggage and reduce the boarding time strategy [18].

2.4. COVID-19 Precautions in Air Transport

The Covid 19 virus, which emerged in Wuhan, China and spread all over the world, had a very negative impact on the air transport industry in 2020.There was a 50% decrease in the number of seats offered by airlines, 60% in the number of passengers, and a loss of 371 billion dollars in airline revenues in 2020, compared to 2019 [19]. There was a 45 % decrease in the number of flights, 58% in overflight, 50.5% in the number of domestic passengers, 70.5% in the number of international passengers in Turkey in the same period [20]. It is stated that the improvement in the aviation sector will be in the second quarter of 2021 in Europe and will be in the third quarter with an upward trend [19].

The COVID-19 process has led to the design of previously unprecedented flow processes in the airport and terminal operations as passenger numbers decrease. It can be said that COVID-19 disease poses more significant risks in busy centers such as airport terminals. Therefore, the International Civil Aviation Organization (ICAO) has taken the most severe measures since the September 11 attacks with the DOC 10144 publication [21]. Kierzkowski ve Kisiel (2020) pointed out that the social distance between people should be maintained due to the pandemic and stated that this situation caused a density at the airport security checkpoint and that the performance decreased dramatically [22]. Different configurations were developed to ensure passenger flow on the security checkpoint road, and the possible delays and precautions were shown with simulations.

Directorate General of Civil Aviation (DGCA) in Turkey, Airport Pandemic Measures and Certification Circular issued under the name of some measures. Some restrictions have been placed on accepting cabin baggage, such as at the check-in stage. Passengers had to hand their cabin baggage under the plane instead of taking them with them. In the past simulation studies, it has been predicted that obstructions may occur at airports due to overload in luggage systems caused by density [23].

2.5. Simulation Input Probability Distribution Methods

Determining input probability distributions in simulations is one of the critical stages of the study.

Incorrect assumptions such as selecting the wrong distribution in the inputs prevent the intended output from the simulation model. Essential steps in determining the input distributions are a collection of data, selection of distribution family, parameter usage and, eligibility [24]. Discrete probability distributions in simulation studies can be listed as Bernoulli distribution, discrete uniform distribution, binomial distribution, etc. [25].

The discrete uniform distribution itself is not parametric. However, it is convenient to represent their values in general by all integers in a range [a, b] so that a and b become the main parameters of the distribution (usually the interval [1, n] with a single parameter n). With these rules, the cumulative distribution function (CDF) of the discrete uniform can be expressed for any k ∈ [a, b] [26].

Considering the biosafty expectations, the regulation of passenger flows within the terminal will protect passengers against biological risks (especially COVID-19). However, social distancing can cause fluctuations in passenger flows. This means that passenger waiting queues at airports will use different statistical distributions than usual.

3. Methodology

Simulation is the process of creating a model that can illustrate the system. This modeling can be performed through operations that require very costly and time [27].

The use case covered by the simulation study were selected as Izmir Adnan Menderes Airport in Turkey. The assets of this airport are:

- Number of Domestic Counters: 67
- Domestic Gate Number: 14
- Number of International Counters: 66
- Number of International Gate Gates: 17
- Number of Transit Counters: 4
- Number of VIP Counters: 2
- Number of CIP Counters: 4
- CIP Gate Number: 2

Izmir Adnan Menderes airport selected for the case study manages the passenger flow under the passenger flow procedures "Airport Pandemic Measures and Certification Circular" during the COVID-19 period. It has also ensured compliance with the measures about the social distance determined by EASA at the airport. Seating area of the Domestic Terminal building of the Izmir Adnan Menderes Airport is 63,210,46 m2, total area of the terminal building is 203,279 m2, with a capacity of 20 million passengers/year [28]. The International Terminal building of the Izmir Adnan Menderes Airport has a seating area of 33,648.50 m2 and a total area of 107,699 m2 with a capacity of 10 million passengers/year [28].

The random entries of the time between arrivals during the passengers' check-in, security control, and boarding stages were evaluated with a hypothetical methodology.

A specially developed simulation tool Departure Passenger Flow Simulator (DPFs), is used. Within the scope of the simulation, 300 flights and 30 thousand passenger scenarios were studied in 3 days.

Simulation data were generated using IATA Code parameters. In addition to IATA data, Flight Number and Destination Airport data were used as input data in all simulation stages.

Although the data generated for input for simulation is created with an artificially designed generator, it is designed to be tightly compatible with actual data. Izmir airport technical specifications such as walking distance between counters, number of counters, and number of gates are considered. Scenarios were created by considering aviation rules in simulation design. The opening and closing times of Check-in counters and gates were manipulated to understand how to manage passenger flow before and after COVID-19.

4. Findings and Analysis

4.1. Simulation Model Definitions

The passenger flow simulation models are generated within this study are built on the actual event formats of CUPPS, TDAS, and AODB systems. As seen in Figure-1, passengers are subjected to controls or processes at counters, border control points, and gates until they get on the plane.

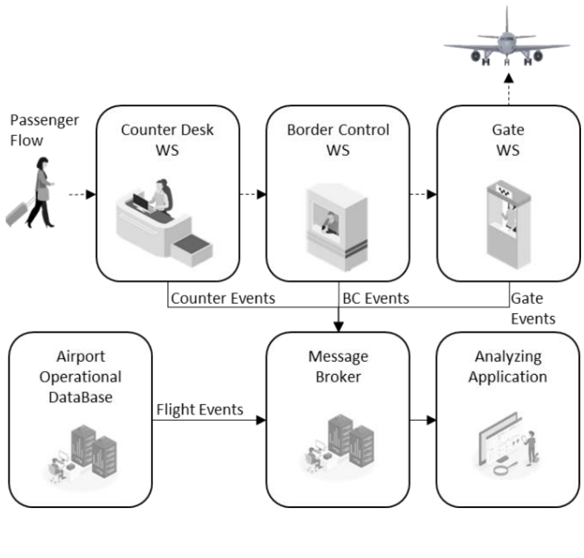


Figure 1 – Passenger and event flows

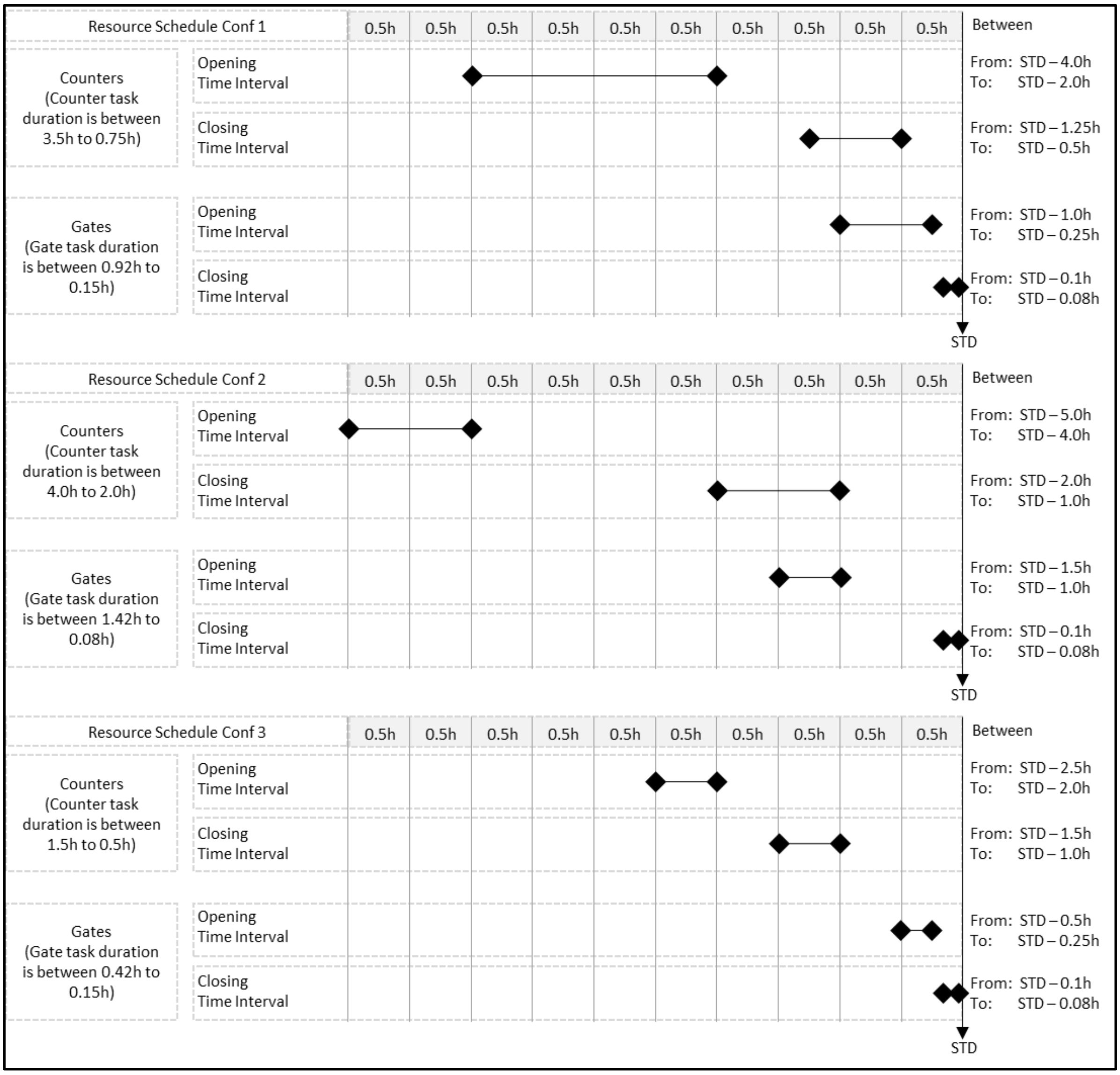
Passengers could be categorized into four different profiles in terms of the counter processes according to their luggage and boarding pass code existence. Passengers who do not have luggage and have created the boarding passcode with the mobile application usually proceed directly to the border control point without visiting the counters. However, passengers with luggage/s need to stop at the counters to deliver their luggage even if they have a boarding passcode printed by mobile application. This study's simulation models generate approximately equal numbers of passengers in these four profiles using even distribution. So, almost 25% of the passengers proceed to border control without ever visiting counters. Thus, the landside passenger counts do not include passengers with this profile in the following figures. The model produces the following events for passenger's processed by counters:

- Boarding pass printed
- Bag tag printed

At border control and gate points, the processes are different from the counters, and all passengers must pass through these points. The model produces the following events for passengers' processed by border control desks and gates:

- Passenger passed from the border control desk
- Passenger passed from the gate control desk

Figure 2 – Counter and gate opening/closing schedule configurations



Final events produced by the model are STD (Scheduled Time of Departure), ETD (Estimated Time of Departure), ATOT (Actual Take Off Time), Counter Opened, Counter Closed, Gate Opened, Gate Closed events. In actual operation, these events are generated by the AODB system.

Check-In Sequence Number was generated and used as a unique identifier, as recommended by IATA, to identify assengers in all events produced for different workstations. With this parameter, individual passenger flow tracking inside the terminal without a personal data breach became possible. Also, to track the uniqueness of the flights, Date of Flight, Carrier Airline, Flight Number + Suffix, Destination Airport IATA Code parameters were generated and used in all events. Although the built system outputs are simulation data, all model outputs are strictly compatible with the actual data and not prevented by any airport procedure.

4.2. Test Definitions

All tests carried out with the simulation model developed within the study's scope were carried out by randomly generated 300 flights and 30 thousand passengers within three days. As seen in Table 1, normal distribution was used in the first three tests by defining 12:00 as the Mean and with a 3-hour standard deviation, and even distribution was used in the last three tests within the 08:00 – 21:00 interval for the distribution of flight departure times over the three-day interval. Also, resource scheduling configurations shared in Figure 2 are used for counter and gate opening/closing time definitions for each flight in the tests.

Table 1. Test Configurations

Test ID	Flight Schedule	Resource Schedule
1	Normal Dist.	Conf 1
2	Normal Dist.	Conf 2
3	Normal Dist.	Conf 3
4	Even Dist.	Conf 1
5	Even Dist.	Conf 2
6	Even Dist.	Conf 3

The simulation model has generated randomly opening and closing times for counters and gates according to the intervals defined in Figure 2 by using even distribution.

T distribution is used for defining passenger’s arrivals randomly to the counters and border controls in defined resource schedule intervals. For defining passenger gate arrivals, even distribution is used, taking into account the border control events and the gate's schedule.

4.3. Test Results and Findings

As indicated in Table 2, in test number 1, 300 flights were randomly placed on the 3-day calendar with defined normal distribution parameters. Later, 30 thousand passengers were produced for these flights and assigned to these flights, and flow simulation was run.

Test 1, in which the gate and counter schedules are set according to the Resource Schedule Conf 1, and the STD of flights are defined according to the normal distribution, are shared in Figure 3. When the results are examined, it is seen that the number of passengers on the landside can reach up to 1330, and the number of passengers on the airside can reach up to 670 at the pick hours. The number of passengers arriving at counters, gates, and border control desks within 5 minutes intervals can reach up orderly to 131, 210, and 186. Dwell times spent by the passengers on the air and landside is examined. It is seen that they stay with an average of 61 minutes on the land and 18 minutes on the airside.

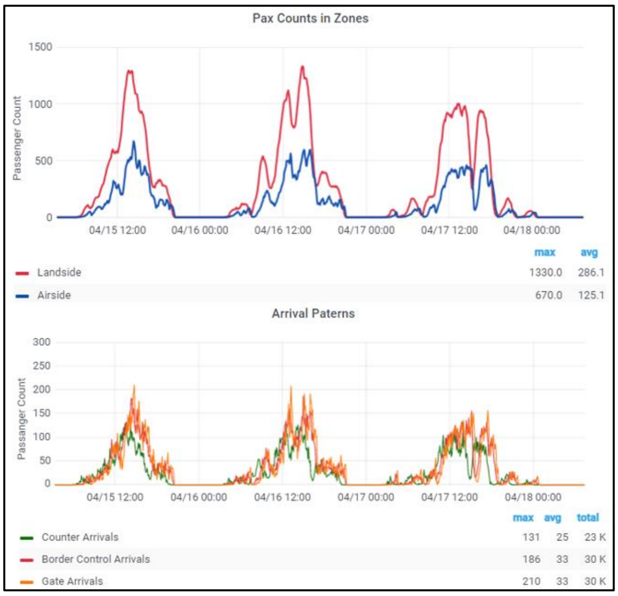


Figure 3 – Results of Test 1 (STD of flights with Normal dist., resource schedule conf 1)

Test 2, in which the gate and counter schedules are set according to the Resource Schedule Conf 2, and the STD of flights are defined according to the normal distribution, are shared in Figure 4. When the results are examined, it is seen that the number of passengers on the landside can reach up to 1628, and the number of passengers on the airside can reach up to 759 at the pick hours. The number of passengers arriving at counters, gates, and border control desks within 5 minutes intervals can reach up orderly to 109, 156, 139. Dwell times spent by the passengers on the air and landside is examined. It is seen that they stay with an average of 92 minutes on the land and 26 minutes on the airside.

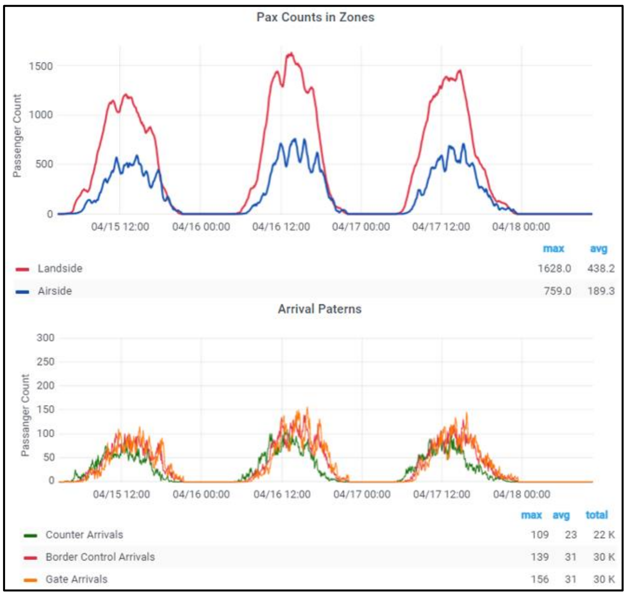


Figure 4 – Results of Test 2 (STD of flights with Normal dist., resource schedule conf 2)

Results of Test 3, in which the gate and counter schedules are set according to the Resource Schedule Conf 3 and the STD of flights are defined according to the normal distribution, are shared in Figure 5. When the results are examined, it is seen that the number of passengers on the landside can reach up to 1327, and the number of passengers on the airside can reach up to 613 at the pick hours. The number of passengers arriving at counters, gates, and border control desks within 5 minutes intervals can reach up orderly to 157, 205, 190. Dwell times spent by the passengers on the air and landside is examined. It is seen that they stay with an average of 55 minutes on the land and 22 minutes on the airside.

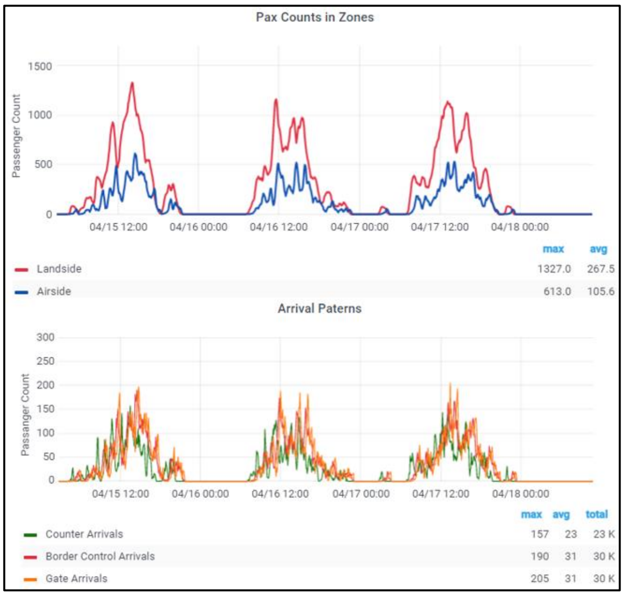


Figure 5 – Result of Test 3 (STD of flights with Normal dist., resource schedule conf 3)

If the first three tests are analyzed together from the perspective of the Covid-19 fight, it is seen that no configuration reduces the number of people on the air and land sides, at counters, gates, and border control points in all directions. However, the density of counter and border control becomes more critical since the people on the air and land sides will be scattered in large areas, and the processing at the gates will proceed faster than other points. Therefore, it is seen that Resource Schedule Configuration 2 could minimize the queues in the processing points. Of course, in this case, the airport flight and passenger capacity will be less than in other configurations.

Results of Test 4, in which the gate and counter schedules are set according to the Resource Schedule Conf 1 and the STD of flights are defined according to the even distribution, are shared in Figure 6. When the results are examined, it is seen that the number of passengers on the landside can reach up to 1113, and the number of passengers on the airside can reach up to 500 at the pick hours. The number of passengers arriving at counters, gates, and border control desks within 5 minutes intervals can reach up orderly to 113, 163, 151. Dwell times spent by the passengers on the air and landside are examined, and results are seen precisely with Test 1. When Test 1 and Test 4 are examined together, it is seen that if flights are placed on the calendar with even distribution instead of normal distribution, there is a 16% decrease in the maximum number of passengers on the air and landside and a 19% decrease in resource arrivals.

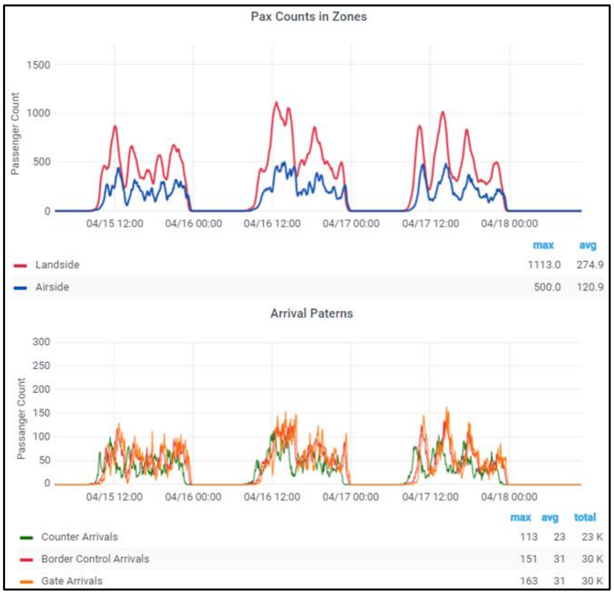


Figure 6 – Results of Test 4 (STD of flights with Even dist., resource schedule conf 1)

Results of Test 5, in which the gate and counter schedules are set according to the Resource Schedule Conf 2 and the STD of flights are defined according to the even distribution, are shared in Figure 7. When the results are examined, it is seen that the number of passengers on the landside can reach up to 1429, and the number of passengers on the airside can reach up to 682 at the pick hours. The number of passengers arriving at counters, gates, and border control desks within 5 minutes intervals can reach up orderly to 94, 144, 123. Dwell times spent by the passengers on the air and landside are examined, and results are seen precisely with Test 2. When Test 2 and Test 5 are examined together, it is seen that if flights are placed on the calendar with even distribution instead of normal distribution, there is a 12% decrease in the maximum number of passengers on the air and landside and an 11% decrease in resource arrivals. When evaluated with the previous pair of tests, the positive effect of using even distribution in flight schedules decreases as the resource task duration increases.

Figure 7 – Results of Test 5 (STD of flights with Even dist., resource schedule conf 2)

Figure 8 – Results of Test 6 (STD of flights with Even dist., resource schedule conf 3)

Test 6, in which the gate and counter schedules are set according to the Resource Schedule Conf 3, and the STD of flights are defined according to the even distribution, are shared in Figure 8. When the results are examined, it is seen that the number of passengers on the landside can reach up to 1231, and the number of passengers on the airside can reach up to 510 at the pick hours. The number of passengers arriving at counters, gates, and border control desks within 5 minutes intervals can reach up orderly to 175, 169, 161. Dwell times spent by the passengers on the air and landside are examined, and results are seen precisely with Test 3. When Test 3 and Test 6 are examined together, it is seen that if flights are placed on the calendar with even distribution instead of normal distribution, there is an 11% decrease in the maximum number of passengers on the air and landside and a 9% decrease in resource arrivals.

When all test results are examined together, even distribution of flight schedules gives successful results in all Resource Schedule Configurations, increasing the counters and gates open times. Moreover, increasing the open time durations of counters and gates also decreases the density at the points where people stand closest. Another advantage of this configuration is that it increases the time passengers spend at the airport and in-airport shopping.

5. Conclusions

A specially developed simulation tool DPFs was used in the study. Simulation studies samples was taken at Izmir Adnan Menderes Airport. In the research, data that will create iterations for DPFs with different distribution methods are presented. The change in the departure flow in the terminal building before and after Covid-19 was analyzed with data. During check-in, security, and boarding, the time spent by passengers was produced following the original using generator programming. The passengers' departure process duration was examined in 6 scenarios, with the total departure and travel time before and after COVID-19. Thus, system saturation points were determined.

Three configurations were examined together at Izmir Adnan Menderes Airport from the perspective of pre and post Covid-19. While the number of resources was kept constant, the usage timelines of the resources were manipulated. It is seen that the data obtained does not reduce the service configuration of the existing assets on the air and land sides.

The study understood that the passengers would be spread over Izmir Adnan Menderes Airport departure terminal, which in the check-in and restricted areas (after the passport control point) on the land side, and the operations at the gates could proceed faster.

It is recommended to investigate the arrival terminal flow for further simulation research. It is predicted that baggage purchase and border control of the arriving passengers will become more critical due to the intensity of the area measurement limitation because of the rule of the social distance. In addition, the using of unmanned service processes and technologies at airports will contribute to the increasing in the departure passenger flow rate.

Acknowledgment

This work is supported by the Research, Development and Innovation Department of TAV Technologies and Faculty of Aeronautics and Astronautics of Eskişehir Technical University. Savaş Selahattin Ateş, Gökhan Koç, and Talha Koç worked together in the literature research, determination of the methods, building test scenarios, and analysis of the results of the work. Also, Gökhan Koç and Mustafa Bolat worked together to develop Departure Passenger Flow Simulator under the defined requirements. The baseline data of this research were presented at the 24th ATRS World Conference. The research was supported by 20ADP193 numbered Eskisehir Technical University Scientific Research Support Project.

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