Sensitivity analysis of counter utilization in an airport terminal

by

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Executive Summary

Virtual Consultant Engineering is a multi-disciplined organization and was established in 1999. Currently they are situated across South Africa with offices in Pretoria, Durban and Cape Town. They have a variety of projects running from Infrastructure maintenance to project management services.

For a new project they are developing a design proposal for an upgraded airport at Lanseria. The new design will differ a considerable amount from the current airport. The idea is to develop an airport, which will be able to control the same capacity and even more as O.R. Tambo International.

In this project the passenger queue time will be observed using simulation techniques. The influence the number of checkpoints have on the system will be monitored. There are also possibilities of constraints in the process, which is identified and given possible solutions through constraint management. The time it will take a passenger from the terminal to the specific boarding station is calculated. Queuing Theory is used to explain the concept of a system. Time studies is done since it depicts what is actually happening in the system. The model provides passenger flow analysis obtained by using the simulation and generate trends for future references.

New methodologies of biometric technology currently being tested on the market is investigated. In the simulation model, these methodologies is implemented to observe the affect it have on the system.

Four different processes is used in the project. Sensitivity analysis is done on each of these process to identify the influence the changes in the system parameters have on the process. The utilization of the process counters is compared to the number of counters and the queue time of the passengers.

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1. Introduction and Background

Virtual Consulting Engineering was established in 1999 as a professional project management consultancy under the name 'Virtual Buro'. Over the years the multi disciplinary company has been a leading force as project managers on several projects, which among others includes employment creation, infrastructure maintenance and infrastructure provision programs.

As a turn-key service provider, Virtual Consulting Engineers offers clients a complete, inclusive range of consulting engineering and project and program management services. The company is active in various sectors, as illustrated below:

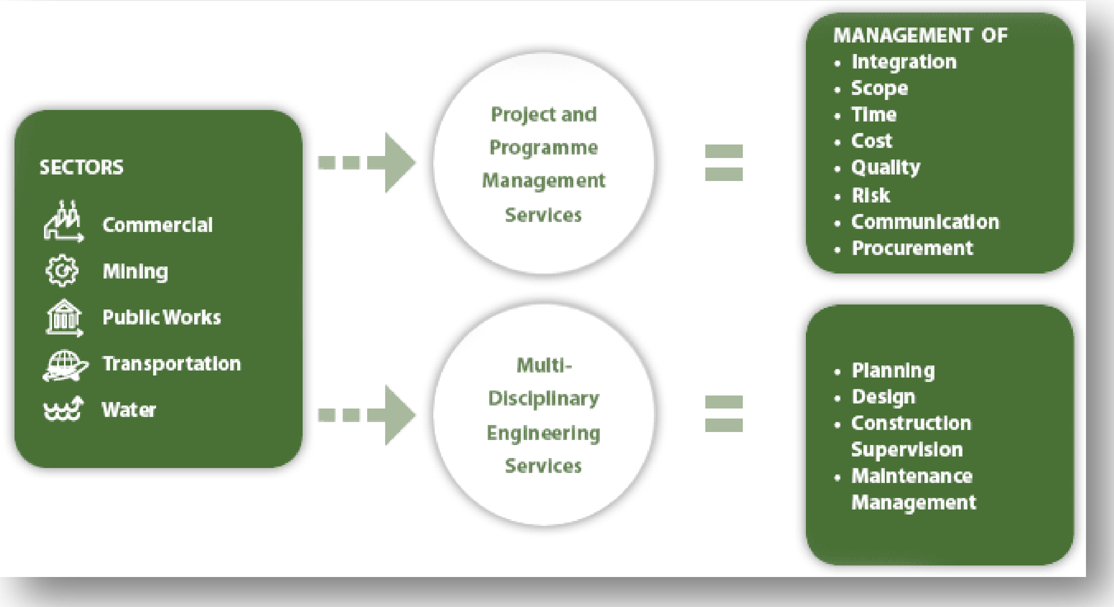


Figure 1: Illustration of active sectors

Virtual Consultant Engineering is currently developing a design proposal for a new airport for Lanseria. The new design will render a whole new concept of Lanseria, since the airport will be considerably larger than the current airport. The project's aim is increase the capacity and size to be equal or even larger than O.R. Tambo International.

The new design will consist of a terminal and several piers. Various boarding station will be allocated in the piers. Each pier will consist of two levels, an arrival level and a departure level. The arrival process in the international piers will be divided into South African passport holders and international passport holders. There will be different piers for international and domestic flights, since there is a difference in processing these passengers. The transportation from the terminal to the various piers will be under ground.

Different processes are simulated. The two main processes are domestic and international. The simulation is built to simulate the arrivals for one or two flights respectively for each of the main processes. The arrivals occur over a period of two hours. The amount of passengers in the system is equal to the amount of passengers boarding an aircraft.

The dwelling time of passengers is not included in the simulation. Dwelling time is used when the area capacity is calculated, which is not included in the project.

2. Project Aim

The aim of the project is to investigate the throughput of the terminal and determine the influence the number of checkpoints have on the system by using simulation techniques. By making the checkpoints the variable in the simulation model, the airport can identify the optimum utilization of the different counters and the influence it have on the queuing time. The bottlenecks of the system are identified and possible solutions suggested. Another requirement for this project is to determine the traveling time from the terminal to a boarding station. Sensitivity analysis is done on the utilization of each type of process counter and the effect it has on the queuing time in the check-in process.

3. Project Scope

There are various aspects to consider in the project. An explanation of Queuing Theory gives an understanding of how a system work in terms of arrivals, services and departures. The peak times in the terminal is determined through time studies. Other new methodologies of biometric technology on decreasing queue lengths that is currently being tested on the market is tested in the simulation. The effect the new methodologies have on the system is investigated. The number of checkpoints is a variable in the simulation; to determine the effect the amount of counters have on the passenger queuing time. The results of the sensitivity analysis is used to indentify constraints in the system. Domestic and International piers should be taken into consideration, since there is a difference between the related processes. Only departures for both domestic and international will be investigated.

The project scope does not include a practical implementation.

4. Literature Study

4.1 Simulation

Law, Kelton (1982, p.9) suggests before deciding on the appropriateness of a simulation application, the relevant factors of the problem on hand should be closely examined. This is because in most cases a simulation and analytical approach is equally viable. A simulation model can also be used to verify if the assumptions of the analytical model is valid.

4.1.1 Definition of Simulation

According toe Kelton, Sadowski, Sturrock (2007, p. 1) simulation "mimics the behavior of actual systems by using various methods and applications."

Simulating a real system, the user can observe any techniques or change in the system before implementing the changes in the actual system. A simulation model can be seen as the testing component in any planning situation.

4.1.2 Simulation Terminologies

Wayne L. Winston (2004, p. 403) defines the basic terminologies for simulations. Because there are large variety of systems and various ways to define each system, terminologies are used to identify and understand the "concept of the system." The terminologies are as follow:

4.1.3 Definition of a System

Each system has to accomplish some kind of end. The system includes both the entities waiting in line and the entities being served. All these entities interact with one another to complete the specific task.

4.1.4 Definition of a State

A system consists of numerous variables that describe the system. These variables are known as the state variables. These variables can apply to the entities of the system and their attributes and resources, and to all the events in system, that is arrivals, departures and the end.

4.1.5 Discrete System

In the system the state variable will only change when an entity arrives and enter the system and when an entity leave the system after the serving process. Winston calls this the “discrete or countable point in time”

4.1.6 Continuous System

Were the state variables in a discrete system change over countable points in time, the state variables in a continuous system “change continuously over time.”

4.1.7 Static Simulation Model

This is a representation of a system at a specific point in time. Monte Carlo simulation models are static models.

4.1.8 Dynamic Simulation Model

This is a representation of a “system as it evolves over a period of time.”

4.1.9 Deterministic and Stochastic Models

Kelton, Sadowski, Sturrock (2007, p.7) describes a deterministic model as a model with no random variables. A stochastic model operates with random variables present at some point in the system.

4.1.10 Why use Simulation?

Simulation can provide a pictorial illustration of what is happening in the system. Changes in the simulation model are easier than in the actual systems. The effect various scenarios have on the system can by investigated without much difficulty.

Law, Kelton (1982, p.1) indicated to obtain a better understanding of a system, various assumptions should be made about how that system works. These assumptions generally consist out of mathematical and logical reasoning. With the constructed model the interaction and behavior of corresponding systems can be investigated.

Altiok, Malamed (2001, p.1) states that a simulation model “provides predictions of the system’s performance measures.”

4.1.11 Advantages of Simulation

Law, Kelton (1982, p.8) describe the advantages of simulation as follow:

In some cases when dealing with complex systems, systems with "stochastic elements cannot accurately be described by mathematical models." In these cases the only evaluation and testing of the system is mostly dependant on the simulation model. If there is assigned performance conditions, the system can be investigated, to observe the influence these conditions have on the system and the performance of the system. Various different design types of a system can be observed to achieve the best possible solution. Because it is easier to change a simulation model, changes in the system can easily be observed and rectified. Simulation is able to study systems over a long period of time.

4.1.12 Disadvantages of Simulation

Law, Kelton (1982, p.8) describe the disadvantages of simulation as follow:

Simulation models can be "expensive and time consuming to develop." Simulation is not ideal for optimizing a system, rather comparing systems, because for each set of input parameters, a number of independent runs of the model will be required. In some cases the model can produce the "actual true characteristic" of a system, this will be a 'valid' model. If the model is not 'valid' there can be a tendency of to much confidence in the model that is vindicated, this is if there is enough numbers produced.

4.2 Time Study

Since the data of the time studies depicts what is actually happening in the system, it will be used when constructing the simulation model.

4.2.1 Definition of Time Study

According to Niebel, Freivalds (1993, p.317) time study is most commonly defined as a "fair day's work." Time studies are used to "establish time standards", were time standards can be determined by three elements: estimates, historical records and work measurement procedures. The time standard is the allowable time allocated to performing a specific task, always regarding the measurement of the work content for the specific task. The technique also includes the "allowance for fatigue and for personal and unavoidable delays."

4.2.2 Purpose of Time Studies

Time studies will be used to determine the peak hours (Section 4.4) at the check-in counters. The values will be plotted and the type of distribution identified with the specific mean and standard deviation calculated. These values will be used in the simulation model.

4.3 Queues

Queuing is used to explain the concept of arrivals, service delivery and the outcome of a system. The answers obtain is merely theoretical and will not be used in the simulation model.

4.3.1 Definition of a Queue

According to Kelton, Sadowski, Sturrock (2007, p. 22) a queue is when an entity is not able to move, a place where an entity can wait before being served.

When an entity is waiting in a queue it is waiting, for instance, for another entity that is being served. Queues can also have a certain capacity determined by the size of the system or available space.

4.3.2 Definition of a Queuing System

Gross, Shortle, Thompson, Harris (2008, p. 2) describes a queuing system as entity arriving in a system for a specific service and waiting for that service if it is not immediately available.

A queuing system can differ in various ways. Example, the number of servers, the capacity of the line and the number of services the system can provide.

4.3.3 Definition of Queuing Theory

According to Gross, Shortle, Thompson, Harris (2008, p.2) queuing theory is the means of modeling a system to observe the behavior within that system. The objective of the system is to provide a service to arising entities.

Thomas G. Robertazzi (1994, p.1) describes “the study of queuing “ as the “study of waiting.”

In queuing theory there is numerous types of models. Each one of these models describes a different queuing system.

4.3.4 Characteristics of a Queuing Process

All queuing systems should have an input process and an output process. The characteristics of a queuing process describes the queuing system in term of the input and output processes, the capacity of the system, the queuing discipline and the number of servers and services.

4.3.4.1 Input or Arrival Process

According to Wayne L. Winston (2004, p. 308) “arrivals are called customers.” Arrivals can be unaffected or affected by the number of entities in the system. When the number of entities affects the customer in the system, it can either be a finite source model, where an arrival is drawn from a small population or, the customer fails to enter the system, thus balked. When the customer is unaffected, the interarrival times should be specified with a probability distribution.

Gross, Shortle, Thompson, Harris (2008, p. 3) says it is necessary to know the probability distribution describing the interarrival times, because arrivals are stochastic. Arrivals can occur as a single arrival, a batch arrival and bulk arrival.

4.3.4.2 Output or Service Process

According to Wayne L. Winston (2004, p. 309) a ‘service time distribution’ should be specified, to indicate the time it will take to service a customer. There are two arrangements of services; “service in parallel and service in series.” Parallel servers all provide the same service to all customers, thus the customers can only pass through one server. Series servers, is a series of servers providing different services which the customers should all pass through.

According to Gross, Shortle, Thompson, Harris (2008, p. 4) the “sequence of customer service times” should be defined by a probability distribution. “Service can also be single or batch.” The number of customer in line can also have an influence on the service process. If the queue is getting longer, the server may work a bit faster. Working faster can also cause the server to be less accurate.

4.3.4.3 Queue Discipline

Wayne L. Winston (2004, p. 309) describes queuing discipline as the “method used to determine the order in which customers are served.”

Gross, Shortle, Thompson, Harris (2008, p.4) refers to queuing discipline as “the manner in which customers are selected for service when a queue has formed.”

There are various queue disciplines; the most commonly known is the first come first serve (FCFS). Other known models are the last come last serve (LCLS), and service in random order (SIRO).

4.3.4.4 System Capacity

According to Gross, Shortle, Thompson, Harris (2008, p.5) the system capacity is the maximum number of customers in the available space. When the system reaches a specific capacity, a customer cannot enter until another customer leaves the system.

4.3.4.5 Number of Service Channels

The amount of servers can differ. According to Gross, Shortle, Thompson, Harris (2008, p.5), it is preferred to design a system with multiple servers, which is fed by a single queue. Thus design makes use of parallel service stations that can serve various customers at the same time.

4.4 Determine Peak Periods

According to Ashford, Stanton, Moore (1997, p. 29) airports have large variations on the demand. This is caused by peak times of passengers. The variation can be described in 4 ways.

- Annual variation
- Monthly peaks
- Daily peaks
- Hourly peaks

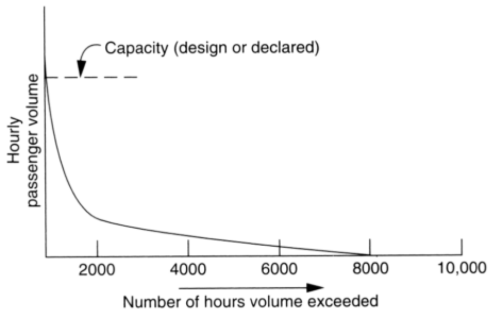


Figure 2: Typical distribution of hourly passenger traffic volumes at an air transport airport throughout the year

4.4.1 Methods of Describing Peaking

Ashford, Stanton, Moore (1997, p. 31) states that an airport is sometimes busier than other times. These are called the peak times. The airport cannot plan their capacity according to the busiest time of the year. There will always be a few hours in a year that the system will be in overload. With delays and inconvenience as a result. The system cannot be planned otherwise because it will lead to "uneconomical and wasteful operations." The peaking can be described in the following manner:

4.4.1.1 Standard Busy Rate (SBR)

The SBR is also defined as the "30th highest hour of passenger flow" and has been used for years to determine the design volumes. According to this method the system will not run its capacity in overload or beyond for more than 30 hours per year, there is of course no way to guarantee this. The relationship is described as:

absolute peak hour volume = 1.2 x standard busy rate

Studies showed that as the traffic at an airport develops the extremes tend to disappear. The higher the volume in the system the lower the ratio between SBR and absolute peak will be.

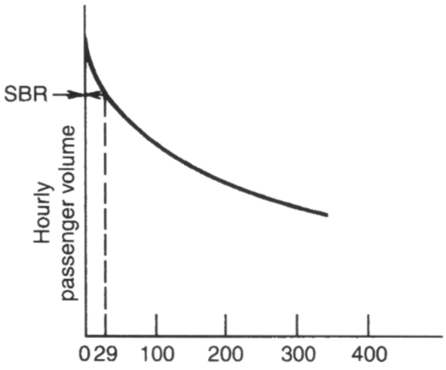


Figure 3: Location of the standard busy rate

4.4.1.2 Busy Hour Rate (BHR)

The Busy Hour Rate is also known as the “5 percent busy hour.” This indicates the hourly rate above which 5 percent of the traffic at the airport is handled. Using this method:

- Arrange all volumes in magnitude
- Calculate the cumulative sum of all the volumes that amount to 5 percent of the annual volume

The next ranked volume is the BHR. Because a large amount of data should be collected to use this method, it is not recommended for small airports.

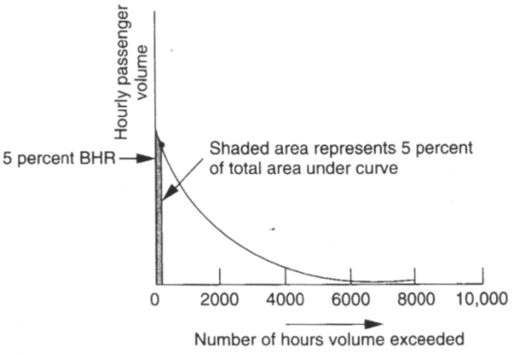
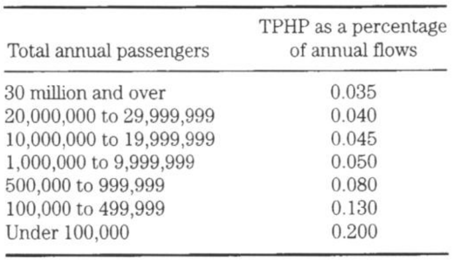


Figure 4: Five percent busy rate hour

4.4.1.3 Typical Peak Hour Passengers (TPHP)

Typical Peak Hour Passengers is a peak measure that is defined as “the peak hour of the average peak day of the peak month.” By looking at the relationship between the annual figures and the TPHP as a percentage of annual flow, it is apparent that the smaller the airport, the more prominent the peak will be. The peak will level the larger the airport grows and the troughs between the peaks will become less prominent.



Total annual passengers	TPHP as a percentage of annual flows
30 million and over	0.035
20,000,000 to 29,999,999	0.040
10,000,000 to 19,999,999	0.045
1,000,000 to 9,999,999	0.050
500,000 to 999,999	0.080
100,000 to 499,999	0.130
Under 100,000	0.200

Table 1: FAA Relationships for TPHP Computations from Annual Figures

4.4.1.4 Busiest Timetable Hour (BTH)

The BTH is calculated by using average load factors and existing or projected timetables. The method is used for small airports with limited databases. A disadvantage is that the method is subject to errors in forecasting and variations in average load factors.

4.4.1.5 Peak Profile Hour

Also called the "average daily peak." The method for calculating the Peak Profile Hour:

- Select peak months
- Compute the average hourly for each hour across the month

This will provide an average hourly volume for an "average peak day." The largest hourly value in the average peak day will indicate the Peak Profile Hour.

4.5 Capacity Planning

According to Solak, Clarke, Johnson (2009) the goal of terminal capacity analysis "is to minimize congestion related passenger delay in the terminals." Because demand in a terminal can be very transient, most estimations for a simulation model is based on observation. The procedures derived by Solak, Clarke, Johnson can be used for testing and comparing the system. The capacity for an airport is calculated by looking at the available area. Area is not considered in the project.

4.5.1 Approximation of maximum peak period delay

To determine the capacity of the system, the walking and processing times are considered separately. Solak, Clarke, Johnson (2009) developed delay time approximations for the two areas.

4.5.1.1 Maximum delay in passageways

Though the studies related to pedestrians in transportation terminals are rare, there was exception, Young (1999), evaluated the pedestrian walking speed in a terminal. The result showed that the terminals are normally distributed with mean of 80.5 m per minute and a standard deviation of 15.9 m per minute.

Solak, Clarke, Johnson (2009) makes use of the following variables to determine maximum walking time in a system:

- Maximum density of the passageway
- Peak flow rate
- Interarrival times
- Effective area of passageway

4.5.1.2 Maximum delay in processing stations

Most of the congestion is at some kind of service point. The maximum delay in processing stations is developed as a function of flow and capacity. By observing the arrival times, the passenger arrival rate can be calculated. The data is then plotted; the highest peak on the plot will be used for peak demand analysis. A peak is defined as “a period during which the arrival rate remains above the average arrival rate.” Depending on the sharpness and shape of the peak either triangular, parabolic of half-elliptical approximation can be used.

4.6 Methods to Identify Constraints

Constraints are present in all systems. In this project the most likely constraints will be queue lengths and queue waiting times.

4.6.1 Goldratt's Theory of Constraints (TOC)

Jacobs, Chase, Aquilano (2009, p.681) defines the Theory of Constraints as follow:

1. Identify the system constraints
2. Decide how to exploit the system constraints
3. Subordinate everything else to that decision
4. Evaluate the system constraints
5. If constraints have been broken in previous step, go back to step one

4.6.2 Definition of Bottleneck

Jacobs, Chase, Aquilano (2009, p.686) defines a bottleneck as any resource whose demand is more than its capacity.

When there is a bottleneck, there will be long queues. If there are not any bottlenecks present, the system has excess capacity and will lead to "uneconomical and wasteful operations" according to Ashford, Stanton, Moore (1997, p. 31). Thus, when the airport is running on the average capacity, there should be no bottlenecks. Only during the peak hours should bottlenecks be present.

5. Improvement Methods

The improvement methods is tested in the simulation model to indicate if there is any improvement if applied.

5.1 Queue Improvements

All travelers are on the lookout for “queue-less travel.” There is a variation of products available on the market that can reduce queues.

5.1.1 Biometrics Technology

Stuart Thorn (Airport International September 2007, p. 28), Chief Executive of Electron Europe, wrote in his article that Biometrics Technology could offer a “plethora of benefits” to airports and passengers. These benefits include increased airline security, shorter check-in queues and passport-free traveling. However, he warns that there are some concerns to examine closely, such as health and safety, privacy and security.

5.1.2 What is Biometrics?

According to Steven Furnell, Nathan Clarke (2005) the International Biometric Group defines biometrics as “The auto- mated use of physiological or behavioral characteristics to determine or verify identity.” There are two stages:

1. Initial registration and the creation of a biometric template for the user.
2. Authentication by comparing a required sample against a template already held.

There are various methods from two main categories being considered:

⇒ Physiological
  - Facial recognition
  - Facial thermogram
  - Fingerprint recognition
  - Hand geometry
  - Iris scanning
  - Retinal scanning
  - Vein checking

⇒ Behavioral

- Gait recognition
- Keystroke analysis
- Mouse dynamics
- Signature analysis
- Voice verification

5.1.3 Types of Biometrics

Francis Weiss (Airports International April 2007, p.32), from the e-Border department of Sagem Dèfense Sècuritè gives an explanation of various types of Biometric technologies which is currently being tested.

5.1.3.1 Pegase

A study started in June 2005 until May 2007 by Sagem with Air France concerning a fingerprint scanner. Using fingerprints stored in a database, the scheme could evaluate technologies that include uniqueness detection, staff procedures and passenger acceptance.

5.1.3.2 Biodev1 and Visabio

In 2006 Segem integrated a scheme test of "Europe-wide multi-biometric visas containing face and fingerprint data." The system will be connected to "European Union's Visa Integrated Circuit Card Specifications (VIS)."

5.1.3.3 IRIS

IRIS is the United Kingdom's immigration control system, developed by Sagem. An iris recognition camera is used to allow enrolled passengers to pass through an automated immigration control gate.

5.1.3.4 SMARTGATE

SMARTGATE makes use of facial recognition technology; this matches the traveler's identity to a photograph. For the facial recognition scheme to work, biometric passports should be used (e-passports). The photographs are located in an e-passport system.

Tom Allett (Airport International Jan/Feb 2008, p.29) reports the technology of SMARTGATE kiosk. Some technologies used are touch screen, thermal/magnetic ticket printer/readers and an electronic passport reader. Further the gate has digital cameras, sensors and mechanical doors.

5.1.3.5 miSense

Uses the latest technologies to “simplify a passenger’s journey through the airport while strengthening security.” This include the check-in, ticket control, boarding and immigration control procedures.

5.1.3.6 Body Scanner

There are two methods, the millimeter-wave or the X-Ray part of the spectrum. The scanner scans the body in full length to determine if any concealed objects are present. The millimeter-wave is new technology. Different materials have different properties. What the scanner does is detect anything foreign to the human body. The scanner will show the object on a fully clothed image on a screen.

5.1.4 Various Check-In Methods

Shawn Richards (Airport International March 2007, p.32) discuss a number of check-in methods. He states that airports should provide a number of check-in channels before they arrive on the airport and in the airport self.

5.1.4.1 Internet Check-In

Since most passengers purchase their tickets online, online check-in is the most convenient. According to studies a combined 80% of the passengers will use this channel, clearly indicating the benefit.

5.1.4.2 Remote Check-In

A third party is used for the check-in process. The idea is for the travelers to check-in at the Hotels, railway stations and transport interchanges, which provide assisted check-in on demand.

5.1.4.3 SMS Check-In

Cell phones are commonly used in most of the counties. Texting has become part of our daily lives. With SMS Check-in, the passengers can check-in by sending a text message. The passenger should be well aware of the common mistakes people make with mobile phones. The communication between the airline and the passenger should be clear, short and precise.

5.1.4.4 Common Use Systems

This system shares the hardware that the various software systems run on, with the exception of the needed dedicated system. According to Richards this is the "key to maximizing the throughput of the passengers through the check-in area." Wherever desk and kiosk are shared the passenger throughput can increase by multiples.

5.1.4.5 Kiosk Check-In

The passengers have to serve themselves; they are able to retrieve their boarding passes.

According to Carroll McCormick (Airports International March 2008, p.26) passengers can use the kiosk for self-serve baggage tagging. In some countries this is not possible, because it is illegal for passengers to tag their own baggage.

6. Simulation Model

The simulation is done in sections. Each section is a simulation of a different process, the domestic and international process. These processes and the logic followed during the simulation model are explained in this section. The time studies used was provided by VCE.

6.1 Domestic process

The basic steps of the domestic process are arrivals, check-in, bag drop, security check-point and boarding of the passengers. Figure 5 is a simplified version of what is happening in the system.

Figure 5: The basic steps of the Domestic Process

When simulating the whole process, the process looks quite different while the same concept is being followed. The figure below will create an idea of how the simulation model is designed.

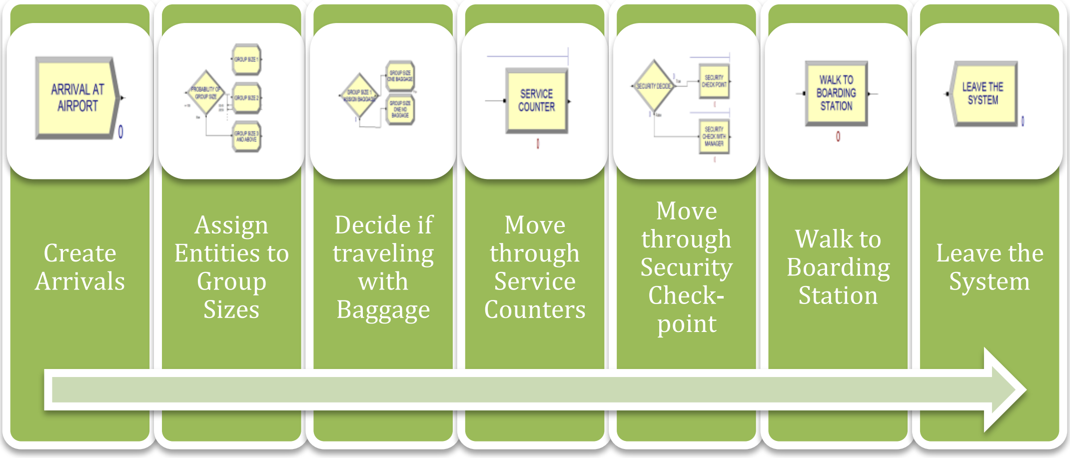


Figure 6: An illustration of how the simulation model is designed for the domestic process

Firstly the passenger arrivals is created. The arriving entities are then assigned to three different group sizes. Not all passengers travel with baggage when flying domestic, thus the groups are divided into groups traveling with baggage and traveling without baggage. The passenger then move through the service counters in the allocated groups to be checked-in. After the check-in process the passengers move on to the security check-point, were they are checked individually. The next step is for the passenger to walk to the boarding station to board the plane and then leave the system. The boarding of the plane is not simulated, only the arrival at the boarding station is included.

6.2 International Process

There are only two changes in the simulation model when modeling the international process. There are no passengers travelling without baggage and the passport control process is added. A simplified version of the basic steps of the international process is seen below.

Figure 7: The basic steps of the international process

Again, when looking at the simulation the process can look quite different while following the same concept. Below is an illustration of what happens in the simulation model.

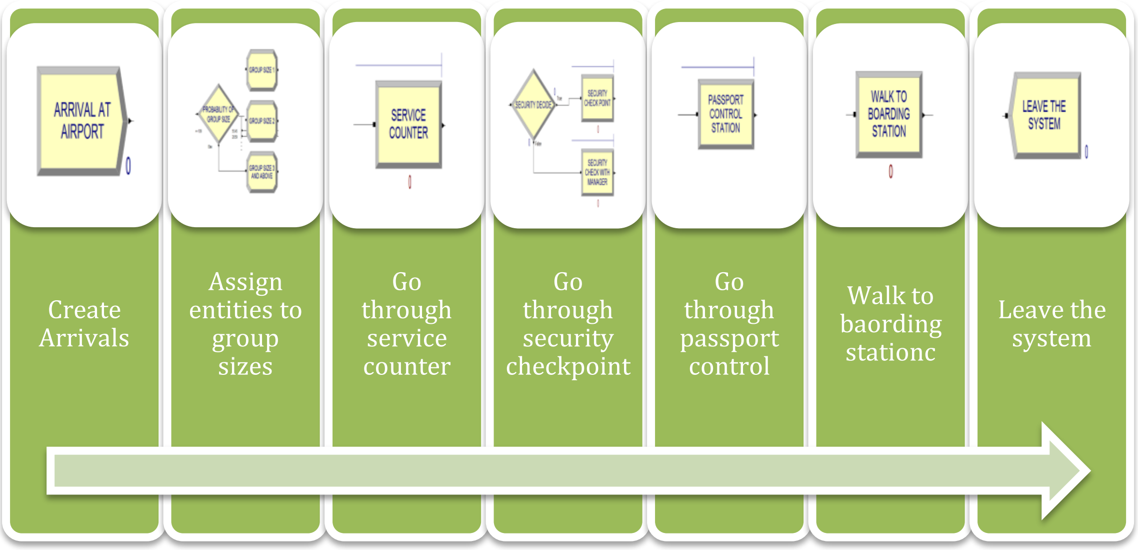


Figure 8: An illustration of how the simulation model is designed for the domestic process

Passengers arrive at the airport, and is then allocated to a group size. All passengers arriving for an international flight have baggage to check-in at the service counters. After moving through the check-in process, passengers have to pass the security check-point and the passport control process. Once through all these processes the passenger can walk to the respective boarding stations and leave the system.

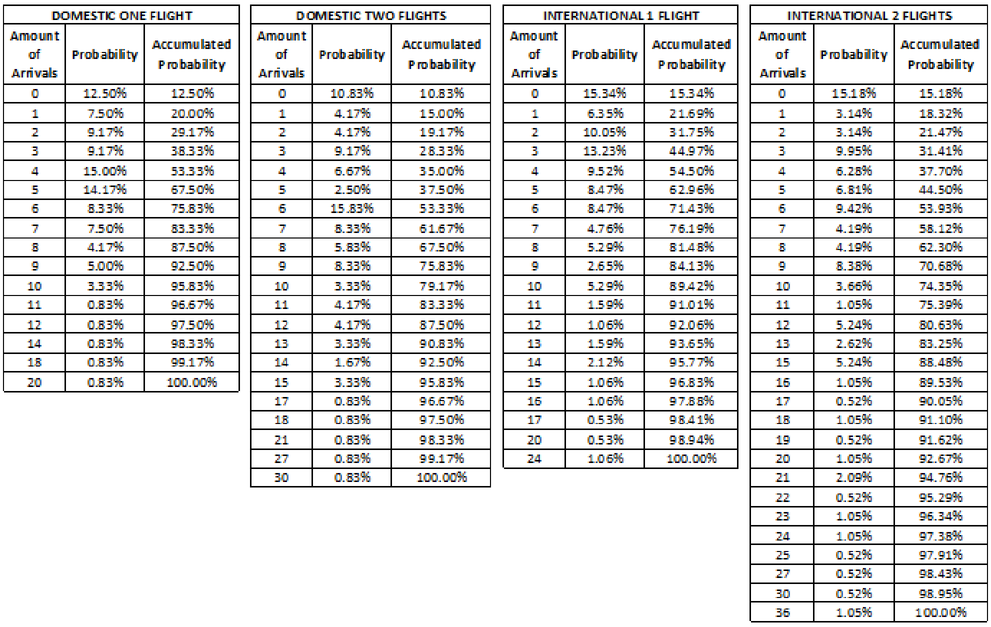
6.3 Model Breakdown

6.3.1 Arrivals

The arrivals of the passengers are obtained through a time study. Through these time studies the probability of the amount of arrivals per minute is calculated. An arrival does not necessarily represent a single entity, as the group size is determined by a discrete probability based on the a study explained in section 6.3.2. The probability of passengers arriving is calculated over a period of two hours. Two simulation models are built, one for the arrivals of only one flight and the other for the arrivals of two flights with the same departure time.

Figure 9: Creation node used for arrivals

A create node is used to create the arrivals for the model. By looking at the amount of entities arriving per minute the probabilities illustrated in the figures and tables below are obtained. The probability of passenger arrivals of each simulation is done separately, because the arrival rate of each of these instances is different from the other.



DOMESTIC ONE FLIGHT		
Amount of Arrivals	Probability	Accumulated Probability
0	12.50%	12.50%
1	7.50%	20.00%
2	9.17%	29.17%
3	9.17%	38.33%
4	15.00%	53.33%
5	14.17%	67.50%
6	8.33%	75.83%
7	7.50%	83.33%
8	4.17%	87.50%
9	5.00%	92.50%
10	3.33%	95.83%
11	0.83%	96.67%
12	0.83%	97.50%
14	0.83%	98.33%
18	0.83%	99.17%
20	0.83%	100.00%

DOMESTIC TWO FLIGHTS		
Amount of Arrivals	Probability	Accumulated Probability
0	10.83%	10.83%
1	4.17%	15.00%
2	4.17%	19.17%
3	9.17%	28.33%
4	6.67%	35.00%
5	2.50%	37.50%
6	15.83%	53.33%
7	8.33%	61.67%
8	5.83%	67.50%
9	8.33%	75.83%
10	3.33%	79.17%
11	4.17%	83.33%
12	4.17%	87.50%
13	3.33%	90.83%
14	1.67%	92.50%
15	3.33%	95.83%
17	0.83%	96.67%
18	0.83%	97.50%
21	0.83%	98.33%
27	0.83%	99.17%
30	0.83%	100.00%

INTERNATIONAL 1 FLIGHT		
Amount of Arrivals	Probability	Accumulated Probability
0	15.34%	15.34%
1	6.35%	21.69%
2	10.05%	31.75%
3	13.23%	44.97%
4	9.52%	54.50%
5	8.47%	62.96%
6	8.47%	71.43%
7	4.76%	76.19%
8	5.29%	81.48%
9	2.65%	84.13%
10	5.29%	89.42%
11	1.59%	91.01%
12	1.06%	92.06%
13	1.59%	93.65%
14	2.12%	95.77%
15	1.06%	96.83%
16	1.06%	97.88%
17	0.53%	98.41%
20	0.53%	98.94%
24	1.06%	100.00%

INTERNATIONAL 2 FLIGHTS		
Amount of Arrivals	Probability	Accumulated Probability
0	15.18%	15.18%
1	3.14%	18.32%
2	3.14%	21.47%
3	9.95%	31.41%
4	6.28%	37.70%
5	6.81%	44.50%
6	9.42%	53.93%
7	4.19%	58.12%
8	4.19%	62.30%
9	8.38%	70.68%
10	3.66%	74.35%
11	1.05%	75.39%
12	5.24%	80.63%
13	2.62%	83.25%
15	5.24%	88.48%
16	1.05%	89.53%
17	0.52%	90.05%
18	1.05%	91.10%
19	0.52%	91.62%
20	1.05%	92.67%
21	2.09%	94.76%
22	0.52%	95.29%
23	1.05%	96.34%
24	1.05%	97.38%
25	0.52%	97.91%
27	0.52%	98.43%
30	0.52%	98.95%
36	1.05%	100.00%

Table 2: The probability of passenger arrivals

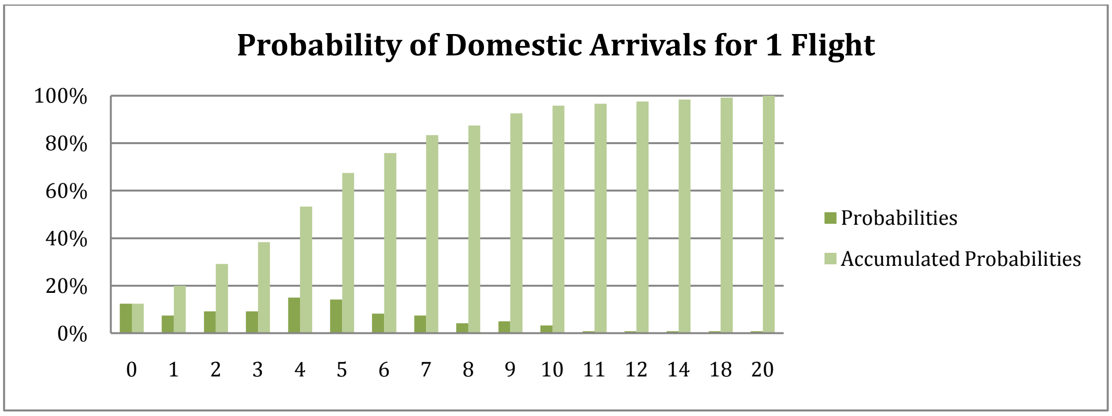


Figure 10: Probability of Domestic Arrivals for a single flight

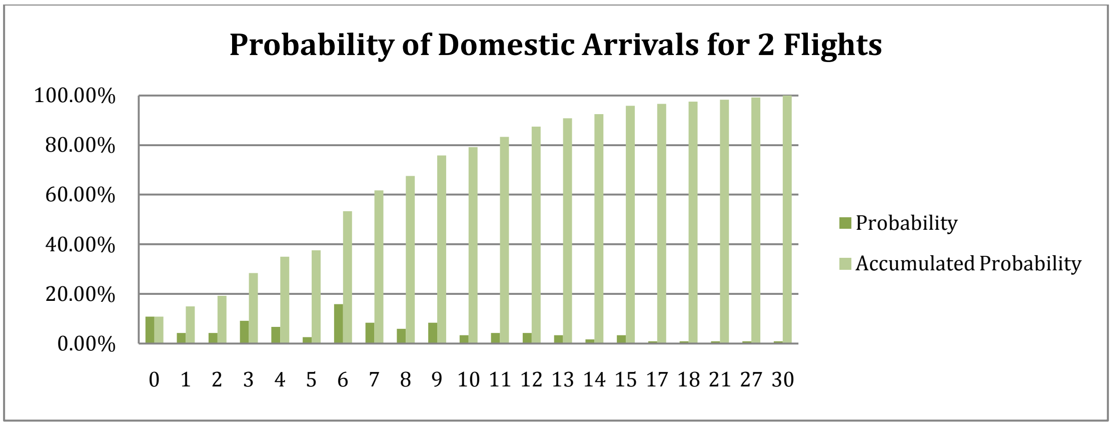


Figure 11: Probability of Domestic Arrivals for two flights

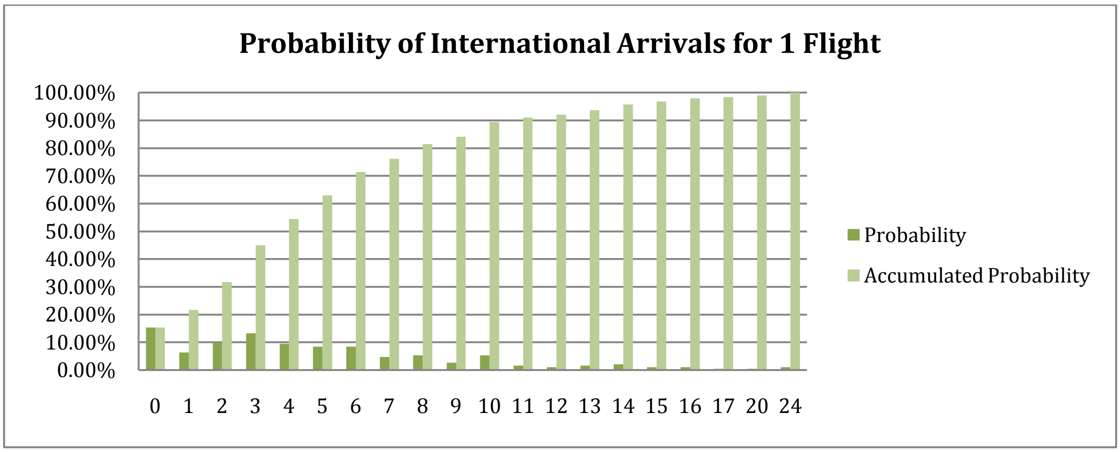


Figure 12: Probability of International Arrivals for a single flight

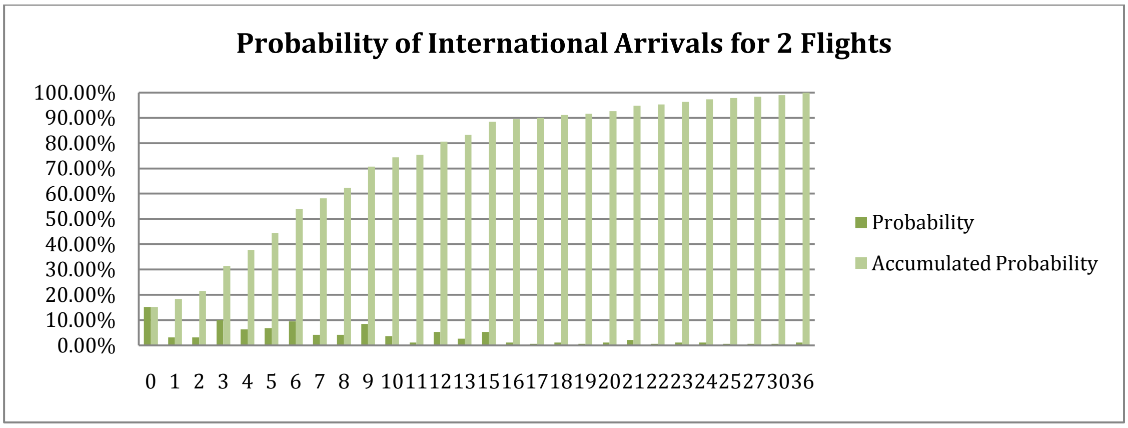
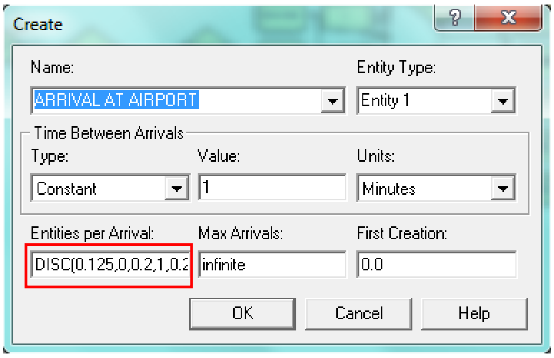


Figure 13: Probability of International Arrivals for two flights

The probability of arrival and the accumulated probability is calculated. The accumulated probability is used to define the entities per arrival, using discrete probability as seen below.



Name: ARRIVAL AT AIRPORT
Entity Type: Entity 1
Time Between Arrivals
Type: Constant
Value: 1
Units: Minutes
Entities per Arrival: DISC(0.125,0,0.2,1,0.2
Max Arrivals: infinite
First Creation: 0.0

Figure 14: Create node properties

6.3.2 Group Allocation

When doing the group allocation, three group sizes are considered:

1. Group with size 1
2. Group with size 2
3. Group with size 3 and above

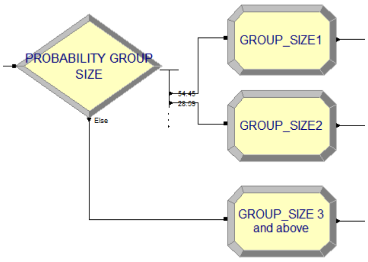


Figure 15: Nodes used to allocate groups

The picture above is an illustration of how the group sizes are allocated. A decision node is used to allocate the percentage of entities for a certain group to an assign node. These probabilities were obtained through time studies and is illustrated below.

	Probability of Group Size
Group Size 1	55.45%
Group Size 2	28.59%
Group Size 3 & Above	15.96%

Table 3: Probability of Group Size

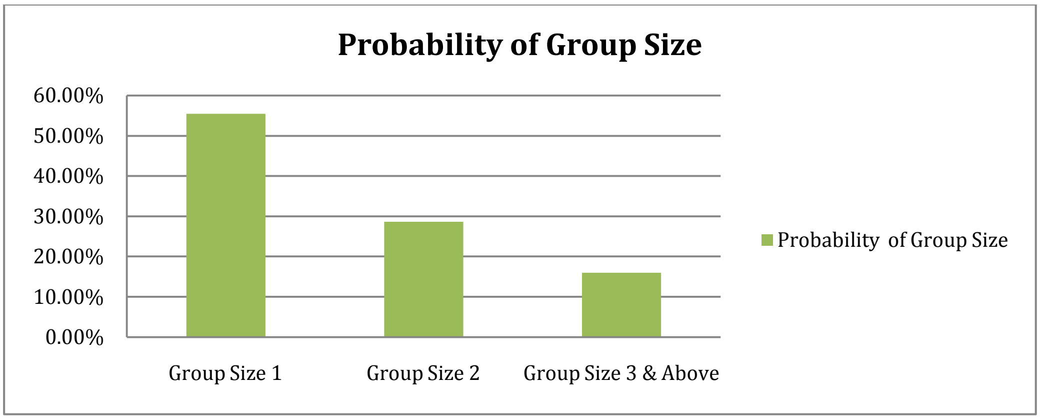
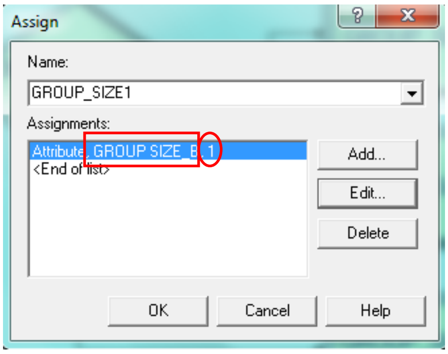


Figure 16: Probability of Group Size



Name:
GROUP_SIZE1

Assignments:
Attribute, GROUP SIZE_B, 1
<End of list>

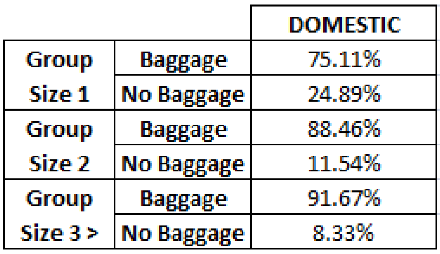
Figure 17: Properties of the assign node

The name of the assign node is according to the group size. The type is an attribute which is named “GROUP SIZE_B”. The value of the attribute is respective to the group size. The attribute is created so that the groups can be separated later in the model to go through the security checkpoint. This is illustrate later in the document when the security checkpoint is explained.

6.3.3 Assigning Baggage

Not all the passengers arrive with luggage when flying domestic. When assigning the baggage the passengers are divided into two groups; passengers with baggage and passengers with no baggage. A passenger who has enough luggage so that it should be checked in at the check-in counter is considered having baggage. Passengers only traveling with hand luggage are considered without baggage.

The percentage of passengers arriving with or without baggage is obtained through studies. These studies indicate the probability that each group size will arrive with or without baggage.



		DOMESTIC
Group Size 1	Baggage	75.11%
	No Baggage	24.89%
Group Size 2	Baggage	88.46%
	No Baggage	11.54%
Group Size 3 >	Baggage	91.67%
	No Baggage	8.33%

Table 4: Probability of group baggage

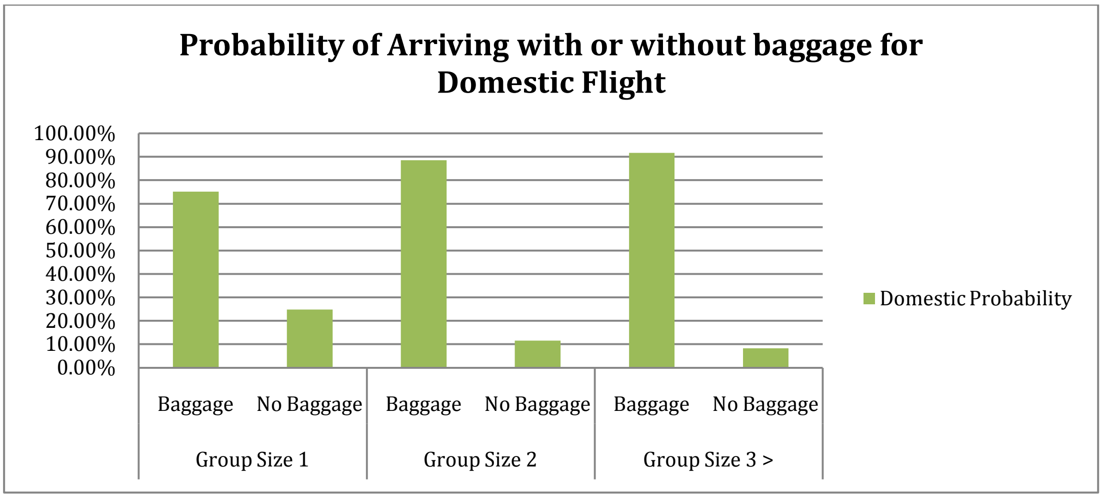


Figure 18: Probability of Arriving with or without baggage for Domestic Flight

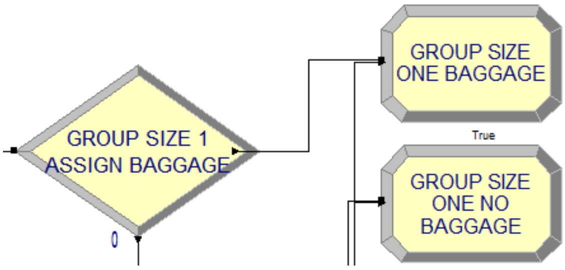


Figure 19: Nodes to assign baggage to group

When simulating the baggage, a decision node with type “2-way-by-chance” is chosen. The respective probabilities of table 4 is used and illustrated in figure 18. The decision is true when the passenger/group has baggage and false when the passenger/group has no baggage.

The assign node allocates the respective service time to the passengers or groups. The service time for passengers who has to check-in their luggage during the check-in process will be different from those passengers only travelling with hand luggage.

By naming the attribute "SERVICE_TIME", and assigning a value using a normal distribution, the service time is calculated for each respective passenger or group. The values used to calculated the service time is shown in table 5.

	AVERAGE	STDEV
1 without baggage	1.206667	0.66439
1 with baggage	1.873994	1.087001
2 without baggage	1.487432	0.419994
2 with baggage	2.502885	1.573396
>3 without baggage	2.674167	0.655157
>3 with baggage	3.949673	1.340189

Table 5: Service time for groups with baggage options

The average or mean and standard deviation is used for a normal distribution.

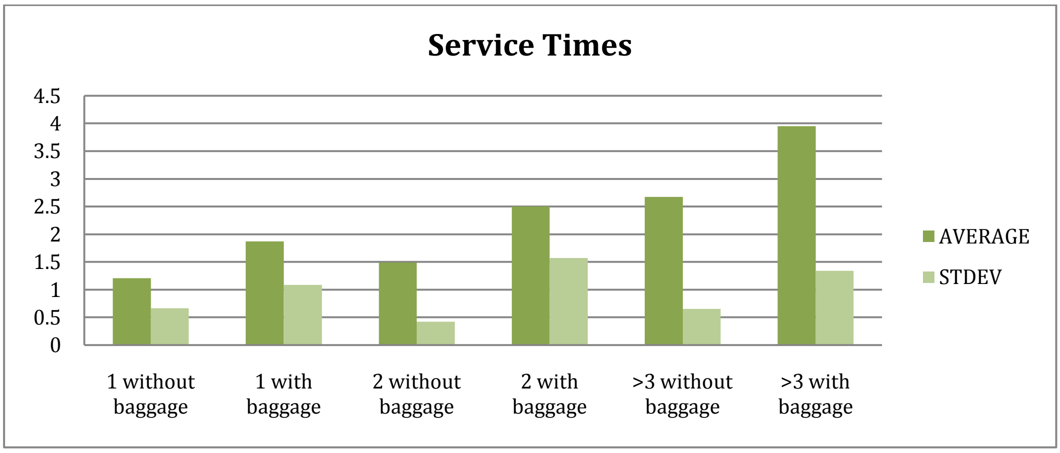


Figure 20: Service time for groups with baggage options

Type: Attribute

Attribute Name: SERVICE_TIME

New Value: NORM(1.93,1.087)

Figure 21: Properties of assign node

During the international process it is assumed that all passengers arrive with baggage that has to be checked-in.

6.3.4 Check-in Counter

At the service counter passenger go through the check-in process. The passengers are served at a rate called “SERVICE_TIME”. The service time is different for each group size and also differs depending if the passenger has baggage or no baggage. A process node is used to simulate the service counters.

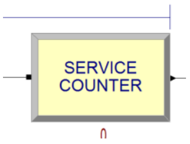
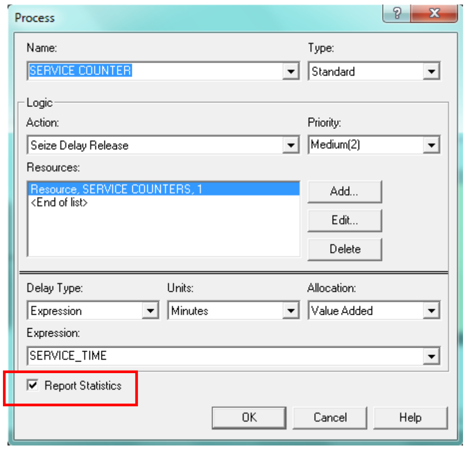


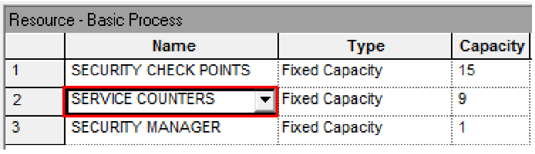
Figure 22: Process node used for service counter

The process is given a resource which is called “SERVICE COUNTERS”. As seen below in Figure 23, the resource has a quantity of 1. This quantity indicate the amount of attributes/entities the service counter can service at a certain time, and not the amount of service counters available. The amount of service counters is changed by changing the resource capacity in the Basic Processes indicated in table 6. The processing time given in the Expression box is the “SERVICE_TIME”, thus, the “SERVICE_TIME” explained in section 6.3.3 is the processing time.



Name: SERVICE COUNTER
Type: Standard
Action: Seize Delay Release
Priority: Medium(2)
Resources:
Resource, SERVICE COUNTERS, 1
<End of list>
Delay Type: Expression
Units: Minutes
Allocation: Value Added
Expression: SERVICE_TIME
☑ Report Statistics

Figure 23: Properties of Process Node



Resource - Basic Process

	Name	Type	Capacity
1	SECURITY CHECK POINTS	Fixed Capacity	15
2	SERVICE COUNTERS	Fixed Capacity	9
3	SECURITY MANAGER	Fixed Capacity	1

Table 6: Resources in the system with capacity

6.3.5 Security Check-point

Before the passengers can go through the security check-point, the groups should be separated, because the passengers are checked individually during this process.

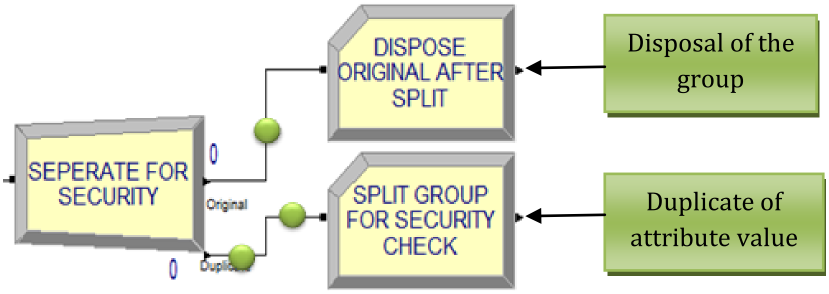
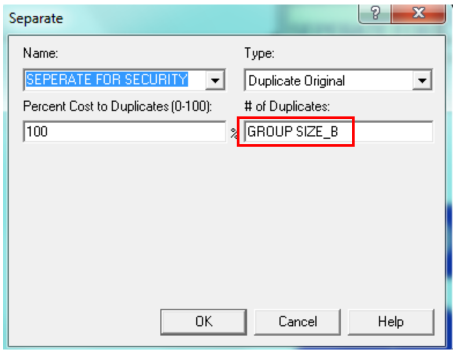


Figure 24: Nodes used to divide groups



Name: SEPERATE FOR SECURITY

Type: Duplicate Original

Percent Cost to Duplicates (0-100): 100 %

# of Duplicates: GROUP SIZE_B

Figure 25: Properties of Separate node

In figure 24 and 25 it is shown that a separate node is used to create duplicates of the attribute “GROUP_SIZE_B”. As previously explained in section 6.3.2, there are different values for this attribute. These values are duplicated so that passengers can move through the security check-point individually. The green balls in Figure 24 visually illustrates how the duplications work. Suppose the group size is two, thus, when the value two of the attribute “GROUP_SIZE_B” is duplicated, two attributes are the result. The original attribute, which is the group, are disposed.

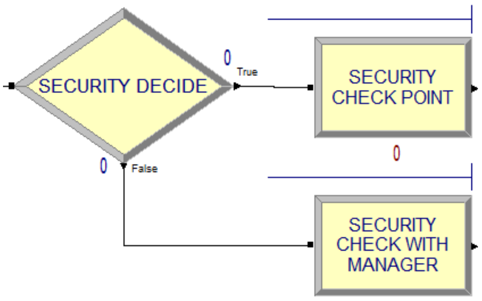
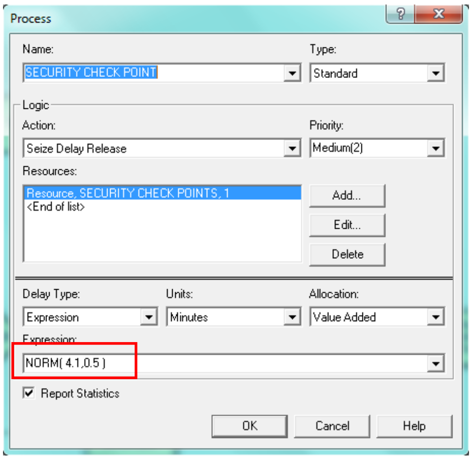


Figure 26: Nodes used for security check-point

After the groups are separated, the passenger can move individually through the security check-point. A decide node is used to determine the amount of passengers who are thoroughly searched by the manager and those passing through the process without any problems.



Name: SECURITY CHECK POINT
Type: Standard
Logic
Action: Seize Delay Release
Priority: Medium(2)
Resources:
Resource, SECURITY CHECK POINTS, 1
<End of list>
Delay Type: Expression
Units: Minutes
Allocation: Value Added
Expression: NORM(4.1,0.5)
☑ Report Statistics

Figure 27: Properties of security check-point

As seen in figure 27, a normal distribution with a mean of 4.1 minutes and a standard deviation of 30 seconds is used for the security check-point. The process is given a resource called “SECURITY CHECK POINT” with a value of 1. The value indicate the amount of passengers one security check-point can service. The amount of security counters can be changed by changing the resource capacity in table 6.

6.3.6 Passport Control

The passport control process only occur during the international process. Here passengers have to move through the process individually.

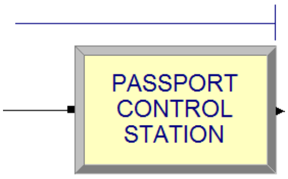
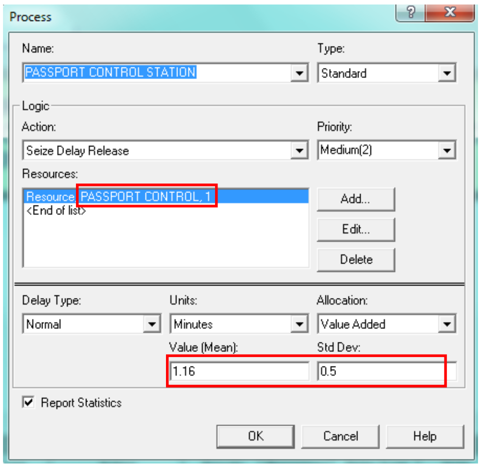


Figure 28: Process node used for passport control



Name: PASSPORT CONTROL STATION
Type: Standard
Logic
Action: Seize Delay Release
Priority: Medium(2)
Resources:
Resource, PASSPORT CONTROL, 1
<End of list>
Delay Type: Normal
Units: Minutes
Allocation: Value Added
Value (Mean): 1.16
Std Dev: 0.5
☑ Report Statistics

Figure 29: Properties of passport control process

A normal distribution with mean 1.16 minutes and standard deviation of 30 seconds is used for the process. A resource called “PASSPORT CONTROL” with a value of one is created for the process. Again the value indicate the number of passengers a passport control counter can serve. The amount of counters can be changed by changing the resource capacity seen in table 6.

6.3.7 Walk to Boarding Stations

A requirement for the project is to determine the walking time from the terminal to the respective boarding stations. The figure below is a simplified illustration of the airport layout. The blocks marked from A1 to E10 is the docking station for an aircraft and represent a boarding station.

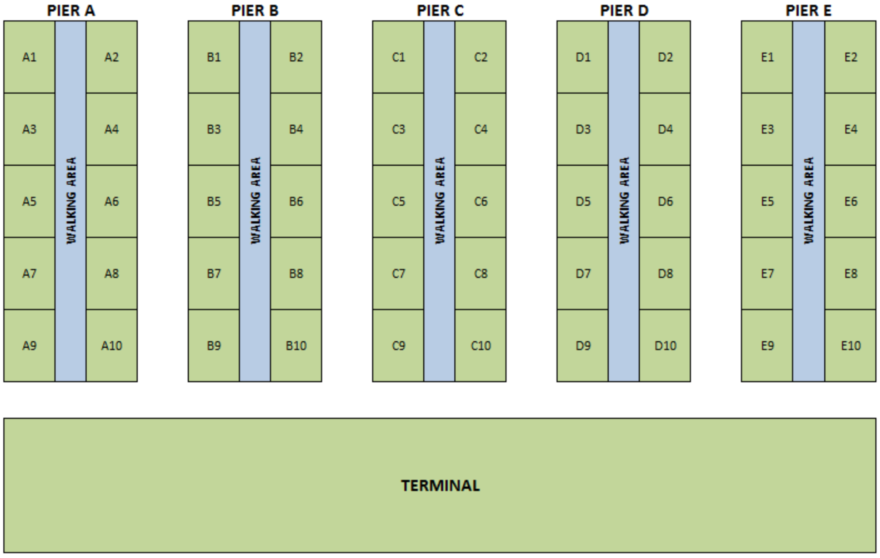


Figure 30: A simplified version of the airport layout

Figure 31: Process node used for walking to boarding station

A simple process node is used to simulate the walking to the boarding stations. The average walking time per passenger was calculated using the formula:

$$\frac{Walking\ distance\ (meters)}{Average\ walking\ speed\ (\frac{meters}{minute})} = Average\ walking\ time\ (minutes)$$

See section 4.5.1.1 for the average walking speed of 85.5 meters/minute.

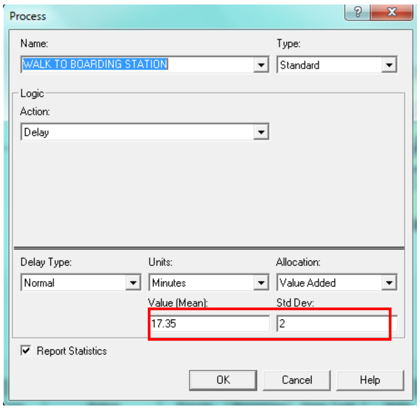
In table 7 the average walking time it will take a passenger to walk from the terminal to the respective boarding station is illustrated. The walking time for Pier A and Pier E is the same, and the walking time for Pier B and Pier D is the same, which is way Pier D en E is not included in the table.

BOARDING STATION	WALKING DISTANCE	AVERAGE WALKING SPEED	AVERAGE WALKING TIME
A1	1025	80.5	17:35:24
A2	1025	80.5	17:35:24
A3	945	80.5	17:44:21
A4	945	80.5	17:44:21
A5	865	80.5	17:53:18
A6	865	80.5	17:53:18
A7	785	80.5	18:02:14
A8	785	80.5	18:02:14
A9	705	80.5	18:11:11
A10	705	80.5	18:11:11

BOARDING STATION	WALKING DISTANCE	AVERAGE WALKING SPEED	AVERAGE WALKING TIME
B1	758	80.5	09:59:15
B2	758	80.5	09:59:15
B3	678	80.5	10:08:12
B4	678	80.5	10:08:12
B5	598	80.5	10:17:09
B6	598	80.5	10:17:09
B7	518	80.5	10:26:05
B8	518	80.5	10:26:05
B9	438	80.5	10:35:02
B10	438	80.5	10:35:02

BOARDING STATION	WALKING DISTANCE	AVERAGE WALKING SPEED	AVERAGE WALKING TIME
C1	485	80.5	00:35:47
C2	485	80.5	00:35:47
C3	405	80.5	00:44:43
C4	405	80.5	00:44:43
C5	325	80.5	00:53:40
C6	325	80.5	00:53:40
C7	245	80.5	01:02:37
C8	245	80.5	01:02:37
C9	165	80.5	01:11:33
C10	165	80.5	01:11:33

Table 7: The average walking time from terminal to respective boarding stations



Process

Name: WALK TO BOARDING STATION

Type: Standard

Logic

Action: Delay

Delay Type: Normal

Units: Minutes

Allocation: Value Added

Value (Mean): 17.35

Std Dev: 2

☑ Report Statistics

Figure 32: Process properties for walk to boarding station

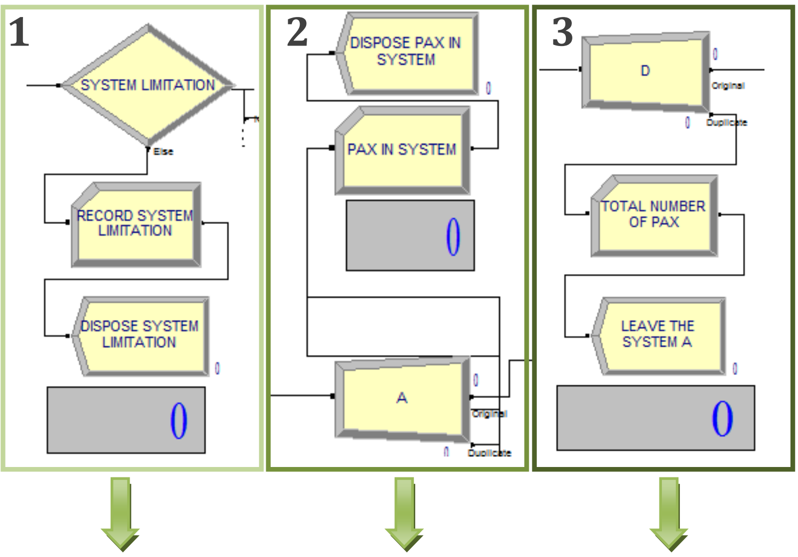
A normal distribution with a mean of “the average walking time” and standard deviations of 2 minutes is used for the simulation.

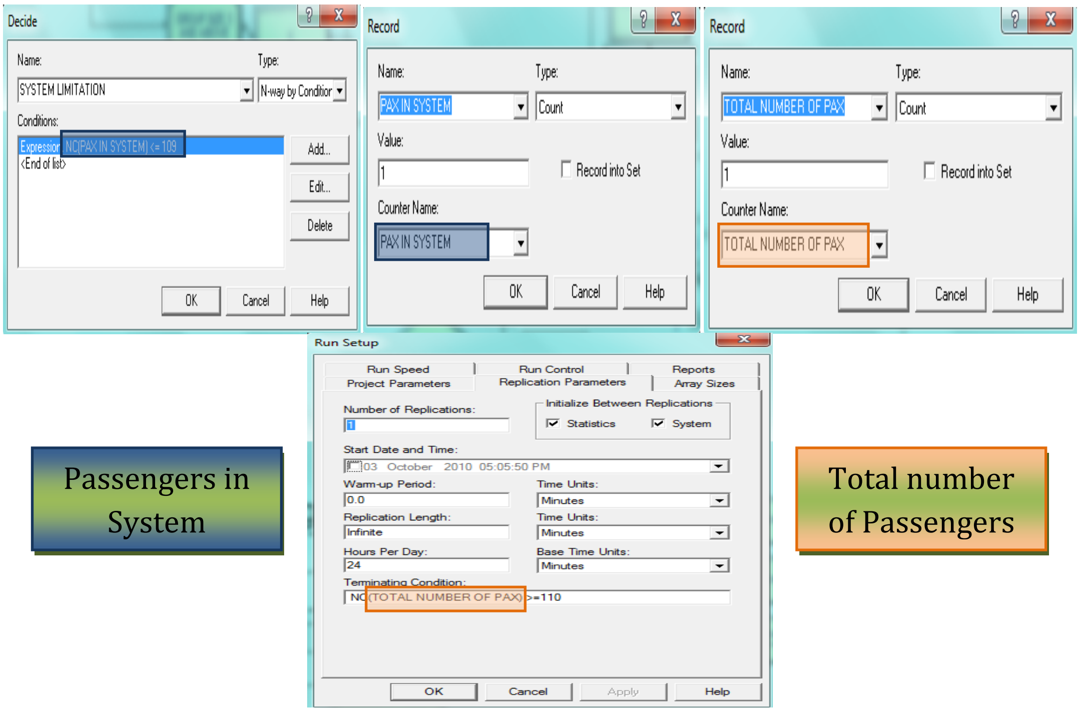
6.3.7 Stopping the Model

Since the simulation is done for the domestic process with 1 or 2 flights, the number of passengers in the system cannot be more than the aircraft capacity. It is assumed that 85% of seats available on the aircraft will be occupied. Table 8 indicates the capacity per aircraft. The A340 is used for the international process, while the B737-400 is used for the domestic process. The capacity used during the processes with two flights, is the 85% capacity multiplied by two.

AIRCRAFT NAME	CAPACITY	85%
A340	230	196
B737-400	129	110

Table 8: Capacity of aircrafts





Decide

Name: SYSTEM LIMITATION

Type: N-way by Condition

Conditions:

Expression NC(PAX IN SYSTEM) <= 109

<End of list>

Record

Name: PAX IN SYSTEM

Type: Count

Value: 1

☐ Record into Set

Counter Name: PAX IN SYSTEM

Record

Name: TOTAL NUMBER OF PAX

Type: Count

Value: 1

☐ Record into Set

Counter Name: TOTAL NUMBER OF PAX

Run Setup

Number of Replications: 1

Initialize Between Replications: ☑ Statistics ☑ System

Start Date and Time: 03 October 2010 05:05:50 PM

Warm-up Period: 0.0

Time Units: Minutes

Replication Length: Infinite

Time Units: Minutes

Hours Per Day: 24

Base Time Units: Minutes

Terminating Condition: NC(TOTAL NUMBER OF PAX) >=110

Figure 33: Properties of nodes used for stopping the model

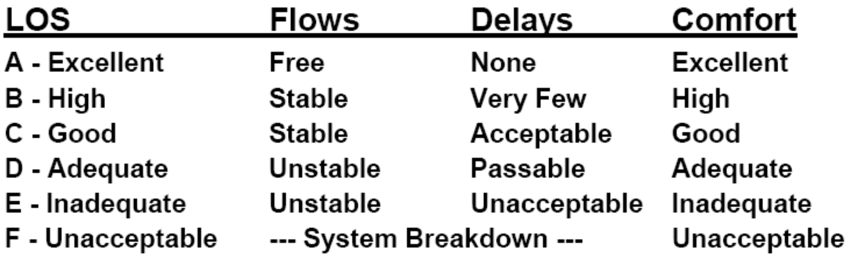
Block 2 makes use of a record node to count the number of individual passengers in the system, named “PAX IN SYSTEM”. A separate node is used on the same principle as explained in section 6.3.6 to make duplicates of the service time. When the “PAX IN SYSTEM” is above or equal to the 85% capacity of the aircraft in table 8, block 1 will not allow any new entities to enter the system. While new entities cannot enter the system, the entities in the system at that stage should be able to move through the whole model. By creating a counter name “TOTAL NUMBER OF PAX” seen in block 3, the setup of the model can be modified. If the “TOTAL NUMBER OF PAX” is above the 85% capacity, the model will stop, ensuring that all entities go through the whole model.

7. Results

Sensitivity analysis is used to study the outcome of the simulation model. According to L. Breierova, M. Choudhari (1996, p.47) sensitivity analysis is a test in how “sensitive” a model is to change in its values and parameters. By showing how the model react to change and change in behaviour if the changes are made, sensitivity analysis can be handy tool.

Sensitivity Analysis is used for the following:

- Easy reference for the client
- In depth insight into the model for people who do not understand the software
- It can highlight the uncertainties in the parameters of the model
- Can indicate what parameters are best to use in the model
- Gives a better understanding of the dynamics of the model
- Indicated possible constraints in the system



LOS	Flows	Delays	Comfort
A - Excellent	Free	None	Excellent
B - High	Stable	Very Few	High
C - Good	Stable	Acceptable	Good
D - Adequate	Unstable	Passable	Adequate
E - Inadequate	Unstable	Unacceptable	Inadequate
F - Unacceptable	--- System Breakdown ---		Unacceptable

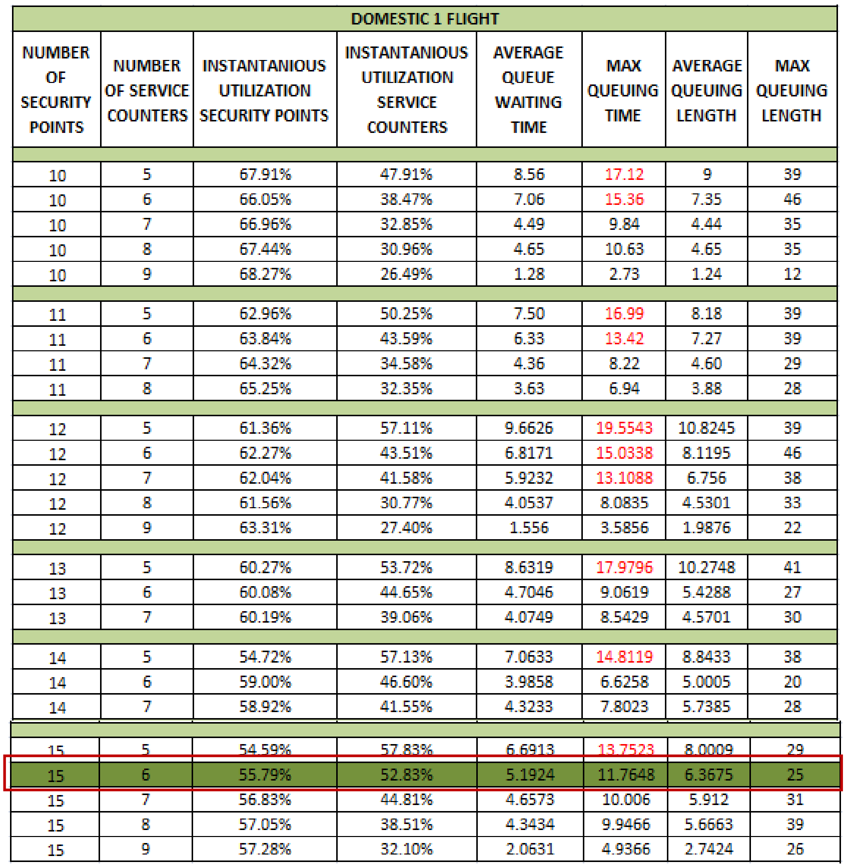
Table 9: Six Categories of the level of service according to the IATA Manual

Table 9 indicates the level of service (LOS) of an airport according to the IATA manual. According to the manual, “the acceptable” queue waiting time for the check-in process is maximum 12 minutes, considering the airport operates at level C. In the figures below the utilization of the service counters in the check-in process is compared to the queue time at the service counters. The utilization of all the different processes is also investigated.

7.1 Domestic

The variable in the domestic process is the service counters for the check-in process, while the number of security check-points stay unchanged. In the tables below the utilization for both the check-in counters and the security check-points are tabulated. The waiting times and queuing lengths is only for the check-in counters. All the queue waiting times written in red is not up to standard according to level C of the IATA Manual.

7.1.1 Domestic with one flight



DOMESTIC 1 FLIGHT							
NUMBER OF SECURITY POINTS	NUMBER OF SERVICE COUNTERS	INSTANTANIOUS UTILIZATION SECURITY POINTS	INSTANTANIOUS UTILIZATION SERVICE COUNTERS	AVERAGE QUEUE WAITING TIME	MAX QUEUING TIME	AVERAGE QUEUING LENGTH	MAX QUEUING LENGTH
10	5	67.91%	47.91%	8.56	17.12	9	39
10	6	66.05%	38.47%	7.06	15.36	7.35	46
10	7	66.96%	32.85%	4.49	9.84	4.44	35
10	8	67.44%	30.96%	4.65	10.63	4.65	35
10	9	68.27%	26.49%	1.28	2.73	1.24	12
11	5	62.96%	50.25%	7.50	16.99	8.18	39
11	6	63.84%	43.59%	6.33	13.42	7.27	39
11	7	64.32%	34.58%	4.36	8.22	4.60	29
11	8	65.25%	32.35%	3.63	6.94	3.88	28
12	5	61.36%	57.11%	9.6626	19.5543	10.8245	39
12	6	62.27%	43.51%	6.8171	15.0338	8.1195	46
12	7	62.04%	41.58%	5.9232	13.1088	6.756	38
12	8	61.56%	30.77%	4.0537	8.0835	4.5301	33
12	9	63.31%	27.40%	1.556	3.5856	1.9876	22
13	5	60.27%	53.72%	8.6319	17.9796	10.2748	41
13	6	60.08%	44.65%	4.7046	9.0619	5.4288	27
13	7	60.19%	39.06%	4.0749	8.5429	4.5701	30
14	5	54.72%	57.13%	7.0633	14.8119	8.8433	38
14	6	59.00%	46.60%	3.9858	6.6258	5.0005	20
14	7	58.92%	41.55%	4.3233	7.8023	5.7385	28
15	5	54.59%	57.83%	6.6913	13.7523	8.0009	29
15	6	55.79%	52.83%	5.1924	11.7648	6.3675	25
15	7	56.83%	44.81%	4.6573	10.006	5.912	31
15	8	57.05%	38.51%	4.3434	9.9466	5.6663	39
15	9	57.28%	32.10%	2.0631	4.9366	2.7424	26

Table 10: Sensitivity Analysis of Domestic one Flight

In figure 35 the relationship between the two utilizations in table 10 is illustrated. In the data used for the figure, the security counters is a constant, thus the small change in the counter's utilization. A definite decrease in the check-in counter utilization is visible. Figure 36 illustrates the utilization of the security check-point when the amount of check-in counters is the constant.

From both these figures the observation is that the utilization do not change much if the counters are the constant in the analysis. Figure 37 in turn illustrates that as the amount of counters increase, the counter utilization will decrease. While the utilization of the counters is very important it is also of importance to keep in mind that the maximum waiting time is 12 minutes. According to the analysis, the most favourable option will be to have 15 security counters and 6 check-in counters with a maximum waiting time of 11.76 minutes.

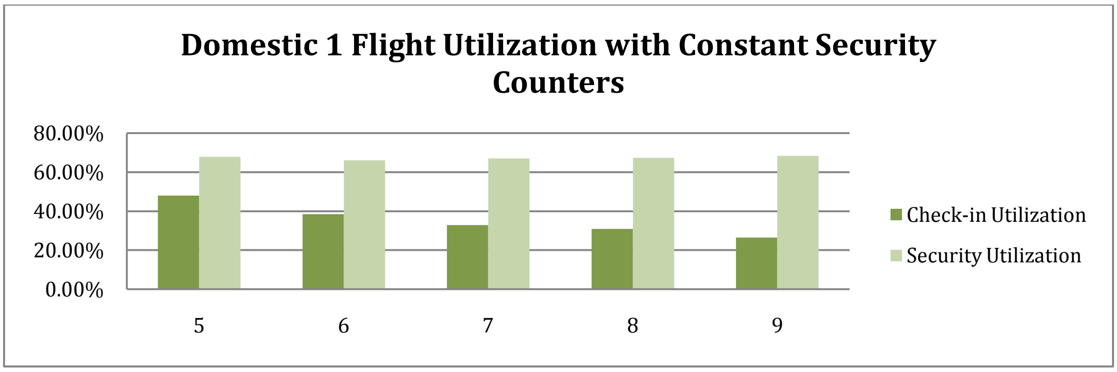


Figure 34 : Domestic one flight Utilization with constant security counters

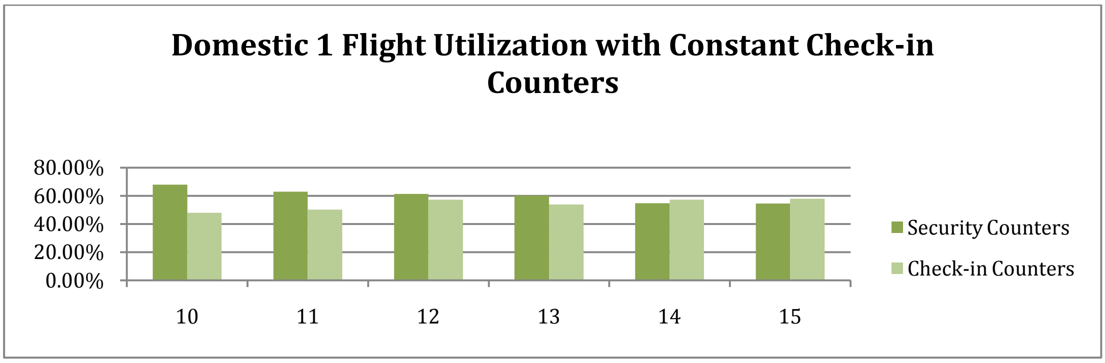


Figure 35: Domestic one flight Utilization with constant check-in counters

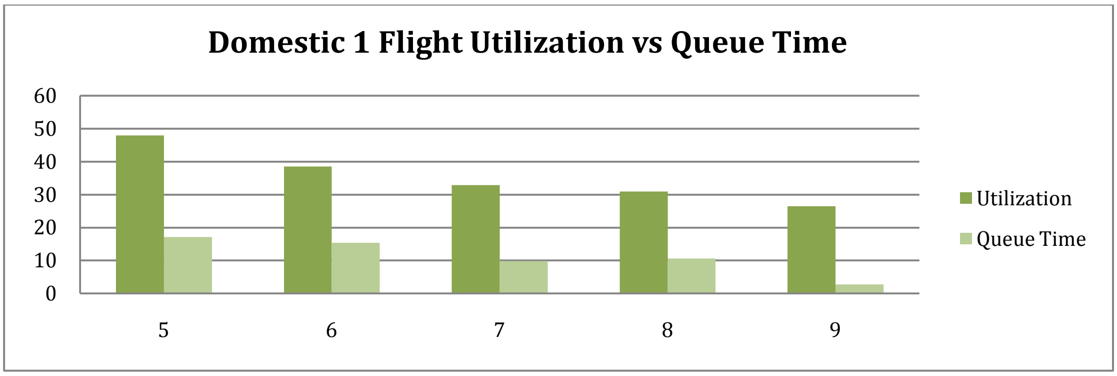


Figure 36: Domestic 1 Flight: Utilization vs Queue Time

7.1.2 Domestic with two flights

DOMESTIC 2 FLIGHTS

NUMBER OF SECURITY POINTS	NUMBER OF SERVICE COUNTERS	INSTANTANIOUS UTILIZATION SECURITY POINTS	INSTANTANIOUS UTILIZATION SERVICE COUNTERS	AVERAGE QUEUE WAITING TIME	MAX QUEUING TIME	AVERAGE QUEUING LENGTH	MAX QUEUING LENGTH
10	5	56.40%	35.17%	16.54	34.83	13.5653	81
10	6	55.00%	28.76%	13.04	26.51	10.02	74
10	7	50.06%	25.34%	10.10	21.91	7.76	67
10	8	51.43%	21.71%	7.27	14.53	5.84	59
10	9	56.73%	20.29%	4.62	10.18	3.97	52
10	10	55.07%	18.59%	3.56	8.90	2.94	45
10	11	54.28%	18.19%	3.09	7.33	2.70	37
11	5	52.88%	38.98%	19.44	37.44	16.80	90
11	6	49.53%	31.42%	14.88	29.89	11.91	77
11	7	53.16%	26.86%	9.23	19.07	7.99	68
11	8	48.09%	24.57%	8.04	18.52	6.71	60
11	9	50.63%	20.49%	4.29	10.66	3.58	45
11	10	52.06%	20.88%	3.99	9.32	3.67	44
11	11	52.94%	18.49%	2.70	7.06	2.29	37
12	5	52.00%	46.60%	20.2841	42.8451	19.2393	87
12	6	45.97%	32.81%	14.4876	39.4244	12.5333	78
12	7	48.09%	25.53%	9.0041	18.7243	7.6317	63
12	8	45.72%	23.02%	6.998	14.2519	5.9704	57
12	9	50.67%	24.97%	5.8834	13.8402	5.592	53
12	10	46.77%	18.09%	1.9714	5.6442	1.7609	30
12	11	46.43%	19.39%	2.5479	5.7198	2.2355	36
13	7	43.46%	28.67%	10.5291	23.4208	9.0938	69
13	8	47.51%	28.36%	8.2612	16.265	8.2027	64
13	9	49.79%	26.32%	6.1612	13.6713	5.9403	54
13	10	48.17%	21.87%	3.5138	8.3872	3.3802	43
13	11	46.72%	18.17%	2.4255	6.2074	2.1337	34
14	7	42.59%	28.83%	8.8226	19.3574	8.2143	62
14	8	46.87%	28.91%	7.8073	17.0689	7.439	59
14	9	43.78%	20.37%	3.7326	8.6832	3.3258	43
14	10	45.15%	21.06%	3.0226	8.2639	2.8457	38
14	11	41.93%	18.64%	2.6993	6.7935	2.4145	36
15	7	42.72%	31.37%	9.5701	21.6281	9.0922	71
15	8	46.44%	31.31%	7.6294	16.1589	8.3576	59
15	9	42.13%	24.74%	5.5042	13.1323	5.3048	55
15	10	40.01%	21.91%	4.0228	10.3151	3.6864	43
15	11	40.43%	20.60%	3.3277	8.295	3.1623	40

Table 11: Sensitivity Analysis of Domestic two Flights

Figure 37 and figure 38 respectively illustrates the utilization of the counters. If the counter is a constant, the utilization does not change much, but if the counter is the variable, the utilization will show a definite change. In figure 39 the relationship between the counter utilization and the waiting time can be seen. The result is the same as in section 7.1.1. As the waiting time decrease so will the utilization of the counter decrease.

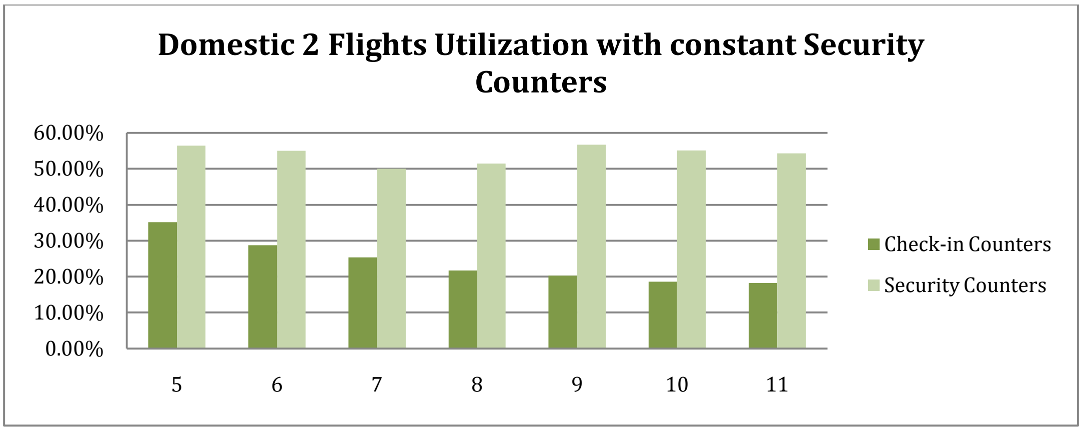


Figure 37: Domestic 2 Flights utilization with constant Security Counters

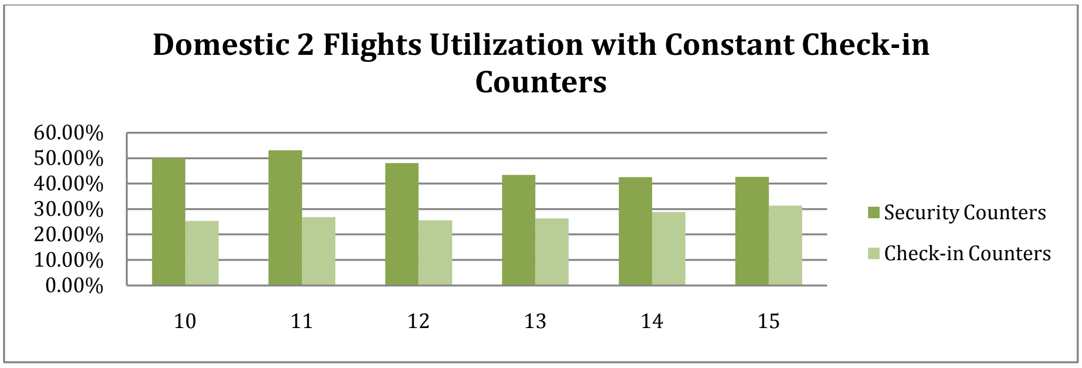


Figure 38: Domestic 2 Flights utilization with constant Check-in Counters

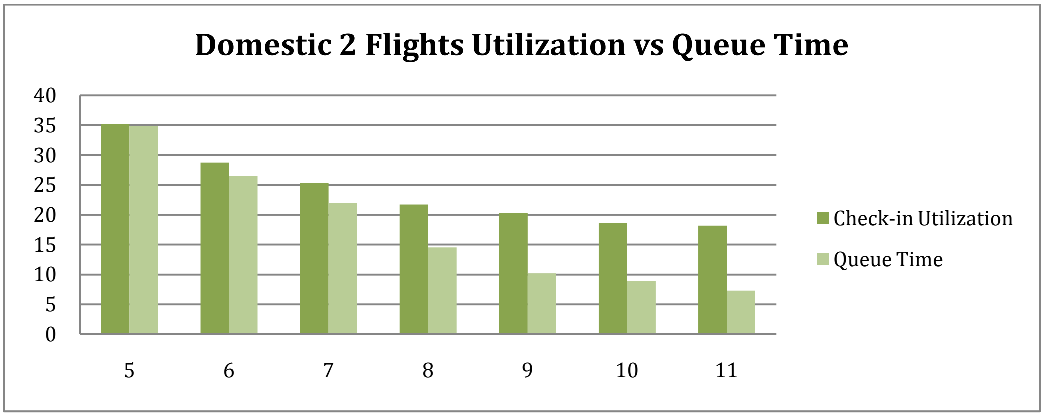
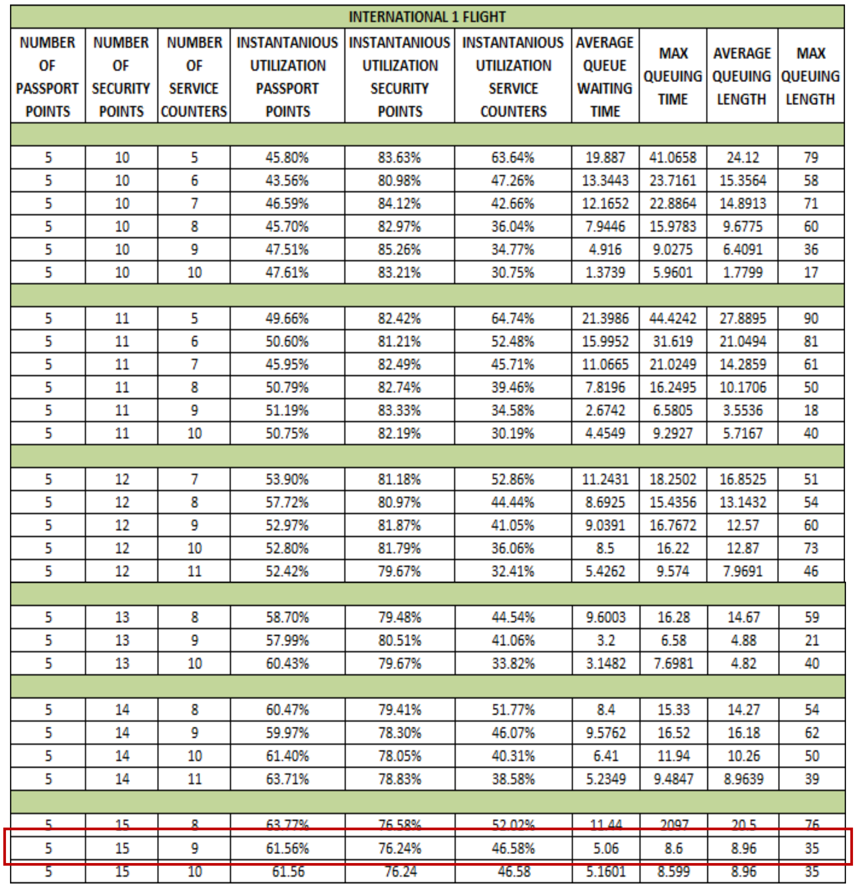


Figure 39: Domestic 2 Flights Utilization vs Queue Time

7.2 International

During the international process's sensitivity analysis, the passport control counter, security check-point counter and check-in counter is analyzed. Again the check-in counter is the variable, but the passport and security counters are also tested as variables.

7.2.1 International with one flight



INTERNATIONAL 1 FLIGHT									
NUMBER OF PASSPORT POINTS	NUMBER OF SECURITY POINTS	NUMBER OF SERVICE COUNTERS	INSTANTANIOUS UTILIZATION PASSPORT POINTS	INSTANTANIOUS UTILIZATION SECURITY POINTS	INSTANTANIOUS UTILIZATION SERVICE COUNTERS	AVERAGE QUEUE WAITING TIME	MAX QUEUING TIME	AVERAGE QUEUING LENGTH	MAX QUEUING LENGTH
5	10	5	45.80%	83.63%	63.64%	19.887	41.0658	24.12	79
5	10	6	43.56%	80.98%	47.26%	13.3443	23.7161	15.3564	58
5	10	7	46.59%	84.12%	42.66%	12.1652	22.8864	14.8913	71
5	10	8	45.70%	82.97%	36.04%	7.9446	15.9783	9.6775	60
5	10	9	47.51%	85.26%	34.77%	4.916	9.0275	6.4091	36
5	10	10	47.61%	83.21%	30.75%	1.3739	5.9601	1.7799	17
5	11	5	49.66%	82.42%	64.74%	21.3986	44.4242	27.8895	90
5	11	6	50.60%	81.21%	52.48%	15.9952	31.619	21.0494	81
5	11	7	45.95%	82.49%	45.71%	11.0665	21.0249	14.2859	61
5	11	8	50.79%	82.74%	39.46%	7.8196	16.2495	10.1706	50
5	11	9	51.19%	83.33%	34.58%	2.6742	6.5805	3.5536	18
5	11	10	50.75%	82.19%	30.19%	4.4549	9.2927	5.7167	40
5	12	7	53.90%	81.18%	52.86%	11.2431	18.2502	16.8525	51
5	12	8	57.72%	80.97%	44.44%	8.6925	15.4356	13.1432	54
5	12	9	52.97%	81.87%	41.05%	9.0391	16.7672	12.57	60
5	12	10	52.80%	81.79%	36.06%	8.5	16.22	12.87	73
5	12	11	52.42%	79.67%	32.41%	5.4262	9.574	7.9691	46
5	13	8	58.70%	79.48%	44.54%	9.6003	16.28	14.67	59
5	13	9	57.99%	80.51%	41.06%	3.2	6.58	4.88	21
5	13	10	60.43%	79.67%	33.82%	3.1482	7.6981	4.82	40
5	14	8	60.47%	79.41%	51.77%	8.4	15.33	14.27	54
5	14	9	59.97%	78.30%	46.07%	9.5762	16.52	16.18	62
5	14	10	61.40%	78.05%	40.31%	6.41	11.94	10.26	50
5	14	11	63.71%	78.83%	38.58%	5.2349	9.4847	8.9639	39
5	15	8	63.77%	76.58%	52.02%	11.44	2097	20.5	76
5	15	9	61.56%	76.24%	46.58%	5.06	8.6	8.96	35
5	15	10	61.56	76.24	46.58	5.1601	8.599	8.96	35

Table 12: Sensitivity Analysis International one Flight

In figure 40 the utilization of all three counters can been seen, with the passport and security counters as constants. Again as in the previous two sections, if the counters are constant, the change in the utilization is minimal. Only when the amount of counters change, the utilization will have significant changes. The optimum usage for this process would be to have 15 security counters, 5 passport counters and 9 check-in counters with a maximum waiting time of 8.6 minutes.

Figure 41 illustrates the relationship between the counter utilization and the queue time. As the queue time decrease, the utilization will also decrease. As the amount of counters increase, the queue time will decrease.

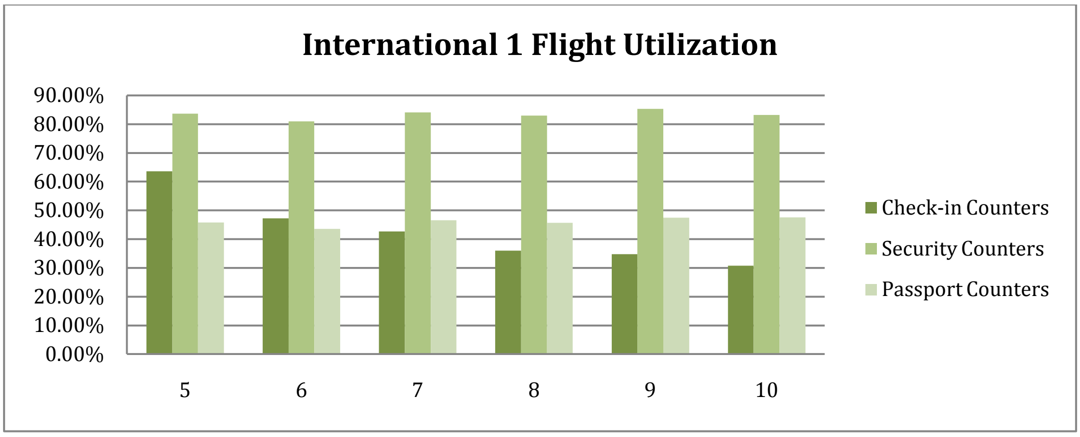


Figure 40: International one Flight Utilization

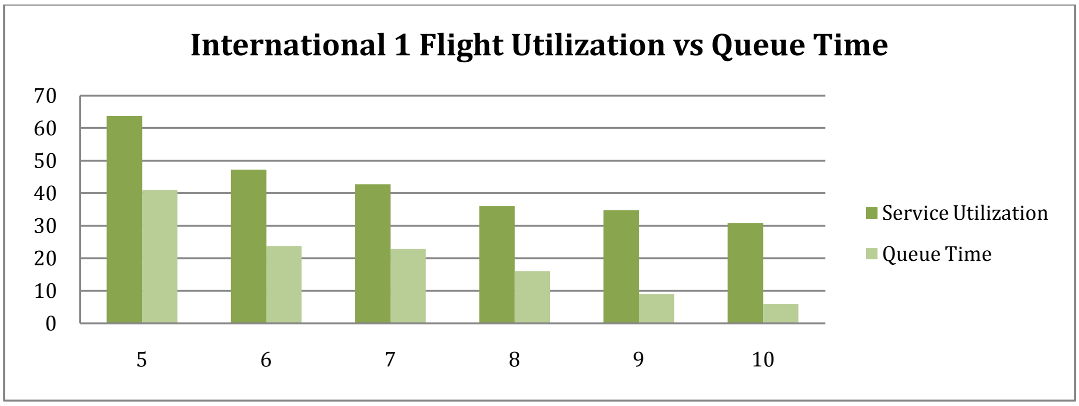
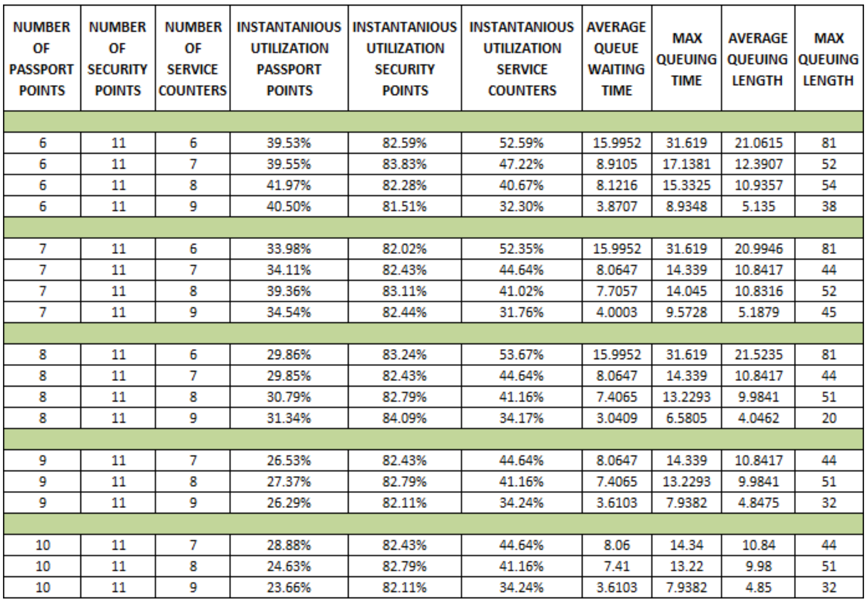


Figure 41: International 1 Flight Utilization vs Queue Time

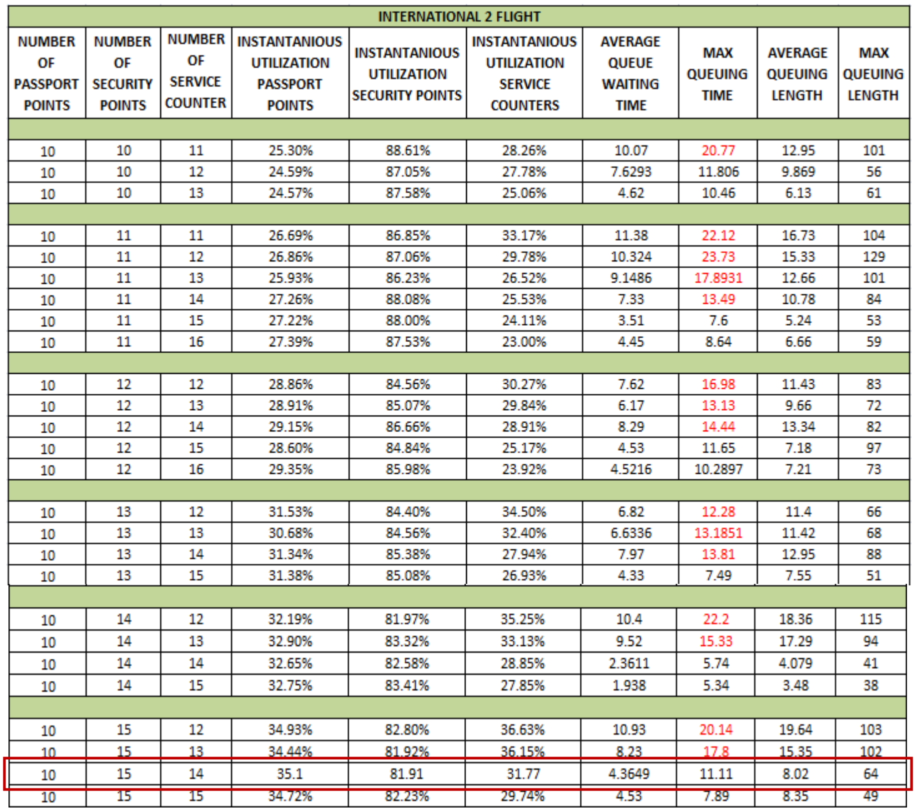


NUMBER OF PASSPORT POINTS	NUMBER OF SECURITY POINTS	NUMBER OF SERVICE COUNTERS	INSTANTANIOUS UTILIZATION PASSPORT POINTS	INSTANTANIOUS UTILIZATION SECURITY POINTS	INSTANTANIOUS UTILIZATION SERVICE COUNTERS	AVERAGE QUEUE WAITING TIME	MAX QUEUING TIME	AVERAGE QUEUING LENGTH	MAX QUEUING LENGTH
6	11	6	39.53%	82.59%	52.59%	15.9952	31.619	21.0615	81
6	11	7	39.55%	83.83%	47.22%	8.9105	17.1381	12.3907	52
6	11	8	41.97%	82.28%	40.67%	8.1216	15.3325	10.9357	54
6	11	9	40.50%	81.51%	32.30%	3.8707	8.9348	5.135	38
7	11	6	33.98%	82.02%	52.35%	15.9952	31.619	20.9946	81
7	11	7	34.11%	82.43%	44.64%	8.0647	14.339	10.8417	44
7	11	8	39.36%	83.11%	41.02%	7.7057	14.045	10.8316	52
7	11	9	34.54%	82.44%	31.76%	4.0003	9.5728	5.1879	45
8	11	6	29.86%	83.24%	53.67%	15.9952	31.619	21.5235	81
8	11	7	29.85%	82.43%	44.64%	8.0647	14.339	10.8417	44
8	11	8	30.79%	82.79%	41.16%	7.4065	13.2293	9.9841	51
8	11	9	31.34%	84.09%	34.17%	3.0409	6.5805	4.0462	20
9	11	7	26.53%	82.43%	44.64%	8.0647	14.339	10.8417	44
9	11	8	27.37%	82.79%	41.16%	7.4065	13.2293	9.9841	51
9	11	9	26.29%	82.11%	34.24%	3.6103	7.9382	4.8475	32
10	11	7	28.88%	82.43%	44.64%	8.06	14.34	10.84	44
10	11	8	24.63%	82.79%	41.16%	7.41	13.22	9.98	51
10	11	9	23.66%	82.11%	34.24%	3.6103	7.9382	4.85	32

Table 13: Sensitivity Analysis with constant security counters

In table 13 above, the amount of security counters are kept constant. The result of the analysis is the same as for table 12.

7.2.2 International with two Flights



INTERNATIONAL 2 FLIGHT									
NUMBER OF PASSPORT POINTS	NUMBER OF SECURITY POINTS	NUMBER OF SERVICE COUNTER	INSTANTANIOUS UTILIZATION PASSPORT POINTS	INSTANTANIOUS UTILIZATION SECURITY POINTS	INSTANTANIOUS UTILIZATION SERVICE COUNTERS	AVERAGE QUEUE WAITING TIME	MAX QUEUING TIME	AVERAGE QUEUING LENGTH	MAX QUEUING LENGTH
10	10	11	25.30%	88.61%	28.26%	10.07	20.77	12.95	101
10	10	12	24.59%	87.05%	27.78%	7.6293	11.806	9.869	56
10	10	13	24.57%	87.58%	25.06%	4.62	10.46	6.13	61
10	11	11	26.69%	86.85%	33.17%	11.38	22.12	16.73	104
10	11	12	26.86%	87.06%	29.78%	10.324	23.73	15.33	129
10	11	13	25.93%	86.23%	26.52%	9.1486	17.8931	12.66	101
10	11	14	27.26%	88.08%	25.53%	7.33	13.49	10.78	84
10	11	15	27.22%	88.00%	24.11%	3.51	7.6	5.24	53
10	11	16	27.39%	87.53%	23.00%	4.45	8.64	6.66	59
10	12	12	28.86%	84.56%	30.27%	7.62	16.98	11.43	83
10	12	13	28.91%	85.07%	29.84%	6.17	13.13	9.66	72
10	12	14	29.15%	86.66%	28.91%	8.29	14.44	13.34	82
10	12	15	28.60%	84.84%	25.17%	4.53	11.65	7.18	97
10	12	16	29.35%	85.98%	23.92%	4.5216	10.2897	7.21	73
10	13	12	31.53%	84.40%	34.50%	6.82	12.28	11.4	66
10	13	13	30.68%	84.56%	32.40%	6.6336	13.1851	11.42	68
10	13	14	31.34%	85.38%	27.94%	7.97	13.81	12.95	88
10	13	15	31.38%	85.08%	26.93%	4.33	7.49	7.55	51
10	14	12	32.19%	81.97%	35.25%	10.4	22.2	18.36	115
10	14	13	32.90%	83.32%	33.13%	9.52	15.33	17.29	94
10	14	14	32.65%	82.58%	28.85%	2.3611	5.74	4.079	41
10	14	15	32.75%	83.41%	27.85%	1.938	5.34	3.48	38
10	15	12	34.93%	82.80%	36.63%	10.93	20.14	19.64	103
10	15	13	34.44%	81.92%	36.15%	8.23	17.8	15.35	102
10	15	14	35.1	81.91	31.77	4.3649	11.11	8.02	64
10	15	15	34.72%	82.23%	29.74%	4.53	7.89	8.35	49

Table 14: Sensitivity Analysis International two Flights

Figure 42 illustrates the utilization of the counters of an international process with two flights. Regardless of the change in the amount of counters, the security counters always work with a very high utilization compared to the other counters. From the previous sections it is clear that when the utilization is high, the queue time for that process is also very high. Thus, the security counters is a constraint in the system. A possible solution is to increase the amount of counters. The optimum usage for this process from the sensitivity analysis would be to use 15 security counters, 10 passport counters and 14 check-in counters with a maximum waiting time of 11.11 minutes.

Figure 43 illustrates that as the queue decrease, the utilization of that counters will decrease.

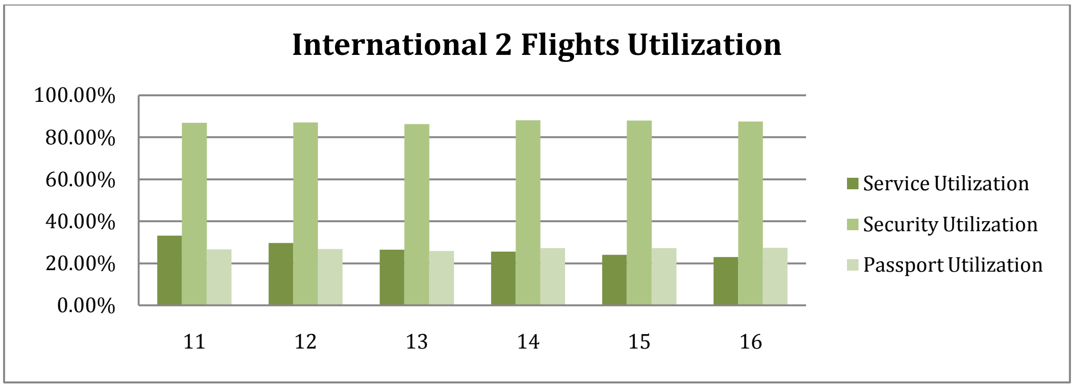


Figure 42: International two flights Utilization

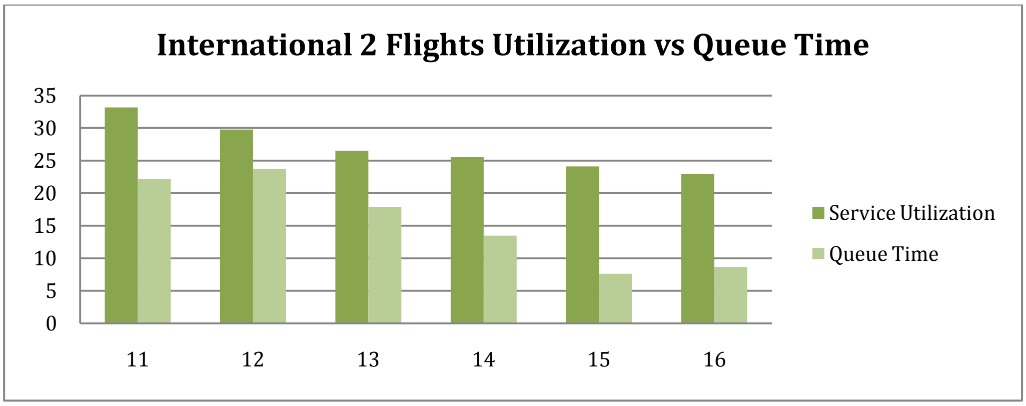


Figure 43: International two flights utilization vs Queue Time

8. Future Analysis

For future references, a sensitive analysis is done using the biometric methods explained in section 5. Not a specific method was used for the simulation and the assumption was made that 50% of arriving passengers will make use of the biometric methods.

DOMESTIC 1 FLIGHT WITH BIOMETRICS													
NUMBER OF COUNTERS			UTILIZATION			SERVICE COUNTERS				BIOMETRIC COUNTERS			
NUMBER OF BIOMETRIC POINTS	NUMBER OF SECURITY POINTS	NUMBER OF SERVICE COUNTERS	INSTANTANIOUS UTILIZATION BIOMETRIC POINTS	INSTANTANIOUS UTILIZATION SECURITY POINTS	INSTANTANIOUS UTILIZATION SERVICE COUNTERS	AVERAGE QUEUE WAITING TIME	MAX QUEUING TIME	AVERAGE QUEUING LENGTH	MAX QUEUING LENGTH	AVERAGE QUEUE WAITING TIME	MAX QUEUING TIME	AVERAGE QUEUING LENGTH	MAX QUEUING LENGTH
3	10	5	18.55%	66.25%	23.91%	0.87	2.87	0.383	5	0.44	1.50	0.207	4
3	10	6	18.55%	66.35%	25.71%	3.59	7.71	2.11	18	1.02	2.60	0.43	6
3	10	7	20.97%	65.27%	15.71%	0.10	0.72	0.04	3	1.14	3.88	0.57	9
3	10	8	19.01%	68.76%	14.37%	0.05	0.54	0.02	2	0.63	1.94	0.28	5
5	10	5	14.91%	65.25%	24.32%	0.79	3.49	0.329	4	0.21	1.40	0.1172	4
5	10	6	13.36%	67.64%	21.43%	0.19	2.03	0.10	3	0.21	1.40	0.06	3
5	10	7	15.21%	67.06%	16.68%	0.18	1.15	0.07	3	0.33	1.44	0.19	4
5	10	8	14.46%	66.50%	15.29%	0.04	0.68	0.02	1	0.29	1.71	0.17	6
6	10	6	11.16%	65.61%	18.91%	0	0	0	0	0.159	1.315	0.078	5
7	10	7	9.32%	65.37%	17.77%	0.159	1.416	0.0667	4	0.0374	0.4152	0.0189	3
8	10	8	9.33%	64.51%	13.59%	0	0	0	0	0.007	0.2216	0.004	2
9	10	9	7.16%	64.46%	13.96%	0.007	0.213	0.003	1	0.002	0.09	0.001	1

Table 15: Sensitivity Analysis with Biometric Methods

In table 15 it can clearly be seen that the maximum queuing time at the service counters drastically decrease when using the improved methods. By increasing the number of biometric counters/check-in points, the utilization decrease. Figure 44 illustrates the relationship between the queuing times of a system making use and a system not making use of biometric technology. It is clear that the queuing time significantly decrease when using biometric technology.

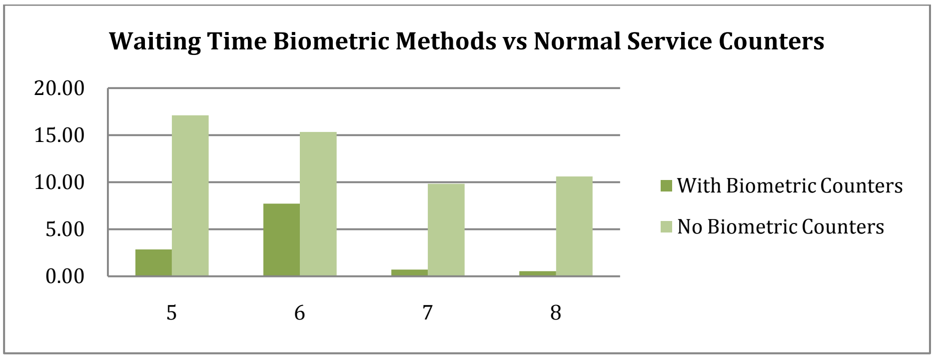


Figure 44: Waiting Time Biometric methods vs Normal service counter

9. Conclusion

Sensitivity analysis indicate that as the number of processing counters increase, the queue time will decrease and in turn the utilization of those processing counters will also decrease. The utilization for any process will increase when that process has a high usage. By increasing the number of counters, the usage for some of the counters will decrease because the workload is divided between more counters. The queuing time and queuing length is the constraints within the system. Solutions for these constraints are found by using the sensitivity analysis to identify the optimum amount of counters for each process.

Using the biometric technology it is clear that the queue time at the check-in counters is drastically decreased. For implementation in the future, the biometric technology is a very good solution to the above constraints in the system.

The simulation model can also be used to test alternative counter utilization if VCE finds the need for the change.

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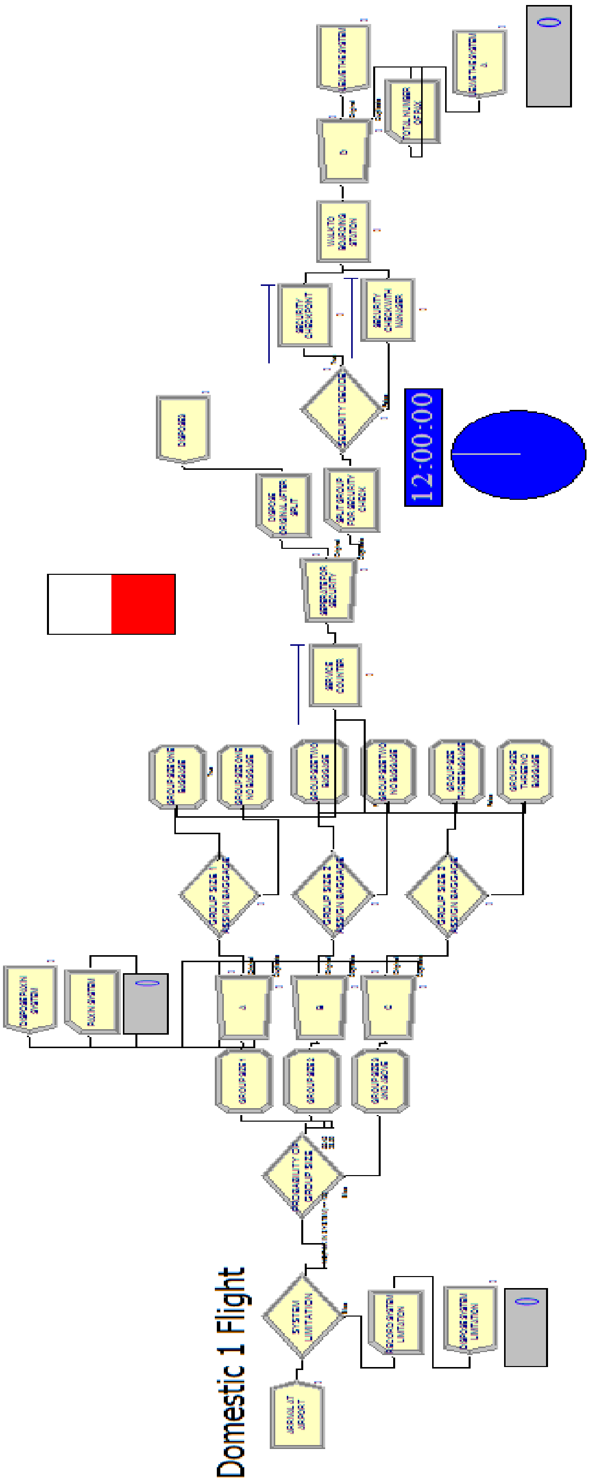
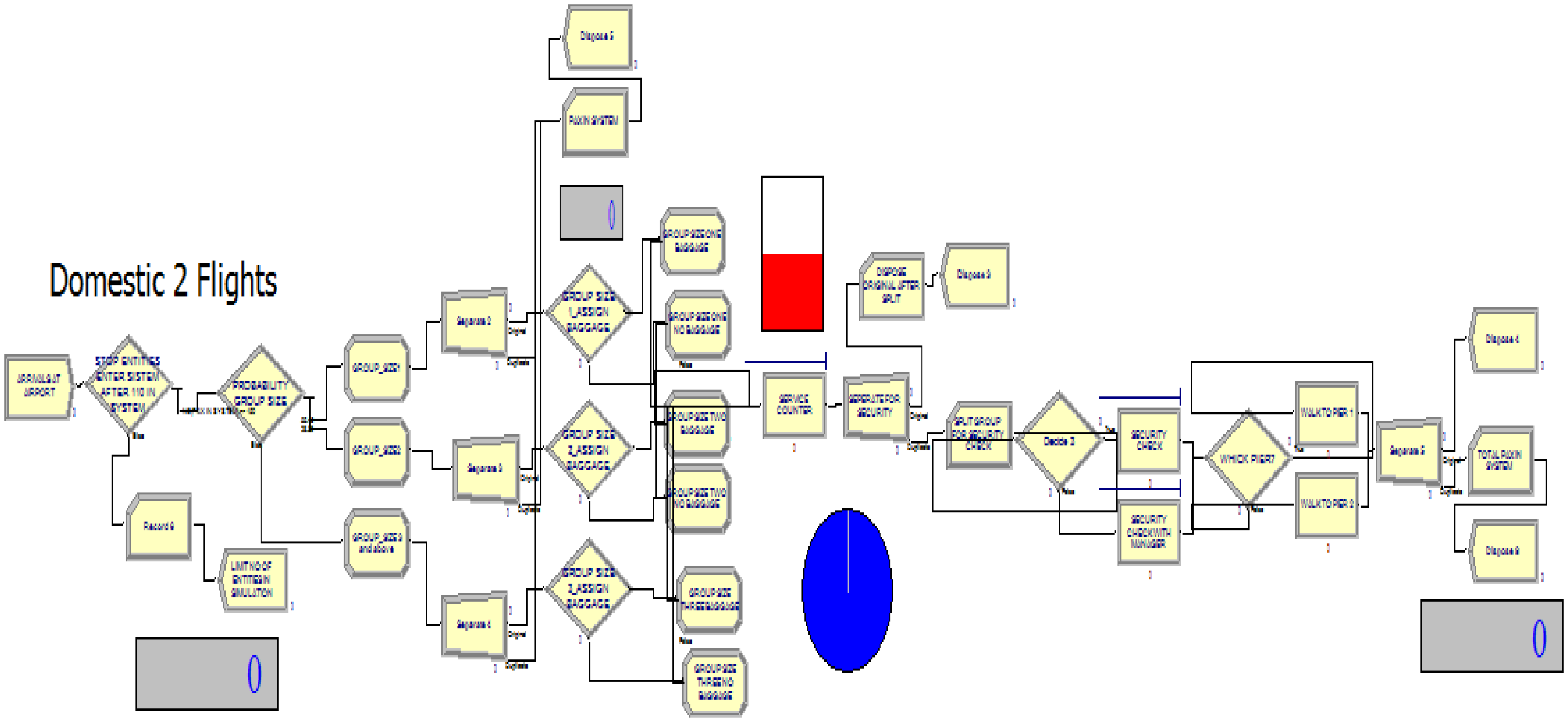
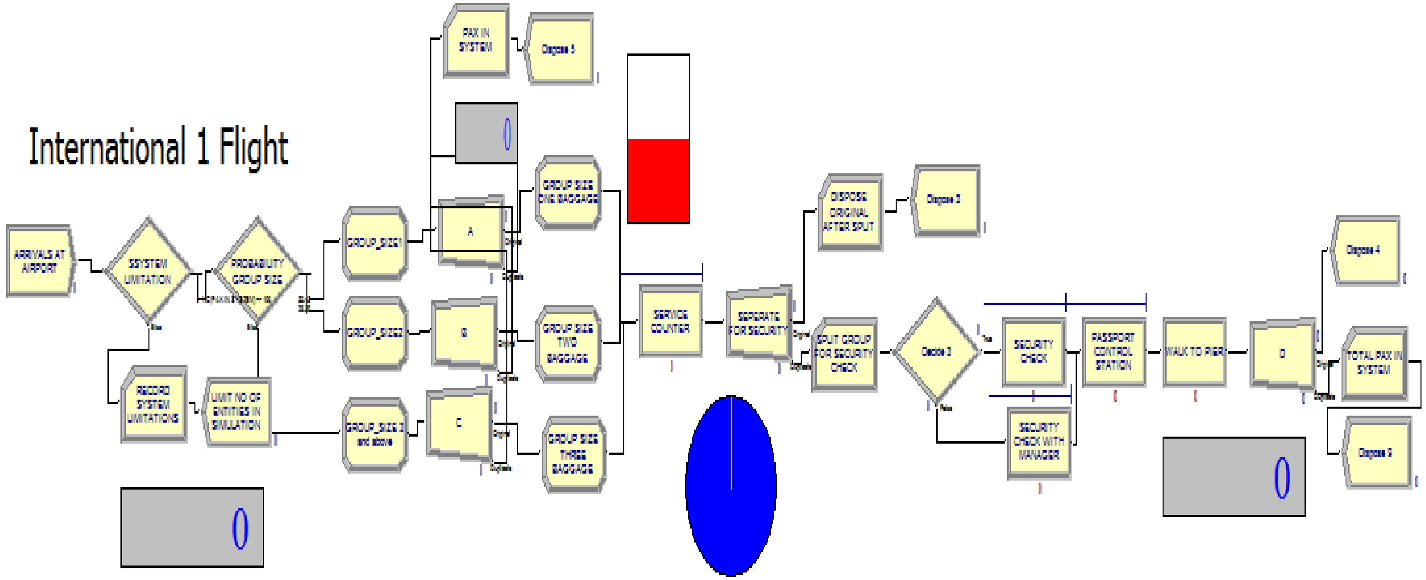
Appendix

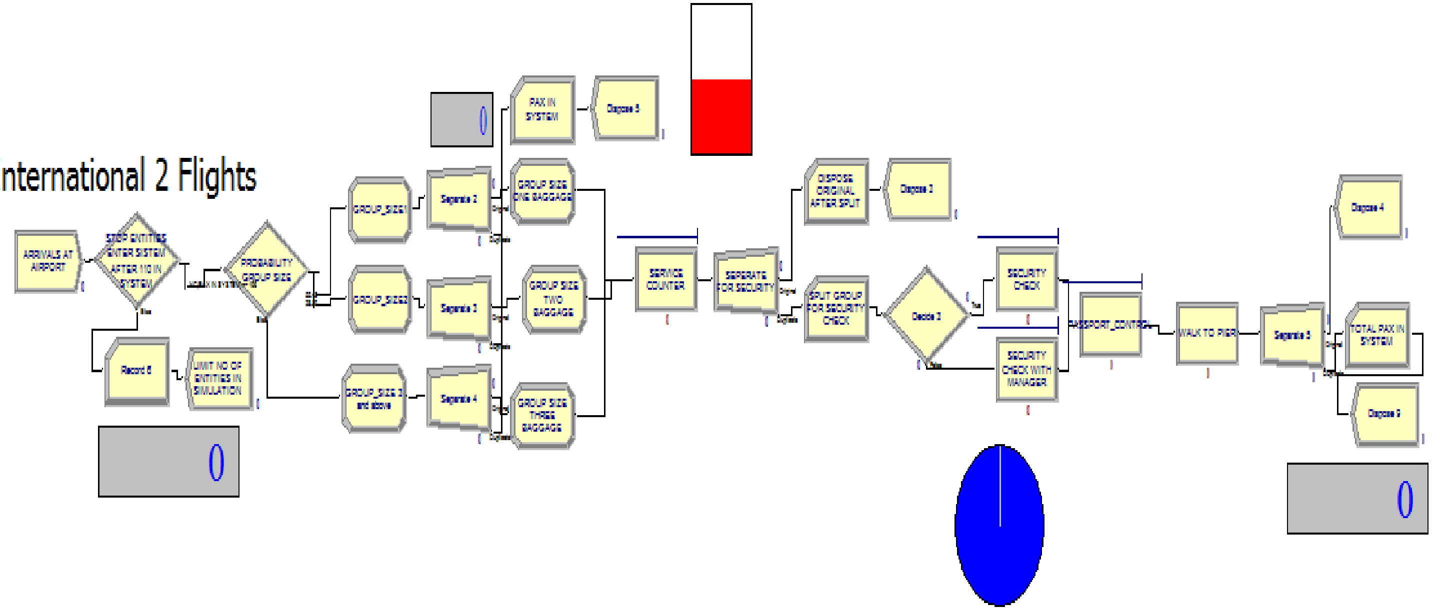

Domestic 1 Flight
SYSTEM LIMITATION
PROBABILITY OF GROUP SIZE
GROUP SIZE 1
GROUP SIZE 2
GROUP SIZE 3 AND ABOVE
A
B
C
GROUP SIZE 1 ASSIGN BAGGAGE
GROUP SIZE 2 ASSIGN BAGGAGE
GROUP SIZE 3 ASSIGN BAGGAGE
SERVICE COUNTER
SECURITY CHECKPOINT
WALK TO BOARDING STATION
12:00:00

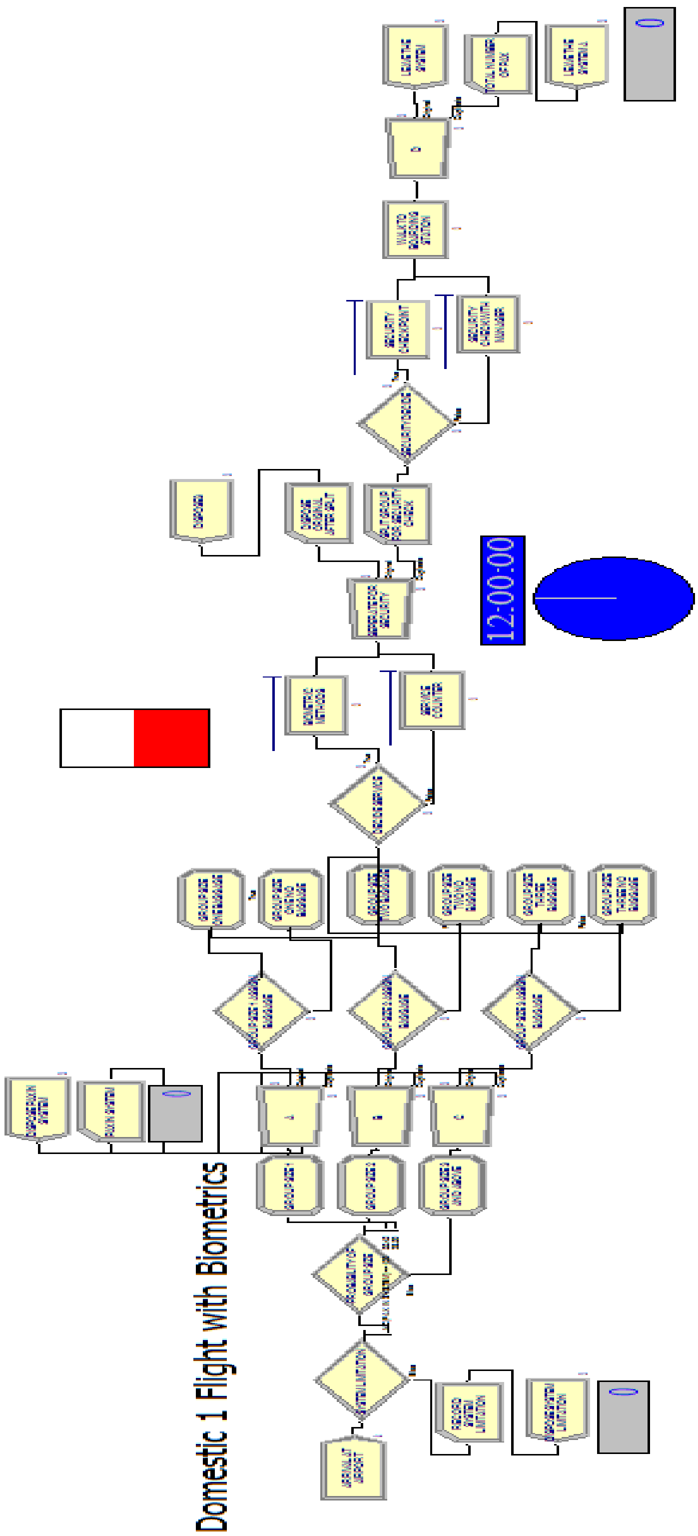
Domestic 2 Flights




International 1 Flight
ARRIVALS AT AIRPORT
SYSTEM LIMITATION
PROBABILITY GROUP SIZE
RECORD SYSTEM LIMITATIONS
LIMIT NO OF ENTITIES IN SIMULATION
0
GROUP_SIZE1
GROUP_SIZE2
GROUP_SIZE 3 and above
PAX IN SYSTEM
Dispose 5
0
A
B
C
GROUP SIZE ONE BAGGAGE
GROUP SIZE TWO BAGGAGE
GROUP SIZE THREE BAGGAGE
SERVICE COUNTER
SEPERATE FOR SECURITY
DISPOSE ORIGINAL AFTER SPLIT
Dispose 3
SPLIT GROUP FOR SECURITY CHECK
Decide 3
SECURITY CHECK
SECURITY CHECK WITH MANAGER
PASSPORT CONTROL STATION
WALK TO PIER
D
0
Dispose 4
TOTAL PAX IN SYSTEM
Dispose 6

International 2 Flights




Domestic 1 Flight with Biometrics
12:00:00