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SIMULATION OF PASSENGER PROCESS IN AIRPORT TERMINAL

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SIMULATION OF PASSENGER PROCESS IN AIRPORT TERMINAL

A thesis submitted by Reyhan Pınar PARKAN in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** is approved by the committee on 21.12.2017 in Department of Industrial Engineering, Industrial Engineering Program.

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Reyhan Pınar PARKAN

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LIST OF ABBREVIATIONS

DHMI	General Directorate of State Airports Authority
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
LoS	Level of Service
TA	Turkish Airlines

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ABSTRACT

SIMULATION OF PASSENGER PROCESS IN AIRPORT TERMINAL

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MSc. Thesis

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One of the transport subsystems, air transport, is in intense competition. The demand for fast, reliable and time-saving air transport continues to increase day by day. The increase in the number of passengers carried by airlines requires that airports servicing these passengers work on criteria affecting the quality of service. Punctuality and reliability are at the top of the criteria for determining the quality of a transport subsystem. The ability to maintain these criteria at the desired level can also be provided by an effective passenger flow during terminal processes.

In this study, it is aimed to examine the passenger processes at Istanbul Atatürk Airport Terminal, which is the hub of Turkey's leading airline, using a simulation model. Thus, service quality will be determined by investigated the source of bottlenecks and customer satisfaction will be tried to be increased. For this purpose, all flows related to local and transfer passengers are modeled and data is collected and scenarios are generated and integrated into the simulation program. Looking at the results, it is clear that the importance of transfer process flows is better understood with the increase of Turkish Airlines' number of transfer passengers. After validation of model, improvement proposals are made in processes where problems occur by using simulation models.

As a result, bottlenecks have been identified and favorable solutions have been achieved in airport terminals. In addition to this, this work will provide an insight on taking precautions correctly by using it as an important decision support system that will reduce the potential passengers for the developing airlines and airports.

Key words: Airport terminal, airline, simulation, modelling

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ÖZET

HAVAALANI TERMİNALİNDE YOLCU SÜRECİ SİMÜLASYONU

Reyhan Pınar PARKAN

Endüstri Mühendisliği Anabilim Dalı

Yüksek Lisans Tezi

Tez Danışmanı: Yrd.Doç.Dr. Vildan ÖZKIR

Ulaştırma alt sistemlerinden biri olan havayolu taşımacılığı yoğun bir rekabet halinde bulunmaktadır. Hızlı, güvenilir ve zaman tasarrufu sağlayan havayolu taşımacılığına olan talep her geçen gün artarak devam etmektedir. Havayollarının taşıdıkları yolcu sayılarındaki artış bu yolculara hizmet sağlayan havalimanlarının hizmet kalitelerini etkileyen ölçütler üzerinde çalışmalarını gerektirmektedir. Dakiklik ve güvenilirlik bir ulaştırma alt sisteminin kalitesini belirleyen ölçütlerin başında gelmektedir. Bu ölçütlerin istenilen seviyede tutulabilmesi de terminal süreçlerinde etkin bir yolcu akışı ile sağlanabilir.

Bu çalışmada, Türkiye’nin lider havayolunun hub olarak kullandığı İstanbul Atatürk Havalimanı’nda terminalindeki yolcu süreçlerinin simülasyon modeliyle incelenmesi amaçlanmıştır. Böylece darboğazların kaynağı belirlenerek hizmet kaliteleri belirlenecek ve müşteri memnuniyeti arttırılmaya çalışılacaktır. Bu amaçla, lokal ve transfer yolcularla ilgili tüm akışlar modellenerek veriler toplanmış ve senaryolar üretilerek simülasyon programına entegre edilmiştir. Sonuçlara bakıldığında, Türk Hava Yolları'nın transfer yolcu sayılarının artışıyla birlikte transfer süreç akışlarının önemi daha iyi anlaşılmıştır. Çalıştırılan modelin doğruluğu ve geçerliliği onaylandıktan sonra problemlerin oluştuğu süreçlerde simülasyon modelleri kullanılarak iyileştirme önerileri yapılmıştır.

Sonuç olarak, havalimanlarında terminal süreçlerinde darboğazların belirlenip uygun çözüme gidilmesi sağlanmıştır. Bununla birlikte çalışma; gelişen havayollarında ve havalimanlarında, potansiyel yolcular için olası beklemelerin azalmasını sağlayacak, önlemlerin alınması ve öngörülerin doğru bir şekilde yapılması adına ışık tutacaktır.

Anahtar Kelimeler: Havalimanı, havayolu, yolcu, terminal, simülasyon, modelleme

YILDIZ TEKNİK ÜNİVERSİTESİ FEN BİLİMLERİ ENSTİTÜSÜ

CHAPTER 1

INTRODUCTION

In today's society, transportation is perceived as a necessity rather than a desire to go to a desired place as soon as possible. Since the community has a fast-paced lifestyle, the use of air transport is becoming more preferred option day by day. Air transport enables passengers to travel around the world in a shorter time and provides a more secure, intensive and faster process than other types of transportation does. The development in air transport capability of a region produces an economic, political and social progress around the region. Increasing available physical (air) connections fosters the interactions between economies.

Airports, along with rapid transport, provide significant contributions to the development of regional and international economies. The development of relations between countries during the globalization period and the rise of airport services will be more important in the future. Therefore, airport terminals aim to increase the quality of service and require to expand the capacity to support expanding volume of passengers.

Airports provide service to airplanes and passengers on a national/ international scale. According to the traffic patterns, airports can be classified into two groups: Point-to-Point and Hub Airports. Point-to-point airports provide flights between the origin and destination to the point-to-point passengers, where hub airports also serve transfer passengers with coordinated flights in a bank structure. Therefore, design factors for hub airports are more inclusive, regarding the number and location of terminals, flow of passengers and baggages.

According to World Bank Data, air passengers carried including both domestic and international aircraft passengers is exponentially increasing by years, as shown in Figure 1.1 [1].

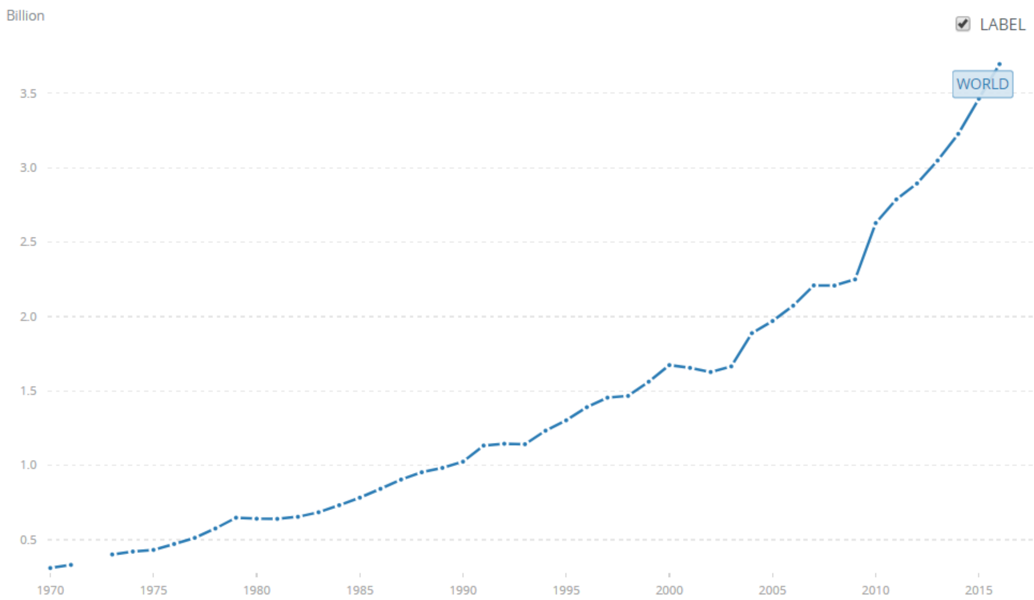

Figure 1.1 The Total Number of Air Passengers by Years –World Data

According ICAO's annual global statistics, the total number of passengers carried on scheduled services rose to 3.5 billion in 2015, which is 6.8 per cent higher than the previous year, while the number of departures reached 34 million in 2015, 2.6 per cent increase compared to 2014 [2]. The total number of air passengers is expected to reach 7.3 billion passengers by 2034 [3].

The Air Passenger Forecast Service is the most comprehensive set of projections on how the airline industry will evolve over the coming decades. The service, which was created by Tourism Economics, an Oxford Economics company, in partnership with the International Air Transport Association (IATA), provides annual forecasts of air passenger flows for almost 4,000 routes and 185 major markets over the next 20 years, representing over 90% of all air travel in that time period. Regional flows are included and important rapidly growing new routes are also covered [4].

IATA forecasts the number of global air passenger journeys to increase at an average rate of 4.0% each year over the next 20 years. Between 2014 and 2034, it is expected growth in passenger journeys as 5.1 % in Middle East, 4.9 % in Africa, 4.9 % in Asia Pacific and 3.3 % in North America [3]. IATA expects 7.2 billion passengers to travel in 2035, a near doubling of the 3.8 billion air travelers in 2016. The prediction is based on a 3.7% annual Compound Average Growth Rate (CAGR) noted in the release of the latest update to the association's 20-Year Air Passenger Forecast [5].

Atatürk Airport connects Turkish cities with major cities and markets around the world. It takes the part in the busiest airports in the world. Figure 1.2 illustrates number of passengers for the top busiest airports in the world for 2015 and 2016 [6]. Atatürk Airport ranks 14th.

Rank	Airport	Location	Country	Code (IATA/ICAO)	Total passengers
1.	Hartsfield–Jackson Atlanta International Airport	Atlanta, Georgia	United States	ATL/KATL	104,171,935
2.	Beijing Capital International Airport	Chaoyang-Shunyi, Beijing	China	PEK/ZBAA	94,393,454
3.	Dubai International Airport	Garhoud, Dubai	United Arab Emirates	DXB/OMDB	83,654,250
4.	Los Angeles International Airport	Los Angeles, California	United States	LAX/KLAX	80,921,527
5.	Tokyo International Airport	Ōta, Tokyo	Japan	HND/RJTT	79,699,762
6.	O'Hare International Airport	Chicago, Illinois	United States	ORD/KORD	78,327,479
7.	Heathrow Airport	Hillingdon, London	United Kingdom	LHR/EGLL	75,715,474
8.	Hong Kong International Airport	Chek Lap Kok, Hong Kong	China	HKG/VHHH	70,314,462
9.	Shanghai Pudong International Airport	Pudong, Shanghai	China	PVG/ZSPD	66,002,414
10.	Charles de Gaulle Airport	Paris (Roissy-en-France), Île-de-France	France	CDG/LFPG	65,933,145
11.	Dallas/Fort Worth International Airport	Dallas-Fort Worth, Texas	United States	DFW/KDFW	65,670,697
12.	Amsterdam Airport Schiphol	Haarlemmermeer, North Holland	The Netherlands	AMS/EHAM	63,625,534
13.	Frankfurt Airport	Frankfurt, Hesse	Germany	FRA/EDDF	60,786,937
14.	Istanbul Atatürk Airport	Yeşilköy, Istanbul	Turkey	IST/LTBA	60,248,741
15.	Guangzhou Baiyun International Airport	Baiyun-Huadu, Guangzhou, Guangdong	China	CAN/ZGGG	59,732,147
16.	John F. Kennedy International Airport	Queens, New York City, New York	United States	JFK/KJFK	58,813,103
17.	Singapore Changi Airport	Changi, Singapore	Singapore	SIN/WSSS	58,698,000

Figure 1.2 The Busiest Airports in the World

It is expected to cement its position in the top- 10 largest domestic markets throughout our forecast horizon in Turkey. Also, it is forecasted 112,877 thousand additional pax per year by 2034 with 4.8 % annual growth in Turkey. This is a quite significant change for Turkey in the long term. Other European domestic markets, including Italy, France and the UK, are all expected to drop down the ranks, with the latter two dropping out of the top-20 altogether [7].

1.1 Literature Review

Currently, demand for air transport increases the passenger density which is becoming inextensible in some cases. These densities can be caused by the fact that airports are constructed with poor projections incomplete or incorrect placement of resources, lack of use of technology and lack of a customer oriented approach. Consequently, passenger queues at airports cause disruptions in scheduled arrivals and departures of flights which produce customer dissatisfaction. Academic studies, which are aimed to solve the experienced queuing problems, generally propose mathematical formulations and simulation studies. In this section, we summarize the literature on increasing the quality of airport terminal operations.

Simulation is a useful tool to analyze dynamic real-world applications within IATA Airport Development Reference Manuel. In these cases, the simulation model itself provides an abstract representation of the original system and an environment for "what-if" experiments. The system may be an entire airport or part of an airport [8].

To our knowledge, the first study on the airport terminals, which is done by Baron [1969] attempt to simulate passenger-terminal buildings as systems in Germany [9].

Horonjeff and Mckelvey [1986] emphasize the use of network models, queuing models and simulation models for the planning and design of passenger terminal. The authors claim that simulation models are particularly useful when analysis of the operations of passenger terminal activities if to be performed at a relatively more detailed level [10].

Mumayiz [1990] develops analytical queuing methods and simulation approaches in various ways to model terminal passenger flows and to detect system performance [11].

Setti and Hutchinson [1994] present a fluid approximation model, which is designed as high-level passenger terminal simulation language, TERMSIM, for the simulation of passenger terminals [12].

Jim and Chang [1998] suggest a generic simulation model for the final design of airport passenger terminal and the model is applied by using Slam II Simulation Language for Singapore Changi Airport. The software presents on facility diagram which graphically portrays the layout of passenger terminal and the entities of the system [13].

Gatersleben and Weij [1999] present LOT project (the project Logistics Development Terminal) regarding analysis and simulation of passenger handling at Schiphol Airport. In order to prevent future bottlenecks, the project interprets on insights to make pro-active measurements possible [14].

Kiran et al. [2000] implement a project involving the development of simulation models for the new international terminal at Istanbul Ataturk Airport. They develop an Excel Driven User Interface and ProModel to analyze the service bottlenecks for the passengers which are used from the terminal entrance to boarding. They conclude that the new terminal was capable of serving the targeted number of passengers per year and the capacity of the services were adequate for departing and arriving passengers [15].

Joustra and Van Dijk [2001] present why simulation is necessary to evaluate check-in, a simulation toolbox for check-in counters and two simulation studies using the toolbox at Amsterdam Airport Schiphol. They aim to determine the maximum possible growth in terms of the number of departing flights at Schiphol with respect to existing check-in facilities, whilst all flights meet the required quality standard. The study gives insights in alternative check-in methods, the personnel planning of the check-in counters and determine the maximum possible growth of Schiphol Airport with respect to check-in facilities [16].

Ballis et al. [2002] implement a simulation model to investigate charter passenger effects and level of service offered on air terminal facilities in the master plan of two Greek airports [17].

Lozano et al. [2004] suggest a simulation model for passengers' traffic within the departures terminal of Málaga Airport in Spain where charter flights service with European destinations outside Spain [18].

Chow and Ng [2006] study simulation for the time during emergency evacuation in crowded halls. They build evacuation models, Exodus and Simulex, to carry out scenarios and different occupancy levels in local codes are considered under fire and normal conditions in the departure hall. They analyze that there was jamming around the exits of the departure hall [19].

Appelt et al. [2007] propose a simulation model to focus on check-in procedure at the Buffalo Niagara International Airport in USA. Arena software is used to show the passenger flow through the check-in process given the different types of check-in modes as curbside, kiosk, counter, and online check-in process. They analyze waiting times in queue and total average time of the check-in system [20].

Curcio et al. [2007] study passengers flow and security issues of an Italian airport terminal, the International Airport of Lamezia Terme. The simulation model is implemented in Anylogic™ for investigation system behavior under the effect different scenarios obtaining varying critical input parameters [21].

Freivalde and Lace [2008] analyze the capacity and bottlenecks in Riga Airport with GRADE software [22]. A similar work, Tuna [2009], in which a simulation model in ProModel is proposed to simulate Kayseri Airport International Terminal departing passengers. The historical data of the airport is analyzed and a simulation model is proposed to understand the queuing system. The findings were made to allow all weekly planning traffic from the week with the least traffic to the week when the busiest traffic and detailed examination of the whole week [23].

Akdeniz and Tatar [2009] use Arena for waiting optimization of airplanes in Adnan Menderes Airport due to expected increase of the density because of 23rd International Universiade Olimpic Games in İzmir. Waiting times of the arriving and departing aircrafts are examined in Arena simulation software in order to analyze whether the airport needs a new runway or not [24].

Solak et al. [2009] study multistage stochastic programming model based on a multi commodity flow network to investigate the whole airport terminal capacity planning problem. It provided optimal capacity requirements for each area in the airport terminal during the initial building phase [25].

Chawdhry [2009] suggests Monte Carlo simulation for airport security to determine passenger process permeability of large airport hubs in a system of interconnected airports [26].

A discrete event theory approach is applied to develop a simulation model for the analysis of passenger flow in the terminal airport and tested in Naples International Airport by

Guizzi et al. [2009]. The simulation study which is developed in Rockwell Arena, assists to predict delay and produces a logical and rational management of check-in desks and security checkpoints at the airport terminal 1 [27].

Bruno and Genovese [2010] develop a mathematical model for the optimization number of check-in gates in order to balance the operative costs of the service and the passenger waiting time at the Naples International Airport [28].

Stolletz [2011] implements passenger queueing model for a check-in system with a single queue and a time-dependent number of check-in counters in airport terminals. A stationary backlog carryover (SBC) approach is developed to approximate the passenger check-in system performance measures such as required number of check-in operators and service level agreements between the ground handler and the airline [29].

Wu and Mengersen [2013] develop the Concept of Operations (CONOPS) framework to help development of modelling capabilities and scenarios and reviewing of existing airport terminal models. Although there is an emerging focus on the need to be able to capture trade-offs between multiple criteria such as security and processing time, it is found that capacity and operational planning models predominantly focus on performance metrics such as waiting time, service time and congestion whereas performance review models attempt to link those to passenger satisfaction outcomes [30].

Novrisal et al. [2013] propose a simulation model for departure terminal in Soekarno-Hatta International Airport by using ProModel. They determine the performance of the existing system of the departure terminal. Entity activity and utilization of the locations are obtained from the simulation results. They conclude that the number of check-in counters in the terminal is not adequate [31].

Lange et al. [2013] observe the possibilities of implementing virtual queuing at airport security lanes in a large international airport in Western Europe. In consequence of the study, nearly one million Euro savings on security personnel cost can be achieved without negatively impacting the passenger waiting time [32].

Perboli et al. [2014] present a simulation model by using AirSIM for the new security system. The case study is about a machine to automate operations before the security gates in the Bologna Airport. This project shows the performance and effects of different parameters of the new system [33].

Demirci and Sabetghadam [2015] present a simulation model in Arena for the passenger traffic of the Trabzon Airport Domestic Terminal building. Their model determines the bottlenecks of the system and changes the existing state parameters for the comparison and evaluation [34].

Özdemir and Atalık [2015] develop a simulation model in Arena TM and evaluate Atatürk Airport international departure check-in counters on peak hours. Delays in the counter queues are examined and reasons are explained [35].

In this thesis, we investigate the departing, arriving and transfer passengers at the domestic and international terminals of Istanbul Atatürk Airport. Previous studies have emphasized the advantages of simulation studies on complex systems in particular, the detailed view of queues and waiting places, such as airports.

1.2 Objective of the Thesis

In the rapidly developing global world with the influence of technology and the internet, companies can now easily reach wider markets and numerous customers. They have to compete with numerous large and small companies on the universal market with the advantages of this unlimited access network. This competition continues to grow rapidly. Competition has forced businesses to keep costs and expenses at a minimum while trying to keep customer satisfaction. Businesses should be on the path of improving and constantly streaming system flows. It is important to be able to see the consequences of decisions made during this renewal and remediation, in order to prevent any problems that may arise. It can sometimes be very costly to take a decision without thinking about what will lead to it, or making a decision without making the best of it in the best way. Here, simulation systems are lifesaving systems. Simulation systems are very important in terms of enabling us to look at the system from different directions as well as to be able to see and analyze the results in infinite number of iterations. Simulation helps systems to detect processes and bottlenecks of the enterprises, try different alternatives in the computer environment, understand real life results and changes that can be seen for a short time in front of the system. Moreover, these systems allow results of additional investments to be understood in a very short time and increase the performance of the system with minor changes in some cases without any additional investment. The simulation works for companies as an early warning system. So, it helps to show economical and optimal solutions from the beginning of a new investment to the solution of a present problem.

The airport selected in the thesis study is an airport in a high category as density. The study is carried out to minimize the disruptions of flight schedules caused by crowded queues. With this purpose, we investigate the role of transfer passengers especially at rush hours of the airport terminal. Shortly, we aimed to determine the bottlenecks in the terminal resources, which slows down the passenger flow, if any. Therefore, we employ a simulation model to identify the problems.

While conducting simulation studies, it is necessary to make a good modeling plan, to create a successful workflow and to make an efficient plan of how to use all kinds of existing and integrated resources in the most efficient manner. There are many reasons for doing simulation modeling. The main ones are:

- Performing bottleneck analysis anywhere in the system,
- Controlling of changes to new operating procedures, rules and inputs without disturbing the functioning of the active system in operation,
- Observing the effect of different scenarios on the system.

Information on the interaction of factors that are effective in processes and their effect on the functioning of the system can be obtained by the simulation model.

1.3 Contribution of the Thesis

The main contribution of the thesis is to model the processes of the passenger movements in the whole terminal and understand the behavior of the system under available scenario alternatives. Besides, simulation model has been used for the analysis and improvement methods of the results. There has been no such comprehensive study conducted at hub airports.

CHAPTER 2

PROBLEM DEFINITION

Among other transportation modes, air transportation has the highest total cost for passengers. Besides this economically negative feature, it is more secure and comfortable for longer distances.

Contemporary airport passenger terminals serve many different functions, accommodate a wide variety of stakeholders who frequently have diverging objectives, and have to respond to one of the world's most dynamic industries. Airport terminals need to be functionally and operationally efficient, commercially viable and offer passengers as effortless and straightforward a travel experience as possible [8].

Atatürk Airport, located in Istanbul, is a hub terminal that allows stopovers on long-haul routes. Hub terminal is a central airport that flights are routed through and it allows to offer more flights for passengers. Atatürk Airport as hub terminal serves transfer passengers to get their final destination. Turkish Airline (TA) pioneers the hub-and-spoke system. It operates flights from several non-hub cities to the hub airport and connects spoke cities through the Atatürk Airport. TA has a ratio approximately 55 percent transfer to 45 percent O/D traffic.

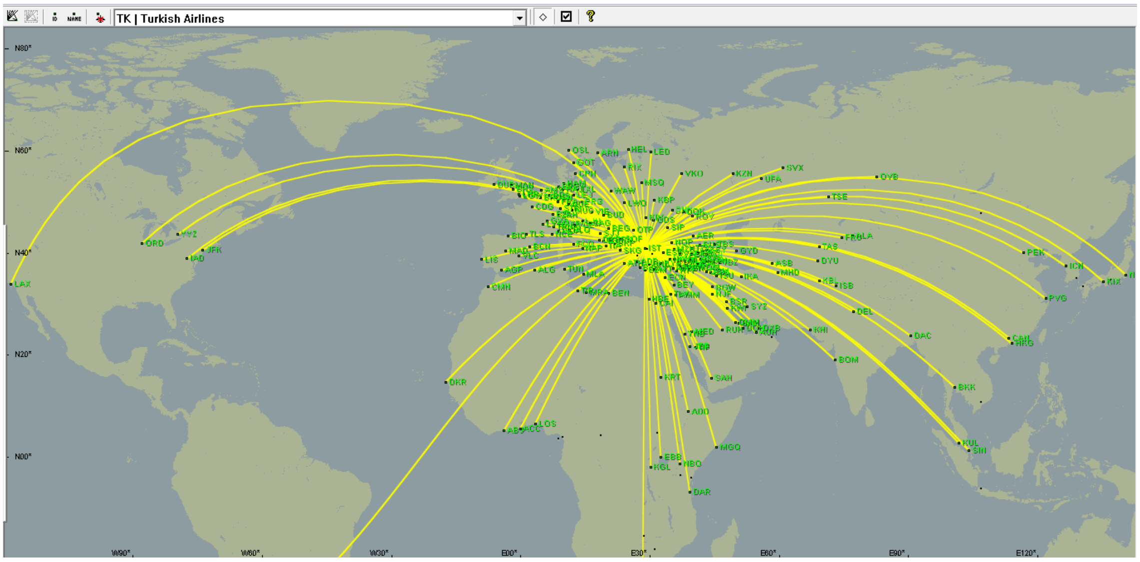

Figure 2.1 Turkish Airlines Route Map – Destinations served from Istanbul [36]

Generally, hub airports works on a wave (bank) system of arriving and departing flights. Mirkovic and Tosic [2017] defined this system as the cyclic exchange of a large number of scheduled gate occupancies followed by a small number [37]. Therefore, in certain time periods, the terminal reaches the maximum capacity of flights and also the maximum number of passengers. During these time period, the number of transfer passengers reaches its maximum level. For example, wide-body aircrafts, which are from United States and Western Europe, arrives early in the morning, carries transfer passengers mostly departing to Middle East. Due to the wave system applied to the airport, the utilization of ground operation services increases its maximum level in these certain time periods and decreases to low levels at the succeeding periods. Along with increased operational complexity, processes applied to passengers from the Member States of the European Union and other countries also differ. The smooth operation is crucial for the transfer passengers to catch up with the flights.

At the airport terminal, passengers have been observed in every process. Especially passport control services and security services for transfer passengers are critical bottleneck points. When passengers miss their flight because of the ground services, this causes a financial cost for TA.

2.1 Passenger Traffic

Istanbul, as a transfer point on global routes, reduces flight time and introduces the flexibility to use a variety of aircraft of diverse capacity. Located at the crossroads of global flight routes, location of Istanbul provides flexibility in the use of different capacities and range of aircraft, while reducing the flight time of the location. Using Istanbul Ataturk Airport as a hub enables TA, the flag carrier airline of the Republic of Turkey, to utilize a narrow body fleet, thus providing a considerable cost advantage and contributing to competitive superiority. Istanbul Ataturk Airport was the 3rd busiest airport in Europe in 2015. TA has grown steadily with double-digit growth rates and has transformed into one of the largest global network carriers in the world [38].

According to the data of DHMI, passenger traffic was 27.876.782 in international line and 13.044.702 in domestic line in the end of August of 2015 in Istanbul Atatürk Airport [39]. The increase in the number of passengers is 3.8% for domestic flights and 1.5% for international flights. Figure 2.2 illustrates the increasing passenger traffic for TA [40].

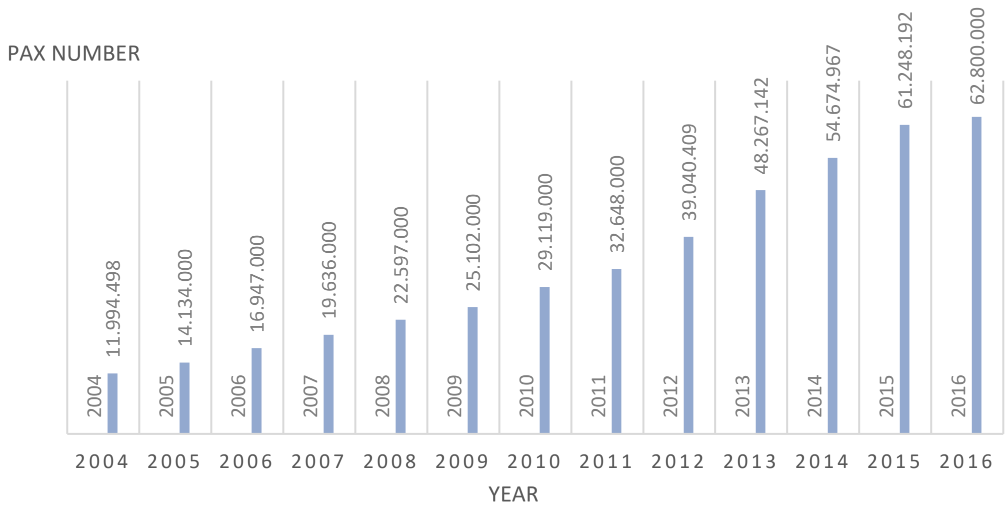

Figure 2.2 Turkish Airlines Passenger Trend by Years

In the service sector, where competition is constantly increasing, businesses need to move as much as possible to innovate and to evolve according to the methods and strategies that keep the open and customer satisfaction ahead.

In order to increase the use of air transport, which is a sign of development, it is necessary to reconstruct the air transport system, which is a very large and complex structure and systems, into as efficient systems as possible.

To deal with the increasing air transportation demand, the use of simulation as a decision-support tool has become an important and integral part of airport development, capacity planning and management [8].

2.2 Passenger Flows

This section introduces the two passenger flow charts which are direct arrival- departure (origin and destination) and transfer flights in the terminal. The model is constructed based on the regular descriptions, functional flows and relevant constraints. Flows to be modeled involve arriving, departing and transferring passengers as well as their bags. In addition, well-wishers and meeters who escort to passengers are considered within model.

2.2.1 Direct Departure Process

The Departure process, which is used for serving both domestic and international passengers, is part of the Passenger Terminal. Domestic and international passengers are served in different halls. Passengers enter the model from different points according to their characteristics.

There are security checkpoints at the departure terminal entrances. After these check points have passed, the passengers will arrive check-in area. The counters assigned to airline companies are separated according to their specifications.

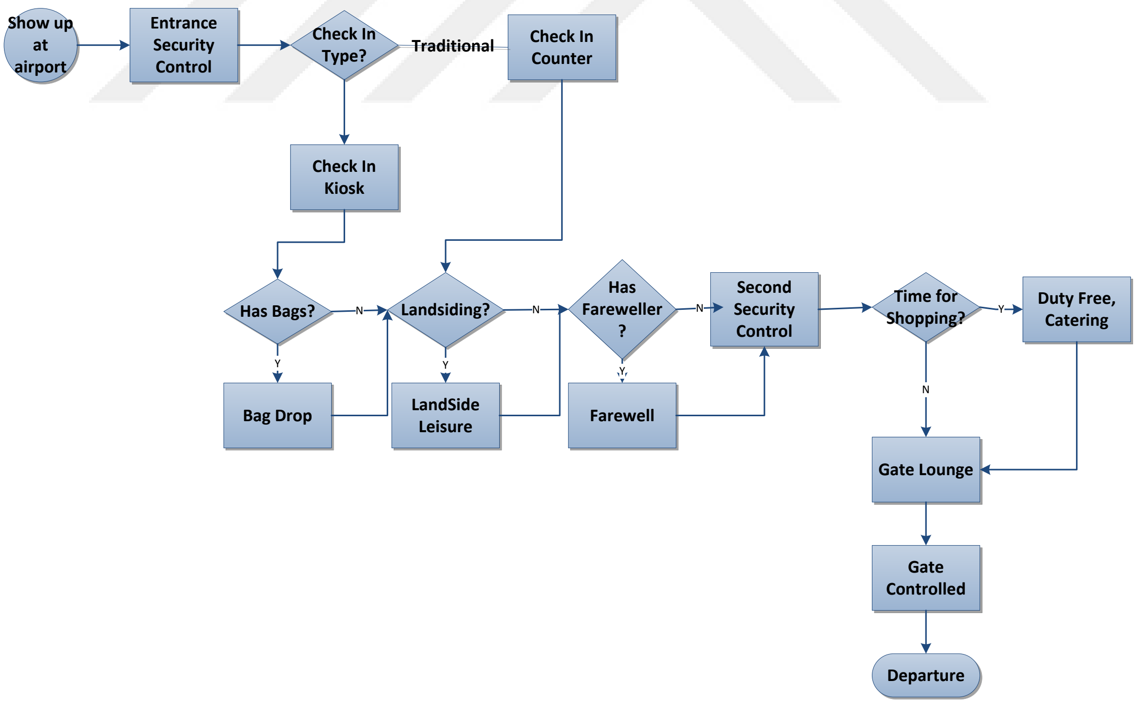

Figure 2.3 Domestic Direct Departure Process Flow Chart

At domestic terminal, after passengers with sufficient time spend their time on the landside, they reach the second security control points to screen passengers by X-ray device for passing to the airside. If they have enough time for shopping, eating etc. before the gate reporting time, they are free to spend their time in supplementary facilities. In Figure 2.3, we illustrate the processes for Domestic Direct Departure.

There are very various passenger processes such as ECAC, Gozen Security and Customs Airport Procedure in Atatürk Airport. Figure 2.4 shows the processes in International Direct Departure.

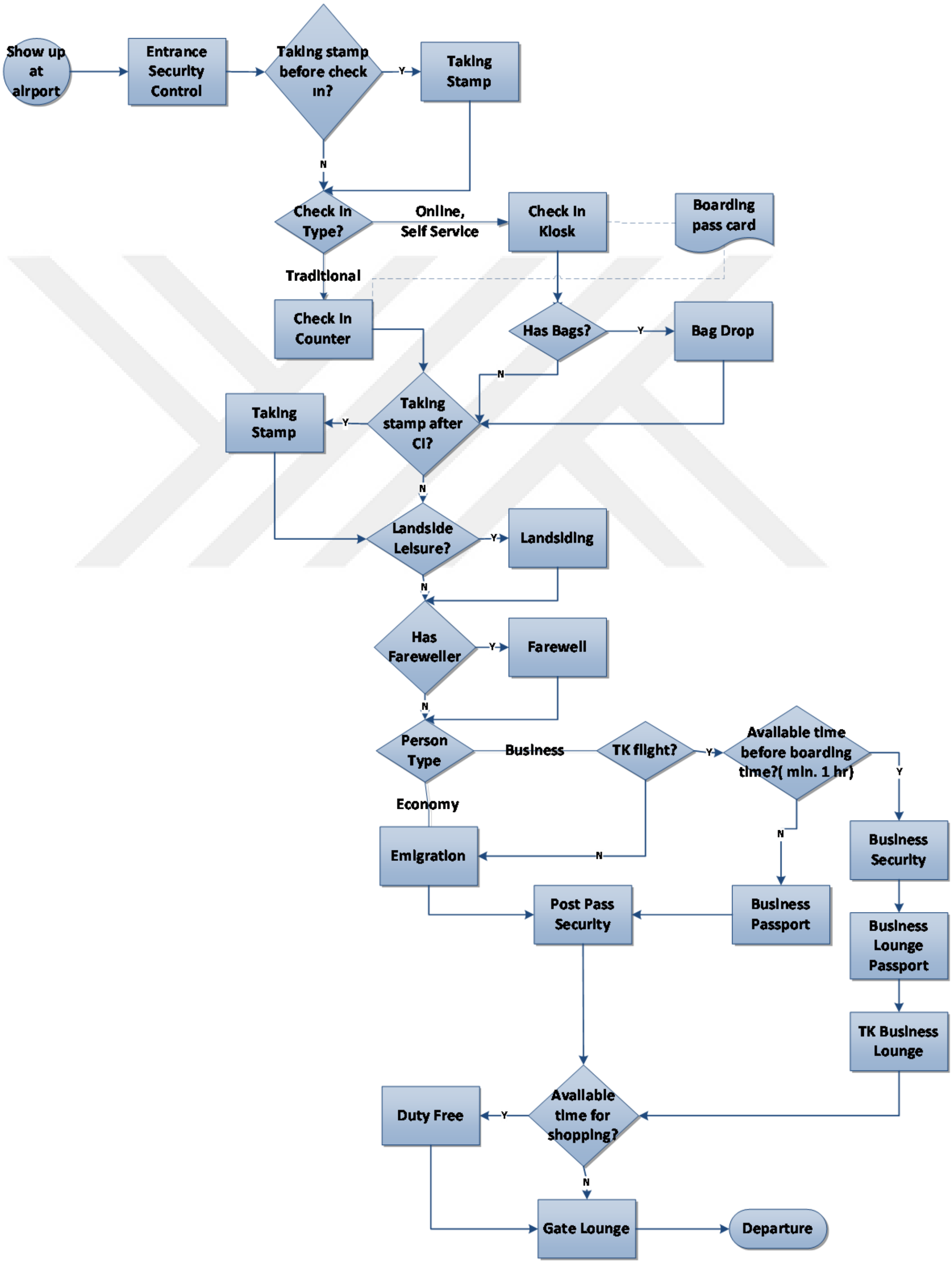

Figure 2.4 International Direct Departure Process Flow Chart

At international terminal, passengers have to buy a stamp before passing to the air side. Check-in type has 3 different procedures such as traditional, kiosk or online and GOZEN. Actually, GOZEN is a security control for passengers to go to Canada, USA, Israel and UK. C counter island is allocated for GOZEN check-in and bag drop so it is classified as check in type.

After these processes (check-in, bag-drop, Gozen control etc.) are completed, they go to the emigration passport controls. If the travel class of a TA passenger is business class, passenger uses business lounge of TA. There are emigration points and second security control points for business class passenger before they come in business lounge. If this passenger does not have enough time before gate reporting time, he/ she goes to emigration area to go to the air side. There are dedicated emigration control and second security control points for business class passengers. Emigration control points are dedicated into different groups according to nationality of passengers.

Finally, passengers go to gate lounge areas before boarding their respective flights and they pass the gate control when their flight time arrives and exit from the model.

2.2.2 Direct Arrival Process

Arrival hall is separated as domestic and international. If the passenger arriving at the domestic terminal is not a transit passenger, he can reach the baggage claim area directly. If inbound passengers have luggage, they pick up their luggage and leave the terminal as shown in Figure 2.5.

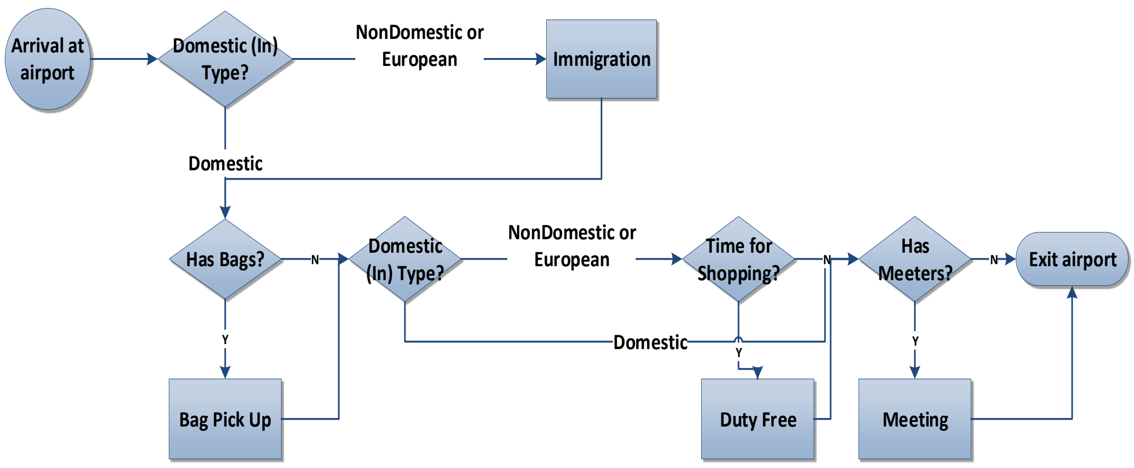

Figure 2.5 Direct Arrival Process Flow Chart

Inbound international passengers, who arrive at the arrival terminal, pass immigration passport control. Passengers are separated into different groups as Turkish and foreign people for control points. After immigration control, they can visit supplementary facilities such as Duty-Free shops. Then, they go to baggage claim area and exit the terminal.

2.2.3 Transfer Process

Passengers arriving from abroad are subject to visa and immigration passport controls to enter the country at the arrival terminal before they go for their domestic connection flight. Mainly, a big confusion procedure is in destination type as CUSTOMS type. Unlike other transfer passengers, the passengers who come from international flights to go to domestic flights have different scenarios according to destination airport type. Figure 2.6 shows the processes from international to domestic transfer.

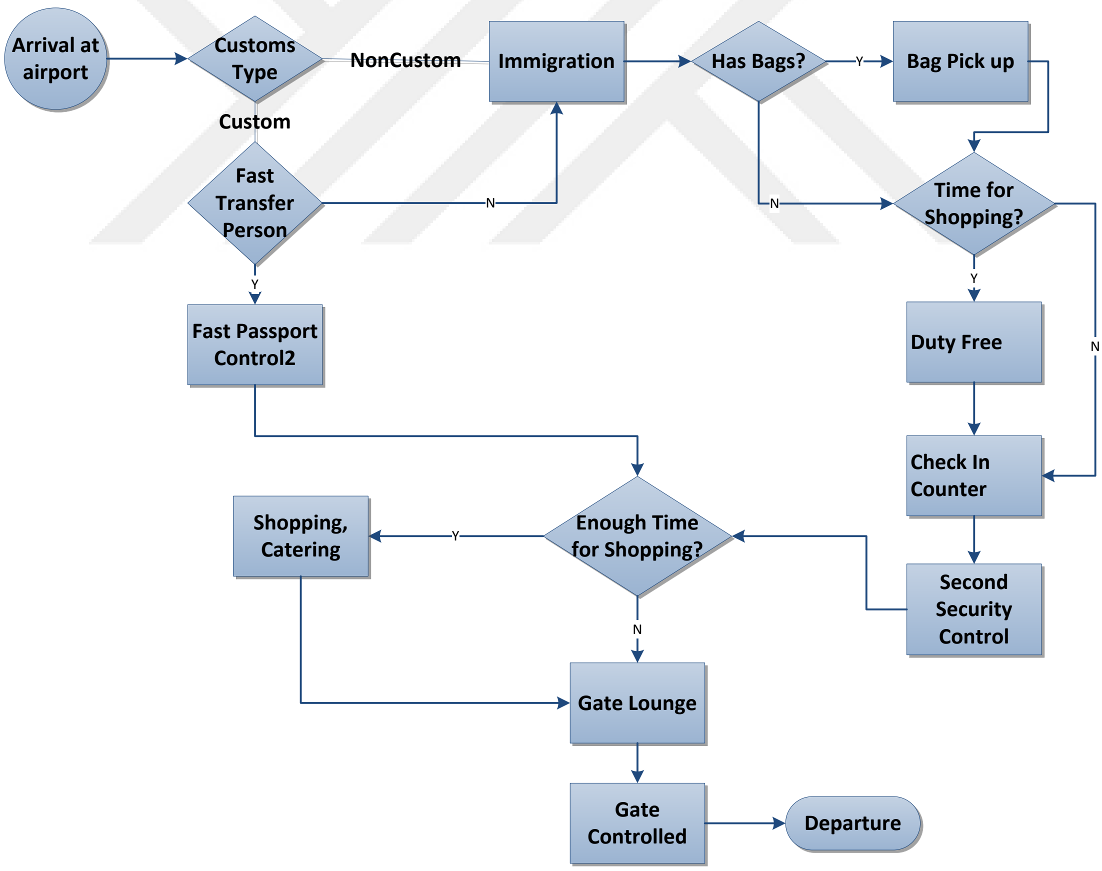

Figure 2.6 International-Domestic Transfer Process Flow Chart

Customs Airport Procedure; passengers, are transferred from international flights to domestic flights, have to pick up their luggage and check them in again in domestic departure area if destination airport is not a customs airport. Otherwise, passengers are transferred to flight directly without picking their luggage up.

Transfer passenger, who comes from international or domestic arrival terminal and goes to international departure terminal, does not have to claim luggage in between flights. Baggage will be automatically transferred to the connecting flight. Figure 2.7 shows the processes from domestic to international transfer.

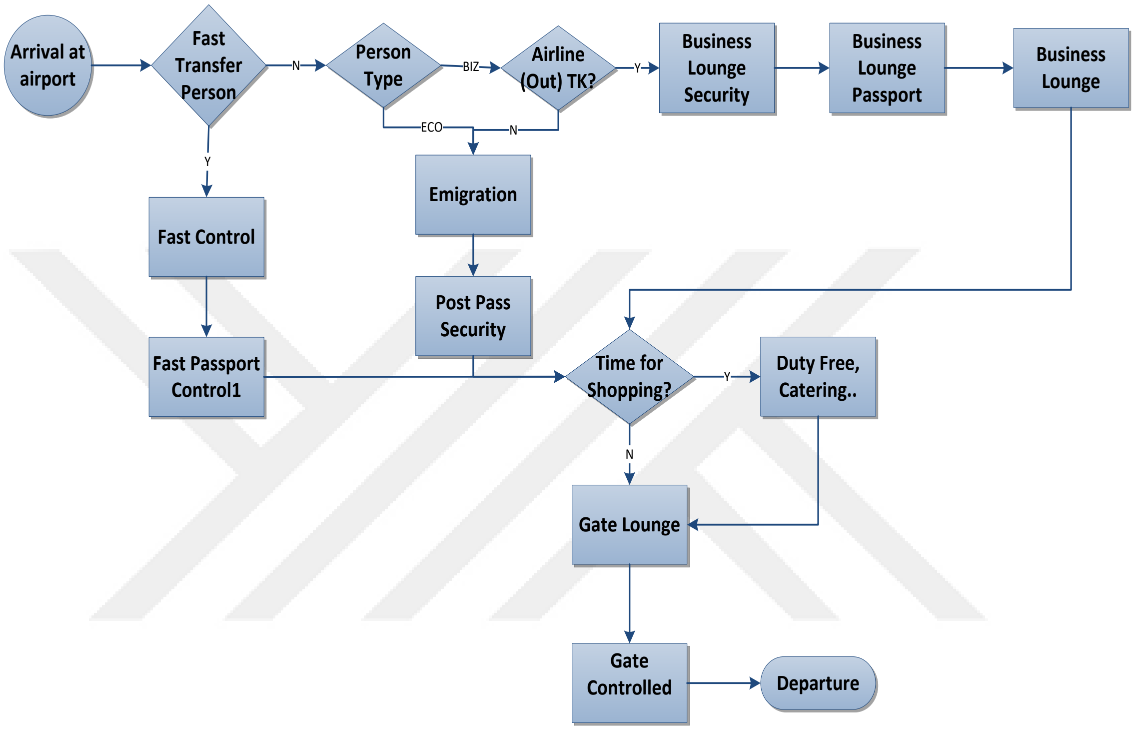

Figure 2.7 Domestic- International Transfer Process Flow Chart

If the passenger is international transfer passenger with an international connection flight, the passenger does not go through passport control. Instead, passenger directly proceeds through the transfer security controls to go to the international departure area directly.

The passengers, come from European Union countries can pass to international airside directly without taking transfer security control, as ECAC procedure. Among them ECAC has different process and scenario in the flow diagram. Figure 2.8 shows the processes from international to international transfer.

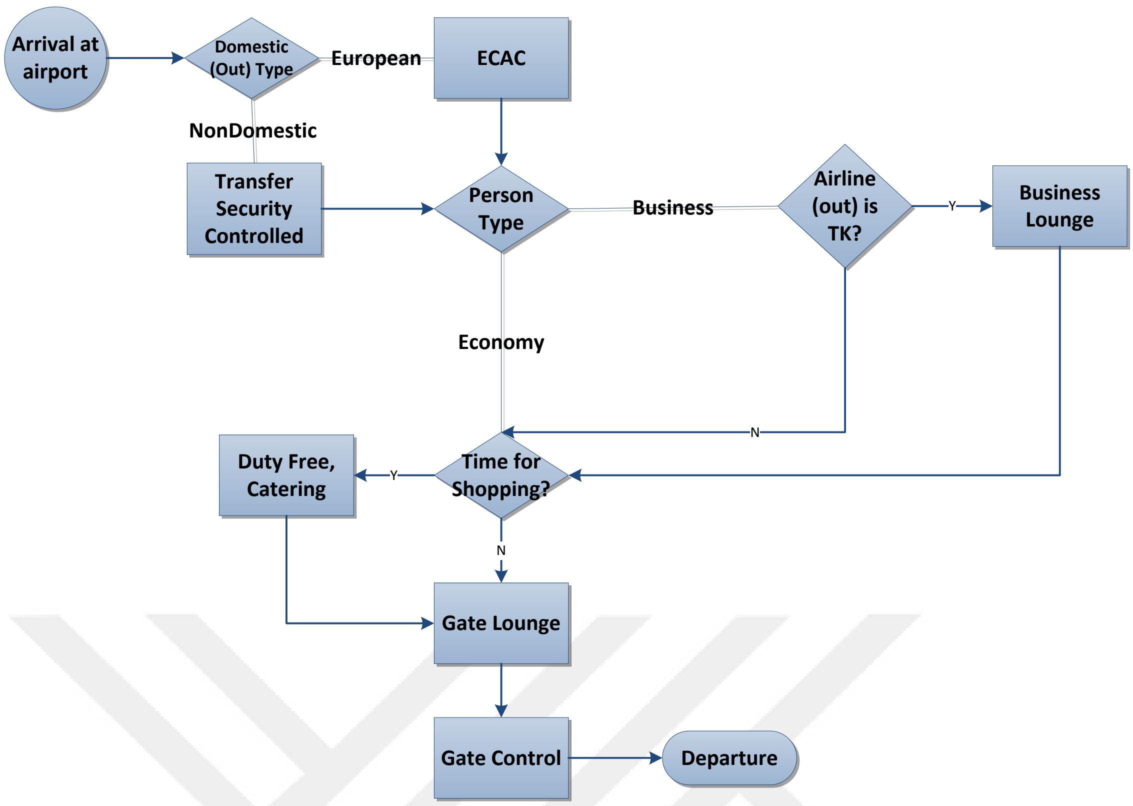

Figure 2.8 International-International Transfer Process Flow Chart

A passenger arriving on a domestic flight to continue flying to domestic, she/he proceeds to the domestic terminal isolated area and then into the relevant lounge. Figure 2.9 shows the processes from domestic to domestic transfer.

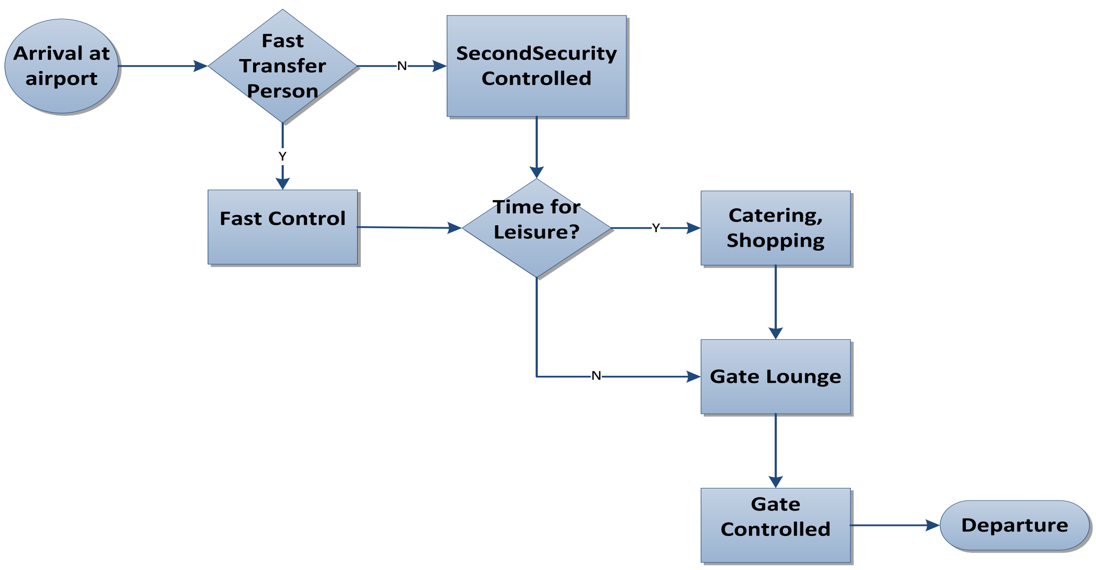

Figure 2.9 Domestic- Domestic Transfer Process Flow Chart

Transfer processes vary depending on where the passenger comes from and where he will go. Therefore, these flows change according to passenger's origin and destination points.

CHAPTER 3

THE MODELING APPROACH

This section presents the simulation model for the passenger services in the airport terminal. Modeling is explained according to its conceptualization, development, assumptions, input data, calibration, and validation in detail.

3.1 Simulation Model

A simulation is the imitation of the operation of a real-world process or system within its dynamics. Simulation involves the generation of an artificial history of a system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system [41].

The best understanding of the system to be modeled is essential for validation of the simulation.

In order to simulate a system in the most accurate way, it is necessary to transfer every input and output of the system, models of interaction points correctly and completely. Detailed information of all the units interacting with the system should be collected and modeled accordingly.

In this study, all the process flowed up the pedestrians' movements from the entrance to the exit of the terminal in the airport are examined by modeling the process flows and the problems were observed by trying to determine the source of the problem with the simulation model.

The existing processes are simulated individually and detailed consequences of the queues, such as number of people, and waiting times are obtained by way of simulation software customized for airport terminals. The software, which is developed in Delphi, is a customized decision-aiding tool for airport terminals, and conducts multi-agent discrete event simulation.

The software aims to reveal the queues leading undesirable waiting and enables to make changes in the current situation in order to increase customer satisfaction. It presents detailed and realistic 3D models of airport terminals and other buildings to enable decision support, planning, design and analysis. By utilizing the tool, we explain the existing situations that lead to queues and methods of improvement in detail.

Simulation allows organizations in the industry to analyze and experiment with their processes in a virtual setting, reducing the time and cost requirements associated with physical testing [42].

Discrete-event systems simulation is the modeling of systems in which the state variable changes only at a discrete set of points in time. The simulation models are analyzed by numerical methods rather than by analytical method [41].

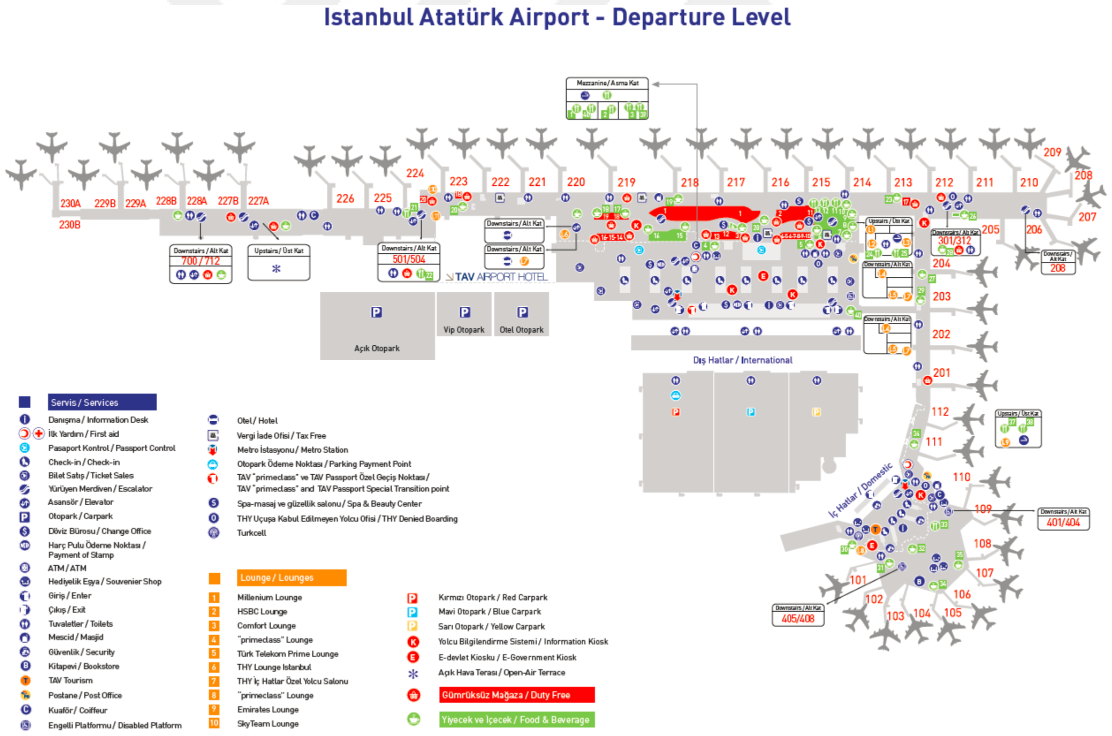

Figure 3.1 Istanbul Atatürk Airport Departure Level

In this thesis, we intend to characterize the different flows of entities and to detect of potential bottlenecks at Istanbul Atatürk Airport.

Model has been created by dividing main partitions as departure and arrival levels which are illustrated as in Figure 3.1 and Figure 3.2, respectively [43]. Firstly, we consider the x-ray security controls where the passengers are logged in the departure floor, the ticket control points, bag drops where baggage delivery is made, and kiosks, passport control points, lounge area, duty free areas where passengers shop without paying the customs tax, waiting areas and apron opening doors. Secondly, we investigate the arrival floor in which passport controls, security areas where transfer passengers use, baggage areas, and duty-free shops areas.

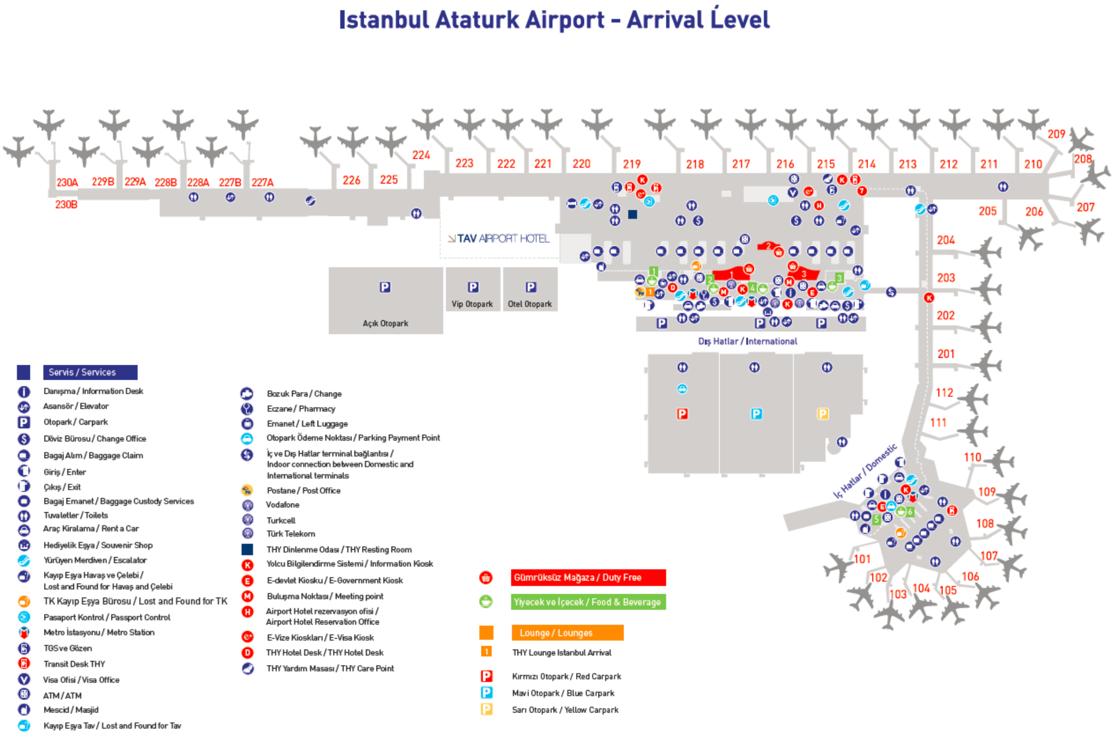

Figure 3.2 Istanbul Atatürk Airport Arrival Level

A terminal simulation analyzes the passenger handling processes taking place at the various service facilities (sub-systems) within passenger terminals (i.e., check-in, security, emigration, immigration, baggage reclaims, customs and transfer facilities).

The objective of the terminal simulation is to support:

- The planning of well-dimensioned and balanced terminal facilities,
- The quantification of passenger processing requirements,
- The validation of the operational concept of the planned facilities,
- The optimization of the operation of existing facilities,

- Evaluation of Minimum Connection Time (MCT) for transfer passengers [8].

Simulation model, applied in simulation software customized for airport terminals, includes passenger activities including arrival and departure for all processes inside the terminal.

Discrete-event simulation approach that used in simulation software customized for airport terminals recalculates the system status whenever an event occurs. The sequence of the system states describes the process flow and interaction of flow objects in the system. These models imitate the behavior of entities in complex systems by using the discrete event simulation approach to follow system resources and activities performed. This kind of simulation modelling technique is widely used to simulate airport operations [8].

In the present case, it is necessary to see whether the resources are sufficient in the passenger flow, and if so, to determine the bottleneck points. In addition, a modeling work is required to be able to decide whether the terminal will suffice to respond adequately or to be able to source the planning of the new airport to be built because it is possible to see increases in the number of passengers in the forthcoming years.

3.2.1 Model Development

The modeling process begins with the creation of a virtual structure of the existing system. The necessary information is then added to the system. This model shows us the structure and functioning of the system and allows us to understand the relationship between system elements and events. In the application sections, the work done is described in respectively. After defining the problem and determining the objectives, a general structure of the model was established. This structure included the main elements and events of the system. Basic elements and workflows are shown in the drawing and used in application studies.

Information which is used for simulation modelling is shown below:

- Infrastructure layout,
- Facility Information,
- Process flow charts,
- Number of services,

- Process times of the services,
- Flight schedule,
- Operational settings,
- Passenger characteristics,
- Flight characteristics.

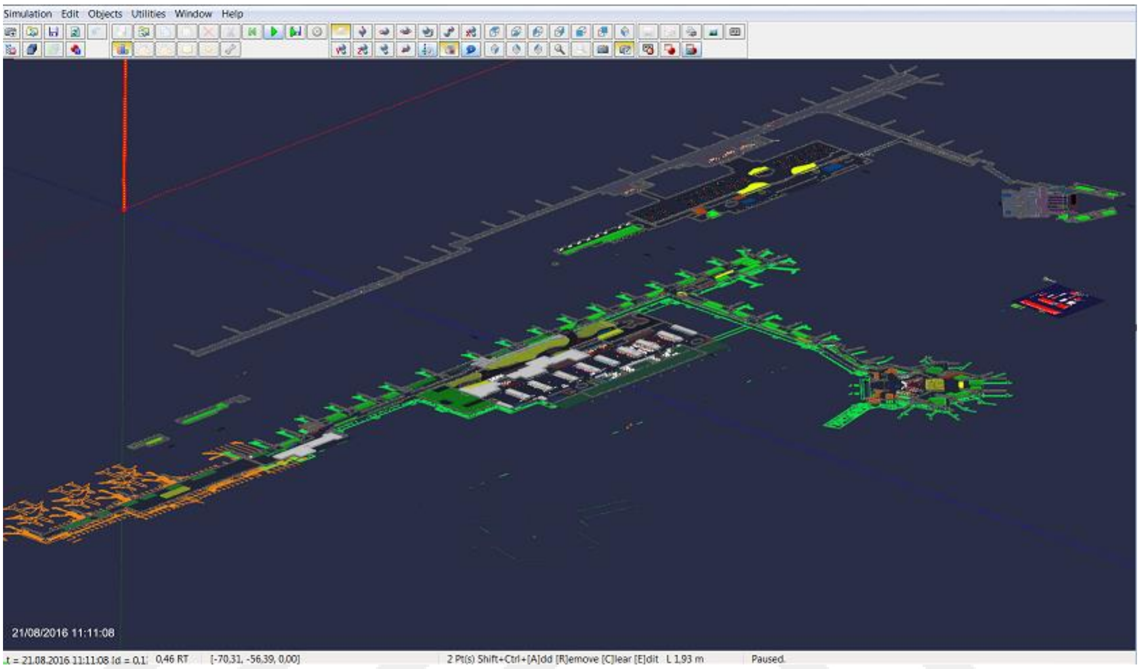

Figure 3.3 Overview of the Passenger Terminal Simulation

In order to determine the processing and waiting places for the application areas observations have been made. As a result of the observations, sections have been identified. The workflows of the determined sections are observed and the information obtained. These examinations are transferred to the drawing model in the terminal's AutoCAD program. DXF drawing is not included in the thesis because it is objectionable in terms of airport security.

When the system is set up, the layout plans which are CAD files are imported from into simulation software customized for airport terminals through an interface.

24-hour flight schedule reflecting a “Typical Busy Day” for direct arrival, direct departure and transfer has been used. For this day, if transfer passengers come before this day, this is also taken into account. The flight schedule for a peak day of August, 2016 has been constituted as PaxGen, which is used as a flight format in the software program. Connected PaxGen has generated due to the fact that the ratio of transfer passenger is very much. Also, 1 day before and after of this day have been calculated for transfers.

This is the most realistic approach to model airport processes with the interaction and interdependencies of flight-driven events taking place at the airport and to capture all the peaks in the different airport facilities.

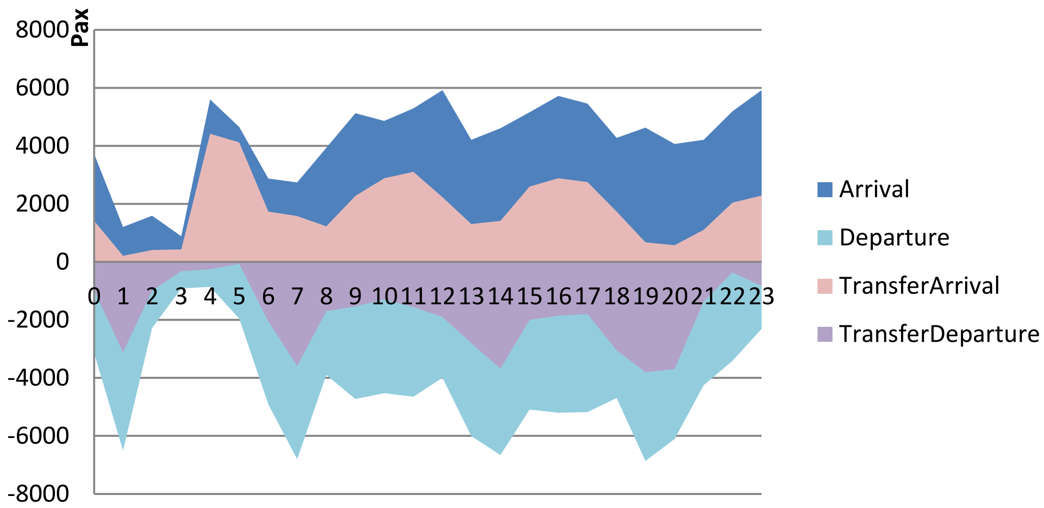

Figure 3.4 Chart of Hourly Passenger Number

When the figure 3.4 is examined, it is seen that it is the busiest period when TA transfer passengers arrive between 4-5 hours in the morning.

If a future situation is to be modeled and no forecast flight schedule is available, one or more flight schedule scenarios can be created as a baseline for the analysis. For this, historic flight schedules can be analyzed regarding their peak structures and characteristics of arriving, departing and transfer peak hours, which might occur during different periods. An assumption model for the airlines serving the airport, their fleet mixes, load factors and possible additional movements during peak times can be set-up. Based on these assumptions, an example scenario flight schedule can be prepared, discussed and agreed upon by the airport stakeholders [8]. Figure 3.5 illustrates flight schedule characteristics in the simulation model.

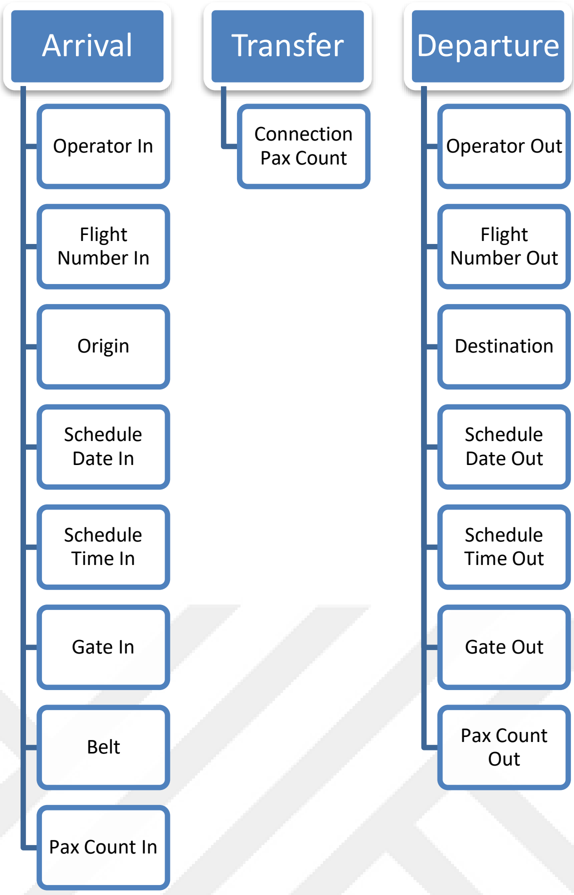

Figure 3.5 Flight Schedule Characteristics

With the current flight plan, it is sufficient to determine whether the service resources are sufficient for the passenger flow and to determine the bottlenecks.

Moreover, some operational rules and specifications of characteristics of flow objects have been implemented. For instance, passenger show-up profiles, shares of properties of the entities are very important to generate objects in correct way.

After the model is set up, it has to be debugged to verify the model's logic has been implemented correctly.

3.2.2 Model Assumptions

It is considered model assumptions to restrict the complexity of reality of passenger terminal and limit computation time. Model assumptions are the following:

Transfer flights that are generated for PaxGen are figured out only for TA transfer flights. In this point, the transfer passenger is considered if both his/ her arrival flight and departure flight are with TA.

Service time distributions are independent of time and server workload. These distributions are measured as a constant number for each service object.

For the transfer passengers, a boarding card is issued for the passenger at origin airport. So, when the passenger arrives at hub airport, he/she does not get service from check-in area.

Due to TA is served in a separate CIP hall; the number of domestic passengers for business class is neglected.

3.2.3 Input Data

Once the model scope and objective has been determined, the level of system abstraction needs to be defined to assess which input data, and at what level of detail, have to be collected.

The goal of input data collection should not be to collect as much input data as possible. It is important to select the "right" set of data for the question of interest for the simulation. Based on the objective, a suitable abstraction level for the model and the input has to be chosen.

Table 1 Distribution of total arrivals by hours for the day of simulation

Hour	Domestic	International	Total	Hour	Domestic	International	Total
0-1	6	15	21	12-13	12	24	36
1-2	5	5	10	13-14	13	19	32
2-3	5	7	12	14-15	10	24	34
3-4	1	5	6	15-16	4	29	33
4-5	4	23	27	16-17	8	26	34
5-6	4	23	27	17-18	6	29	35
6-7	3	16	19	18-19	8	23	31
7-8	11	8	19	19-20	11	22	33
8-9	14	15	29	20-21	16	12	28
9-10	18	16	34	21-22	12	18	30
10-11	7	27	34	22-23	2	33	35
11-12	7	26	33	23-24	5	29	34

The collection of input data is a critical phase as the quality and suitability of input data highly influences the quality and usability of the simulation results. On-site cross-check measures are recommended to evaluate whether the provided data is realistic. When collecting input data for the simulation (i.e., processing times, user shares or show-up profiles), it is important to ensure statistical relevance (sufficient sample size) [9].

Measurements with stopwatch time study, surveys with passengers at the airport, past data, general knowledge, the modeler's own experience and expert evaluation from airport operations staff are important data resources when modelling the simulation study. Table 1 shows hourly arrival flights for the simulation.

Table 2 Distribution of total departures by hours for the day of simulation

Hour	Domestic	International	Total	Hour	Domestic	International	Total
0-1	8	14	22	12-13	5	22	27
1-2	1	29	30	13-14	12	24	36
2-3	4	8	12	14-15	5	34	39
3-4	-	6	6	15-16	11	24	35
4-5	-	6	6	16-17	14	21	35
5-6	17	1	18	17-18	13	21	34
6-7	7	23	30	18-19	3	27	30
7-8	3	34	37	19-20	7	31	38
8-9	8	19	27	20-21	7	31	38
9-10	15	18	33	21-22	16	16	32
10-11	10	24	34	22-23	13	15	28
11-12	8	24	32	23-24	7	11	18

Table 2 shows hourly departure flights for the simulation, Table 3 shows hourly transfer passengers for the simulation.

Table 3 Distribution of transfer passengers by hours for the day of simulation

Hour	Departure	Arrival	Hour	Departure	Arrival
0-1	986	1.414	12-13	1.898	2.230
1-2	3.116	216	13-14	2.806	1.310
2-3	989	410	14-15	3.680	1.421
3-4	313	434	15-16	2.002	2.600
4-5	256	4.418	16-17	1.850	2.880
5-6	65	4.118	17-18	1.800	2.749
6-7	2.056	1.738	18-19	3.046	1.733
7-8	3.589	1.579	19-20	3.801	680
8-9	1.700	1.231	20-21	3.695	572
9-10	1.538	2.279	21-22	1.370	1.105
10-11	1.294	2.879	22-23	364	2.043
11-12	1.553	3.101	23-24	832	2.292

Certain information is available for some of the events and processes in the system; it may be insufficient for some processes. In these cases, information has been obtained from the experts about the system concerned, the data has been collected, or the estimates have been made using intuitive methods.

Passengers and baggages are defined as entities entering our system. A passenger list is created in the Functional Object Generator which creates simulation objects. Figure 3.6 shows the all generators and configurators of the simulation model.

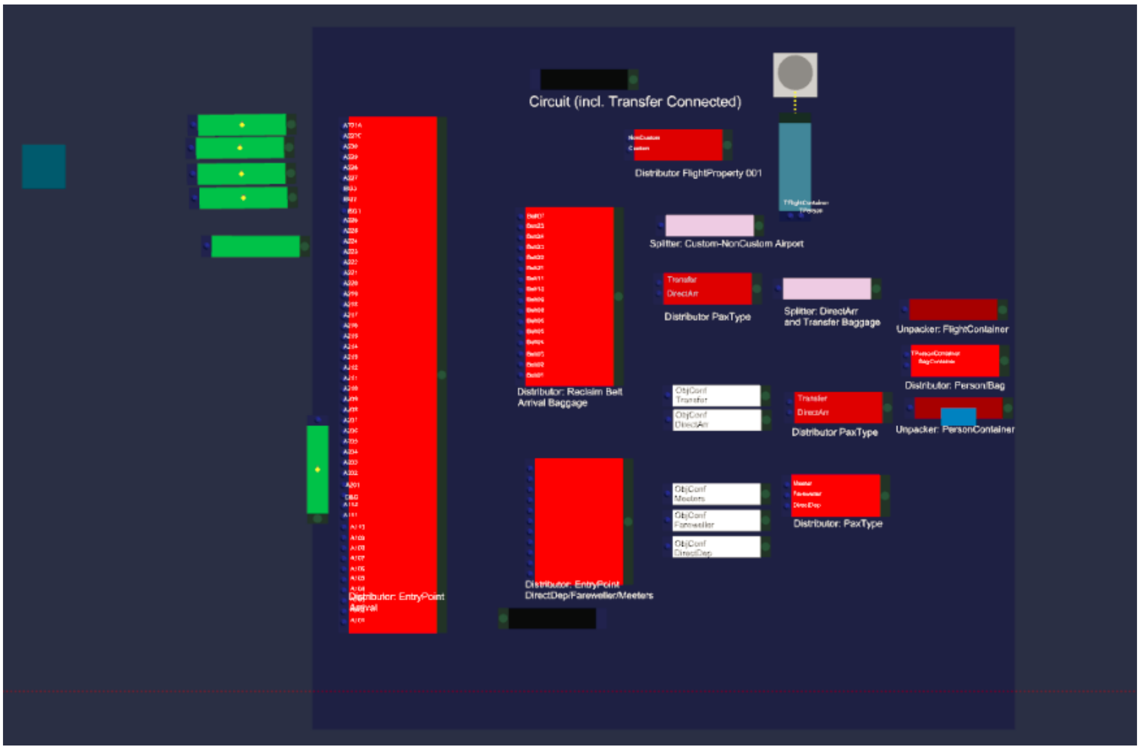

Figure 3.6 Base Circuit

Flight Containers represent for arriving aircraft, departing passengers as individual persons. Arriving persons and baggages of a specific flight enter the model within a Flight Container that contains one passenger container and one Bag Container. Departing persons enter the model as individual persons according to a specified reporting profile reflecting a time distribution related to the scheduled time of departure. Meeters and farewellers enter the model the same way departing passengers do, as individual persons. Farewellers will enter together with their related departing passengers. However, meeters enter the terminal alone and will meet the arriving passengers in the Functional Object Generator which generates passengers according to their properties, baggage, farewellers or meeters. Distributor by Flow Object's Property distributes persons to its different exits according to their properties.

Object Configurator assigns the Job List and properties to passengers. Job List is constituted according to flow charts. Container Unpacker unpacks the contents of the incoming containers. For example, a Flight Container is unpacked into a Bag Container and a Person Container or a Person Container is unpacked into single persons. Distributor for Bag Container distributes Bag Containers according to their properties.

Passengers are distributed to the different Object Configurators according to their PaxType (Direct Pax, Transfer Pax, Meeters, and Farewellers).

The Job List may be different for passengers depending on their properties.

So, departing passengers, meeters and farewellers go to the respective Object Configurator where their job lists get defined depending on their properties. Then they go on to a Distributor, which has an output for every entry point in the model. These outputs must be connected to the respective entry points.

For arriving passengers; firstly, the Flight Container is unpacked into a Person Container and a Bag Container, which are separated in the following Distributor. The Bag Container is transferred to belt area while the Person Container is unpacked and the arriving passengers' job lists are defined in the Object Configurator. Then the passengers are distributed to the different entry points in the model, representing the different arrival gates of a terminal.

A Distributor allocates the Bag Containers to a belt in the baggage reclaim area of the model. The outputs of the Distributor must be connected with the respective BagContainer Unpacker of the belt objects.

The Circuit can be adapted to meet the specific needs of a simulation model.

The routing and the tasks of passengers are controlled by tokens in the simulation model. A Passenger's task is to gather tokens in a certain order; these are acquired by performing passenger-handling processes. Passengers get their tasks from job lists. In addition, every service provides a Service Job's Benefit token. When the job is the Plan Entry at the top of a passengers' Job List, the passenger heads for the service. After passenger finishes the job, the benefit token is written into the passenger's Inventory List. For instance, getting check-in service has been illustrated as "tokBoardingPass" and passport control service has been illustrated as “tokPassportControl”. After a passenger finishes job “tokBoardingPass”, the benefit token “tokBoardingPass” is written into the passenger’s Inventory List and tokPassportControl is written into the passenger’s Plan List. The routing of passengers can not only be controlled by tokens but also by passenger properties. The Property Conditions of a service are identified in the service menu on the Service Usage Definitions.

Moreover, plan tokens can be mandatory or non-mandatory. Mandatory tokens must be gathered by the passenger, non-mandatory tokens may only be gathered when there is still enough time. For example, “Shopping” or “Catering” are identified as non-mandatory tokens because passenger must be at the gate on time.

Table 4 Entity types

Type			
Person	**Flight**	**Bag**	**Person (Meeters-Farewellers)**
Pax Type	Country	BHS Time	Entry Point
Travel Class	Continent	AcTOBhsTime	Entry Time
Entry Time	Dom Status	OutFlowRAte	Exit Point
Exit Time	Customs Type	CustomsType	
Fast Transfer	Gate		
Passport			
Entry Point			
Exit Point			
Gender			
Landside Model Split			
Check In Type			
Retail Type			
Stamp			
Gozen			
Gate Reporting Type			
Check In Reporting Time			
Mobility Impaired			
Walking Speed			
Landside Model Split			

The routing of passengers can not only be controlled by tokens but also by passenger properties. The property conditions of a service are edited like the token settings in the service menu on the Service Usage Definitions.

Qualifications of the flight, passengers, bags and meeters-farewellers are determined in the object generation tool of the software. There are lots of user defined properties of the model as 4 main types. These are “Flight”, “Person”, “Bag” and “Person (Meeters - Farewellers)”. Table 4 illustrates these entities and, it is explained some characteristics of the entities of the model.

PaxType is identified according to passenger flight direction. If the passenger is arriving the airport and exit from the exit door, it is called “DirectArr”. If the passenger is only departing, it is called “DirectDep”. Also, the others are called “Transfer”. Figure 3.7 shows pax type characteristics.

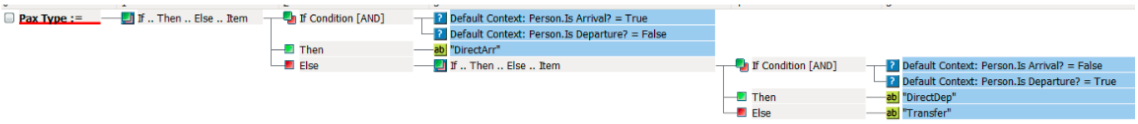

Figure 3.7 Pax Type

All airport codes are defined with their country codes in the airport database. These codes are helpful when it is used for some scenarios.

Retail type is divided 3 categories as catering, shopping and seating. This parameter is used for the passenger who has enough time before going to gate area. Table 5 shows shares of retail types.

Table 5 Retail Type

Retail Type	Shares
Catering	15
Shopping	70
Seating	15

Travel class sharing changes according to passenger type (DirectDep, DirectArr or Transfer) and departure flight country. Figure 3.8 shows characteristics of travel class as business and economy.

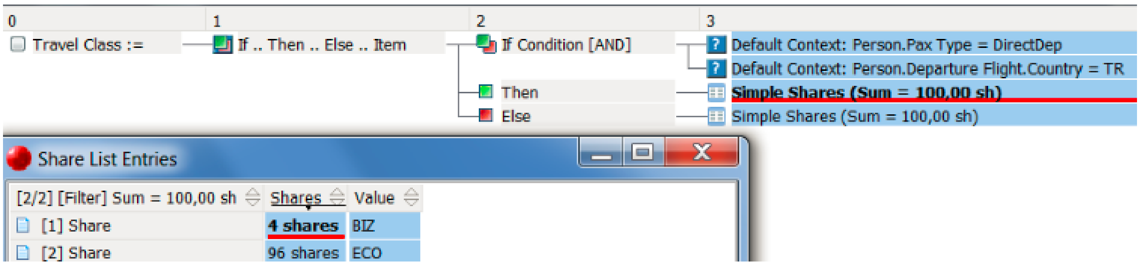

Figure 3.8 Travel Class Parameter for Direct Departure Passengers

Airports without customs control procedure; international transfer passengers continuing to a domestic destination without customs control have to pick up their luggage and check them in again in domestic departure area because; destination airport is not a customs airport. Otherwise, passengers are transferred directly to without picking their luggage up. All Airports without customs control in Turkey have been identified in the model as “NonCustom”.

Entry time tells when the passengers come in to the model. This distribution changes according to some constraints. For instance, if passenger flight is to domestic destination, he/ she starts to come to airport before 4:20 hours from departure time of the flight. 70 % of the domestic passengers will entry before 01:50 hours. Figure 3.9 illustrates entry times for passengers to the model.

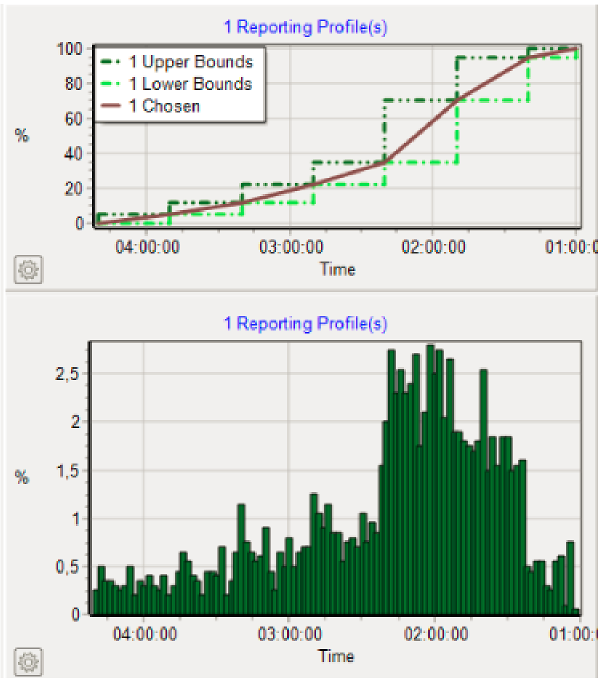

Figure 3.9 Entry Time Reporting Profile

Check-in reporting profile shows us when the passengers come to check-in area. This distribution varies according to domestic, international flights. When passenger arrives at an airport, as airline regulations require passengers to check in by certain times prior to the departure of a flight. This duration spans from 1 hour to 7 hours depending on the destination and airline. In the model, passengers without Gozen start arriving 5 hours before schedule time of their flights at check-in area in international terminal shown in Figure 3.10. All passengers arrive at check-in counters before 1 hour to their flights.

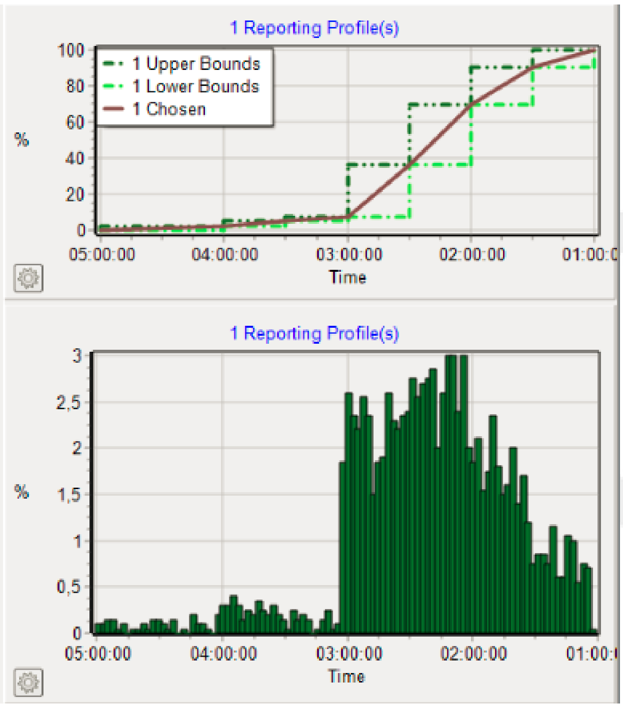

Figure 3.10 Check-in Reporting Profile without Gozen Security

Gate reporting time tells the passenger to go to gate lounge area. Before 15 minutes from the scheduled time, all passengers must be in their related gate lounges shown in Figure 3.11.

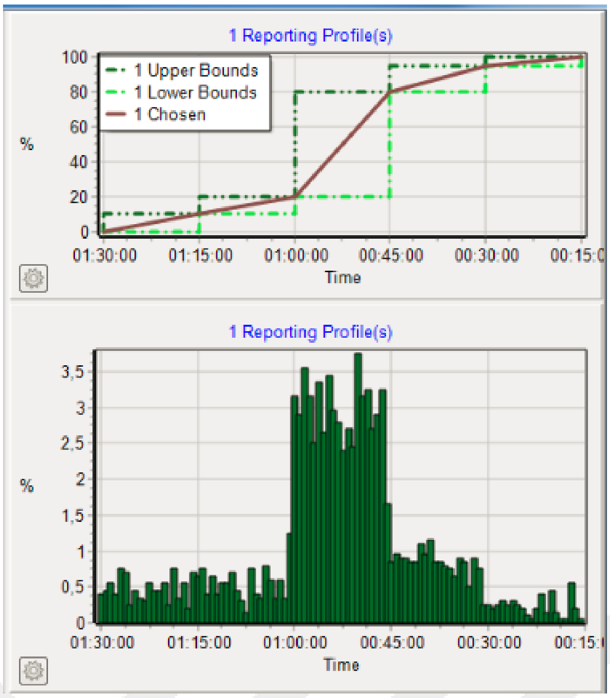

Figure 3.11 Gate Reporting Time

Between 10-20 minutes before the departure time for DirectDep and Transfer passengers, all passengers leave the simulation model. Figure 3.12 illustrates exit time for the entities.

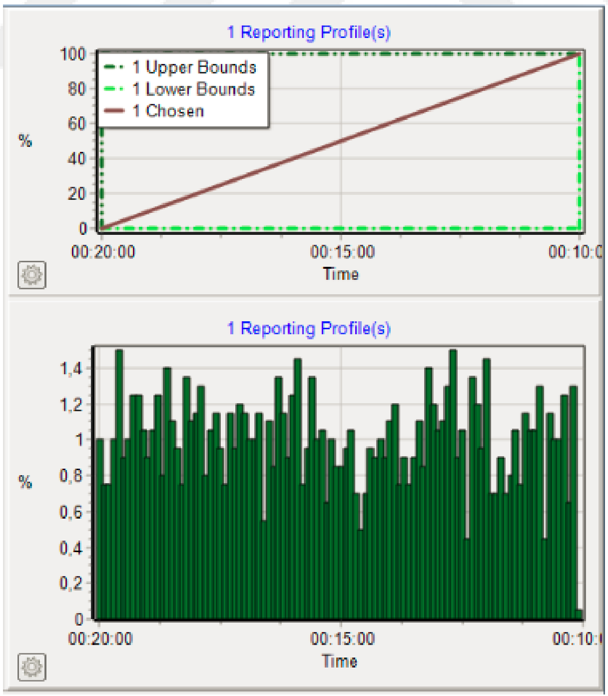

Figure 3.12 Exit Time Reporting Profile

Customs type, shown if figure 3.13, effects transfer passenger bags in the process flow. Passengers are transferred from international flights to domestic flights, they have to pick up their luggage and check them in again in domestic departure area if destination airport is not a customs airport. Otherwise, passengers are transferred directly to without picking their luggage up.

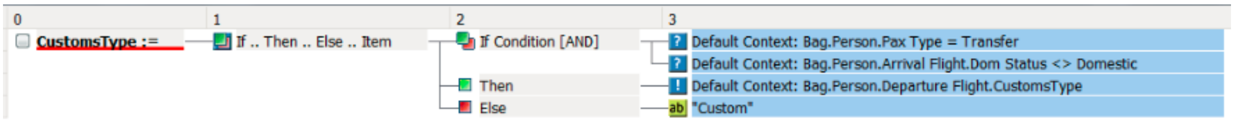

Figure 3.13 Customs Type

Bags are generated for passengers to go to bag drop area and belts.

Table 6 Bags property

	Shares	
Number of Bags to create	Arrival Country = TR	Arrival Country <> TR
0	50	10
1	30	50
2	20	30
3	-	10

Passport type is identified for two categories for Turkish and foreign passengers respectively as "Tur" and "NonTur" with 50 %- 50 % ratio. Passengers whose passenger passport type is Tur buy stamp before going to emigration passport to go to abroad. Figure 3.14 shows stamp property for passengers.

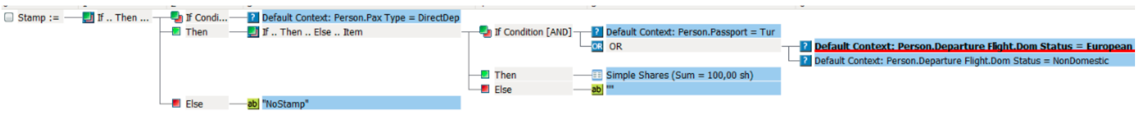

Figure 3.14 Stamp Property

Gaussian distribution has been used for the walking speed with the mean is 1 and standard deviation is 0.03.

3.2.4 Calibration and Validation

After the system has been modeled, the basic simulation runs are carried out based on calibration and verification in the next step. Calibration and validation are very important in order to the model is reliable. Used software allows experiments and multiple repetitions.

Debugging has been done with the installed model according to the technical structure of the software program. However, only this validation was not enough to detect the error. The movements in the system have been monitored in detail by running animations. In this way, the troubles and drawbacks in the system are understood. At each run, the system is monitored step by step and it was understood that it would cause a situation that would disrupt implementation for the process. These repetitions have great necessity for seeing missing or incorrect parts of the model.

Validation is the process of determining whether the generated model accurately reflects the events and problems in the real system. When the model being studied is analyzed for the identified problem and the stated purposes, it means that the model is verified when it is feasible. This validation has been done in common with the experts.

The results of the model should be well documented. So, it is easier to make comparisons between alternatives. As a result, animation and output graphs have been obtained by taking the waiting times with intervals of 5 minutes.

By modifying the input data, the results of the model and the comparison of the system's own results are important for evaluation.

CHAPTER 4

RESULTS

This section provides the outputs of the existing and proposed models. In the simulation model we investigated the services for passengers in the terminal and waiting times. Then, we propose three alternative scenario models for immigration passports and transfer security facilities. These alternative models have been offered to reduce waiting times and the simulation is run again to compare the solutions.

Small changes are done in the input parameters and the changes in the output of the model were investigated. According to results, it is seen that waiting times for immigration passport controls and International-International transfer security checkpoints should be decreased. So, it is helpful for the time that the passenger spends in the terminal. Unit numbers of the services are increased, different options are suggested and the results in the system are monitored.

In order to compare the alternatives regarding the existing system, it is necessary to modify and restart the model.

4.1 Simulation Results of Existing Model

The existing situation analysis has been done with the simulation. The waiting times for each process have been analyzed in the results.

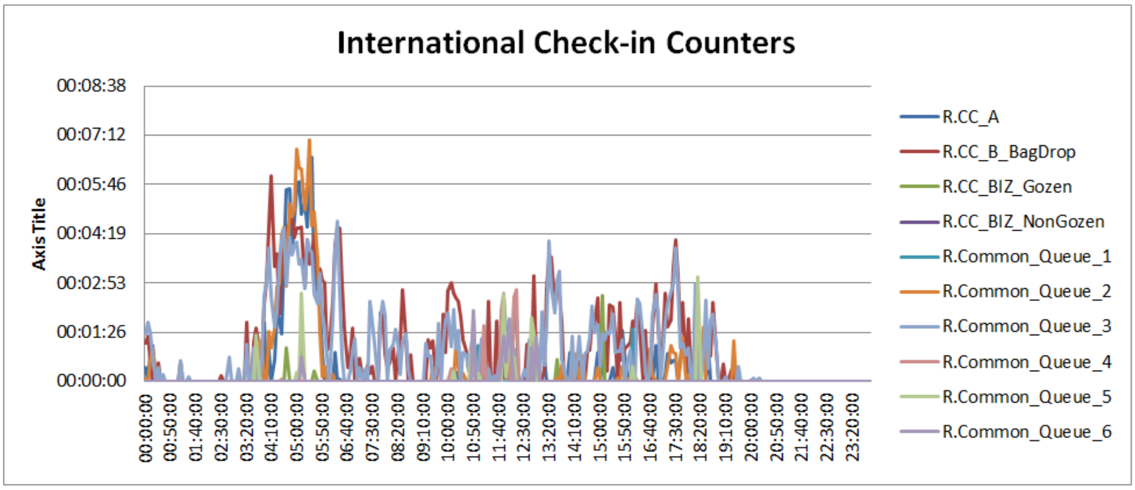

Figure 4.1 Waiting Time for International Check-in Counters

When passengers get service from international check-in counters, it has been observed that there are not too many queues.

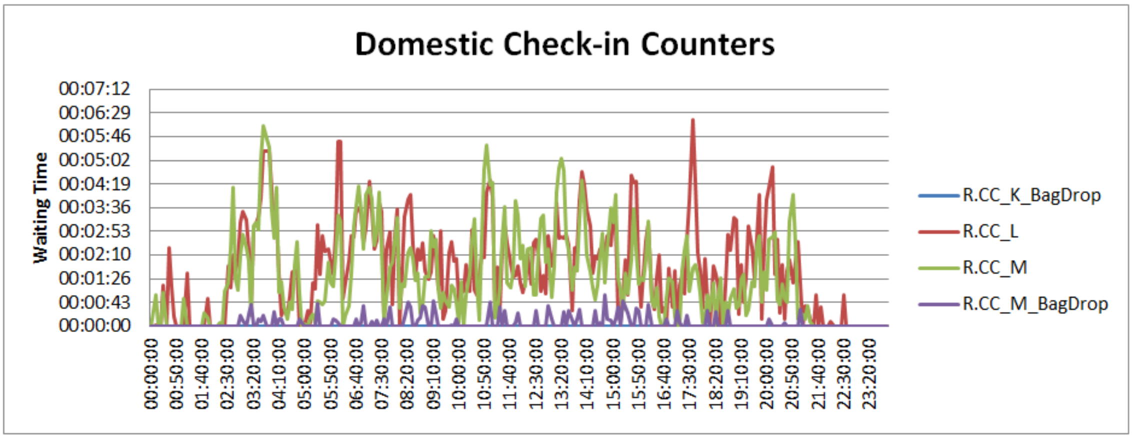

Figure 4.2 Waiting Time for Domestic Check-in Counters

At the domestic check-in counters, waiting time for the services could be acceptable.

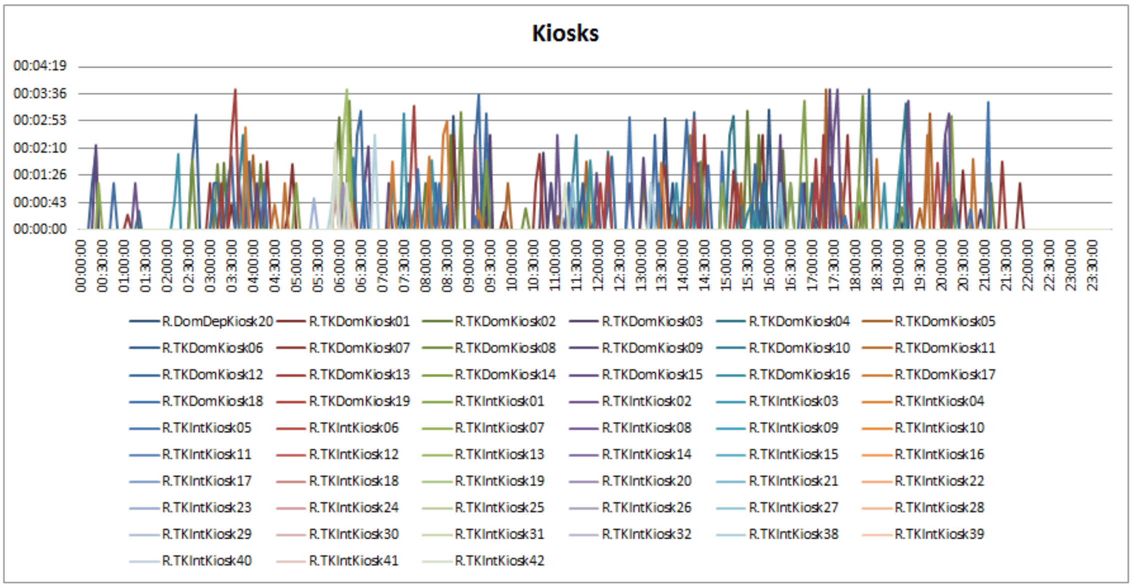

Figure 4.3 Waiting Time for Kiosks

There are enough kiosks in the system, which do not create a bottleneck.

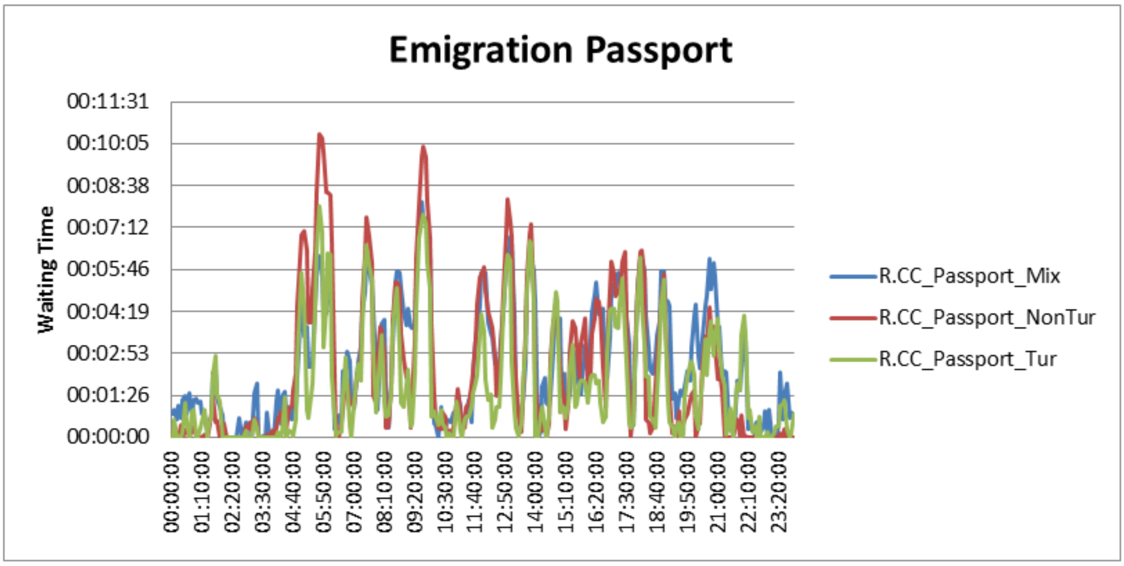

Figure 4.4 Waiting Time for Emigration Passports

At the emigration passport control points show that the waiting time is 8 minutes for Turkish citizens and 11 minutes for foreigners. X-ray security control services after passport controls must be open to avoid queuing.

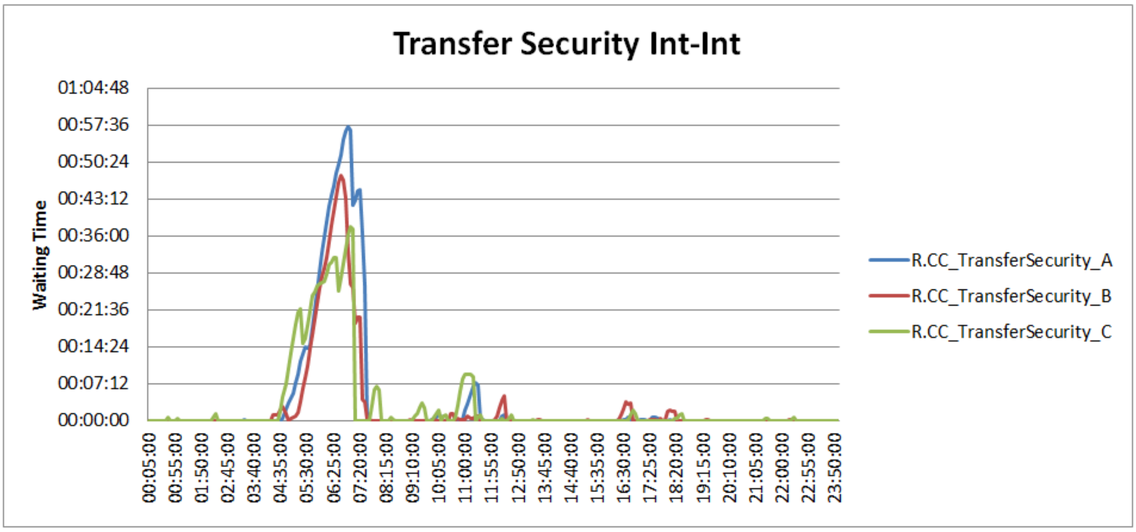

Figure 4.5 Waiting Time for International-International Transfer Security

In transfer x-rays, very long queue and much waiting times occur in earlier times.

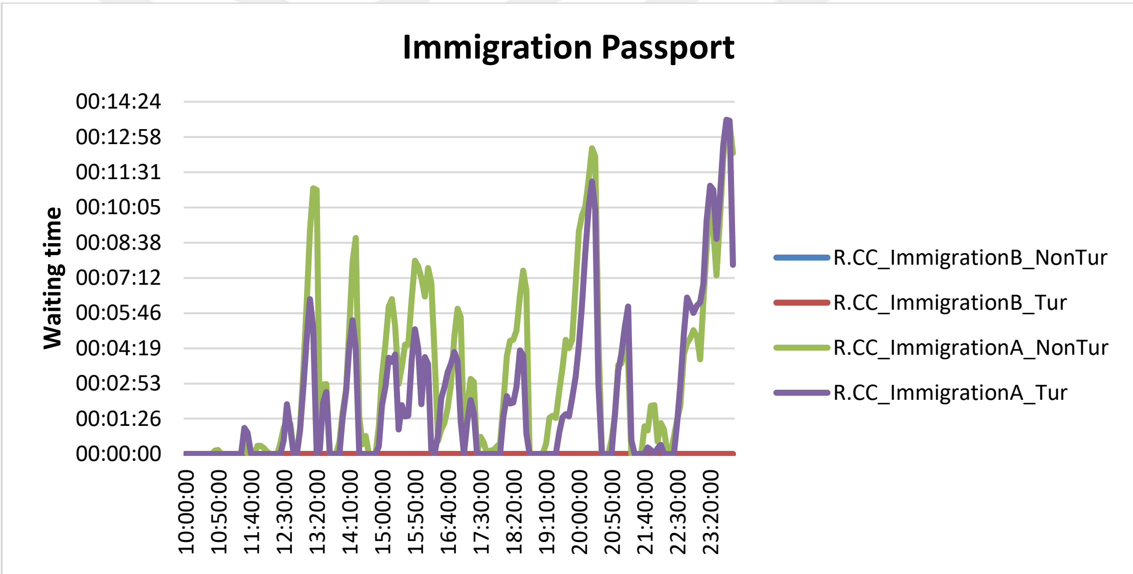

Figure 4.6 Waiting Time for Immigration Passports

Here, it is seen that there is not any queue at immigration passport control points of B area, because they are not in use. Passport control points should be opened at B area when flight waves are over the top.

Once a simulation model is available, it can be regularly updated and used to test, monitor and enhance the capacity of airport facilities. Simulation is also the preferred tool when it comes to assessing the provided Level of Service (LoS), a framework based on the available space per occupant and maximum waiting times at terminal processing units. Once a simulation model has been set up, it can be used as an experimental basis for various purposes. Experimenting in a virtual environment is far more cost-efficient than implementing and testing in the real world. Planning parameters can be corrected quickly in a virtual model without causing major costs whereas, in the real world, significant cost could be incurred by changing or rebuilding existing infrastructure [8].

Passenger Terminal Processor	SPACE STANDARDS FOR WAITING AREAS (m²/pax)			WAITING TIME STANDARDS FOR PROCESSING FACILITIES (Minutes) Economy Class			WAITING TIME STANDARDS FOR PROCESSING FACILITIES (Minutes) Business Class / First Class			PROPORTION OF SEATED OCCUPANTS (%)		
ADRM 9th Edition / **ADRM 10th Edition**	A B Over design	C Optimum	D E Suboptimum	A B Over design	C Optimum	D E Suboptimum	A B Over design	C Optimum	D E Suboptimum	A B Over design	C Optimum	D E Suboptimum
Public Departure Hall	>2.3	2.3	<2.3									
Check-in – Self-Service Boarding Pass / Tagging	>1.8	1.3 - 1.8	<1.3	0	0-2	>2	0	0 - 2	> 3			
Check-in – Bag Drop Desk (queue width 1.4 - 1.6 m)	>1.8	1.3 - 1.8	<1.3	0	0-5	> 5	0	0-3	>3			
Check-in – Check-in Desk (queue width 1.4 - 1.6 m)	>1.8	1.3 - 1.8	<1.3	<10	10-20	>20	Business Class Check-in Desk: < 3	3-5	> 5			
							First Class Check-in Desk: 0	0-3	>3			
Security Checkpoint (queue width: 1.2 m)	>1.2	1.0 - 1.2	<1	<5	5-10	>10	Fast Track: 0	0-3	>3			
Emigration (Passport Control) (queue width: 1.2 m)	>1.2	1.0 - 1.2	<1	<5	5-10	>10	Fast Track: 0	0-3	>3			
Boarding Gate Lounge – Seating	>1.7	1.5 - 1.7	<1.5									
Boarding Gate Lounge – Standing	>1.2	1.0 - 1.2	<1							>70%	50%-70% [1]	<50%
Immigration (Passport Control) (queue width: 1.2 m)	>1.2	1.0 - 1.2	<1	<10	10	>10	Fast Track: <5	5	>5			
Transfers				<5	5	>5	0	0-3	>3			
Baggage Claim Area – Narrow Body	>1.7	1.5 - 1.7	<1.5	First passenger to first bag: <0	0-15	>15	First passenger to first bag: 0	0-15	> 15			
Baggage Claim Area – Wide Body	>1.7	1.5 - 1.7	<1.5	<0	0-25	>25						
Public Arrival Hall	>1.7	1.2 - 1.7	<1.2				*n.b. Priority bags to be delivered before Economy*			>20%	15%-20% [1]	<15%
CIP Lounges		4.0										

[1] The lower limit is only to be considered if extensive F+B seating is provided in the departure lounge, or, concession zone seating available

Source: IATA

Figure 4.7 LoS Guidelines for Airport Terminal Facilities

IATA defines that the concept of LoS is an aggregated guidance framework for the planning of new terminal facilities as well as for monitoring the operational service performance of existing facilities shown in Figure 4.7 [44].

The level of service may be expressed in terms of waiting time per passenger for processing facilities, either as a maximum waiting time during the planning busy hour or as a percentage [45].

4.2 Simulation Results of Proposed Models

Improvements are suggested by determining the bottlenecks in the system with the help of simulation. According to existing model, it is seen that immigration passports and transfer securities, which are important service points for transfer passengers, need to be improved.

4.2.1 Scenario 1: Technological Solution: e-Passport

The immigration passport units are inadequate, especially with the arrivals of large-body aircraft. Automated e-passport gates for the immigration passport control may be a proper alternative instead of conventional passport controls to improve airport efficiency. These machines can do the job of a customs official quickly and effectively. After scanning passenger's e-passport at the barrier, the system runs a face-recognition check against the chip in the passport, and then if passenger is eligible to enter the country, the gate opens automatically. This type passport control is faster than the conventional passport control. In the alternative simulation model, transaction times for the some NonTur and Tur passport controls, have been decreased to 21 seconds and number of passports have been changed for this scenario. Figure 4.8 shows e-gates in the immigration hall [46].

Figure 4.8 E-gates in the Immigration Hall

For type of scenario 1, number of passports for Tur and NonTur are changed and simulation is run for each of them. Table 7 shows that total number of Tur and NonTur passports and waiting times for scenarios.

Table 7 Passport Numbers for Scenario 1

Tur Passports			**NonTur Passports**		
Scenario	Number	Waiting Time	Scenario	Number	Waiting Time
Scenario 1.1	5	02:34:38	Scenario 1.7	5	02:19:06
Scenario 1.2	7	00:24:00	Scenario 1.8	7	00:17:00
Scenario 1.3	8	00:15:00	Scenario 1.9	8	00:08:38
Scenario 1.4	9	00:06:22	Scenario 1.10	9	00:06:12
Scenario 1.5	10	00:02:52	Scenario 1.11	10	00:04:00
Scenario 1.6	11	0	Scenario 1.12	11	00:03:00

In scenario 1.1, 1.2, 1.3, 1.4, 1.5 and 1.6, number of Tur passports changed as respectively 5, 7, 8, 9, 10 and 11 and their transaction time decreased by around 25% because of e-passport. Waiting times for 5 Tur passports are seen in Figure 4.9.

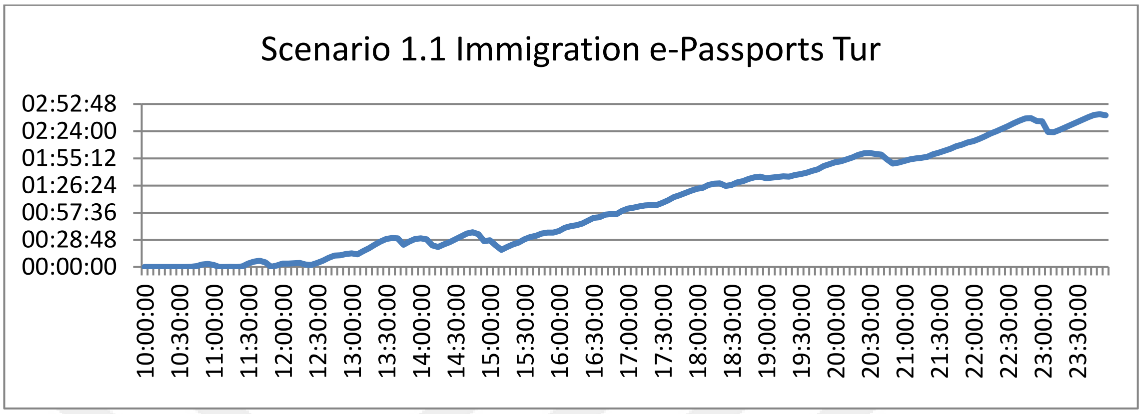

Figure 4.9 Immigration e-Passports Tur Scenario 1.1

Waiting times for 7 Tur passports are seen in Figure 4.10.

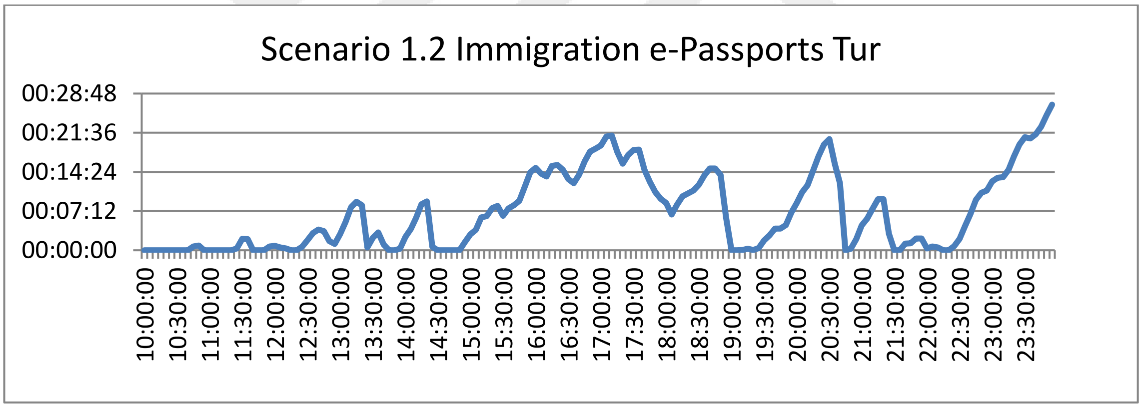

Figure 4.10 Immigration e-Passports Tur Scenario 1.2

Waiting times for 8 Tur passports are seen in Figure 4.11.

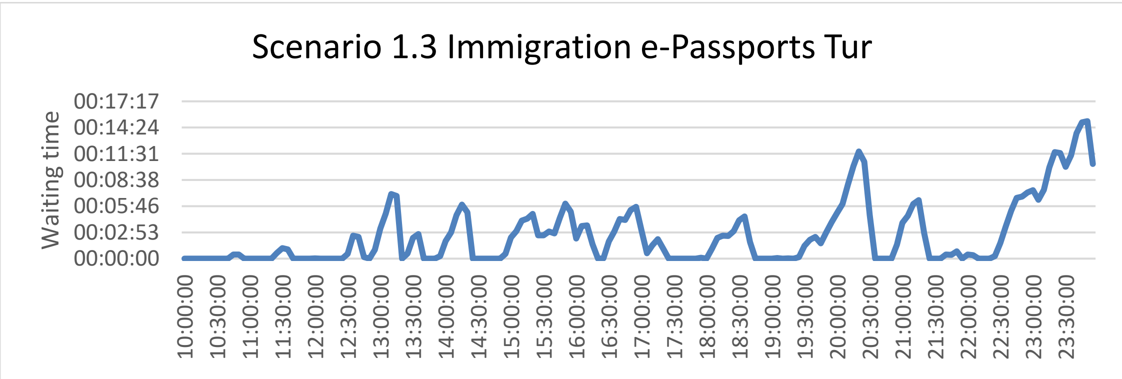

Figure 4.11 Immigration e-Passports Tur Scenario 1.3

Waiting times for 9 Tur passports are seen in Figure 4.12.

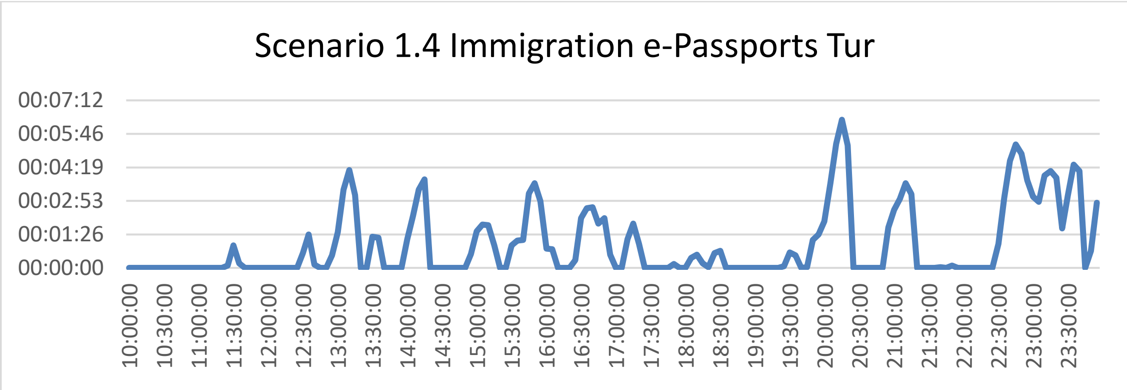

Figure 4.12 Immigration e-Passports Tur Scenario 1.4

Waiting times for 10 Tur passports are seen in Figure 4.13.

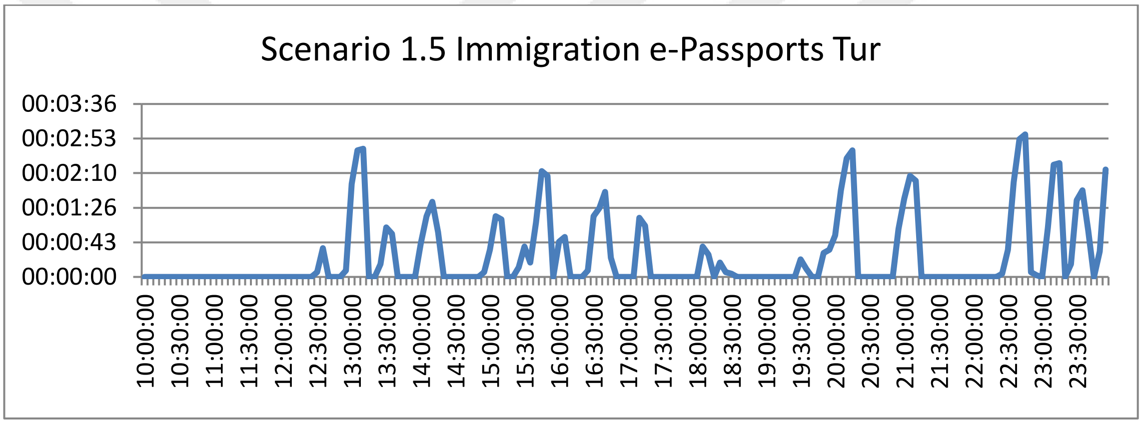

Figure 4.13 Immigration e-Passports Tur Scenario 1.5

In scenario 1.6, there is no queue for 11 Tur passports.

In scenario 1.7, 1.8, 1.9, 1.10, 1.11 and 1.12, number of NonTur passports changed as respectively 5, 7, 8, 9, 10 and 11 and their transaction time decreased by around 25% because of e-passport. Waiting times for 5 NonTur passports are seen in Figure 4.14.

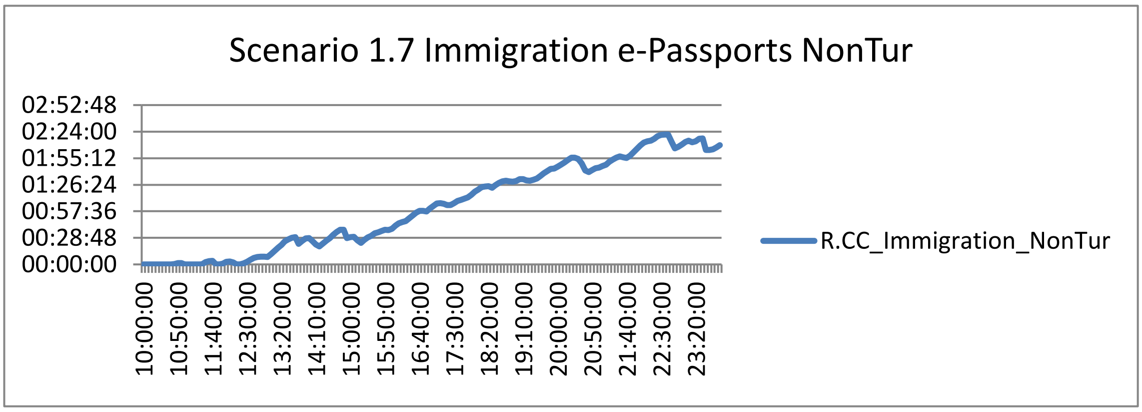

Figure 4.14 Immigration e-Passports NonTur Scenario 1.7

Waiting times for 7 NonTur passports are seen in Figure 4.15.

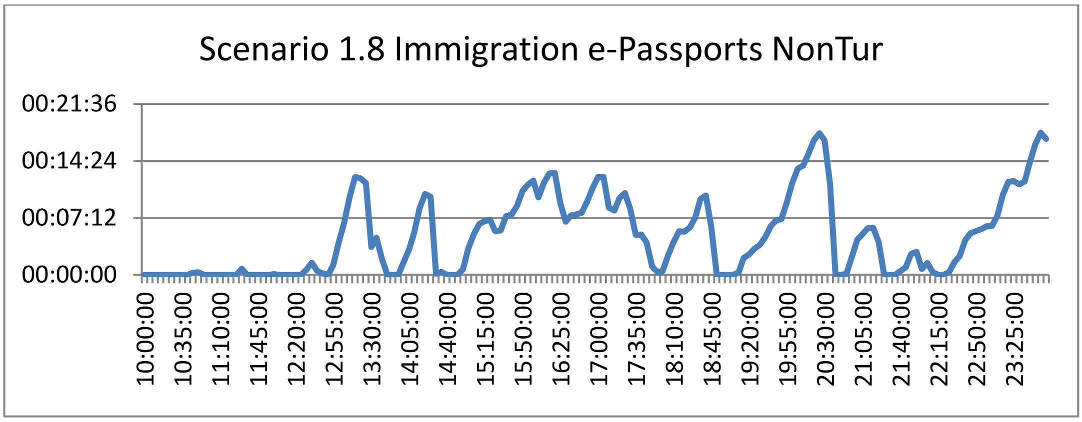

Figure 4.15 Immigration e-Passports NonTur Scenario 1.8

Waiting times for 8 NonTur passports are seen in Figure 4.16.

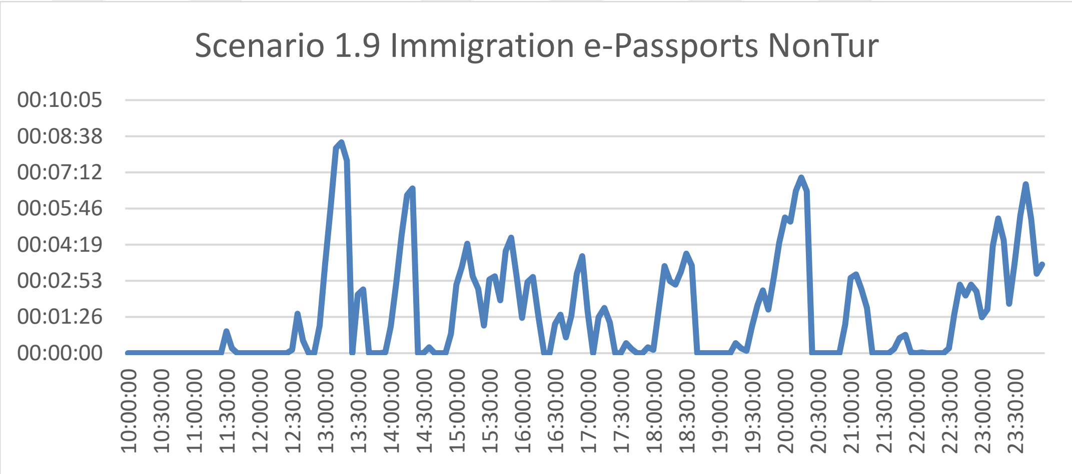

Figure 4.16 Immigration e-Passports NonTur Scenario 1.9

Waiting times for 9 NonTur passports are seen in Figure 4.17.

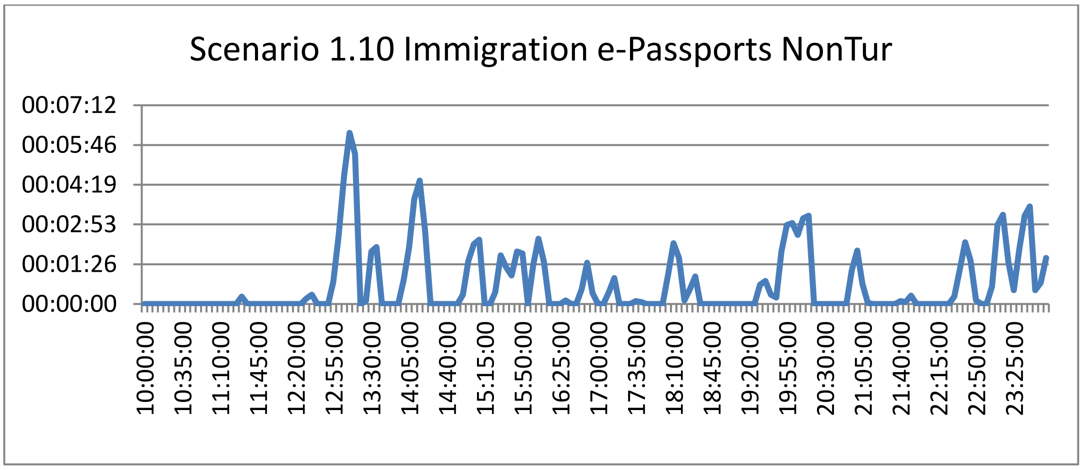

Figure 4.17 Immigration e-Passports NonTur Scenario 1.10

Waiting times for 10 NonTur passports are seen in Figure 4.18.

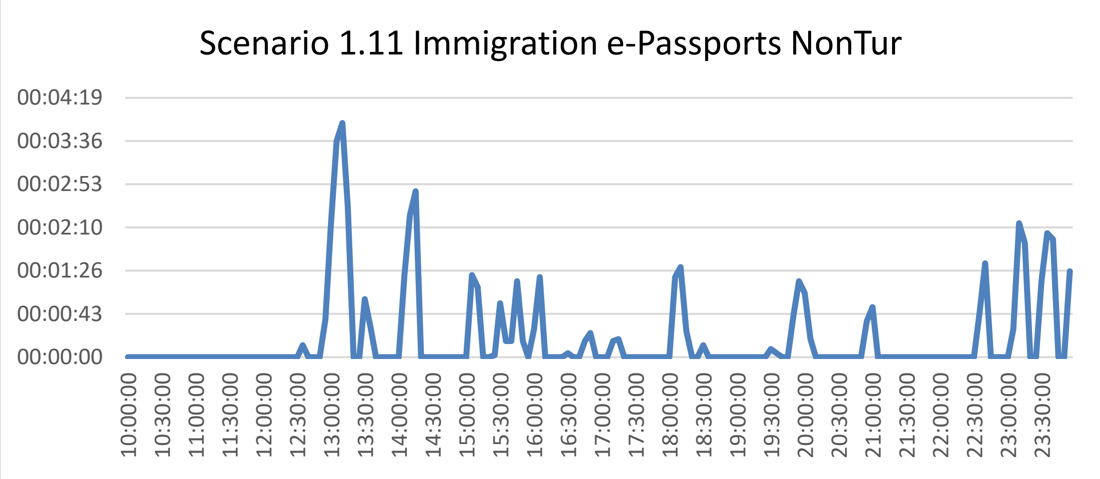

Figure 4.18 Immigration e-Passports NonTur Scenario 1.11

Waiting times for 11 NonTur passports are seen in Figure 4.19.

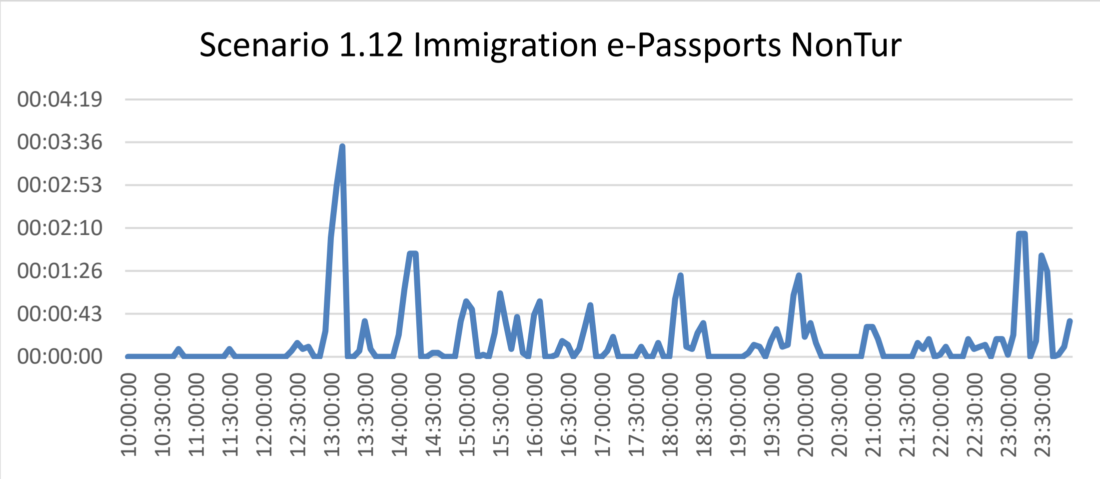

Figure 4.19 Immigration e-Passports NonTur Scenario 1.12

4.2.2 Scenario 2: Opening Immigration Passports in B Area

Arrival passports in B area are not open usually. Opening them at peak times will reduce the waiting period. In the alternative simulation model, transaction times for the NonTur and Tur passport controls do not change. In the scenario 2 of simulation model, 3 different models, which are scenario 2.1, scenario 2.2 and scenario 2.3, have been run. While number of passport controls in A area has not changed, number of passport controls in B area is increased and waiting times are obtained for each simulation run. 1 Turkish and 1 Non-Turkish immigration passports in the B area have been activated in addition to the others in scenario 2.1. 2 Turkish and 2 Non-Turkish immigration passports in the B area have been activated in addition to the others in scenario 2.2. 3 Turkish and 3 Non-Turkish immigration passports in the B area have been activated in addition to the others in scenario 2.3. Table 8 shows that how much is increased for passport control points in B area and their waiting times.

Table 8 Passport Numbers for Scenario 2

	A		B			
	Tur	**NonTur**	**Tur**		**NonTur**	
Scenario	Waiting Time	Waiting Time	Number	Waiting Time	Number	Waiting Time
Scenario 2.1	00:07:42	00:05:16	+1	00:17:02	+1	00:12:30
Scenario 2.2	00:01:28	00:02:48	+2	00:08:20	+2	00:07:26
Scenario 2.3	00:03:20	00:03:18	+3	00:10:12	+3	00:09:00

In scenario 2.1, waiting times in A and B area are seen in the figure below with additional 1 control point for Tur and NonTur passports in B area.

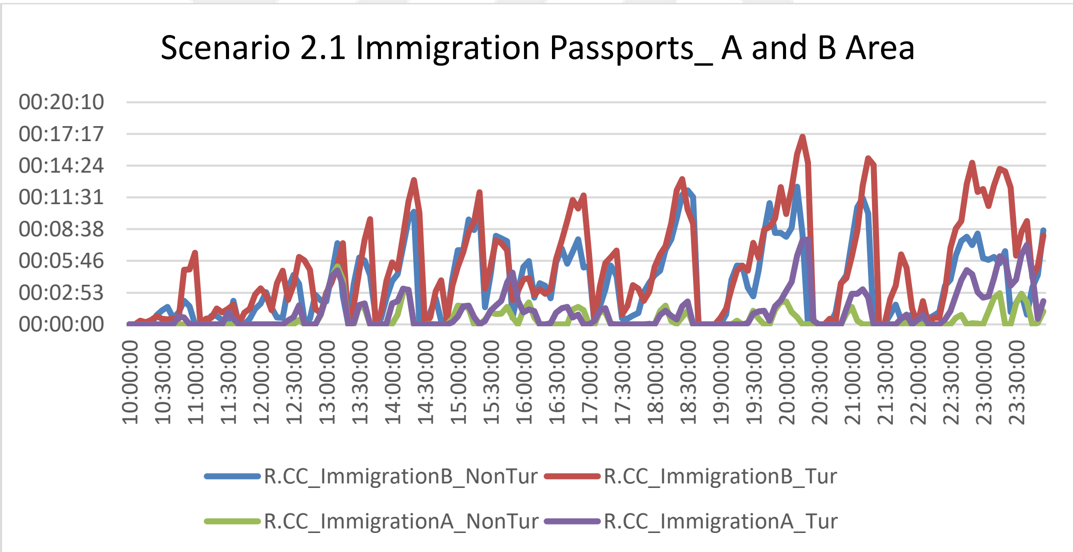

Figure 4.20 Immigration Passports Scenario 2.1

In scenario 2.2, waiting times in A and B area are seen in the figure below with additional 2 control points for Tur and NonTur passports in B area.

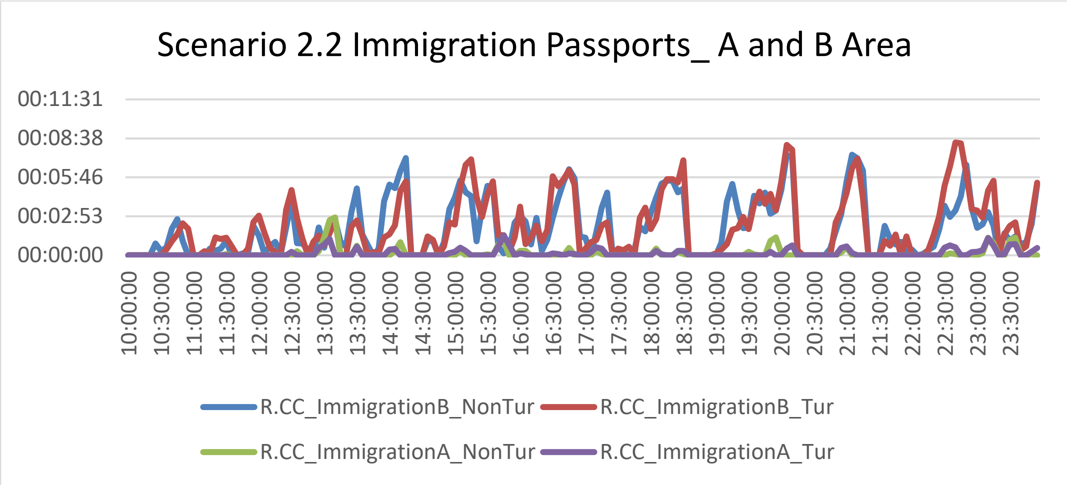

Figure 4.21 Immigration Passports Scenario 2.2

In scenario 2.3, waiting times in A and B area are seen in the figure below with additional 3 control points for Tur and NonTur passports in B area.

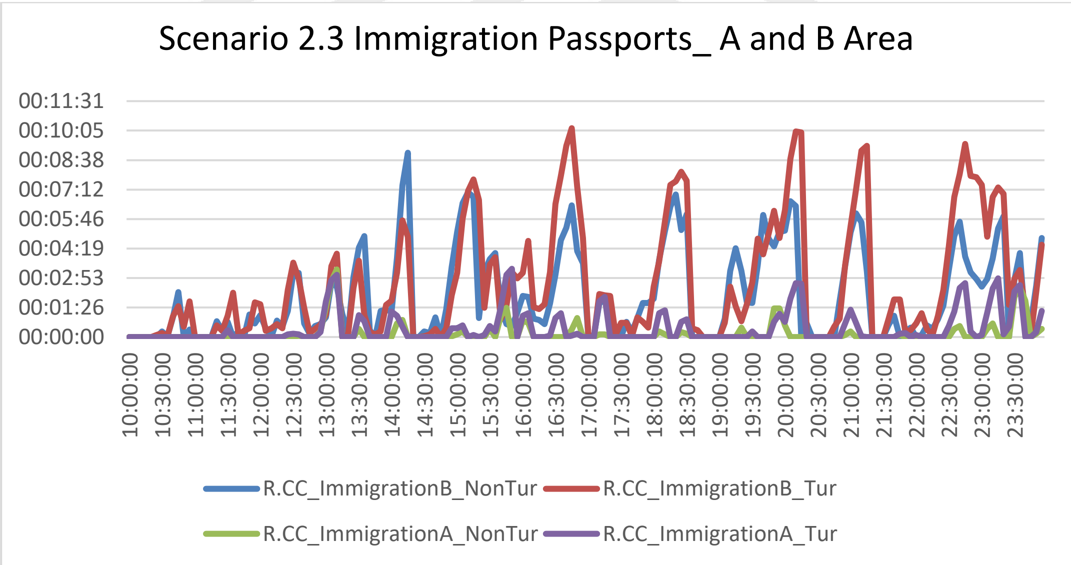

Figure 4.22 Immigration Passports Scenario 2.3

4.2.3 Scenario 3: Opening Transfer X-Ray Security

For type of scenario 3, number of transfer X-ray securities are increased and waiting times are obtained for each simulation run.

Table 9 shows that how much is increased for transfer securities in area A, B and C and their waiting times.

Table 9 Transfer Security Scenario

	Transfer Security_A		**Transfer Security_B**		**Transfer Security_C**	
Scenario	Number	Waiting Time	Number	Waiting Time	Number	Waiting Time
Scenario 3.1	+5	00:11:38	+5	00:16:32	+4	00:03:34
Scenario 3.2	+6	00:09:08	+6	00:12:10	+5	00:01:38
Scenario 3.3	+6	00:08:12	+6	00:11:02	+6	00:00:20
Scenario 3.4	+7	00:07:46	+6	00:08:58	+2	00:10:44
Scenario 3.5	+7	00:07:28	+6	00:08:58	+3	00:06:28
Scenario 3.6	+7	00:07:00	+7	00:07:00	+3	00:06:00
Scenario 3.7	+8	00:05:18	+8	00:05:04	+6	00:00:26
Scenario 3.8	+10	-	+10	-	+6	-

Location of transfer securities in C area are quite far away from A and B areas and passengers are more oriented to A and B areas. Therefore, waiting times in A and B areas are higher than C area.

In the scenario 3.1 of simulation model, total 14 security services (5 security services in area A, 5 security services in Area B and 4 security services in area C) have been activated in addition to the others. After the simulation has run again, the peak waiting time decreased to around 17 minutes as seen in the figure below.

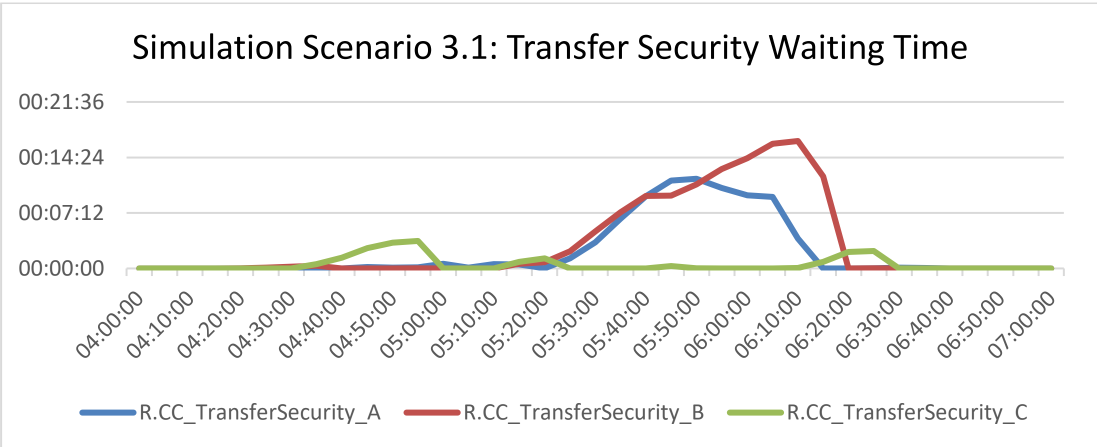

Figure 4.23 Transfer X-Ray Scenario 3.1

In the scenario 3.2 of simulation model, total 17 security services (6 security services in area A, 6 security services in Area B and 5 security services in area C) have been activated in addition to the others. After the simulation has run again, the peak waiting time decreased to around 12 minutes as seen in the figure below.

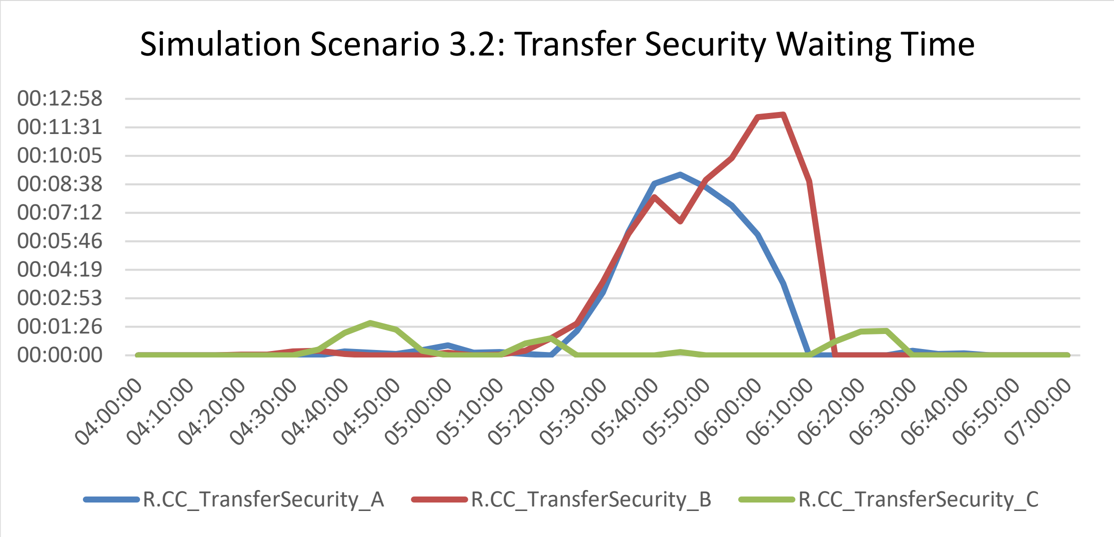

Figure 4.24 Transfer X-Ray Scenario 3.2

In the scenario 3.3 of simulation model, total 18 security services (6 security services in area A, 6 security services in Area B and 6 security services in area C) have been activated in addition to the others. After the simulation has run again, the peak waiting time decreased to around 11 minutes as seen in the figure below.

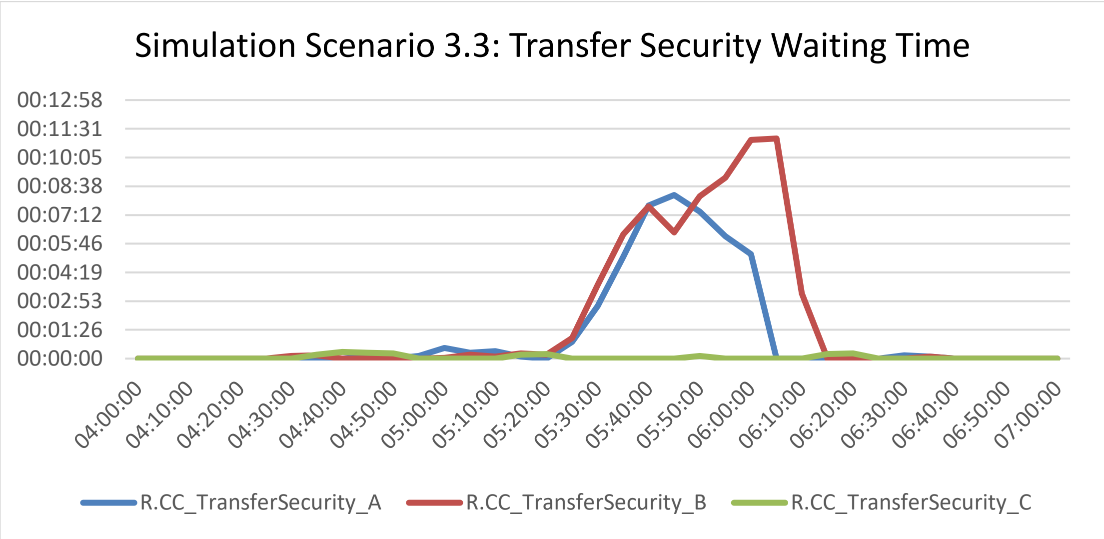

Figure 4.25 Transfer X-Ray Scenario 3.3

In the scenario 3.4 of simulation model, total 15 security services (7 security services in area A, 6 security services in Area B and 2 security services in area C) have been activated in addition to the others. After the simulation has run again, waiting times are seen in the figure below.

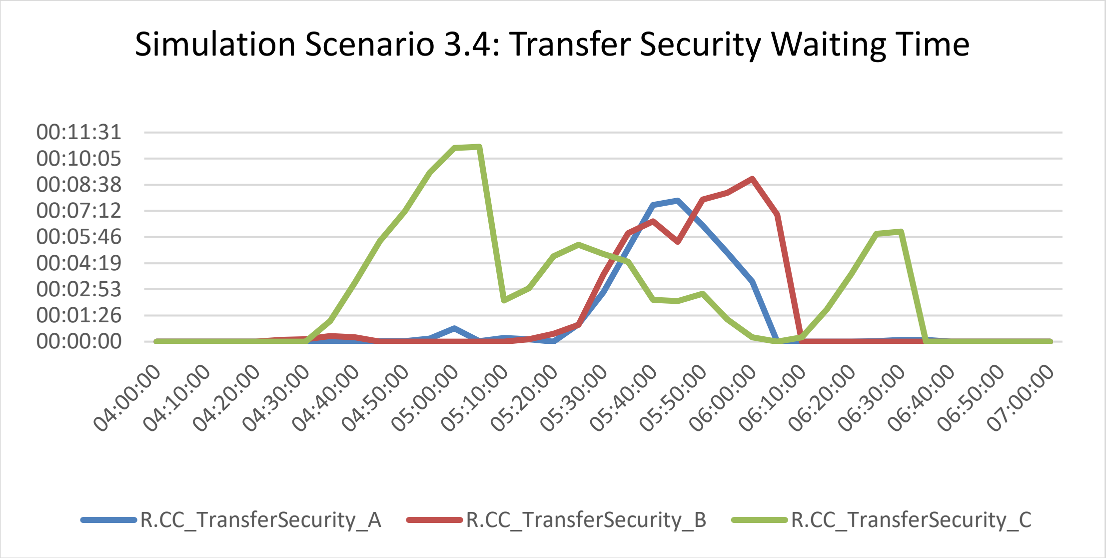

Figure 4.26 Transfer X-Ray Scenario 3.4

In the scenario 3.5 of simulation model, total 16 security services (7 security services in area A, 6 security services in Area B and 3 security services in area C) have been activated in addition to the others. After the simulation has run again, waiting times are seen in the figure below.

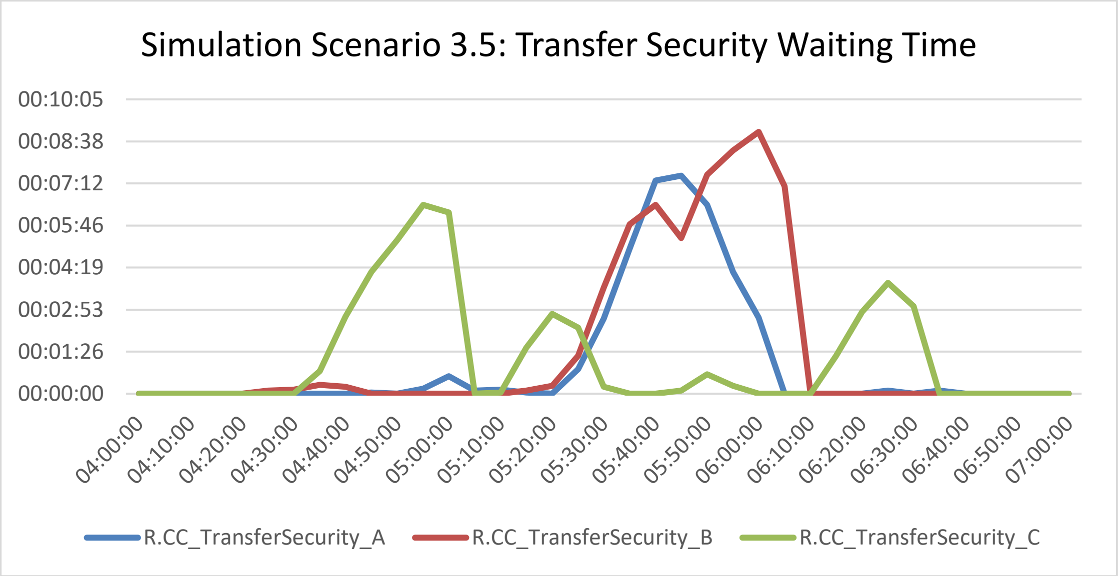

Figure 4.27 Transfer X-Ray Scenario 3.5

In the scenario 3.6 of simulation model, total 17 security services (7 security services in area A, 7 security services in Area B and 3 security services in area C) have been activated in addition to the others. After the simulation has run again, waiting times are seen in the figure below.

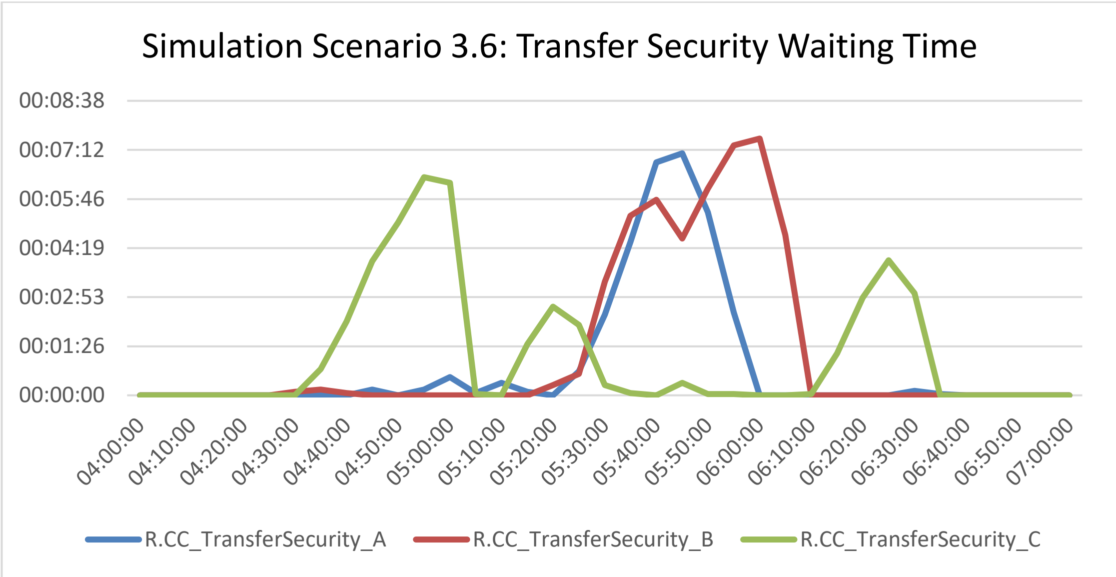

Figure 4.28 Transfer X-Ray Scenario 3.6

In the scenario 3.7 of simulation model, total 22 security services (8 security services in area A, 8 security services in Area B and 6 security services in area C) have been activated in addition to the others. After the simulation has run again, waiting times are seen in the figure below.

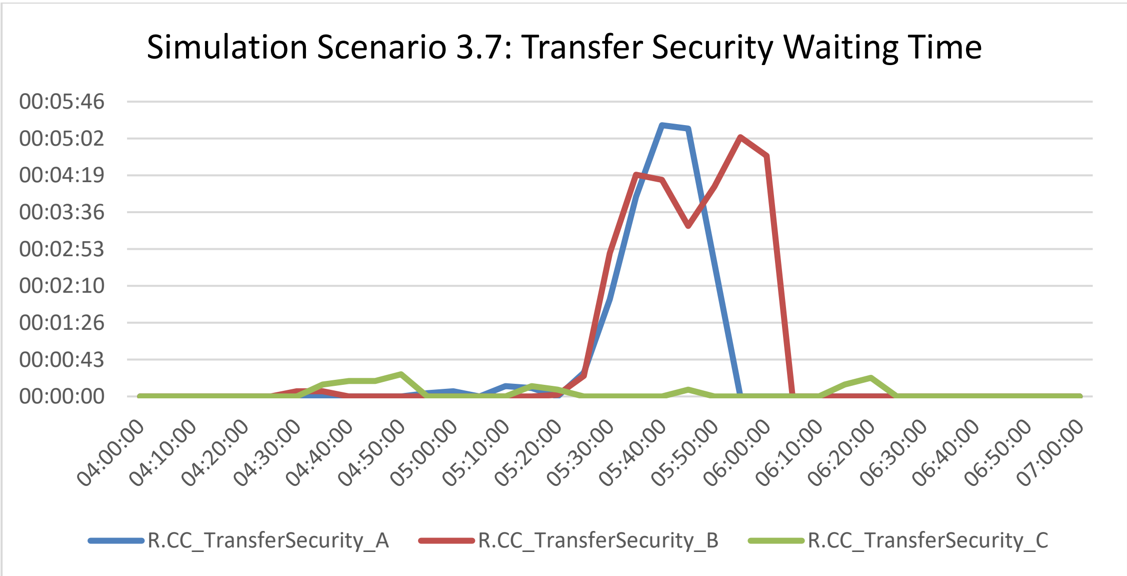

Figure 4.29 Transfer X-Ray Scenario 3.7

In addition to these scenarios, one more scenario called simulation scenario 3.8 has been implemented. In scenario 3.8 of simulation model, 10 security services in area A, 10 security services in Area B and 6 security services in area C have been activated in addition to the others. After the simulation has run again, there has been no queue or no waiting.

4.3 Comparison of Results

According to the scenarios, immigration passports and transfer security services are analyzed by comparing alternatives.

4.3.1 Comparison of Immigration Passport Scenarios

Waiting times of immigration passports have been compared according to the alternatives done in scenario 1. Scenario 1.4 is desired level for Tur passports shown below.

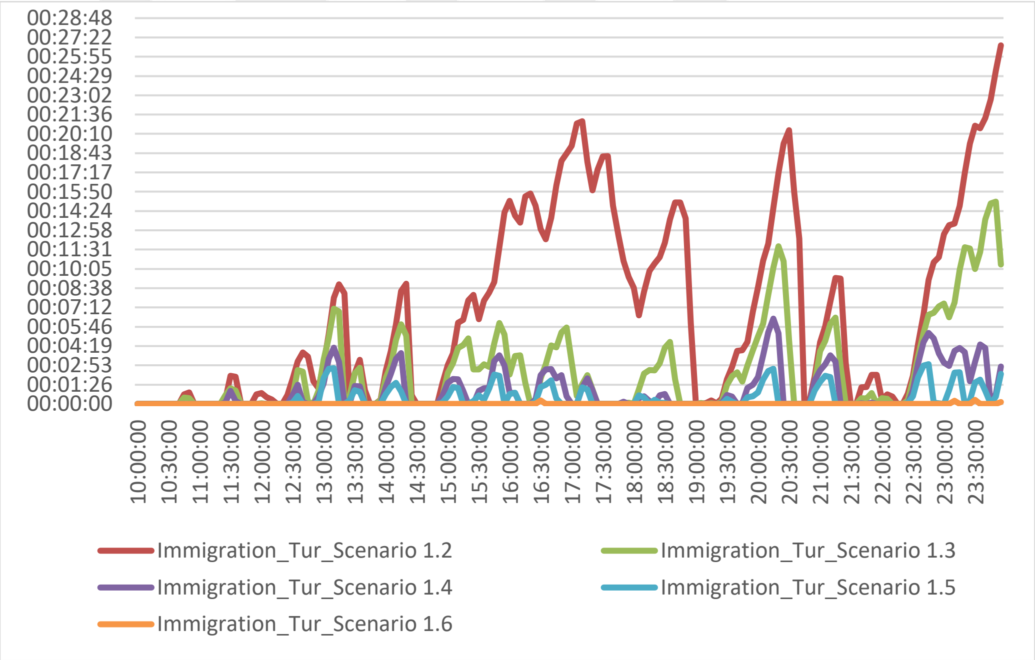

Figure 4.30 Comparison of Immigration Passport Tur Scenarios

Scenario 1.9 is desired level for NonTur passports shown below.

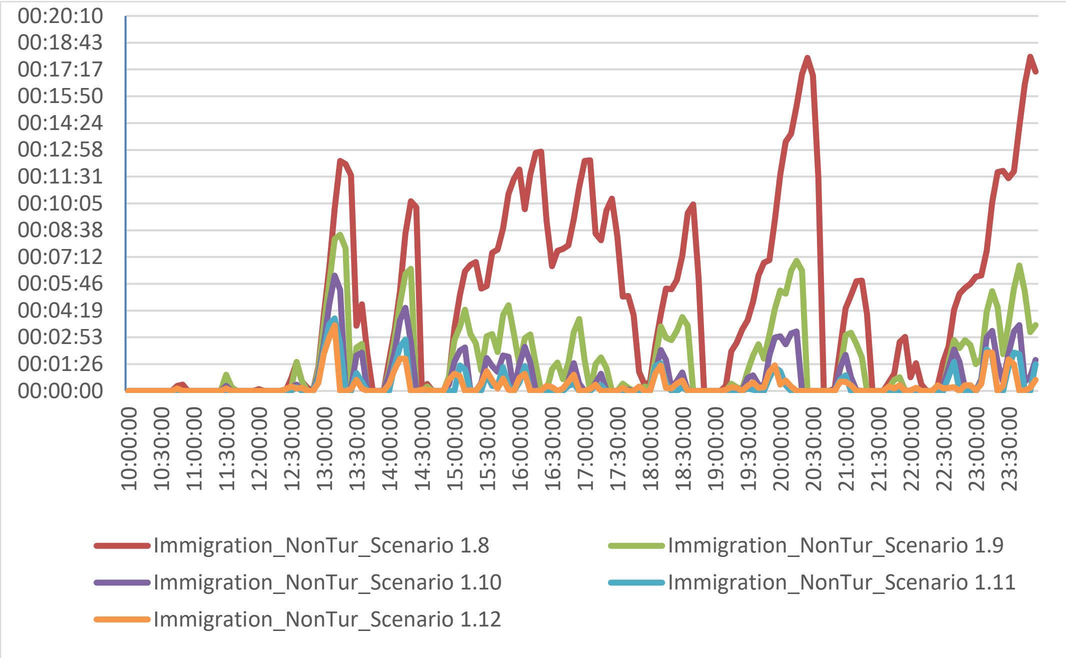

Figure 4.31 Comparison of Immigration Passport NonTur Scenarios

Moreover, waiting times of immigration passports have been compared according to the alternatives done in scenario 2. Scenario 2.2 is also desired level for passports in A and B areas.

4.3.2 Comparison of Transfer Security Scenarios

In the created Scenario 3, the waiting times of transfer securities have been compared. The most important and critical bottleneck in the system is the transfer security X-rays that can be understood from the results of the simulation. Figure 4.5 shows that waiting times requested by transfer passengers are concentrated between 04:00-07:00 hours. According to the LoS guideline, waiting for 10 minutes as serving transfer security checkpoints is acceptable and determined as optimum level. Therefore, simulation scenario 3.4 with its additional transfer security number and waiting times is the best solution with regard to the study.

CHAPTER 5

CONCLUSIONS AND DISCUSSION

The aviation industry is one of the fastest growing sectors of the world. In Turkey, it has also made a great leap in recent years. As a result of investments with increasing number of passengers, the terminals have been brought to a contemporary structure. It is necessary to use modelling methods in order to manage these sophisticated systems in accordance with the developing techniques. It is understood that the appropriate solutions can be found through simulation in terms of providing both customer satisfaction at the airports and provision of the service qualities of the airlines.

Time is very important for the service expected from airlines. In order to be at an adequate level of service, it is important that the hub airports used by airlines with high passenger density should be also sufficient capacity. With this study, it is seen that capacity is important factor when planning the facility. It is observed that Istanbul Atatürk Airport experiences capacity issues during some time intervals in this thesis study. The aim is to be able to create a more efficient system, to produce ideas and to present solution proposals.

The results of waiting times for each models can be obtained in a short span of time. The airport terminal system, which has periodically different system parameters, can be transformed into a dynamic business structure in the light of the studies on the simulation model. Passport control and transfer security points in arrival have been obtained as bottlenecks in the system. It can be seen that it is possible to make improvements by arranging the unit numbers of different services and technological infrastructure in simulation scenarios.

The model is flexible enough to be used for any number of passengers. When planning the system, the conditions and constraints in subsystems should be considered.

Coordinated planning work by airports and airline companies in dynamic construction will provide efficiency in high-density services such as transfer processes and passports.

This study has shown that process improvement activities has to be carried out at airports such as simulation. Moreover, new technological developments affect the process positively. Particularly, e-passports will decrease the processing times of passports.

Consequently, airport terminals are a large set of systems and should be conducted in coordination with airline companies. When planning related to the system, the conditions in the subsystems should be considered. A simulation model has been established for all queuing systems in the passenger flow at the airport terminal and improvements have been proposed by studying simulation models. With the models presented, less waiting time is obtained for customer satisfaction. The approach of models provide an useful decision support for hub airports. This study makes it possible to make estimates for other airlines and airports and to reduce the uncertainties in front of airline industry players.

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APPENDIX-A

ECAC AIRPORT CODES

In Table A.1, the area codes for different subjects are listed. The first column of the Table B.1 shows the name of the country and the other columns are for the codes of these countries.

Table A.1 ECAC Airport codes

AIRPORT CODE	DOM/INT	ECAC
TIA	INT	ECAC
VIE	INT	ECAC
GRZ	INT	ECAC
SZG	INT	ECAC
KVD	INT	ECAC
GYD	INT	ECAC
NAJ	INT	ECAC
BRU	INT	ECAC
SJJ	INT	ECAC
SOF	INT	ECAC
VAR	INT	ECAC
ZAG	INT	ECAC
ECN	INT	ECAC
PRG	INT	ECAC
AAL	INT	ECAC
BLL	INT	ECAC
CPH	INT	ECAC
TLL	INT	ECAC
HEL	INT	ECAC
SKP	INT	ECAC

Table A.1 (cont'd)

TLS	INT	ECAC
CDG	INT	ECAC
NCE	INT	ECAC
MRS	INT	ECAC
BOD	INT	ECAC
LYS	INT	ECAC
BUS	INT	ECAC
TBS	INT	ECAC
TXL	INT	ECAC
BRE	INT	ECAC
CGN	INT	ECAC
DUS	INT	ECAC
FRA	INT	ECAC
MUC	INT	ECAC
FDH	INT	ECAC
FMO	INT	ECAC
HAM	INT	ECAC
HAJ	INT	ECAC
LEJ	INT	ECAC
NUE	INT	ECAC
FKB	INT	ECAC
STR	INT	ECAC
ATH	INT	ECAC
SKG	INT	ECAC
BUD	INT	ECAC
DUB	INT	ECAC
NAP	INT	ECAC
GOA	INT	ECAC
CTA	INT	ECAC
PSA	INT	ECAC
BLQ	INT	ECAC
FCO	INT	ECAC
MXP	INT	ECAC
VCE	INT	ECAC
BRI	INT	ECAC
TRN	INT	ECAC

Table A.1 (cont'd)

RIX	INT	ECAC
VNO	INT	ECAC
LUX	INT	ECAC
MLA	INT	ECAC
KIV	INT	ECAC
TGD	INT	ECAC
AMS	INT	ECAC
RTM	INT	ECAC
OSL	INT	ECAC
WAW	INT	ECAC
OPO	INT	ECAC
LIS	INT	ECAC
OTP	INT	ECAC
CND	INT	ECAC
BEG	INT	ECAC
LJU	INT	ECAC
MAD	INT	ECAC
BCN	INT	ECAC
AGP	INT	ECAC
SCQ	INT	ECAC
BIO	INT	ECAC
VLC	INT	ECAC
ARN	INT	ECAC
GOT	INT	ECAC
BSL	INT	ECAC
GVA	INT	ECAC
ZRH	INT	ECAC
KBP	INT	ECAC
DNK	INT	ECAC
DOK	INT	ECAC
IFO	INT	ECAC
KHE	INT	ECAC
ODS	INT	ECAC
SIP	INT	ECAC
LWO	INT	ECAC
OZH	INT	ECAC

Table A.1 (cont'd)

BHX	INT	ECAC
LGW	INT	ECAC
LHR	INT	ECAC
MAN	INT	ECAC

APPENDIX-B

CUSTOMS AIRPORT CODES

In Table B.1, the airport codes are listed. The first column of the Table B.1 shows the name of the country and the other columns are for the codes of these countries.

Table B.1 Customs Airport codes

AIRPORT CODE	DOM/INT	ECAC	CUSTOMS CONTROL
ADA	DOM	-	CUSTOMS
ADB	DOM	-	CUSTOMS
AYT	DOM	-	CUSTOMS
IST	DOM	-	CUSTOMS
ERZ	DOM	-	CUSTOMS
DNZ	DOM	-	CUSTOMS
SZF	DOM	-	CUSTOMS
DLM	DOM	-	CUSTOMS
DIY	DOM	-	CUSTOMS
EZS	DOM	-	CUSTOMS
ASR	DOM	-	CUSTOMS
ERC	DOM	-	CUSTOMS
ESB	DOM	-	CUSTOMS
GZT	DOM	-	CUSTOMS
KYA	DOM	-	CUSTOMS
MLX	DOM	-	CUSTOMS
BJV	DOM	-	CUSTOMS
SAW	DOM	-	CUSTOMS
VAS	DOM	-	CUSTOMS
TZX	DOM	-	CUSTOMS
HTY	DOM	-	CUSTOMS
GNY	DOM	-	CUSTOMS
NAV	DOM	-	CUSTOMS
KZR	DOM	-	CUSTOMS
ISE	DOM	-	CUSTOMS
OGU	DOM	-	CUSTOMS
GZP	DOM	-	CUSTOMS

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PUBLISHMENTS

Conference Papers

Hub Havaalanında Terminal Simülasyon Modeli- YAEM 2017

Projects

Quality Function Deployment Application for Ground Operations of Turkish Airlines

AWARDS

1. Best Design Project Award
2. Honor Degree / Graduated in 3rd place