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Chiung-Yu Chiu and C. Michael Walton

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University of Texas at Austin
3208 Red River, Suite 200
Austin, Texas 78705-2650

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16. Abstract

The development of New Large Aircraft (NLA) has been a topic of considerable interest and speculation. The first generation of the NLA with 555-seat capacity will presumably be entering into commercial service by 2006. Due to the greater dimensions of the NLA and more simultaneous arriving passengers, there will be substantial impacts on existing airports after its launch. Terminal operations, particularly individual passenger processing facilities, will be one of the significantly affected components of the entire airport system. The analysis of these impacts on individual terminal facilities, which will be strongly influenced, have been lacking because of the uncertain characteristics of NLA operations. Therefore, a method that is capable of investigating the impact of the NLA under such uncertainty is needed for airport operators to determine the potential effects and to accommodate the possible required changes in terminal facilities.

This report proposes an integrated simulation method to investigate the potential impacts on the operation performance of primary processing facilities. The method utilizes scenario analysis in a before and after context, and attempts to analyze the impacts under current uncertainty regarding the operating characteristics of the NLA and its market share. This study focuses on analyzing the impacts on international arriving passengers. The arriving passenger flow is modeled as a queuing network system in this study, comprised of a series of passenger processing facilities. The derivation of arrival and service probability distributions in the simulation model are based on a survey of international airports and by observational data collected at selected international terminals. The simulation model can be used to examine the potential bottlenecks in the arriving passenger flow and to evaluate the operational strategies. Major impacts at the baggage claim system are detected in the simulation model, and the related strategies of increasing baggage processing capacity are thus evaluated. The results obtained from impact analyses and the evaluation of operational strategies may assist airport operators first in investigating the compatibility of existing terminal processing facilities with the introduction of the NLA, and ultimately in preparing the future development plan.

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New Large Aircraft, NLA, Airport, Passenger Flow, Terminal, Passenger Terminal System, Passenger Volume

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IMPACTS OF NEW LARGE AIRCRAFT ON PASSENGER FLOWS AT INTERNATIONAL AIRPORT TERMINALS

by

Chiung-Yu Chiu

C. Michael Walton

Research Report SWUTC/03/167530-1

Combined final report for the following two SWUTC projects:
Evaluating the Performance of Arrival Passenger Processing Facilities for Large Aircraft—167530
& Impact of New Large Aircraft on Arrival Passenger Flows at Airport Terminals—167230

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EXECUTIVE SUMMARY

Major market forecasts indicate that air traffic will continue to grow steadily in the foreseeable future. This expected growth represents a challenge for the entire aviation industry: airlines, airports, air traffic control systems, and manufacturers. The development of new technologies, such as aircraft with higher carrying capability known as the New Large Aircraft (NLA), is one of alternative ways to accommodate the soaring demand. The first generation of the NLA with 555-seat capacity will presumably be entering into commercial service by 2006. Due to the greater dimensions of the NLA and more simultaneous arriving passengers, there will be substantial impacts on existing airports after its launch. The impacts on airside planning and design have been extensively studied in recent years. The terminal landside related issues are still less studied, however, because of the uncertain operating characteristics of the NLA.

This study presents the potential impacts of NLA introduction on the operation performance of primary processing facilities by utilizing an integrated simulation method. Essentially, this study focuses on the analysis of arriving passenger flows. The integrated simulation method comprises of five major tasks: establishment of a passenger terminal system, determination of demand and supply of the terminal, development of the simulation model, model validation, and model applications using scenario analysis. The first objective is to model a typical international terminal, which has potential to operate the NLA in the future. The next task is to generate the arrivals at the terminal and to determine the capacity of each processing facility as well as its associated service characteristics. A global survey is one means for obtaining the operational characteristics of these airports in this study. Fifteen international airports worldwide participated in the survey. The results obtained from the first two tasks serve as model inputs to the simulation model.

Third, the validation of the model is to use comparable measurements to replicate expectation of operations at an active international terminal. Through a statistical comparison with survey data from fifteen international airports, the simulation model is validated. The validation covers three major measurements: Daily arriving passenger volumes, average time in the terminal, and time spent by passengers from gates to immigration, from immigration to baggage claim, from baggage claim to customs, and from customs to curbside. Since there is no

specific terminal to observe the actual passenger flow, the comparison bases for these three measurements are obtained from the airport survey.

Finally, by using various scenarios with a varying proportion of NLA, the impacts on individual facilities can be evaluated based on the change in key performance measures, such as waiting time and queuing length. In this study, the impacts of NLA introduction are evaluated in a before and after context. Three scenarios for demand forecasts, including conservative (3%), moderate (4%), and optimistic (5%) are developed. Using the conservative scenario at a growth rate of 3%, the study estimates the demand in the design year 2010 to simulate the terminal passenger flows before and after NLA introduction. In order to examine the impact of NLA introduction, two scenarios of gate utilization are considered in simulation model applications. The first scenario is to assign gates for NLA operations only, and the second one is to assign gates as for both NLA and other wide-body aircraft. The main assumption for gate assignment policies is that when a gate is assigned for NLA operations, its adjacent gates will not operate the NLA, B747, and B777. Four terminal cases are simulated and analyzed based on the queuing time, including linear terminals with 20 and 30 gates, and pier/finger terminals with 30 and 40 gates.

Major impacts of NLA introduction at terminal facilities are discussed in this study. The analysis of simulation results demonstrates that all processing facilities would be affected, in terms of the average queuing time. The most affected area is the baggage claim system when the NLA arrivals reach some specific share of the fleet mix. The higher fleet share of the NLA implies that there are probably more NLA operations in the terminal. Due to more NLA operations, the system will have higher probability of closer NLA arrivals. More closer arrivals would result in congestion at the baggage claim area. Results of the impact analysis also demonstrate that the terminal providing the gates for NLA operations only is more compatible with NLA operations than providing the gates for NLA and other wide-bodied operations, under the same level of NLA demand. With respect to the evaluation of related operational strategies, the simulation results demonstrate that providing the gates for NLA operations only will be an efficient strategy to accommodate NLA introduction. The evaluation framework proposed in this study may assist airport operators to examine the potential bottlenecks in the terminal and to evaluate the operational compatibility of existing processing facilities.

ABSTRACT

The development of New Large Aircraft (NLA) has been a topic of considerable interest and speculation. The first generation of the NLA with 555-seat capacity will presumably be entering into commercial service by 2006. Due to the greater dimensions of the NLA and more simultaneous arriving passengers, there will be substantial impacts on existing airports after its launch. Terminal operations, particularly individual passenger processing facilities, will be one of the significantly affected components of the entire airport system. The analysis of these impacts on individual terminal facilities, which will be strongly influenced, have been lacking because of the uncertain characteristics of NLA operations. Therefore, a method that is capable of investigating the impact of the NLA under such uncertainty is needed for airport operators to determine the potential effects and to accommodate the possible required changes in terminal facilities.

This report proposes an integrated simulation method to investigate the potential impacts on the operation performance of primary processing facilities. The method utilizes scenario analysis in a before and after context, and attempts to analyze the impacts under current uncertainty regarding the operating characteristics of the NLA and its market share. This study focuses on analyzing the impacts on international arriving passengers. The arriving passenger flow is modeled as a queuing network system in this study, comprised of a series of passenger processing facilities. The derivation of arrival and service probability distributions in the simulation model are based on a survey of international airports and by observational data collected at selected international terminals. The simulation model can be used to examine the potential bottlenecks in the arriving passenger flow and to evaluate the operational strategies. Major impacts at the baggage claim system are detected in the simulation model, and the related strategies of increasing baggage processing capacity are thus evaluated. The results obtained from impact analyses and the evaluation of operational strategies may assist airport operators first in investigating the compatibility of existing terminal processing facilities with the introduction of the NLA, and ultimately in preparing the future development plan.

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CHAPTER 1. INTRODUCTION

1.1 PROBLEM STATEMENT

This study investigates the operational compatibility of current facilities at airport terminals with the introduction of New Large Aircraft (NLA). In order to accommodate the future demand in air transportation, airlines and airframe manufacturers have been discussing over the past few years the development of a new, larger aircraft capable of carrying between 500 and 1,000 passengers. According to its planned specifications, the NLA will be significantly greater in dimensions, weight, as well as seat capacity. Therefore, the development of the NLA is expected to have major impacts on existing airport facilities.

The impacts of the NLA on airside planning and design have been extensively studied in recent years. The terminal landside related issues remain less studied, however, because of the uncertain operating characteristics of the NLA. The main goal of this study is to primarily examine the effect of NLA introduction on terminal passenger flows. As might be expected, the NLA will aggravate the peak characteristics of terminal operations for arriving passengers, due to more passengers arriving at the terminal simultaneously by a single flight.

Essentially this study focuses on the analysis of the arriving passenger flow in the terminal area utilizing scenario analysis and simulation technology. Scenarios are developed by considering the various combinations of passenger capacity of the NLA, basic terminal concepts, and terminal sizes classified by the number of gates. The passenger flow is simulated for each scenario and is examined using performance measures, such as total time spent in system and the queuing length at each server before and after introducing the NLA and exploiting various operational strategies.

1.2 MOTIVATION

Major market forecasts indicate that air traffic will continue to grow steadily in the foreseeable future. This expected growth represents a challenge for the entire aviation industry: airlines, airports, air traffic control systems, and manufacturers. The development of new technologies, such as aircraft with higher carrying capability known as the New Large Aircraft, is one of alternative ways to accommodate the soaring demand. Due to the increase in NLA orders, it is likely that the 555-seat NLA will enter service into the 400-plus-seat intensive airways by 2006. Its greater dimension and higher seat capacity will cause significant impacts on many aspects of airport planning, design, and operations. Among the major affected components of the airport, airfield geometric issues have been extensively studied [Barros, 1997; FAA, 1998; Barros, 1998]. Terminal landside related studies have addressed several challenging issues as well, covering the review of criteria for terminal design [FAA, 1998; Barros, 1998], sizing the passenger area [Barros, 1998], and selecting the gate position for the NLA [Barros, 2000]. The operational impacts on individual terminal facilities, which will be strongly influenced, have been lacking because of the uncertain characteristics of NLA operations [Barros, 1998]. Therefore, a method that is capable of evaluating the impact of the NLA under such uncertainty is needed for airport operators to determine the potential effects and to accommodate the possible required changes in terminal facilities.

The analysis of terminal operations has been the primary focus of terminal landside research since the late 1960s. Analytical queuing methods and simulation approaches have been developed in various ways to model terminal passenger flows and to assess system performance [Mumayiz, 1990; Tosic, 1992; Mumayiz, 1997]. One of the early objectives of using simulation in terminal landside modeling was to investigate the passenger delay in the terminal resulting from the introduction of wide-bodied aircraft [Mumayiz, 1990]. In comparison with analytical methods, airport organizations worldwide credited simulation techniques as the most feasible method of terminal landside analysis, because it can cope with the time-varying demand and the stochastic system. Today, simulation is still widely used by airports as a decision-making support tool in evaluating existing facilities and improvement alternatives. Due to continuous software development and the capability to capture the stochastic nature of passenger flows, simulation can be viewed as one of the most efficient approaches to evaluate the impacts of the NLA on terminal operations.

From a technical perspective, previous simulation models presented methods to replicate a specific terminal system by utilizing its flight schedule as model inputs. This approach can approximate the programmed schedule system, however, it does not account for the unknown schedule of the NLA. It implies that there is no arriving information for the NLA in the model inputs. Therefore, this study attempts to model this problem without actual NLA arriving data, and to investigate the impacts prior to the introduction of the NLA by using simulation techniques.

1.3 RESEARCH OBJECTIVES

The primary objectives of this study are:

1) To develop a conceptual framework for airport operators to investigate the impacts of a new-technology aircraft when no operational information is known
2) To evaluate the impacts of higher demands of simultaneous arrivals on existing terminal facilities under various scenarios
3) To analyze the operating conditions in the terminal area
4) To devise and examine alternative strategies for terminal operations
5) To assist airport operators in making better informed planning and investment decisions.

At the conclusion of this study, airport operators will have an evaluation method, which will consist of a decision-making supported framework comprised of methodologies, system descriptions, programs, numerical tests, simulations, strategies and evaluations that can be used to enhance future airport operations.

1.4 RESEARCH APPROACH

This study presents an integrated simulation method to examine the effect of the NLA on terminal passenger flow under uncertain conditions. Essentially the impacts on the international arriving passenger flow in the terminal area will be analyzed. The arriving passenger flow is typically defined as a queuing network system with a series of processors, including gates, concourse, immigration checks, baggage claim systems, customs declaration, secondary examination, and lobby [FAA, 1988]. Hence, the method needs to be capable of modeling tandem queues with multiple servers, probabilistic arrivals and services, pooled and separate queues, as well as various aircraft mixes. With the capability of handling various aircraft mixes, this model can also be applied in determining the impacts on domestic terminal operations for any larger aircraft.

The integrated simulation method comprises of five major tasks: establishment of a passenger terminal system, determination of demand and supply of the terminal, development of the simulation model, model validation, and model applications using scenario analysis. The objective of the first task is to model a typical international terminal, which has the potential to accommodate the NLA in the future. The next task is to generate the arrivals at the terminal and to determine the capacity of each processing facility as well as its associated service characteristics. The required information for these two tasks will be based on the operations of 50 top-ranked airports in the world. The assumption is that top-ranked busiest airport terminals have the potential to operate the NLA in the future, and hold mutual passenger processing characteristics. A global survey is one means for obtaining the operational characteristics of these airports in this study. The results obtained from the first two tasks will serve as model inputs to the simulation model.

Model validation is an important part of the simulation work. The objective of model validation is to test if the model actually represents the system of interest. Since there is no specific observed passenger flow that can be used to validate the model in this study, several comparable measurements to validate the simulation model will be introduced. These measurements, including daily passenger volumes and time that passengers spend in the terminal, are obtained from the airport survey.

Finally, a validated model will be used to investigate the impacts of the NLA. By using various scenarios with a varying proportion of NLA, the impacts on individual facilities can be evaluated based on the change in key performance measures, such as passenger waiting time and passenger queuing length. The main purpose in using scenario analysis is to take various fleet mixes into consideration, since the market share of the NLA is unknown. Once the potential bottlenecks are detected, the corresponding operational strategies will further be evaluated. The evaluation results can thus provide a basis for airport operators to investigate the compatibility of their terminal facilities. The main concept of the research approach is illustrated in Figure 1.1.

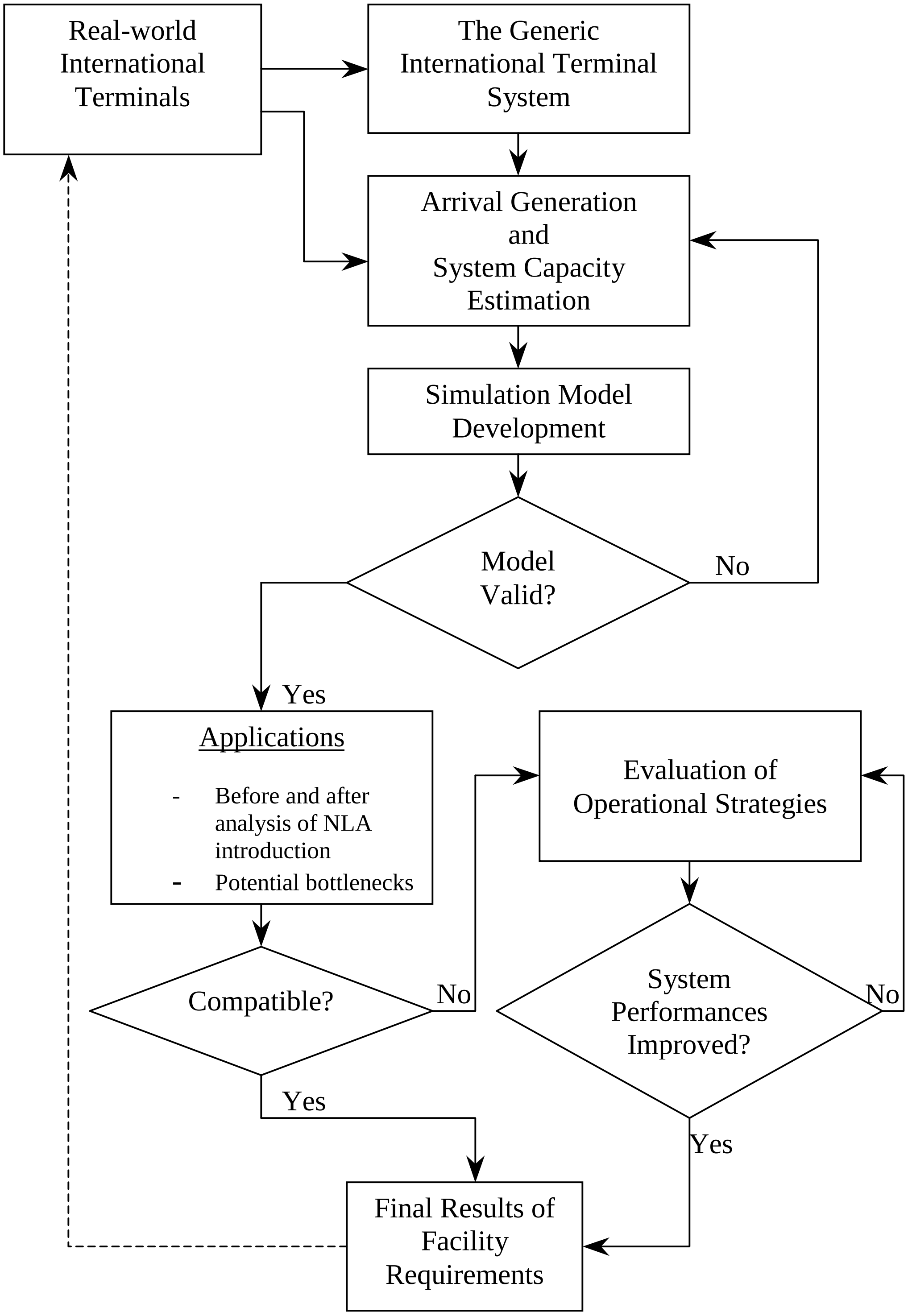


Figure 1.1 The Research Approach Framework

1.5 REPORT ORGANIZATION

This report is organized and presented in six chapters. Following this introductory chapter, Chapter two presents a review of the background on NLA development and the research associated with the development. The review covers the primary characteristics of the NLA and recent compatibility analyses, and summarizes research related to terminal landside modeling. Chapter three introduces the conceptual framework for the analysis of the impacts of the NLA. The framework consists of a model which represents a typical international terminal and a method which generates arrivals and estimates service functions. Chapter four presents the development of the simulation base cases and the results for these cases. This chapter also discusses the validation of the simulation model based on comparable measurements. Model validation in this study examines if the generation methods and service functions can accurately approximate terminal operations. Chapter five contains the procedure for applying the integrated simulation model to investigate the impacts of the NLA and to evaluate operational strategies. This chapter also presents the simulation results of four terminal simulation examples. The final chapter in this report summarizes the findings and recommendations for future NLA research.

CHAPTER 2. BACKGROUND REVIEW

This chapter reviews background material relevant to the development of the New Large Aircraft (NLA) and to the modeling of airport terminal systems. First, Section 2.1 begins with a brief introduction on the development of the NLA and its dimension information. Second, Section 2.2 introduces recent NLA-airport compatibility analyses, including both airside and landside issues. To ensure this study adequately covers a full scope of the impact of the NLA, the impact of airport design will be briefly summarized from the FAA perspective as well as recent studies. Finally, Section 2.3 presents a review of passenger flow analysis, including queuing models and various other simulation models. Mumayiz [1990, 1997] and Tosic [1992] have presented exhaustive overviews on the development of terminal simulation technology and on their applications to airport terminals. Computer-based tools that have been recently used to simulate terminal activities are also outlined in this section.

2.1 NEW LARGE AIRCRAFT

The NLA has been termed by the air transportation community to describe all new aircraft being developed that is larger than the current B747-400. Major airframe manufacturers such as Boeing and Airbus are planning to introduce the NLA in the upcoming decade in order to accommodate demand and to improve capacity.

2.1.1 The Development of the NLA

The development of the NLA has been extensively discussed by flying public in recent years. Boeing, the current dominant builder of over-400-seat aircraft, initiated a mega-jumbo program in 1994. This program included B747-500X, B747-600X, and Boeing NLA. Boeing's market forecasts showed that the market for large aircraft would be comparatively small causing them to discontinue the program in 1997. Boeing later proposed a revised program with slight modifications in 1999. B747X and B747X Stretch are two types of Boeing's NLA which are included in the revised program and are both the derivatives of the current B747-400 model. This program, however, was postponed in 2001 after receiving no orders. Boeing announced that the B747-400 family, with continued improvements, would meet the needs of the large aircraft market. Boeing decided to continue the current Long Range B747-400 with higher gross weight and new engines to improve the operating efficiency. Boeing also claims that they will retain flexibility to do a larger 747 if and when market shows the needs. The first Long Range B747-400 will be delivered in late 2002 [Boeing, 2001].

Airbus, intending to enter the large aircraft market and to compete with Boeing's monopoly during past decades, started with its A3XX program in 1994. After a long period of arguments and revisions, the A3XX aircraft was finally confirmed as A380 in late 2000 [Aircraft Economics, 2001]. A380 is planned to launch the first flight in 2004 and to enter commercial services in 2006 [Aircraft Economics, 2002]. The main difference between Boeing and Airbus' NLA models is that the A380 would have an upper-deck all along the fuselage, allowing a tremendous increase in seat capacity [Airbus, 2001].

2.1.2 Preliminary Characteristics

During a series of debates between Boeing and Airbus, numerous comparisons and discussions have been comprehensively addressed in terms of aircraft characteristics, development and acquisition costs, operating economics, air market forecasts, aircraft-airport compatibility, as well as funding programs [Pilling, 1995; Aircraft Economics, 1996; Sparaco, 1998; Sparaco, 1999; Aircraft Economics, 2000; Moorman, 2000]. The concurrent perspective of these two manufacturers, however, is to focus on the NLA configuration in order to fit existing airport conditions and relevant design standards, and to alleviate major alterations on airport infrastructure [Pilling, 1995; Aircraft Economics, 1996]. Therefore, the manufacturers adopted the strategy of designing the NLA under certain dimensional criteria that the wingspan and length have to be less than 80 meters (80-meter square box), in order to accommodate existing airport classification systems. In addition, manufacturers claim that runway loading and wing tip vortex (wake turbulence) will be no higher than that of the B747-400. Higher wing tip vortex would mean an increased traffic separation. Due to the design limitations described above, the maximum seat capacity of the NLA has been decreased from originally planned 600-800 seats to current 555 seats. The preliminary characteristics of the NLA are compared to other existing wide-body aircraft, including B747-400s, B777s, MD11, and A340s. These comparisons are shown in Table 2.1. The specifications of the NLA can be found in Appendix A.

Table 2.1 Existing Wide-Body Aircraft and NLA Preliminary Characteristics

Aircraft Type		Wingspan (m)	Length (m)	Tail Height (m)	Maximum Takeoff weight (kg)	Passenger Capacity	Range (km)
Wide Body	A340-300	60.3	63.6	16.7	230,000	335	10,400
	A340-500	63.5	67.9	17.1	365,000	313	15,800
	A340-600	63.5	75.3	17.3	365,000	380	13,900
	B777-200	60.9	63.7	18.5	247,210	320	9,525
	B777-200 LR	64.8	63.7	18.6	341,105	301	16,405
	B777-300	60.9	73.9	18.5	299,370	386	11,030
	B777-300 LR	64.8	73.9	18.6	341,105	365	13,330
	B747-400	64.9	70.6	19.4	396,890	416	13,570
NLA	B747-400 LR	64.4	70.6	19.4	412,770	416	14,240
	A380	79.8	73.0	24.1	562,000	555	14,800
TBD*	B747X	72.2	72.2	21.5	473,100	430/442	16,640
	B747X stretch	72.2	80.5	19.9	473,100	504/522	14,450

Source: Aircraft Economics, 1999; Boeing, 2001; Airbus, 2002

* Planned entry into services in 2005, depending on market demand.

2.2 COMPATIBILITY ANALYSES

In recent years, airframe manufacturers have adjusted the original configuration concept of the NLA in order to accommodate the current airport design standards and to eliminate the investment on infrastructure alterations. The overall effects of the NLA, however, will still be quite significant on every airport intending to operate them, both airside and landside, because of their enlarged dimension and increased carrying capacity. Fife [1994], Chevallier et al. [1996], Barros et al. [1998], and the FAA [1998] have addressed the NLA-airport compatibility issues thoroughly with respect to air traffic control, airfield design, terminal design, and some other aspects such as safety and environmental concerns. This section summarizes these findings and points out the less studied areas that need to be more deeply investigated.

2.2.1 Air Traffic Control

The major impact of the NLA on air traffic control is the increase of the minimum separation requirement between aircraft approaching an airport. The minimum separation rules of the FAA, based on aircraft weight which affects wake turbulence of the aircraft under IFR conditions, are listed in Table 2.2. To date, there are presently no specific conclusions on the wake turbulence effects generated by the NLA. However, it is assumed that separation requirements will have to be increased by 1 to 2 nautical miles for the NLA, given that its height could be as much as twice the 747's [Chevallier et al., 1996]. This increase will cause a decrease in the number of aircraft that can be safely operated and will have a major impact on runway capacity.

Table 2.2 IFR Minimum Separation Rules on Approach (Unit: nm)

	Trailing Aircraft Type[a]		
Leading Aircraft Type[a]	Small	Large	Heavy
Small	3.0	3.0	3.0
Large	4.0	3.0	3.0
Heavy	6.0	5.0	4.0

Source: FAA, 1978

[a] Small: aircraft weighting no more than 12,500 lb (5,625 kg).
Large: aircraft weighting more than 12,500 lb (5,625 kg) and less than 300,000 lb (135,000 kg)
Heavy: aircraft weighting in excess of 300,000 lb (135,000 Kg)

2.2.2 Airside Impact Issues

The airfield design, including the configuration and dimensions for runways, taxiways, and aprons, is probably the area in airports that will require the most modifications due to NLA introduction. The FAA [1998] performed a very comprehensive study on the impact on airfield design, including the review for current airport coding systems and for the criteria over geometric design as well as pavement design. The issues, including airport classification system, airfield geometric design, apron design, and pavement design, are summarized as follows.

1. **Airport Classification.** Current airport design standards are primarily based on aircraft dimension, approach speed, and aircraft operation forecasts. The FAA [1989] established the Airport Reference Code (ARC) system to aid designers in properly

determining the requirements for runway length, width and shoulders, taxiway width, runway-to taxiway and taxiway-to-taxiway separations, runway and taxiway bridges, and apron design. According to the ARC system, the geometry of all surfaces at an airport is designed specifically for the largest group of aircraft that will be operating at the airport. This FAA ARC system is shown in Table 2.3. For the ARC system, the NLA will be categorized as aircraft approach category D and airplane design group VI. The current maximum-size aircraft is the B747-400 and the longest range is the B777-300. They are categorized as D-V.

ICAO [1990] used an alternative method to classify airports, as shown in Table 2.4. According to the classification of the ICAO, however, the NLA cannot fit in any current category because the wingspans of all NLA models are greater than 65 meters. With regards to this issue, the ICAO Airport Design Study Group has begun a study on a new code letter ”F” for aircraft with wingspans of up to 80 meters [Fife, 1994; Chevallier et al., 1996].

Table 2.3 FAA Airport Reference Code

Aircraft Approach Category	Aircraft Approach Speed (kn)	Airplane Design Group	Aircraft Wingspan (M)
A	< 91	I	<15
B	91 — 121	II	15 — 24
C	121 — 141	III	24 — 36
D	141 — 166	IV	36 — 52
E	≥ 166	V	52 — 65
		VI	65 — 80

Source: FAA, 1989

Table 2.4 ICAO Aerodrome Reference Code

Aircraft Approach Category	Reference Field Length (M)	Aerodrome Code Letter	Wingspan (M)	Other Main Gear-wheel Span (M)
1	< 91	A	<15	<4.5
2	91 — 121	B	15 — 24	4.5 — 6
3	121 — 141	C	24 — 36	6 — 9
4	141 — 166	D	36 — 52	9 — 14
		E	52 — 65	9 — 14

Source: ICAO, 1990

2. Airfield Geometric Design. Airports that are expecting to operate the NLA will have to expand and upgrade which facilities to comply with the design criteria of design group ARC D-VI. Regarding the design standards, the FAA AC150/5300-13 report [1989] covers all geometrical airport design criteria. The FAA NLA study [1998] indicated that the existing design groups accommodate the NLA by referencing relevant reports of AC150/5300-13. Some standards that do not adequately accommodate the requirements of the NLA are addressed in the report also.

a. Runways

For this category, the runway length requirements are equal to those of the B747-400. This corresponds to 11,000 ft (3,335 meters). Therefore, an airport that can currently accommodate a B747-400 should not require any modification to the length of its runways. Moreover, with new, higher efficiency wing and engine design, the NLA will more likely require less runway length and fly significantly farther.

For width requirements, typically, the formulae provided in the FAA AC 150/5300-13 report remain applicable. The runway width requirement would increase from 150 ft (ARC D-IV and D-V) to 200 ft (ARC D-VI). Additional research, however, may be required to determine if any safety margins are needed.

Current runway shoulder width requirements, according to the FAA AC 150/5300-13 report, are 25, 35, and 40 feet for design group IV, V, and VI, respectively.

The width for category ARC D-VI might need to be revised due to the higher thrust engines and the distance between engine locations is larger.

The FAA NLA study [1998] has shown that on NLA with wing mounted engines, maximum jet blast velocities could extend up to 20 feet beyond the current 40 feet shoulder width requirement. For blast protection pads, similar to runway shoulders, current design standards for category ARC D-VI will need further tests to verify which ones have the ability to properly contain the NLA jet blast. Based on the current standards, runway blast pads should have a length of 280 ft (84 m) and a width of 500 ft (150 m). The overall review is summarized as table 2.5.

Table 2.5 Runway Modifications

Item	Current ARC D-V Standards	ARC D-VI Modifications
Length	11,000 ft (3,335m)	None
Width	150 ft	200 ft
Shoulders	35 ft	40 ft (more studies needed)
Blast Pads (L,W)	(220 ft, 500 ft)	(280 ft, 500 ft)

Source: FAA, 1998

b. Taxiways

Current taxiway design has been acknowledged as potentially one of the most affected airport design features due to NLA introduction [FAA, 1998]. The taxiway dimensional data identified in the FAA AC 150/5300-13 report provide appropriate standards for airports serving all design groups of aircraft including the NLA. Taxiway width requirements would increase from 75 ft (ARC D-IV and D-V) to 100 ft (ARC D-VI). Taxiway edge safety margin would also be increased from 15 ft to 20 ft.

For taxiway shoulder requirements, the figures are the same as those for runways. Design group VI would require stabilized or paved surfaces on the taxiway shoulders. Similarly, due to jet blast effects, its width will have to be extended beyond the limits of the current recommended taxiway shoulders. Requirements for wider taxiway shoulders may be needed to prevent damage to the aircraft itself, the airport ground, other aircraft, vehicles, or any objects around the taxiways.

Taxiway turns will need to accommodate the standards of the design group VI, because of the significantly increased wheelbase dimensions of the NLA. The charts presented in the FAA AC 150/5300-13 report only provided taxiway turn dimension information for wheelbase up to 110ft. The current NLA design is 118-ft wheelbase, and therefore does not fall within this range.

For taxiway separation standards, the NLA is compatible with the current FAA design standards for design group VI criteria. The separation standards are listed in Table 2.6. FAA airport design standards also state that taxiway holding bays and bypass taxiways are required to possess similar standard taxiway edge safety margins, separation, and clearance standards as parallel taxiways. Airports intending to operate the NLA will therefore need to expand them to meet the adequate clearance and separation for the NLA. However, many airports do not have space available for relocation. Therefore, this would restrict NLA operations to certain periods of low traffic or limit NLA operations to certain taxiway routes that provide adequate clearance.

Table 2.6 Taxiway Modifications

Item	Current ARC D-V Standards	ARC D-VI Modifications
Taxiway Width	75 ft (23 m)	100 ft (30 m)
Taxiway Edge Safety Margin	15 ft (4.5 m)	20 ft (6 m)
Runway Centerline to:		
Taxiway Centerline	400 ft[a] (120 m)	600 ft (180 m)
Taxiway Centerline to:		
Parallel Taxiway Centerline	267 ft (81 m)	324 ft (99 m)
Fixed or Movable Object	160 ft (48.5 m)	193 ft (59 m)
Taxilane Centerline to:		
Parallel Taxilane Centerline	245 ft (74.5 m)	298 ft (91 m)
Fixed or Movable Object	138 ft (42 m)	167 ft (51 m)

Source: FAA, 1998

[a] Separation distance is 400 ft for airports below a field elevation of 1,345 ft, 450 ft for airports between 1,345 and 6,560 ft, and 500 ft for airports above an elevation of 6,560 ft.

c. Runway and Taxiway Bridges

Current standards for runway and taxiway bridges as presented in the FAA AC 150/5300-13 report require the same clearance and width for design group ARC D-VI as for runways and taxiways. The weight of the NLA, however, could cause other problems for some existing airport bridges. Regarding this issue, airport authorities should examine the existing bridge structures and evaluate the potential need to accommodate heavier aircraft, such as the NLA which weigh between 850,000 and 1.2 million pounds.

3. Apron Design. Recent research, including FAA [1998] and Barros et al [1999], considered the impact of NLA on the apron-gate system as a landside impact. However, based on the definition [TRB, 1987], airside includes the facilities and services used by "aircraft" to transport passengers and cargo. Therefore, this study categorizes the impacts on the apron-gate system into airside. These issues include gate type identification system, gate requirements, apron separation clearances, and ground servicing systems. The passenger loading bridges will be discussed in the following landside section.

a. Gate Type Identification System

The FAA AC 150/5360-13 [1988] describes the methodology for determining the different gate types, such as the ARC system for airfield design criteria. Currently, four gate type categories exist. These are listed in Table 2.7. The NLA or design group VI aircraft does not fit within any gate category set forth in the FAA AC 150/5360-13 report. The FAA NLA study [1998] also points out that either this gate rating system needs to be updated to include a new gate type "E" or an alternative method of determining gate sizing needs to be developed. Due to the greater wingspan of the NLA, more spacing between gates is needed. Therefore, many airports would most likely find it difficult to park the NLA at typical gate locations. Thus, adaptation of gates and relevant facilities must be carefully planned to lessen a significant loss of aircraft parking positions and as not to have a negative impact on airport gate capacity [Barros et al, 1998]. For practical purposes, it seems logical that the potential NLA gate positions for such airports will be at the end of pier or on a satellite/island terminal [FAA, 1998]. From an analytical perspective, however, the optimal NLA gate positions will be in the middle of a pier or linear terminal [Barros et al, 2000], in order to minimize walking distances for passengers.

Table 2.7 Current Gate Type Identification Systems

Gate Type	Airplane Design Group	Wingspan (ft)	Fuselage Length (ft)
Gate Type A	III	79 - 118	-
Gate Type B	IV	118 - 171	< 160
Gate Type C	IV	-	>160
Gate Type D	V	171 - 213	-

Source: FAA, 1988

b. Gate Requirements

The number of required gates is directly proportional to both the aircraft turnaround time and the aircraft arrival rate, which are random variables with known probability distributions [Bandara et al, 1989]. First, with respect to the turnaround time, airframe manufacturers would consider the turnaround time of the NLA not to be much higher than that for the current B747-400. Two hours is believed to be the maximum acceptable turnaround time [Chevallier et al, 1996]. Second, the aircraft arrival rate of the NLA cannot be investigated right now. Therefore, the determination of the precise NLA gate requirements cannot be specified at this point of time. Nevertheless, forecast methodologies, such as that of Bandara et al. [1989] or that presented in the FAA AC 150/5360-13 report [1988], can be used to determine the NLA gate requirements.

c. Apron Separation Clearances

The FAA NLA study [1998] shows that current gate type D clearance standards for apron separation will provide sufficient clearance for the NLA. These standards are listed in Table 2.8. However, new clearance standards for the new gate type to accommodate the NLA will have to be developed. Moreover, terminals with some specific concepts, such as parallel pier, will not have the available space to allow the NLA to maneuver simultaneously on dual taxilanes between piers.

Table 2.8 Current Apron Separation Clearance Standards

Gate Type	Wingtip to Wingtip (ft)	Nose Clearance (ft)	Aircraft Extremities to building (ft)
Gate Type A	15	30	20
Gate Type B	25	20	20
Gate Type C	25	20	20
Gate Type D	25	15	20

Source: FAA, 1988

d. Ground Servicing

Specific ground servicing requirements for the NLA have not yet been determined. The preliminary data indicates that the NLA will utilize receptacles and equipment very similar to those used by current wide-body aircraft, such as the B747-400. In addition, airports may need to supply new aircraft tugs, additional electrical capacity, increased preconditioned air, and modified fueling facilities.

4. Pavement Design. Existing design methodologies for the B777 airplane, as described in the FAA AC150/5320-16 report, can be used to design and evaluate the pavement for the NLA as well. However, stronger and thicker pavement and specific design standards will be required as the aircraft is getting substantially heavier in the future.

2.2.3 Landside Impact Issues

The airport terminal is presumably the most complex element of the overall airport design that will be affected by the introduction of the NLA. Many landside issues have been addressed in the FAA NLA study [1998], including ticketing lobbies, waiting lobbies, baggage lobbies, public corridors, security inspection stations, departure lounges and parking facilities. This section will discuss the impacts on departures, arrivals and other facilities that serve both departing and arriving passengers.

1. Departures. Facilities for departure passengers typically include ticketing lobbies, waiting lobbies, security inspection stations, and departure lounges. For ticketing lobbies, increased passenger traffic will require more ticket counters and larger spaces. Current FAA AC 150/5360-13 can be used for design guidance. More flexible operational strategies currently adopted by some airlines, such as check-in at intermodal ground access stations or at hotels, will eliminate the space requirements for ticketing lobbies. The impact on passenger waiting lobbies is similar. Airport operators may consider adding additional seats and related facilities in these areas in order to accommodate the increases in passengers and visitors.

With regards to security stations and current checking requirements, security checks are likely to be one of the possible bottlenecks caused by the NLA. Airport operators may be required to expand those stations to facilitate the increased number of passengers, by installing extra detectors and X-ray machines. For departure lounges, the current maximum seating capacity used to estimate the size of departure lounge areas is still 420 passengers, as shown in Table 2.9. The FAA will need to resize this chart to include seating capacities equal to those of the largest NLA.

Table 2.9 Current Departure Lounge Area Space Requirements

Aircraft Seating Capacity	Departure Lounge Area Square Feet (Square Meters)		
	Boarding Load Factors		
	35-45 %	55-65%	75-85%
Up to 80	350 (33)	515 (48)	675 (63)
81 to 110	600 (56)	880 (79)	1,110 (102)
111 to 160	850 (79)	1,175 (109)	1,500 (139)
161 to 220	1,200 (111)	1,600 (149)	2,000 (186)
221 to 280	1,500 (139)	2,000 (186)	2,500 (232)
281 to 420	2,200 (204)	3,000 (279)	3,800 (353)

Source: FAA, 1988

Besides the FAA NLA study, Barros et al. [1998] altered their methodology developed in 1988 for departure lounge sizing by using cost approach to enable sizing of the departure lounge for the NLA. The approach consists of a set of parameters such as the maximum number of passengers in the lounge (calculated from the arrival and boarding rates and the time at which boarding begins), level of service standards such as the minimum area per sitting passenger and the minimum area per standing passenger (in normal and flight delay situations), a multiplier accounting for passenger circulation and airline activities, and cost of one seat per aircraft departure. There are several constraints that arise from these parameters, for instance, an upper limit to the amount of seats, to provide a minimum standing area to passengers in overcrowded flight delay situations. The method arrives at an equation that describes the total cost of the lounge per aircraft departure that is minimized using graphical optimization. The model uses a cost approach and a 0-1-decision variable to minimize the overall cost of the lounge per aircraft departure. The output consists of the minimum required lounge area and the optimal number of seats.

Airport retail areas and restaurants, which provide a significant amounts of waiting areas for passengers, are not involved in both departure lounge sizing studies described above. Further examination of the impacts on departure facilities may focus on this issue in order to avoid oversizing departure lounges.

2. Arrivals. The FAA's current design standards for baggage lobbies should be adequate to design facilities for arriving passengers, as long as airports have the available space needed to expand and meet such requirements derived from the increases of passengers and bags. For baggage claim areas, the facilities might be one of the biggest concerns in the terminal. The FAA NLA study [1998] indicated that, despite the prospective increase in baggage loads, current baggage facilities at large airports would be expected to handle NLA baggage loads in the same manner as they handle those of current aircraft. The FAA estimated that an NLA with 555 passengers would produce approximately 722 bags per flight based on the assumption that passengers are estimated to carry 1.3 bags per passenger for a typical commercial aircraft. According to the FAA AC 150/5360-13 report, typical baggage conveyor belts are capable of handling 16 to 50 bags per minute. At this rate, it would take up to 14.5 minutes for all of the bags on a 555-seat NLA. It concluded that airports might have major problems on baggage processing system without the development of new facilities. Since the report only performed a brief discussion, the baggage claim system needs to be studied more in detail. The report did not focus on the impact on the time of passengers waiting in this area either.

Moreover, the report did not mention the impacts on the Federal Inspection System (FIS) facilities, such as immigration checks, customs and agriculture services, which are important servers for arriving passenger flows. No studies related to these facilities have been done thus far. Additional research on these impacts may be required.

3. Other Facilities. The other facilities serve both departure and arrival passengers. They include public corridors, passenger loading bridges, and parking. First, in the area of public corridors, the FAA study [1998] indicated that airports should possibly plan modifications such as the removal of obstacles that reduce the effective width of corridors and limit the rate of passenger deplanements to avoid congestion in areas such as the corridors and escalators. Second, loading bridge compatibility with NLA is a great concern for airports. Current NLA design data indicate that the aircraft will be compatible with many loading bridges servicing the B747-400. Standard loading bridges, therefore, should be capable of handling NLA without significant modifications. However, the FAA may recommend that future terminal designs incorporate double level loading bridges into gate design. Finally, airport parking facilities may also be affected by the introduction of the NLA because of the increased number of passengers that will be transported on a single flight. According to the rules of thumb provided in AC 150/5360-13, more parking spaces may be required. The impact, however, is considered as a smaller problem caused by the NLA, because it is unlikely that multiple NLAs will arrive or depart around the same time.

2.2.4 Safety Issues

The FAA Aircraft Rescue and Firefighting (ARFF) Index groups the NLA with the B747 as category E, as shown in Table 2.10. Using the ICAO categorization system, the NLA will be classified as category 9, as shown in Table 2.11. It is anticipated that special equipment, such as longer ladders to reach doorsills, and more firefighters will be needed. The FAA will still need to perform further research on this subject to determine whether changes to the current standards are required.

Table 2.10 FAA ARFF Index Determination

Index Category	Largest Aircraft Length (m)
A	<27
B	27-38
C	38-48
D	48-61
E	>61

Source: FAA, 1989

Table 2.11 ICAO Airport Categorization for Security Purpose

Airport Category	Airplane Overall Length (m)
1	0-9
2	9-12
3	12-18
4	18-24
5	24-28
6	28-39
7	39-49
8	49-61
9	61-76

Source: ICAO [1983]

Concerning emergency procedures, an Airport Emergency Plan (AEP) in the FAA AC 150/5200-31 report, provides a framework that identified and organized various response capabilities and the outline for response management. Since the NLA will carry significantly more passengers in a single flight, the current procedure will need to be enhanced, along with additional equipment, supplies, and personnel that are available to properly deal with a possible NLA emergency. Airports expecting to serve NLA will also need to verify which current airport emergency plan can encompass the capacity of a potential aircraft emergency. Other surrounding elements, airport medical facilities as well as rescue and firefighting personnel training facilities, should be updated in the NLA manners

For winter operations, the NLA will probably have impacts on deicing facilities. Airports that currently have dedicated deicing facilities will most likely be required to modify the size of these facilities, due to the aircraft's larger size and greater overall surface area. For snow removal requirements, NLA dimensions do not appear to present a significant problem under current recommendations. Similarly, standards for sign clearances for the NLA will need to be evaluated. In order to eliminate possible damages to airport signs that could be harmfully exposed to higher level of the aircraft's jet blast and wake vortices, more studies should be perform once the exact turbulence characteristics of the NLA are known.

2.2.5 Environmental Issues

The concerns about how the operations of the NLA are going to affect the environment have been addressed in several aspects, such as noise and air quality. The design of the NLA has to comply with today's noise and emission restrictions. Due to the innovative design of aircraft's engines, the manufacturer claims that the NLA will be quieter, in comparison with many aircraft in operation today. With respect to the aircraft noise during approaching, however, the NLA with high gross weights will be noisier. With regard to pollutants and emissions, the NLA has higher efficiency jet engines and therefore is believed to be cleaner than many currently used aircraft. Generally speaking, the NLA will have positive effects from an environmental perspective.

2.2.6 Brief Summary

The review on relevant compatibility studies clearly shows that the issues in design perspective have been comprehensively covered, particularly with respect to airfield design. Landside impacts within terminal buildings, specifically from the operating viewpoints, have been less discussed in these research efforts. The impact, however, will concern to the entire flying public, airport authorities, airlines, and passengers. For example, the impact on the service performance of passenger processing facilities, such as the increase in total time spent by passengers in the terminal and in individual facilities, will need to be explored. For arriving passengers, current studies only mentioned the impacts on space requirements of baggage lobbies and on the baggage claim equipment itself. Moreover, for international arrivals, FIS facilities play a main role in passenger flow. Therefore, the impacts on FIS facilities, such as space and position requirements for check booths, will need to be considered. The impact on baggage claim areas also needs to be investigated more thoroughly, especially with respect to the possible increase in average time for waiting and picking up bags.

2.3 ANALYSIS OF TERMINAL PASEENGER FLOWS

Passenger flows at airport terminals can be viewed as a network of queues with successive passenger processors. Analytical methods developed during the 1970s used deterministic queuing models. As complexity increases, a queuing system might not have exact analytical solutions. Therefore, approximation methods are widely used to estimate the performance measures of the queues with general distributions, such as queuing length and waiting time. The numerical results have shown that the approximation method performs an accurate approximation as the system is heavily loaded [Kleinrock, 1976]. The Diffusion approximation methods for M/G/1 and M/G/m queues developed by Kimura [1983] and Yao [1985] are good examples for approximation techniques. Nevertheless, for a queuing network modeled as a real-world terminal system, analytical methods are still found to have limitations. Primary passenger processors operate stochastically according to an associated probability distribution. Such a system may not be able to be described as a mathematical expression.

Another approach to analyze a queuing system is simulation. Simulation models, being regarded as behavioral imitation of the real-world system over time, can replicate real-world behavior by studying interactions among its components [Mumayiz, 1990]. Thus, they have been applied in many aspects of airport operations. After 1970, the application of simulation technology to airport planning, design, and management became the major decision-making support tools to assist airport operators not only to evaluate existing facilities but also to provide appropriate solutions to improve the performance of the system.

2.3.1 Queuing Models

Most of analytical queuing models were developed in 1960s. Tosic [1992] performed a comprehensive review on the development of analytical queuing models. This study briefly summarized early studies on the system with single server type facilities as follows. The earliest study on modeling a terminal with the stochastic queuing theory approach was an analysis of Copenhagen airport terminal. M/D/1 and M/M/n queuing systems were first used in modeling the terminal building. Lee [1966] applied the M/M/n queuing system to describe the passenger check-in procedure. Ashford [1976] concluded from an airport survey that arrivals at passenger check-in is Poisson distributed and service time of check-in services is Erlang (k=2) distributed.

Previous studies also utilized deterministic queues to analyze the operations of passenger boarding lounge [Paullin, 1969], baggage claim facilities [Horonjeff, 1969], and the entire flow as tandem queues [Dunlay et al., 1978]. The tandem queue algorithm developed by Dunlay et al. [1978] can also be employed to analyze stochastic queuing models (namely the M/M/1). Horonjeff [1969] proposed an early deterministic queuing model for passenger and baggage flows in airport terminal buildings. Browne et al. [1970] analyzed passenger and bag queues and inventories, by using inventory type models and calculus. The expected maximum inventories of passengers and bags were thus computed. Deterministic queuing models simplify many assumptions. The required estimates, however, can be obtained in a reasonable basis. The basic concept of the model for passenger flow is depicted in Figure 2.1. The curve represents the input passenger flow for a single flight to a server. By superimposing a service rate, μ_j, a curve representing the output of a server can be obtained as the straight line with slope equal to μ_j, where Q is queuing length and W is waiting time for the passenger arrives at time T_1. T_0 is the time when the server starts operating and the queuing length reaches its maximum. After time T_2, the arrival rate is the same as the service rate, which represents that there is no queue in the system. Figure 2.2 shows a deterministic queuing system with two queues in tandem, where $\mu_1 > \mu_2$ [Wolff, 1989]. Theoretically, $\mu_1 < \mu_2$ is not efficient because there will be idle personnel at the second server. For an international terminal system, however, $\mu_1 < \mu_2$ occurs when arriving passengers pick up bags first and then go through customs declaration. Clearly, the service rate of baggage claim systems is lower than that of customs checks.

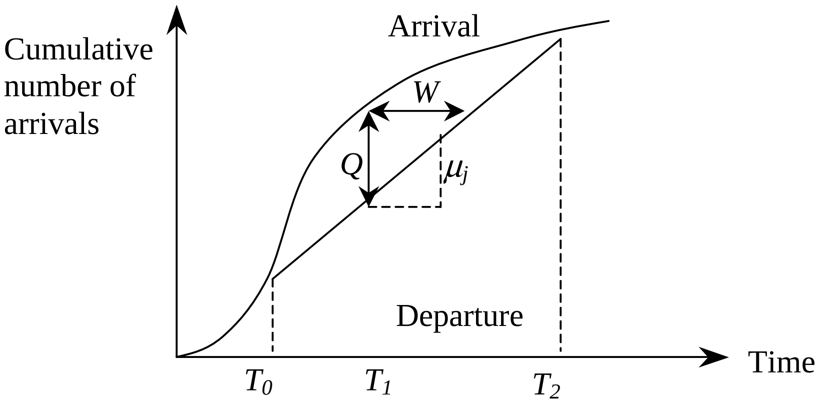


Figure 2.1 Deterministic Queuing Model for Passengers

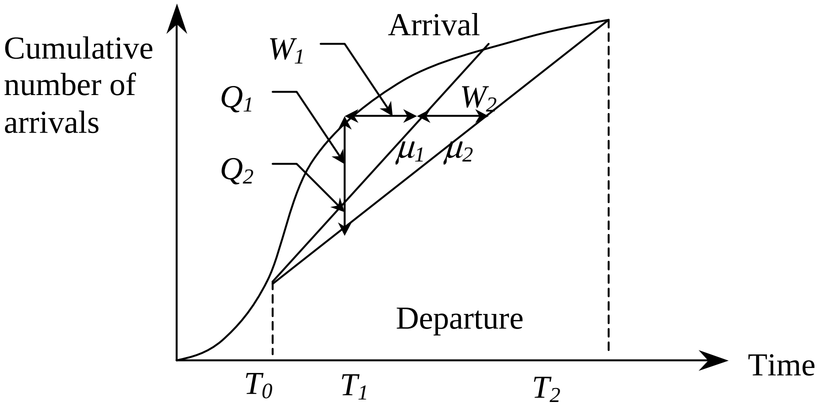


Figure 2.2 Tandem Queuing Model with Two Servers

The typical deterministic queuing model for a baggage claim area is depicted in Figure 2.3 [Horonjeff, 1969]. The arrival rates for passengers and bags can be described as cumulative probability functions, $F_p(t)$ and $F_b(t)$, respectively. The probability distribution function of the time at which both passenger and his bag have arrived at the carousel at time t is $F_p(t)F_b(t)$. The service distribution for the baggage claim system $F_{p \cdot b}(t)$ is then the sum of $F_p(t)F_b(t)$ and the average time for a single passenger to remove bags from the carousel (0.5 minutes used in Horonjeff's deterministic model). By assuming that passengers will remove their bags once both passengers and bags are at the carousel, the average waiting time for a passenger in the baggage claim area is the area between the two curves $F_p(t)$ and $F_{p \cdot b}(t)$. The number of bags occupying the carousel at any time t is computed as $[F_b(t) - F_{p \cdot b}(t)]$ multiplying by total baggage loads for a single flight. T_1 is the time when the baggage carousel starts and T_2 the time when passengers can pick up their bags with waiting. The probability distribution functions for passengers and bags need to be known to utilize this model in analyzing the actual system.

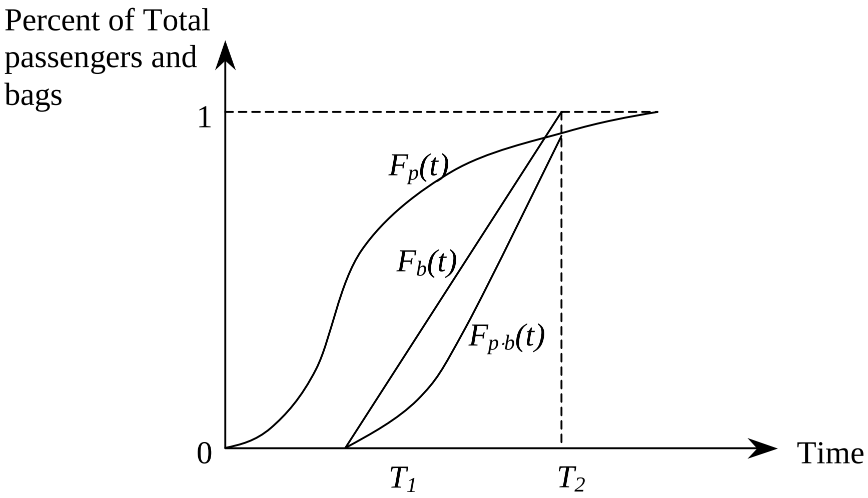


Figure 2.3 Deterministic Queuing Model for Baggage Claim System

2.3.2 Airport Terminal Simulation

Simulation techniques have been widely applied to assess the airport system in many aspects, including airside (airfield and airspace), landside (terminal building and traffic), ground access systems, aviation demand forecasts, capacity analysis, airline operations management, airport economic-financial planning, and environmental issues [Mumayiz, 1997]. This section will focus on the review of terminal landside simulation and its application. Landside related researches started in the late 1960s to investigate the terminal congestion delay resulting from the substantial growth in air travel and the introduction of wide-bodied jets [Mumayiz, 1990].

Simulation technology which was considered to be a convenient, reliable, and efficient tool in analysis, was thus developed rapidly. Typically, an airport terminal can be modeled on two scales, macroscopic and microscopic. At the macroscopic level, the terminal is viewed as one integral system with various segments. Each segment has an individual processing function with the level of demand and service measure. It can efficiently show the functional interactions between individual facilities. Individual facilities at airport terminals can also be modeled separately in microscopic view.

Mumayiz [1990] categorized airport terminal simulation models in various ways based on functional types, programming language or computer background, and developers. Due to the continuous development of simulation technology, recent simulation software has been developed to handle probabilistic arrival and service rates and applied to many terminal studies with regard to planning/design alternatives assessment and operation strategy evaluation. Mumayiz [1990] and Tosic [1992] both performed a comprehensive review for simulation models for airport terminal buildings. These models were intended to allow analysis of the activities or a particular broader problem regarding terminal planning, design, and operation. A brief summary of previous reviews and other related simulation studies is provided below. This study classifies them into two categories, model development and airport studies.

1. **Model Development.** The development of landside simulation tools was started by the FAA-sponsored research efforts during 1970s. FAA's ALSIM (Airport Landside SIMulation) model was developed to study the operations of the passenger and baggage processing inside terminals. ALSIM is a macroscopic, probabilistic, discrete-event, Fortran-based computer simulation model, which is capable of producing flow and model inputs which contain flight schedule, passenger characteristics, airport geometry, and facility information. Both arrivals prior to flight and facility service times are described as probability distributions. The outputs of ALSIM include total number of persons served, maximum servers busy, occupancy, and flow of persons through the system. Operationally, this model has the capability to simulate a 100-gate airport during a busy 5-hour period involving 20,000 passengers on 165 flights [Mumayiz, 1990]. For the arriving passenger flow, it utilizes the flight arrival time based on its schedule. The major advantage is that the model can better replicate the operations of a specific terminal. In

order to explore the impact of the NLA on arriving passenger flows from a general perspective, however, ALSIM was not capable of handling the unknown schedule for the NLA in this study.

In addition to the FAA's simulation model, many other studies have been performed using different approaches. Baron [1969, 1974] presented one of the first models which could be applied to the whole building. The model was called an input-output macroscopic type model [Tosic, 1992]. The main feature of this model was given the inputs from the airside, then simulating the passenger handling facility as a processor of that input, and finally giving as an output the state of the curbside. A similar conceptual framework can be employed in this study for analyzing the impacts of the NLA on the entire terminal in this study.

Chmores [1978], in the context of the Airport Capacity and Runway Utilisation (ACAP) project sponsored by the FAA, built a model for performing capacity analysis through combining a systems approach with the conventional queuing theory. He used an analytical approach and considered the model partially a simulation model and partially a non-simulation. It is a simulation in that it is stepwise by nature, but it differs in concept from a simulation for two reasons. First, it considers network flow rather than individual units being processed by the system. Second, it derives its measures of congestion not from empirical tabulation, but from analytical calculation. The reason was that the empirical data used in this model on service time and interarrival time could not get a fitted distribution. Hence, the data were reverted back to a multi-regression model and then used in the simulation model. Previous reviews also criticized the fact that the deterministic models used in its modules are regression models derived from survey data collected in the airports studied [Mumayiz, 1990]. This brings up the concern about the ability of the model to sufficiently represent a real-world operation. This model was later refined to simulate passenger processing on the basis of average service time of negative exponential distribution. To simulate an airport terminal, however, data collection from a real system is the significant factor that influences the model validity. Therefore, the extent of data collection for the simulation model in this Report should be covering appropriate airports globally.

McCullough et al. [1979] proposed a system approach for analysis of capacity of airport terminal. This model (ACAP1) primarily introduced the concept of level-of-service. The main purpose was to eliminate the imbalanced passenger flow in previous simulation models. The model defined a subsystem, or a component capacity, as "the maximum level of demand of a given pattern that can be imposed on a subsystem (component) in a given interval of time without violating any specified level-of-service criterion." The model also considered a terminal as a queuing network system. Analytical models were used to calculate average waiting times and queue lengths. Its application was designed to model an enplaning passenger flow at Hobby Airport in Houston, Texas.

Simulation is still widely used to analyze passenger activities in the terminal in the 1990s. Gulewicz et al. [1990] reported a microscopic simulation model of the federal inspection services and baggage claim process for being used to evaluate alternative plans, facilities and equipment, and operations in terms of their expected service levels and adequacy to handle future projected demand. Wong et al. [1998] developed a deterministic model to simulate the departure passenger flow at Taipei CKS International Airport.

Table 2.12 lists the tools developed in the past 30 years from related literature review. In recent years, the total airport analysis tools capable of modeling the entire airport operations (airside and landside) were developed. TAAM (Total Airspace & Airport Modeller) is one of the tools to simulate various aspects of airport operations, including airspace, airfield, and terminal areas. It is a large scale gate-to-gate fast-time simulation package for modeling entire air traffic systems. It can simulate air traffic in detail, including aircraft push-back, taxiing, traffic at the terminal area, and en-route airspace. Typically it is classified as an airside simulation tool. Total AirportSim [Le, 2002], developed by LeTech Inc. in cooperation with IATA from 1996 to 2001, can simulate three aspects of airport operations, including airspace/runway, gates, and the passenger terminal. The gate module functions as an interface between aircraft and passengers. Another software development of total airport simulation tool is TRACS (Terminal, Roadway, and Curbside Simulation). TransSolutions [Hargrove, 2002] developed the integrated tool TRACS that is capable of evaluating the interactions of passengers, their bags, and ground vehicles. In addition of modeling passenger flows and baggage operations, it also supports the evaluation on the roadway performance, including vehicle queues and level-of service analyses.

2. Airport Studies. Since 1970, there has been a large number of airport studies that have adopted simulation technology in assisting terminal design and analysis. Due to the large number of these studies, it is impossible to introduce all simulation projects. The main goal for airport operators to use simulation models is to evaluate layout alternatives of terminal buildings and facilities.

Table 2.12 Simulation Model Development

Country/Organization	Software/Tools
a. Terminal Simulation Models	
FAA, USA	ALSIM
FAA, USA	PBFM
CANADA	Transport Canada Models
CANADA	NAPA
UK	AIR-Q
UK	PAXFLO
FISCHER	TerSim
TransSolutions, USA	ARENA
b. Total Airport Simulation Models	
Preston Group, AUSTRALIA[a]	TAAM
LeTech	Total AirportSim
TransSolutions,USA	TRACS

Source: Mumayiz, 1997; Le, 2002; Hargrove, 2002

[a] Now part of the Boeing Company

Regarding the application of recent simulation tools, ARENA is widely used by the industry to analyze airport landside operations from both a macroscopic and a microscopic perspective. Macroscopically, ARENA has been used to model departure passenger flows at many international airports, such as DFW, HNL, JFK, LAX, MIA, ORD, SFO, SJU, SXF, and TXL [Hargrove, 1997]. Critical performance measurements used in analyzing the operations include required time at check-in, queuing at security screening, passport control, and boarding pass control, congestion in corridor walkways, and available seating in departure lounges. This simulation tool can also be used in evaluating the terminal layout and in sizing processing facilities. Microscopically, ARENA has been used to simulate baggage operations and people mover systems and to analyze capacity or evaluate the alternatives for improvement. According to the reviews and experiences of previous studies, simulation can be considered as the most appropriate approach to investigate the impacts of the NLA on terminal passenger flow. Current software can also provide a user-friendly environment, while maintaining a modeling flexibility, to achieve the objectives of this study.

CHAPTER 3. THE INTEGRATED SIMULATION MODEL

This chapter introduces the conceptual framework of the integrated simulation model for arriving passenger flows. The model represents a typical busy international airport terminal, which could potentially operate the NLA. The framework, depicted in Section 3.1, introduces the major elements incorporated into the simulation model. A variety of input variables embedded in the model describe in detail terminal components, arrival passenger generation logic, processing facility requirements, and service attributes. A global airport survey conducted for this study to achieve the model development is introduced in Section 3.2. Section 3.3 contains a detailed description of all input factors required in the model development, based on the analysis of survey results.

3.1 THE CONCEPTUAL FRAMEWORK

The integrated simulation method developed in this study comprises of five major tasks: establishment of a passenger terminal system, determination of demand and supply of the terminal, development of the simulation model, model validation, and model applications using scenario analysis. The first objective is to model a typical international terminal system. The next task is to generate entities at the terminal and to determine the system capacity as well as its associated service characteristics. The results obtained from the first two tasks serve as model inputs to the simulation model. The validation of the model is to use comparable measurements to replicate expectation of operations at an active international terminal. Finally, by using various scenarios with a varying proportion of NLA, the impacts on individual facilities can be evaluated based on the change in key performance measures, such as waiting time and queuing length.

Based on the variant inspection sequences in terminals, the international arriving passenger flow typically can be divided into two types of flow. The first type occurs when passengers first go through the immigration checks and then pick up bags from the carousel. After this, they go through customs examination. This type of passenger flow, as illustrated in Figure 3.1, is the most common type of flow at airports worldwide. The second type appears in some European international airports. It consists of first picking up bags, and then undergoing the checkpoint combining immigration and customs, as shown in Figure 3.2. This study focuses on the analysis on the first type of passenger flows.

3.1.1 Establishment of the Passenger Terminal System

Horonjeff [1994] described three major components of a passenger terminal system. The first component is the access interface, which includes circulation, parking, and curbside operations. The second component is passenger processing. For international arrival passengers, the processing system includes concourses, FIS facilities, baggage claim areas, and lobbies for passenger and visitor waiting. The third component is the flight interface, which includes departure lounges, gates, boarding and deboarding devices, and some amenities. For the purpose of this study, the major elements that are able to define the arrival passenger flows within a terminal will be taken into account. These elements consist of gates (boarding/deboarding devices), concourses, immigration checks, baggage claim systems, customs, and arrival passenger lobbies. Other amenities, such as restrooms, restaurants, shopping area, are omitted from the model. The facilities associated with each element and their corresponding attributes are listed in Table 3.1 and illustrated in Figure 3.3. The number of related facilities primarily depends on passenger volume, which represents the air traffic demand.

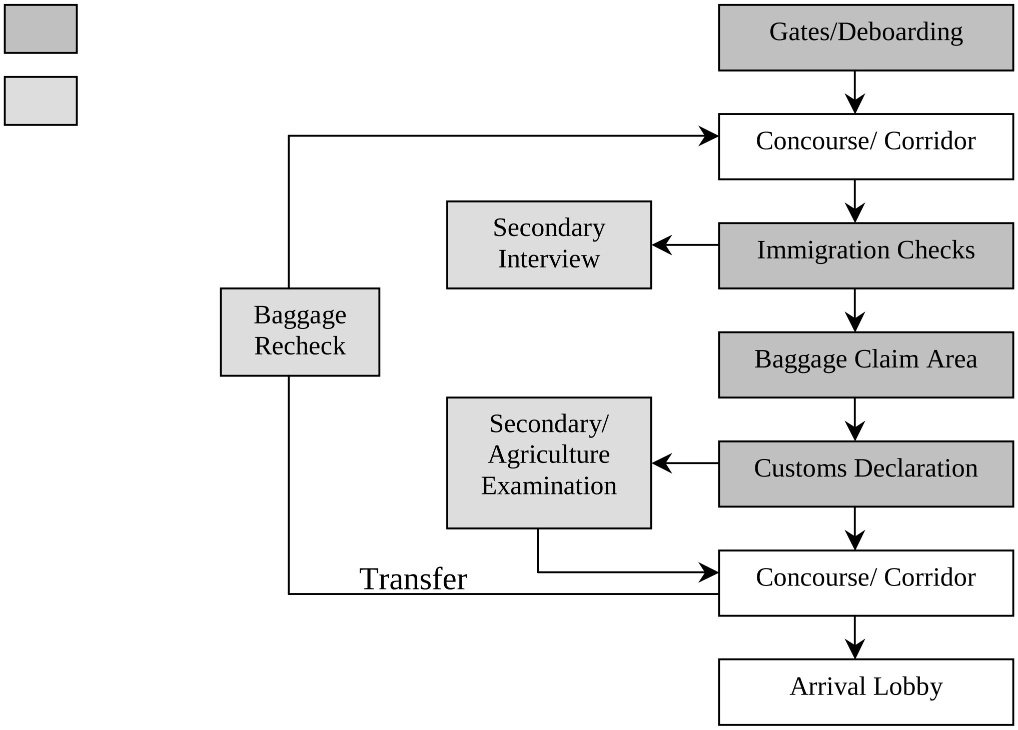


Figure 3.1 Type I International Arrival Passenger Flow

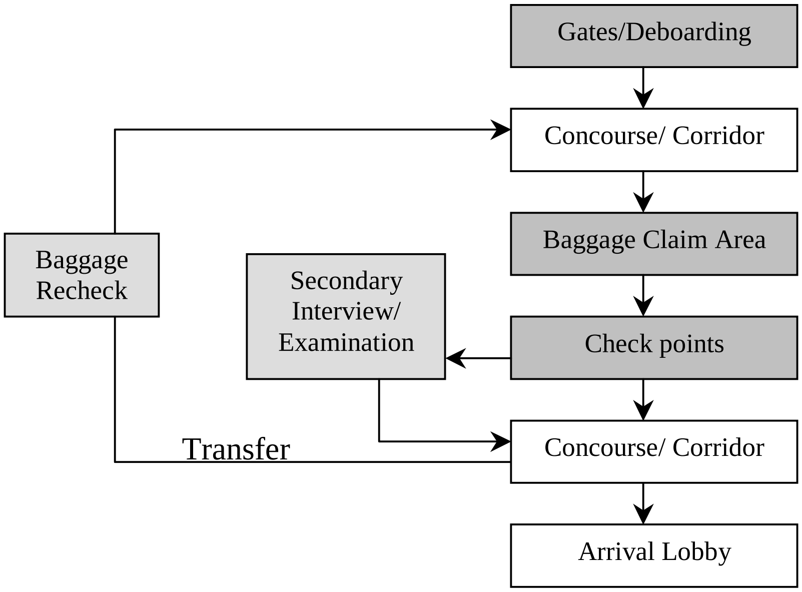


Figure 3.2 Type II International Arrival Passenger Flow

Table 3.1 Major Elements of the Simulated Terminal System

Elements	Processing Facilities	Service Characteristics
Gates	Number of gates	Service rate of boarding/deboarding devices (passenger per minute)
Concourse	--	Time spent in concourses (minutes)
Immigration	Number of check positions	Time for clearance of a passenger (minutes)
Baggage Claim Devices	Number of carousels	Service rate of each carousel (passenger per minute)
Customs and Agriculture	Number of check positions	- Time for clearance of a passenger (minute) - Percentage of secondary-check passengers
Lobby	--	- Time in lobby (minutes) - Percentage of transfer passengers

In order to simulate the passenger flow, a terminal system that can represent the major characteristics of typical busy terminal operations needs to be built. The terminal system can be viewed as a surrogate of the real terminal system. In advance of the establishment of the terminal, major representative elements of a terminal should be extracted. The major elements of a terminal incorporated into the simulation model include the number of gates, annual passenger volume, and terminal concepts. The capacity requirements for processing facilities can therefore be estimated once the related information of passenger volumes is obtained.

1. **Number of Gates and Passenger Volumes.** The number of gates is the primary design factor for a terminal. For simulation purpose, the number of gates and how this relates to other factors needs to be examined. The methods used to determine the number of gates have been discussed in many studies [Tosic, 1992; Horonjeff, 1994; Bandara, 1989; Bandara et al., 1989; Barros et al., 1998]. The number of gates required (G) is a function of the gate occupancy time (T), separation time (S) and the aircraft arrival rate (A) [Bandara et al., 1989; Barros et al., 1998]. An expression for G is shown as Equation 3.1.

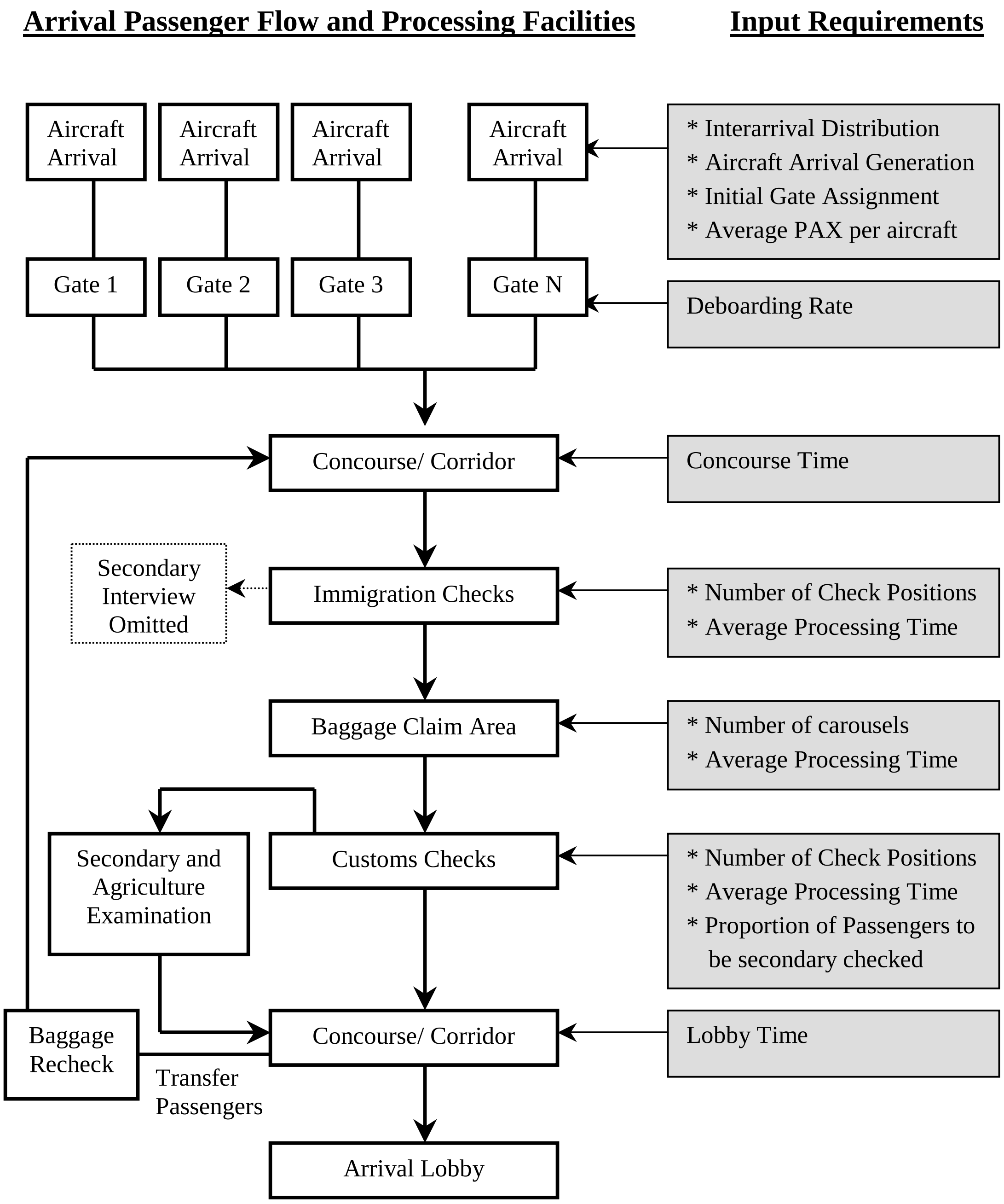


Figure 3.3 Type I Arriving Passenger Flow and Related Input Requirements

$$G = A \cdot (T + S) \qquad (3.1)$$

Conversely, for a given number of gates, the corresponding average aircraft arrival rate (the number of aircraft per unit time) can be estimated. Thus, passenger volumes of the design hour (PAX_p) can be calculated by multiplying (A) by the expected value of the number of passengers per aircraft (PAX_{AC}). An expression for PAX_p is shown as Equation 3.2.

$$PAX_p = A \cdot E(PAX_{AC}) \qquad (3.2)$$

The peak-hour passenger volume can be expressed by multiplying the average daily passenger volume (PAX_d) by a peak hour factor (PHF). The PAX_p can be also expressed as Equation 3.3. PAX_d can also be derived from annual passenger volumes (PAX).

$$PAX_p = PAX_d \cdot PHF \qquad (3.3)$$

Hence, the number of gates can be described as a function of annual passenger volume, as shown in Equations 3.4 to 3.6. This implies that there is an approximately linear relationship between the number of gates and the annual passenger volume (PAX) if $PHF, T, S, E(PAX_{AC})$ are all constant. Generally speaking, gates at most airports will fall in the range of 3 to 5 gates per 1 million passengers [Horonjeff, 1994]. The FAA's Planning and Design Guidelines for Airport Terminal Facilities [FAA, 1988] has also formulated estimations of the level of peak-hour passengers, peak-hour aircraft operations and gate positions, based upon the level of annual enplanements by using a linear relationship [FAA, 1988].

$$G = \frac{PAX \cdot PHF \cdot (T + S)}{365 \cdot E(PAX_{AC})} \qquad (3.4)$$

$$G = f (PAX) \qquad (3.5)$$

$$\approx \beta_0 + \beta \cdot PAX \qquad (3.6)$$

Another major design factor for air terminal planning is the terminal concept. The objective of involving several terminal concepts in the regression model is to examine if there is any difference in the relationship between gates and passengers across different conceptual forms. If any differences exist, the integrated model needs to establish a set of concept terminals as base cases for the model as a means to better estimate the passenger volume for each terminal type (TC_i). Equation 3.6 can thus be modified to Equation 3.7 and 3.8.

$$G = f(PAX, TC_i) \tag{3.7}$$

$$\approx \beta_0 + \beta_1 \cdot TC_i + \beta_2 \cdot PAX \tag{3.8}$$

Therefore, from all these equations, one can use the number of gates and terminal concepts to determine the traffic in the terminal. For a given number of gates, the corresponding annual passenger volume and peak hour arriving passenger volumes can be derived. The peak-hour arriving passenger volume information is one of the major factors estimating the processing facility requirements.

2. Other Passenger Processing Facilities. Other variables required for passenger processing facilities involved in the simulation model include the number of immigration check positions, the number of baggage claim devices, and the number of customs check positions. This study utilizes the capacity calculation formulae of IATA's Airport Development Reference Manual to estimate the facility requirements. The formulae were developed for the purpose of rapidly obtaining some rough idea of the quantity of facilities. Since the integrated model needs to be developed with a standardized basis for before and after NLA introduction, the simplified IATA formulae may be used in calculating the facility requirements under such circumstances. The formulae employ many simplifications and approximations, and assume constant throughput rates [IATA, 1995].

3. Associated Service Characteristics. The associated service characteristics are primarily service times of individual processing facilities. The service time data will be collected through airport surveys, interviews, and by direct observation. The data analysis related to the input requirements of all processing facilities will be discussed in detail in section 3.3.3.

3.1.2 Arrival Generation Method

The generation functions embedded in the integrated model serve to simulate the aircraft and passenger arrival patterns. Arriving passengers at terminals can be considered as batch arrivals in the system. The input requirements in modeling the characteristics of the arrival pattern include aircraft interarrival time distribution (i.e., aircraft turnaround time and separation time), the initial time to generate the arrivals at each gate, as well as the average batch size (which represents the average number of passengers per aircraft).

1. Aircraft Arrival Generation. The logic behind obtaining generations of arrival aircraft is to create arrivals in the system for each gate according to appropriate interarrival distributions. In general, the arrival distributions vary for different airports, terminals, airlines, or even gates. Currently, typical turnaround times for international wide-bodied operations vary from 1.5 to 3.5 hours. The separation times would have much more variance, depending on the demand and the limitations of airport operations.

An approximation method can be used to estimate the interarrival time. In practice, if only the maximum and minimum values of a distribution are specified, one could use the uniform distribution to generate random numbers to simulate such a system [Kelton et al., 1998]. A single day is divided into twelve segments with two-hour time intervals. Within each segment, aircraft arrivals are assumed to be uniformly distributed. The estimates of interarrival information are obtained from the global airport survey.

$P_{i\,(j,\,k)}$: Proportion of the i^{th} category of interarrival time which is between j and k hours, where $i = 1, 2, 3, \ldots, 12$, $0 \le j < k \le 24$ (j, k are both even numbers), and $\sum P_{i\,(j,\,k)} = 1$.

Gates that possess such category of interarrival time can be obtained by multiplying $P_{i(j,\,k)}$ by total number of gates.

$$G_{ai} = G \cdot P_{i\,(j,\,k)} \qquad (3.9)$$

Where G_{ai} : Number of gates with the i^{th} category of interarrival time

G : Total number of gates and $\sum G_{ai} = G$, i = 1, 2, 3,…

Each gate that belongs to a specific category (S_{Gi}) is randomly assigned and associated with its corresponding interarrvial time distribution.

$S_{Gi} = \{ G_{i(j,k)} \}$: a set of gates with the *ith* category of interarrival time distribution which is $U(j,k)$. $G_{i(j,k)} = (1, G)$.

2. Initial Gate Assignment. The logic behind initial gate assignment is to determine the first arrival at each gate. Based on the hourly distribution from various airport daily flight schedules, the initial time of aircraft arrival at each gate can be determined. The average hourly distribution can be obtained from the flight schedule of selected international airports.

$X_{i,\,i+1}$: Proportion of arrivals between the i^{th} and the $(i+1)^{\text{th}}$ hour. $i = (0,23)$. And $\sum X_{i,\,i+1} = 1$.

Number of arrivals within a specific hour can be obtained by multiplying $X_{i,\,i+1}$ by the total number of gates.

$$AC_{n(i,\,i+1)} = G \cdot X_{i,\,i+1} \tag{3.10}$$

Where $AC_{n(i,\,i+1)}$: number of aircraft arrivals between the i^{th} and the $(i+1)^{\text{th}}$ hour.

The elements in the set $S_{AC(i,\,i+1)} = \{ AC_{i,\,i+1} \}$ represent the first generated aircraft which arrive between the i^{th} and the $(i+1)^{th}$ hour. Each aircraft that belongs to $S_{AC(i,i+1)}$ will be assigned into a specific gate randomly. The initial gate assignment program will be terminated at the j^{th} hour once $\sum_{i=0}^{j} AC_{n(i,i+1)} = G$.

3. Average Number of Arrival Passengers per Aircraft. The arriving passenger flow is modeled as batch arrivals. The batch size represented by the average number of passengers per aircraft is determined from the current in-service fleet share around the world, seat capacities, and average passenger load factors in the base year. Both wide-bodied and narrow-bodied operations were used in the modeling. Five wide-bodied categories and one narrow-bodied are specified in this study. The average number of passengers for each aircraft is calculated by multiplying its corresponding seat capacity by the average load factor representing the U.S. international operations in 1999. According to the fleet share and average number of passengers aboard per aircraft, a discrete empirical distribution can be along derived with its cumulative distribution and entered into the simulation model. The objective of the usage of an empirical distribution for batch size is to take the effects of aircraft mix into account. The number of gates that are utilized by wide-bodied aircraft (G_{fw}) can also be obtained by multiplying F_w by total number of gates.

$$G_{fw} = G \cdot F_w \tag{3.11}$$

where F_w : Percentage of wide-bodied aircraft.

Each gate that belongs to the set of wide-bodied aircraft (S_{Fw}) is randomly assigned and associated with an empirical distribution of batch size. The other gates are for narrow-bodied operations.

$S_{Fw} = \{ G_w \}$: a set of gates for wide-bodied aircraft. $G_w = (1, G)$.

3.1.3 Model Development and Validation

After the establishment of a passenger terminal, one can determine the terminal cases to be simulated and the corresponding passenger volume of each terminal case, simply by giving the number of gates. The integrated simulation model divides the arriving passenger flow into four sequential processing segments: from gates to immigration check points (which time is T_{GI}), from immigration checks to baggage claim systems (T_{IB}), from baggage claim systems to customs (T_{BC}), from customs to the curbside (T_{CC}), which represents leaving the system). Each processing segment is modeled as steady-state First-Come-First-Serve (FCFS) queue, with probabilistic arrival and service distributions.

Since the simulation model is only an approximation of an actual system, it should be validated relative to the performance measures that will be used for the evaluation. For the purpose of model validation with comparable data, this study proposes three major measurements: daily arriving passengers, average time spent in the terminal and its proportional distribution over sequential processing segments. The data were obtained from the global airport survey conducted for the study.

3.1.4 Model Applications

A valid integrated simulation model can therefore be applied in evaluating the impact of introducing the NLA in a "before and after" context. The procedure is to, first, determine the design year and the average annual growth rate to be used in forecasting the future demand. Second, the model is run without introducing the NLA operations in the design year. Finally, by adding various scenarios of introducing the NLA, the model will provide results of how the performance measures of interest change. Besides, some strategic alternatives of improving facility operations can be evaluated by adjusting the capacity.

3.2 AIRPORT SURVEY

In order to facilitate the input requirements of the integrated simulation model and to provide a basis for model validation, we conducted an airport survey at the top-ranked international airports worldwide to collect information of terminal design and operations.

The survey included three parts. The survey questionnaire used in this study can be found in Appendix B. The first part consisted of collecting information on airport configuration, terminal facilities, and passenger volumes. The objective of this part was to estimate the relationship between number of gates, terminal passenger volumes, and terminal concepts. In order to calculate related parameters required in the simulation model, such as international passenger volume and peak hour factor, the survey requested information regarding the proportion of international passengers, peak-hour passenger volumes, and proportion of wide-bodied operations.

The second part of this survey primarily collected information of performance measures in the entire terminal system and individual processing facilities. The performance measure used in the study is queuing time. The terminal system was divided into four processing segments. Total time of spent by passenger in the terminal (*TT*) can be expressed as the summation of times spent in individual segments.

$$TT = T_{GI} + T_{IB} + T_{BC} + T_{CC} \tag{3.12}$$

where T_{GI}: Time spent from gate to immigration checks (including service time)

T_{IB}: Time spent from immigration checks to baggage claim area (including service time)

T_{BC}: Time spent from baggage claim area to customs (including service time)

T_{CC}: Time spent from customs to curbside (including service time)

The objective of the second part of the survey is to use this information that was obtained from airport managers' estimations as a comparison for model validation. The variables affecting the total time, such as peak hour passenger volumes or terminal size, will then be able to be evaluated.

The third part of this survey was aimed at obtaining route information on airlines operations to determine aircraft interarrival times for each gate. Surveys were sent to 38 international airports. Most of them were among the top 50 largest international airports. A total of 15 responses were obtained which represented 37% of the survey mailed. The respondent airports, listed by regions, are shown in Table 3.2 and Figure 3.4. The survey results can be found in Appendix C. The data analysis will be discussed in detail in the following sections.

Table 3.2 Respondent Airports to Global Airport Survey

Region	**Airport (Ranking)**
North America	Los Angeles LAX (3), Dallas/Fort Worth DFW (5), San Francisco SFO (9), Detroit DTW (13), Toronto YYZ (26), Boston BOS (29)
Europe	London LHR (4), Paris CDG (8), Munich MUC (40), Oslo OSL (69)
Asia/Pacific	Hong Kong HKG (23), Bangkok BKK (28), Sydney SYD (38), Tokyo NRT (31), Osaka KIX (45)

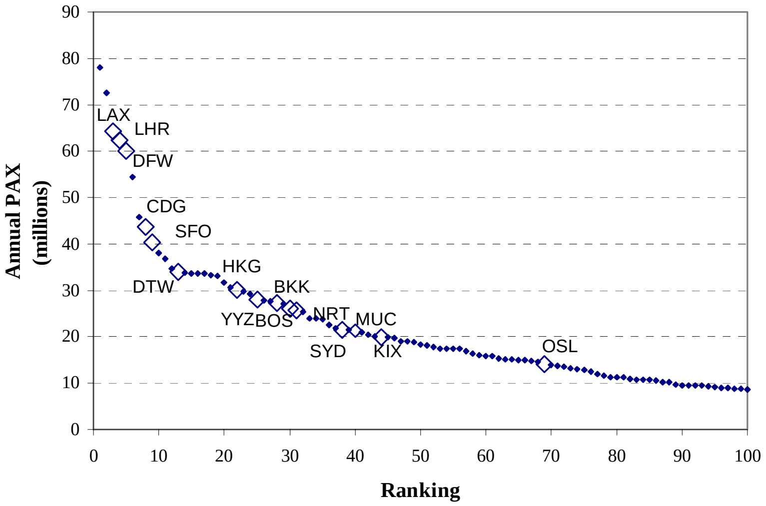


Figure 3.4 Respondent Airports by 1999 Passenger Ranking

3.3 MODEL INPUTS AND DATA ANALYSIS

The inputs for the integrated simulation model include passenger processing facility requirements, service characteristics of individual facilities, and arrival characteristics of the system. Passenger processing facility requirements will be discussed in Section 3.3.1. These include the number of gates, the number of FIS facilities, and the number of baggage claim devices. Next, service characteristics of individual facilities, expressed as probability distribution functions, will be discussed. Lastly, Section 3.3.3 will describe the arriving characteristics of the system, including interarrival time distribution for each gate, hourly distribution, and average batch size of arrivals.

3.3.1 Passenger Processing Facility Requirements

Passenger processing facility requirements included in the model are number of gates, number of immigration check positions, number of customs check positions, and number of baggage claim devices. Individual discussions are described as below.

1. Number of Gates and Passenger Volumes. The number of gates used by the integrated model follows the regression model based on the survey results and the available data from selected airport terminals. The regression results show that the number of gates is related to terminal passenger volume and terminal concept. According to the available data, three concepts are involved in the model: Linear, Pier/finger, and Satellite. Linear includes the concepts of linear, circular, and compact, while Satellite includes the concepts both satellite and island. The details on terminal information are shown in Table 3.3.

Table 3.3 Terminal Information (Gates, Passenger Volumes, and Concepts)

Airport	Number of Gates	Passengers (in Millions)	Terminal Concept
ATL (International)	22	5.10	Island
BOS	7	4.10	Linear
BRU	32	20.00	Pier/finger
CDG (Terminal1)	60	10.99	Satellite
CDG (Terminal 2A)	15	3.51	Linear
CDG (Terminal 2C)	12	5.31	Linear
CDG (Terminal 2F)	12	9.02	Pier/finger
DFW (A, B, E, international)	29	3.90	Linear
DTW	6	3.40	Linear
EWR[a] (Terminal A)	27	7.20	Satellite
EWR (Terminal B)	23	7.80	Satellite
HKG	48	29.70	Pier/finger
JFK (Terminal 1)	11	1.03	Pier/finger
JFK (Terminal 2)	11	2.53	Pier/finger
JFK (Terminal 3)	17	5.49	Pier/finger
JFK (Terminal 4)	16	4.89	Pier/finger
JFK (Terminal 5)	19	4.07	Pier/finger
JFK (Terminal 6)	13	1.62	Linear
JFK (Terminal 7)	12	2.58	Compact
JFK (Terminal 8)	15	3.43	Pier/finger
JFK (Terminal 9)	14	4.14	Pier/finger
KIX	40	11.93	Pier/finger
LAX (TB International)	13	8.43	Linear
LAX (Terminal 2)	9	3.31	Pier/finger
LGW	55	30.60	Pier/finger
LHR (Terminal 2)	16	8.15	Pier/finger
LHR (Terminal 3)	30	15.12	Pier/finger
LHR (Terminal 4)	21	14.18	Liner
MIA (International)	31	15.8	Pier/finger
MUC	19	21.30	Linear
NRT	41	25.67	Satellite/Island
OSL	34	14.10	Pier/finger
ORD (International)	21	9.70	Pier/finger
SFO (Old International)	10	6.00	Pier/finger
SYD (International)	28	7.40	Pier/finger

Sources: Airport Survey, Annual Reports of Airports, and Available data on the web.

[a] For EWR and JFK, 1998 terminal volumes agreed with 1999 total passenger volumes is used in this study.

a. The relationship between number of gates and annual passenger volumes

The regression model of the relationship between the number of gates and annual passenger volume shows that approximately 55% of the variation in number of gates can be explained by the annual terminal passenger volume. The statistical data, shown in Table 3.4 and 3.5, indicate that the annual passenger volume (*PAX*) is a significant explanatory variable. The expression of this model is shown in Equation 3.13.

$$GATE = 10.444 + 1.274\ PAX,\ R^2 = 0.55 \qquad (3.13)$$

Where *GATE*: number of gates

PAX: Annual passenger volumes in a specific terminal

b. The regression model involving terminal concepts

The regression model of adding terminal concepts as qualitative variables shows that the model is improved, for 61% variation in the dependent variable can be explained by the model with two independent variables, annual terminal passenger volumes and terminal concepts (*TC*). The regression results also indicated that the concept of Satellite is not insignificant. Therefore, the variable for Satellite concept is eliminated. The statistical results are shown in Table 3.6 and 3.7. The results can be expression by Equation 3.14 and is shown in Figure 3.5.

$$G = 13.246 – 6.914\ TC + 1.187\ PAX,\ R^2 = 0.61 \qquad (3.14)$$

Where *GATE*: number of gates

PAX: Annual passenger volumes in a specific terminal

TC: 1, if terminal concept is linear or compact; 0, otherwise.

Table 3.4 Analysis of Coefficients for the Regression Model Equation 3.13

Model	Unstandardized	Coefficients	t	Sig.
	B	Std. Error		
Constant	10.444	2.447	4.268	.000
PAX	1.274	0.200	6.367	.000

Table 3.5 ANOVA for the Regression Model Equation 3.13

Model	Sum of Squares	df	F	Sig.
Regression	3371.862	1	40.539	.000
Residual	2744.824	33	--	--
Total	6166.686	34	--	--

Table 3.6 Analysis of Coefficients for the Modified Regression Model

Model	Unstandardized	Coefficients	t	Sig.
	B	Std. Error		
Constant	13.246	2.695	4.915	.000
PAX	1.187	0.195	6.077	.000
TC	-6.914	3.331	-2.076	.046

Table 3.7 ANOVA for the Modified Regression Model

Model	Sum of Squares	df	F	Sig.
Regression	3697.578	2	24.456	.000
Residual	2419.108	32	--	--
Total	6116.686	34	--	--

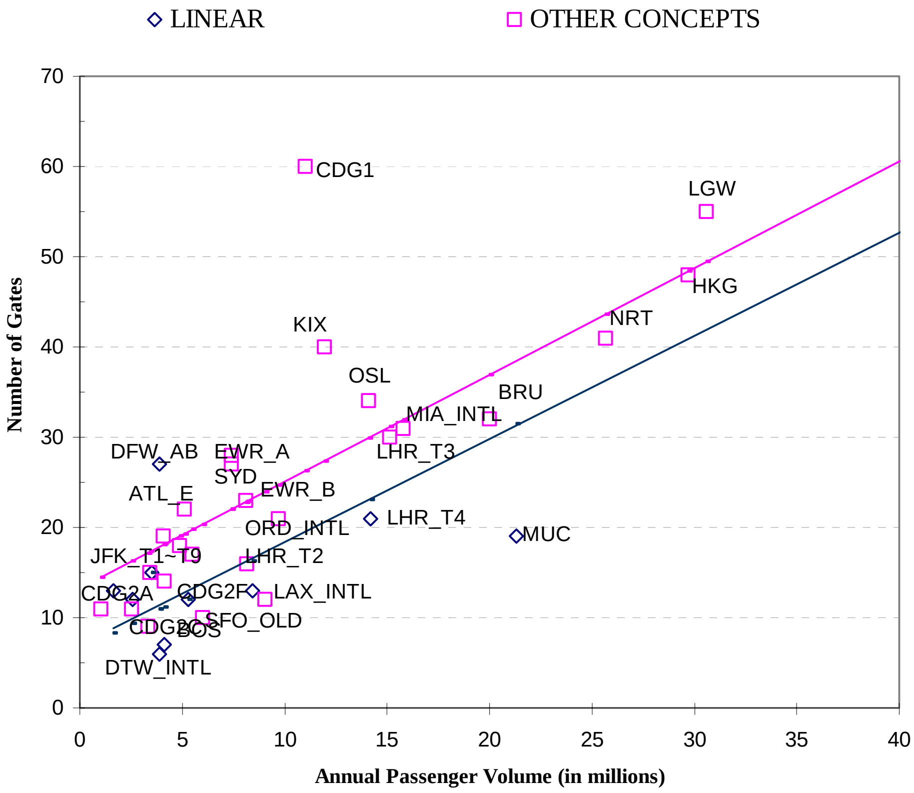


Figure 3.5 The Linear Relationship of Number of Gates and Annual Passenger Volumes[a]

[a] Regression lines of this study represent passenger volumes of the base year (1999).

c. The regression model involving passengers per aircraft

The hypothesis for the regression model involving the average number of passengers per aircraft (PAX_{AC}) is that the airport operates more larger aircraft would result in the less demand on the number of gates in the terminal. The basic assumption is that an airport operates more larger aircraft if it can be found to have a greater average number of passengers per aircraft. The regression results, however, show that the average number of passengers per aircraft is not a significant explanatory variable in the model. T-statistics are shown in parentheses below Equation 3.15.

$$G = 11.699 - 6.751\,TC + 1.15\,PAX + 0.01928\,PAX_{AC},\ R^2 = 0.61 \qquad (3.15)$$

$$(2.283)\quad(-1.982)\quad(5,172)\quad(0.360)$$

Furthermore, a regression analysis shows that there is a linear relationship between annual passenger volume and average number of passengers per aircraft. The related traffic data for the airports worldwide used in this analysis were obtained from Airports Council International. The study selected the top 100 ranked airports, by 1999 total passenger volumes, and computed the average passengers per aircraft by dividing passenger volumes by aircraft movement, as shown in Table 3.8. In particular, the result shows that the average number of passengers per aircraft varies among different areas, as illustrated in Figure 3.6. Four areas considered in the model were North America (*NA*), Europe (*EU*), East Asia and Pacific Area (*AP*), and Others (*OT*, including Latin America, Middle East, South Asia and Africa.). *AP* has the highest number of passengers per aircraft, followed by *OT*, *EU* and *NA*. The regression model for passengers per aircraft and area is shown in Equation 3.16.

$$PAX_{AC} = 29.402 + 29.421EU + 80.940\,AP + 49.698\,OT + 1.095PAX,$$
$$R^2 = 0.68 \qquad (3.16)$$

The statistical analysis of the regression model for passengers per aircraft is shown in Table 3.9 and 3.10. In the formulation, approximately 68% of the variation in the average number of passengers per aircraft can be explained by annual passenger volume. The result indicates that higher annual passenger volume results in more passengers per aircraft. Since annual passenger volumes and the average number of passengers per aircraft are approximately linearly related, the average number of passengers per aircraft can be eliminated from the regression model. The regression model used in the integrated simulation model to estimate passenger volume in a terminal is shown in Equation 3.14.

Table 3.8 1999 Traffic Data of Top 100 Ranked Airports

RANK	AIRPORT	PAX	MOVEMENT	PAX/AC	AREA
1	ATLANTA (ATL)	78,092,940	909,911	86	NA
2	CHICAGO (ORD)	72,609,191	896,228	81	NA
3	LOS ANGELES (LAX)	64,279,571	764,653	84	NA
4	LONDON (LHR)	62,263,365	458,270	136	EU
5	DFW AIRPORT (DFW)	60,000,127	831,959	72	NA
6	TOKYO (HND)	54,338,212	242,118	224	AP
7	FRANKFURT/MAIN (FRA)	45,838,864	439,093	104	EU
8	PARIS (CDG)	43,597,194	475,731	92	EU
9	SAN FRANCISCO (SFO)	40,387,538	438,685	92	NA
10	DENVER (DEN)	38,034,017	488,201	78	NA
11	AMSTERDAM (AMS)	36,772,015	409,999	90	EU
12	MINNEAPOLIS (MSP)	34,721,879	510,421	68	NA
13	DETROIT (DTW)	34,038,381	559,546	61	NA
14	MIAMI (MIA)	33,899,332	519,861	65	NA
15	LAS VEGAS (LAS)	33,669,185	542,922	62	NA
16	NEWARK (EWR)	33,622,686	457,235	74	NA
17	PHOENIX (PHX)	33,554,407	562,714	60	NA
18	SEOUL (SEL)	33,371,071	212,423	157	AP
19	HOUSTON (IAH)	33,051,248	463,173	71	NA
20	NEW YORK (JFK)	31,700,604	343,275	92	NA
21	LONDON (LGW)	30,559,227	255,569	120	EU
22	ST LOUIS (STL)	30,188,973	502,865	60	NA
23	HONG KONG (HKG)	29,728,145	179,870	165	AP
24	ORLANDO (MCO)	29,203,755	355,797	82	NA
25	MADRID (MAD)	27,994,193	306,753	91	EU
26	TORONTO (YYZ)	27,779,675	427,315	65	NA
27	SEATTLE (SEA)	27,705,488	434,425	64	NA
28	BANGKOK (BKK)	27,289,299	181,825	150	AP
29	BOSTON (BOS)	27,052,078	494,816	55	NA
30	SINGAPORE (SIN)	26,064,645	174,731	149	AP
31	TOKYO (NRT)	25,667,634	133,665	192	AP
32	PARIS (ORY)	25,349,112	245,686	103	EU
33	ROME (FCO)	24,029,326	260,581	92	EU
34	NEW YORK (LGA)	23,926,923	362,996	66	NA
35	PHILADELPHIA (PHL)	23,791,761	480,276	50	NA
36	HONOLULU (HNL)	22,560,399	346,609	65	NA
37	CINCINNATI (CVG)	21,771,689	476,128	46	NA
38	SYDNEY (SYD)	21,559,003	287,486	75	AP
39	CHARLOTTE (CLT)	21,441,792	432,128	50	NA
40	MUNICH (MUC)	21,282,906	299,070	71	EU
41	ZURICH (ZRH)	20,875,311	306,182	68	EU
42	MEXICO CITY (MEX)	20,453,568	288,312	71	OT
43	BRUSSELS (BRU)	20,005,122	313,929	64	EU
44	SALT LAKE CITY (SLC)	19,942,795	369,046	54	NA
45	OSAKA (KIX)	19,879,704	117,710	169	AP
46	WASHINGTON (IAD)	19,652,213	469,086	42	NA
47	FUKUOKA (FUK)	19,046,281	134,864	141	AP
48	PALMA DE MALLORCA (PMI)	19,018,075	166,997	114	EU
49	PITTSBURGH (PIT)	18,785,728	437,587	43	NA
50	SAPPORO (CTS)	18,390,126	95,852	192	AP

Source: Airports Council International, 2000

Table 3.8 (Cont.) 1999 Traffic Data of Top 100 Ranked Airports

RANK	AIRPORT	PAX	MOVEMENT	PAX/AC	AREA
51	BEIJING (PEK)	18,190,852	164945	110	AP
52	MANCHESTER (MAN)	17,760,065	185041	96	EU
53	BALTIMORE (BWI)	17,437,663	303283	57	NA
54	BARCELONA (BCN)	17,421,267	233,609	75	EU
55	COPENHAGEN (CPH)	17,402,800	298,533	58	EU
56	STOCKHOLM (ARN)	17,364,309	276,199	63	EU
57	MILAN (MXP)	16,973,765	219,849	77	EU
58	TAIPEI (TPE)	16,368,914	109,669	149	AP
59	VANCOUVER (YVR)	15,982,532	367,249	44	NA
60	OSAKA (ITM)	15,936,768	103,020	155	AP
61	DUSSELDORF (DUS)	15,926,202	194,065	82	EU
62	SAN DIEGO (SAN)	15,301,916	222,354	69	NA
63	KUALA LUMPUR (KUL)	15,171,937	144,342	105	AP
64	TAMPA (TPA)	15,122,326	271,961	56	NA
65	WASHINGTON (DCA)	15,020,852	291,765	51	NA
66	MELBOURNE (MEL)	14,902,167	159,556	93	AP
67	SHANGHAI (SHA)	14,800,913	135,110	110	AP
68	SAO PAULO (GRU)	14,565,793	187,154	78	OT
69	OSLO (OSL)	14,121,154	220,635	64	EU
70	HOLLYWOOD(FLL)	13,990,692	280,860	50	NA
71	PORTLAND (PDX)	13,721,684	322,447	43	NA
72	CHICAGO (MDW)	13,585,395	297,136	46	NA
73	ISTANBUL (IST)	13,207,527	177,319	74	EU
74	CLEVELAND (CLE)	13,020,285	321,420	41	NA
75	DUBLIN (DUB)	12,802,031	170,421	75	EU
76	MANILA (MNL)	12,579,568	170,996	74	AP
77	KANSAS CITY (MCI)	11,911,933	219,816	54	NA
78	SAN JOSE (SJC)	11,594,072	295,200	39	NA
79	JOHANNESBURG (JNB)	11,339,920	154,435	73	OT
80	MUMBAI (BOM)	11,322,158	114,839	99	OT
81	VIENNA (VIE)	11,204,366	191,742	58	EU
82	BRISBANE (BNE)	10,911,532	158,772	69	AP
83	DUBAI (DXB)	10,754,824	132,708	81	OT
84	KAOHSIUNG (KHH)	10,747,210	117,437	92	AP
85	MEMPHIS (MEM)	10,709,881	374,817	29	NA
86	NAGOYA (NGO)	10,598,631	116,966	91	AP
87	JEDDAH (JED)	10,295,343	83,766	123	OT
88	OAKLAND (OAK)	10,248,939	524,203	20	NA
89	BERLIN (TXL)	9,603,679	124,795	77	EU
90	MOSCOW (SVO)	9,557,171	120,336	79	EU
91	HAMBURG (HAM)	9,458,608	156,525	60	EU
92	LONDON (STN)	9,452,906	155,080	61	EU
93	NEW ORLEANS (MSY)	9,443,863	155,868	61	NA
94	SAN JUAN (SJU)	9,421,792	223,612	42	OT
95	GRAN CANARIA (LPA)	9,214,054	98,551	93	OT
96	RALEIGH-DURHAM (RDU)	9,018,426	291,085	31	NA
97	TEL AVIV (TLV)	8,924,277	73,820	121	OT
98	HOUSTON (HOU)	8,864,921	259,454	34	NA
99	TENERIFE SUR (TFS)	8,732,966	64,150	136	OT
100	LISBON (LIS)	8,667,589	110,904	78	EU

Source: Airports Council International, 2000

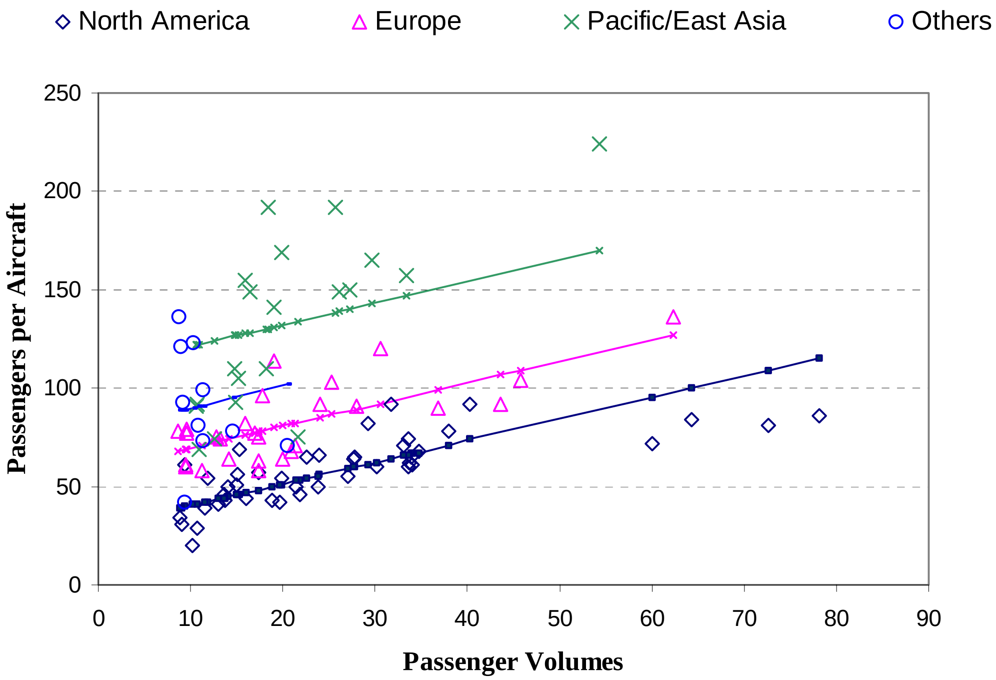


Figure 3.6 The Regression Model for Passengers per Aircraft

Table 3.9 Analysis of Coefficients for the Regression of Passengers per Aircraft

	Unstandardized	Coefficients		
Model	B	Std. Error	t	Sig.
Constant	29.402	5.508	5.338	.000
PAX	1.095	0.165	6.647	.000
Europe	29.421	5.465	5.384	.000
Pacific/Asia	80.940	6.027	13.429	.000
Others	49.698	8.108	6.129	.000

Table 3.10 ANOVA for the Regression of Passengers per Aircraft

Model	Sum of Squares	df	F	Sig.
Regression	98274.117	4	50.790	.000
Residual	45953.923	95	--	--
Total	144228.0	99	--	--

2. FIS Facilities.

a. Number of Passport Control Positions

We used the formula from the IATA Manual to estimate the number of passport control positions for the integrated model. The variables involved into the formula are peak hour number of terminating passengers (V_d), number of transfer passengers not processed airside (V_b), and average processing time per passenger in minutes (t_i), as shown in Equation 3.16. Based on the variables obtained from the results of the survey, peak hour numbers of arrival passengers include both terminating and transfer passengers. The total peak hour passengers for the formula, therefore, would be modified by multiplying the peak hour number of arrival passengers by the proportion of passengers undergoing passport control, as shown in Equation 3.17.

$$N_p = \frac{[(V_d + V_b) \times t_i]}{60} \; (+\ 10\%) \qquad (3.16)$$

$$= \frac{[(V_a \times (1 - P_p) \times t_i]}{60} \; (+\ 10\%) \qquad (3.17)$$

Where N_p: number of passport control positions
V_a : number of arrival passenger
P_p : proportion of passengers processed airside only, e.g. international transfer.

In order to capture more accurate processing times of immigration and customs checks, the service times of the FIS facilities at Terminal A and B at Dallas/Fort Worth (DFW) International Airport were observed. The average processing time (t_i) for immigration checks was found to be 27seconds.

This study uses the annual passenger volumes and peak hour arrival passenger volumes obtained from the airport survey to estimate peak hour arrival passengers (V_a). V_a can thus be obtained by multiplying passenger volume by the PHF for arrival passengers (PHF_a). The passenger volume can be calculated by using Equation 3.14 where the number of gates is given. The estimation results show that the PHF of international passengers is higher than that of total passengers as shown in Table 3.11 and

3.12. This study utilizes the international PHF to estimate peak hour arrival passengers and processing facilities required.

Table 3.11 The Estimation on PHF by 1999 Total Passengers

Airport	Total Annual Passengers	Peak-hour Arrival Passengers	Average Daily Passengers	Average Daily Arrival Passengers	PHF_a
LAX	64,279,571	7,000	176,108	88,054	0.0795
DFW	60,000,127	7,500	164,384	82,192	0.0912
CDG	43,597,194	10,106	119,444	59,722	0.1692
BOS	27,052,075	1,500	74,115	37,058	0.0405
MUC	21,282,906	5,633	58,309	29,155	0.1932
KIX	19,890,350	4,306	54,494	27,247	0.1580
LHR	62,623,365	10,848	171,571	85,785	0.1265
HKG	29,728,145	4,000	81,447	40,723	0.0982
BKK	27,287,847	6,824	74,761	37,381	0.1826
SYD	21,800,000	5,161	59,726	29,863	0.1728
YYZ	27,779,675	4,400	76,109	38,054	0.1156
OSL	14,121,154	1,750	38,688	19,344	0.0905
NRT	25,667,634	5,557	70,322	35,161	0.1580
PHF (TOTAL)					**0.1289**

Source: Airport Survey

Table 3.12 The Estimation on PHF by 1999 International Passengers

Airport	International Annual Passengers	Peak-hour Arrival Passengers	Average Daily Passengers	Average Daily Arrival Passengers	PHF_a
LAX[a]	8,430,000	2,450	23,096	11,548	0.2122
DFW	3,900,000	487	10,685	5,342	0.0912
CDG	37,100,000	8,600	101,644	50,822	0.1692
BOS	4,100,000	227	11,233	5,616	0.0404
MUC	13,479,000	3,553	36,929	18,464	0.1924
KIX	11,934,210	2,584	32,696	16,348	0.1581
LHR	54,800,000	9,493	150,137	75,068	0.1265
SFO[b]	6,000,000	3,400	16,438	8,219	0.4137
HKG	29,728,145	4,000	81,447	40,723	0.0982
BKK	20,500,000	4,380	56,164	28,082	0.1560
SYD	7,630,000	1,806	20,904	10,452	0.1728
YYZ	15,300,000	2,423	41,918	20,959	0.1156
OSL	6,462,000	875	17,704	8,852	0.0988
NRT	25,667,634	5,557	70,322	35,161	0.1580
PHF (INTERNATIONAL)					**0.1574**

Source: Airport Survey

[a] TB International Terminal Only

[b] Old International Terminal

b. Number of Customs

The following formula was utilized in airports where customs checks in the form of baggage inspections are proportional to the number of passengers. The variables include peak hour number of terminating passengers consisting of all international/domestic transfer passengers (V_a), the proportion of passengers to be customs checked (P_f), and the average processing time per passenger in minutes (t_c). Variables V_e and t_c were acquired from the survey. The value of P_f would be 100%, since every international passenger needs to complete customs declaration. The average processing time (t_c) was found to be 13 seconds according to the observation data analysis. The formula is expressed as Equation 3.18.

$$N_c = \frac{V_e \times t_c}{60} \qquad (3.18)$$

where $V_e = V_a \times (1 - P_p)$

3. Baggage Claim Devices. The IATA formulae can be used to calculate the device requirements for wide-body and narrow-body aircraft. The variables used in these calculations include peak hour number of terminating passengers which consists of all international/domestic transfer passengers (V_e), the proportion of passengers arriving by wide-body aircraft (P_w) and by narrow-body aircraft (P_n), the average claim device occupancy time per wide-body aircraft in minutes (t_w) and per narrow-body aircraft (t_n), and the number of passengers per wide-body and narrow-body aircraft with an 80% load factor (V_w and V_n), respectively. Aircraft with 250 or more seats is considered to be wide-bodied in the study. P_w and P_n were obtained by taking the average of the survey results. P_w and P_n were found to be 82.81% and 17.19%, respectively. This study compared the current average number of passengers per aircraft with an 80% load factor (V_w and V_n) to the IATA's figures, and then we selected the greater value and used it to estimate the requirement for baggage carousels. The average number of seats per wide-body and narrow-body aircraft was calculated based on the current fleet share worldwide. These results are shown in Table 3.13 and 3.14, respectively. The average numbers of passengers per aircraft using an 80% load factor for wide-body and narrow-body were found to be 278 and 130. The total number of devices required (N_b) can be calculated by adding the requirements for the wide-body (NW_b) and the narrow-body (NN_b). The formulae for estimating the number baggage claim devices are shown in Equations 3.19 and 3.20.

$$NW_b = \frac{V_e \times F_w \times t_w}{60 \times V_w} = \frac{V_e \times F_w}{425} \qquad (3.19)$$

where NW_b: number of baggage claim devices for wide-bodied aircraft

$t_w = 45$ *minutes*

$V_w = \max(PAX_{ACw}, PAX_{ACw(IATA)}) = \max(278,320) = 320$

Required carousel length: 60 – 70m

$$NN_b = \frac{V_e \times F_n \times t_n}{60 \times V_n} = \frac{V_e \times F_n}{390} \qquad (3.20)$$

where NN_b: number of baggage claim devices for narrow-bodied

$t_n = 20$ minutes

$V_n = \max(PAX_{ACn}, PAX_{ACn(IATA)}) = \max(130,100) = 130$

Required carousel length: 30 – 40m

Table 3.13 Average Seats per Wide-bodied Aircraft

Type	Total Fleet	Average Seats	Fleet%
A330-200	80	289	5.39
A330-300	97	303	6.54
A340-200	20	267	1.35
A340-300	165	290	11.13
B767-400ER	15	276	1.01
DC-10	123	275	8.29
MD11	110	312	7.42
B777-200	70	364	4.72
B777-200ER	213	309	14.36
B777-300	35	421	2.36
B747-400	533	424	35.94
L1011	22	300	1.48
TOTAL	**1483**	**348**	**100.00**

Source: Aircraft Economics No.56, 2001; No.55, 2001; No.54, 2001

Table 3.14 Average Seats per Narrow-bodied Aircraft/ 250-less Seater

Type	Total Fleet	Average Seats	Fleet%
A300[a]	243	231	2.83
A310-200/300	235	191	2.74
A319-100	320	124	3.73
A320-200	872	150	10.17
A321-100	173	185	2.02
B707	260	141	3.03
B717	44	106	0.51
B727-200	804	148	9.38
B737-300	1089	128	12.70
B737-400	465	146	5.42
B737-500	386	108	4.50
B737-600	38	108	0.44
B737-700	281	128	3.28
B737-800	391	162	4.56
B757-200/200ER	918	231	10.71
B757-300	15	239	0.17
B767-300/300ER[a]	564	218	6.58
B767-200/200ER[a]	222	181	2.59
MD83	1142	155	13.32
MD90	112	153	1.31
TOTAL	**8574**	**162**	**100.00**

Source: Aircraft Economics No.50 2000; No.54, 2001

[a] A300 and B767 are the two-aisle aircraft

3.3.2 Service Characteristics of Processing Facilities

1. Service Rate of Gates (Deboarding Rates). In order to obtain the service characteristics of terminal gates/loading bridges for the simulation model inputs, the study used the rates of arrival passengers getting out of gates as a surrogate for the service rate of gates. This study assumed that both gates of international and domestic were homogeneous and that the service rates followed the same distribution. Seventeen flights and 1,887 passengers were observed at Austin Bergstrom (AUS) International Airport. First, the number of arriving passengers getting out of a gate per minute were counted, starting from the first deplaning passenger until five minutes thereafter. Second, the number of arrivals per minute was transformed into the average service time (in minutes) for each passenger. A total of 112 samples were observed. Then, all the observed data values were analyzed by fitting a probability distribution and assessed with goodness-of-fit tests. Finally, a proper probability distribution was chosen as the model input according to the test results and subject matters.

This study used the ARENA Input Analyzer to fit the observations to a statistical distribution and to measure the quality of distribution fit. A smaller square error value, derived from the curve fit results, represents a better fitted distribution to the actual data. Chi-square and Kolmogorov-Smirnov (K-S) goodness of fit hypothesis tests are also provided by the ARENA Input Analyzer. The corresponding p-value can be used to indicate the quality of a fit. A larger p-value implies a better fit [Kelton, 1998]. In general, corresponding p-values less than 0.05 indicate that the distribution is not a very good fit. After analyzing the 1,887 observed arrival data, the results show that the service time of gates follows an exponential distribution, where the square error is 0.025 and the p-value is 0.065 (>0.05), as shown in Table 3.16.

Table 3.16 Fit Summary of Exponential Distribution for Arrivals

Items	Values
Distribution	Exponential
Expression	0.048 + EXP(0.00608)
Square Error	0.025
Chi-square Test	
Test statistics	5.57
Corresponding p-value	0.0653
Data Summary	
Number of Data Points	112
Min. Data Value	0.0483
Max. Data Value	0.0677
Sample mean	0.0541
Sample Standard Deviation	0.00598

Previous FAA airport landside studies showed that most passenger processors within the terminal building were modeled through the use of two multiple-channel queuing models with a First-In First-Out (FIFO) policy [McKelvey, 1988]. Both models assumed that the demand was characterized by a Poisson arrival distribution. For the service rate at a processor, the first model assumed that it was characterized by an exponential distribution, while the second model assumed it was a general random variable characterized by its mean and variance. The first type of model is normally used in situations where the service time is influenced by individual passenger characteristics and is relatively small. The second one is useful in situations where service times for all passengers are similar, and therefore lie within clearly defined limits. The service rate of the gate is best characterized with the first type of processor described above. It can be represented by the number of deplaning passengers getting out of a gate in a unit of time. The service time for individual passenger can thus be obtained simply by taking the inverse. The values are obviously influenced by passenger characteristics, such as age and amount of belongings.

According to the conclusions of previous studies, the exponential distribution can reasonably approximate the distribution on the gate. A simple queuing approach with the assumptions of Poisson arrival and exponential service time is frequently adopted to analyze processing facilities within the terminal building as well [Wong et al., 1998]. The analysis results of this study agree with previous studies regarding the service time distribution.

2. Service Rates of Baggage Claim Systems. The assumption for baggage service rates in this study is that all the baggage claim devices are homogeneous. Fifty-three minutes and 1,194 bags were observed at Austin Bergstrom International Airport. The distribution fit results of both chi-square and K-S tests show that the exponential distribution is a good fit for the interarrival time of baggage claim system. The results of distribution fit and test are listed in Table 3.17.

For the service time per passenger, an average estimate of processing time will be used, because the baggage claim system does not follow an FCFS policy. The procedure used was to observe the occupancy time of the baggage carousel and total processed passengers. The average processed passenger per minute can thus be calculated and transformed into the average processing time per passenger. Thirty-four processing periods and 2,472 passengers were observed. The distribution fit shows that the service pattern follows lognormal distribution, as shown in Table 3.18. By using the average processing time per passenger, the baggage claim system will be modeled as FCFS queues.

Table 3.17 Fit Summary of Bag Interarrival Time (Exponential)

Items	Values
Distribution	Exponential
Expression	0.02 + EXP(0.0335)
Square Error	0.0245
Chi-square Test	
Test statistics	7.09
Corresponding p-value	0.143
Data Summary	
Number of Data Points	53
Min. Data Value	0.0227
Max. Data Value	0.167
Sample mean	0.0535
Sample Standard Deviation	0.0273

Table 3.18 Fit Summary of Service Time per Passenger (Lognormal)

Items	Values
Distribution	Lognormal
Expression	LOGN(0.206, 0.0744)
Square Error	0.00629
Chi-square Test	
Test statistics	1.08
Corresponding p-value	0.314
Data Summary	
Number of Data Points	34
Min. Data Value	0.0821
Max. Data Value	0.438
Sample mean	0.206
Sample Standard Deviation	0.0758

3. Service Rates of FIS facilities. For immigration checks, processing times often vary significantly across countries. In this study, the values of typical FIS processing times in the United States were used as model inputs. Observations were presented at DFW International Airport. One hundred and seven passengers, who were randomly selected among US citizens and non-citizens, were observed through INS. Forty passengers were observed through customs. The objective of combining citizen and non-citizen observations was to reflect the variance of passport check processing in a real system. The distribution fit results show that the exponential distribution is a good fit for the service time of passport checks. The results of distribution fit are listed in Table 3.19. For customs, the distribution fit shows that the service pattern follows the lognormal distribution, as shown in Table 3.20.

Table 3.19 Fit Summary of for Immigration Service Time (Exponential)

Items	Values
Distribution	Exponential
Expression	0.1 + EXP(0.365)
Square Error	0.009561
Chi-square Test	
Test statistics	3.55
Corresponding p-value	0.187
Data Summary	
Number of Data Points	107
Min. Data Value	0.133
Max. Data Value	2.97
Sample mean	0.465
Sample Standard Deviation	0.415

Table 3.20 Fit Summary of for Customs Service Time (Lognormal)

Items	Values
Distribution	Lognormal
Expression	LOGN(0.232, 0.193)
Square Error	0.0286
Chi-square Test	
Test statistics	7.05
Corresponding p-value	0.0846
Data Summary	
Number of Data Points	40
Min. Data Value	0.0463
Max. Data Value	0.598
Sample mean	0.228
Sample Standard Deviation	0.163

4. Concourse Time. The concourse time varies depending on the area of terminal, facilities provided (such as moving sidewalks and escalators), and terminal concepts. According to the airport survey, the average time spent by arriving passengers from gate to clear immigration checks, T(GI), varies from 0 to 30 minutes. Its distribution is shown in Figure 3.7.

The first step to estimate concourse time used in the integrated model was to evaluate if the *T(GI)* varies between terminal concepts. *T(GI)* comprises of concourse time and immigration checking time. In general, time for immigration check varies among countries. This study selected North American airport samples to test if concourse time varies between different concepts, under the assumption that immigration checks hold the same characteristics across North America. The average T(GI)'s for linear and pier terminal samples, $T(GI)_L$ *and* $T(GI)_P$, are 13.75 and 22.5 minutes. And the standard deviations, S_L and S_P, are 10.308 and 7.07, respectively.

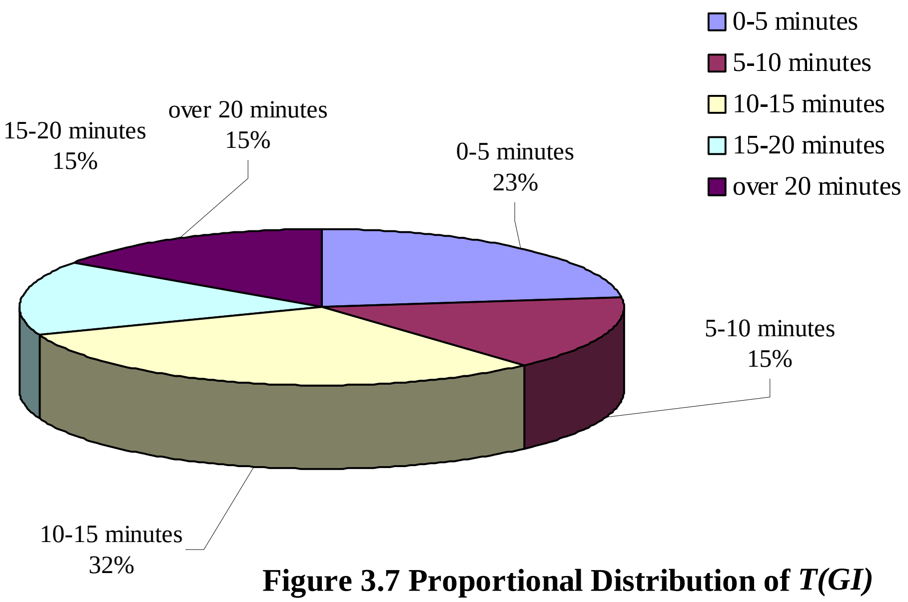


Figure 3.7 Proportional Distribution of *T(GI)*

The hypothesis test employed in evaluating the difference between terminal concepts is described as follows. The null hypothesis is:

$H_0: \mu_P - \mu_L = 0$

$H_a: \mu_P - \mu_L \neq 0$

$$t = \frac{[T(GI)_P - T(GI)_L] - (\mu_P - \mu_L)}{\sqrt{n_P \cdot S_P^2 + n_L \cdot S_L^2}} \cdot \sqrt{\frac{n_P \times n_L (n_p + n_L - 2)}{n_P + n_L}}$$

$$= 0.8 < t_{0.05,4} = 2.132 \qquad (3.21)$$

where μ_P , μ_L: average time from Gate to clear immigration checks of pier and linear terminal, respectively.

n_P , n_L: number of pier and linear terminals.

The hypothesis test was to use t-test, assuming that variances of *T(GI)*'s were equal for all terminal conceptual types across the world. The test results show that there is no significant difference for *T(GI)* between linear terminals and pier terminals because of the large standard deviation obtained from the survey. Since there was no observable difference, this study used the distribution of observed concourse times by fitting data from the DFW International Airport, which is linear concept. Model inputs are shown in Table 3.21.

Table 3.21 Fit Summary for Linear Concourse Time (Lognormal)

Items	Values
Distribution	Lognormal
Expression	LOGN (3.61, 1.74)
Square Error	0.0322
Kolmogorov-Smirnov Test	
Test Statistics	0.104
Corresponding p-value	0.0316
Data Summary	
Number of Data Points	189
Min. Data Value	0.867
Max. Data Value	7.5
Sample mean	3.61
Sample Standard Deviation	1.69

5. Lobby Time. The lobby time varies from 0 to 20 minutes. Its proportional distribution is shown in Figure 3.8. The analysis of distribution shows that it does not follow any theoretical distribution. The model input for lobby time will be therefore using the continuous empirical distribution, as shown in Table 3.22.

Table 3.22 Empirical Distribution for Lobby Time

Time Interval	Percentage	Cumulative Probability
0-5 minutes	57.13	57.13
5-10 minutes	14.29	71.42
10-15 minutes	14.29	85.71
15-20 minutes	14.29	100.00

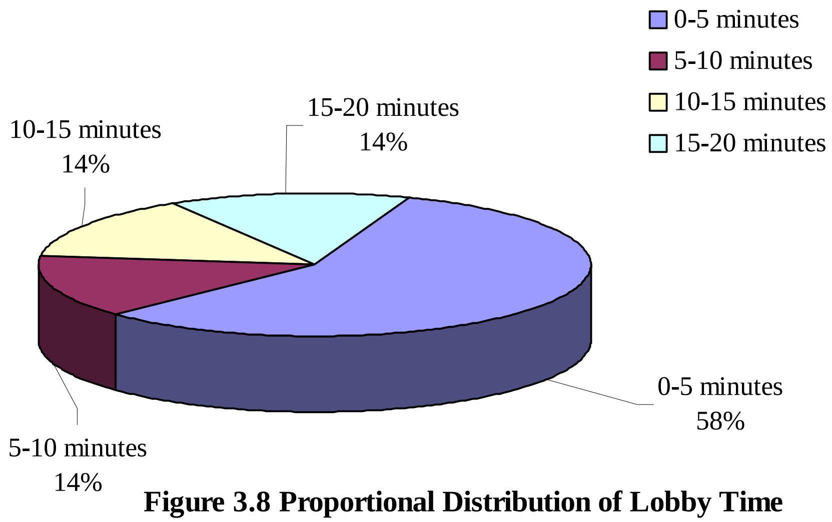


Figure 3.8 Proportional Distribution of Lobby Time

3.3.3 Arrival Characteristics

1. Aircraft Arrivals. The percentage distribution obtained from the airport survey for aircraft interarrival time is shown in Figure 3.9. The interarrival time for each gate can be assigned randomly according to this distribution. Hence, the percentage distribution can be applied to assign aircraft arrivals into gates, as described in Section 3.1.2. For example, with 73% of total daily flights arriving every 2 to 4 hours, 73% of total gates will be assigned with the interarrival distribution of *U(2,4)*.

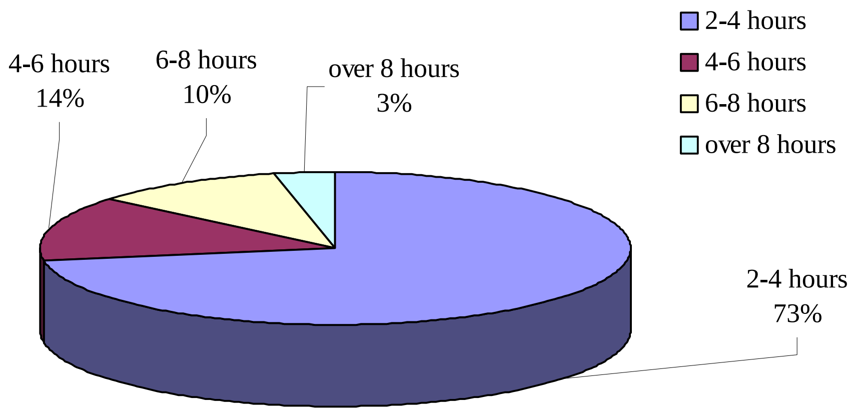


Figure 3.9 Distribution of Interarrival Times

2. Hourly Distribution. According to the available daily flight information, the average hourly distribution for the selected airports can be depicted as Figure 3.10. Most of the airports showed an obvious evening peak hour. The aggregated peak hour operation appears during the 16th and 17th hour of a day, as table shown in Table 3.23. This implies that all processing facilities would be very busy from 4 through 6 pm. It should be noted that the peak hour percentage is based on aircraft operation. Initial gate assignment logic can thus be employed to complete the first arrival creation requirements in the simulation model.

Table 3.23 Average Hourly Distribution

Time	Percentage	Time	Percentage	Time	Percentage
0-1	0.73	8-9	4.56	16-17	8.64
1-2	0.43	9-10	3.55	17-18	5.53
2-3	0.15	10-11	5.73	18-19	6.57
3-4	0.14	11-12	5.04	19-20	6.00
4-5	0.54	12-13	5.83	20-21	6.57
5-6	1.47	13-14	6.23	21-22	4.34
6-7	3.52	14-15	7.03	22-23	4.68
7-8	3.88	15-16	7.58	23-24	1.27

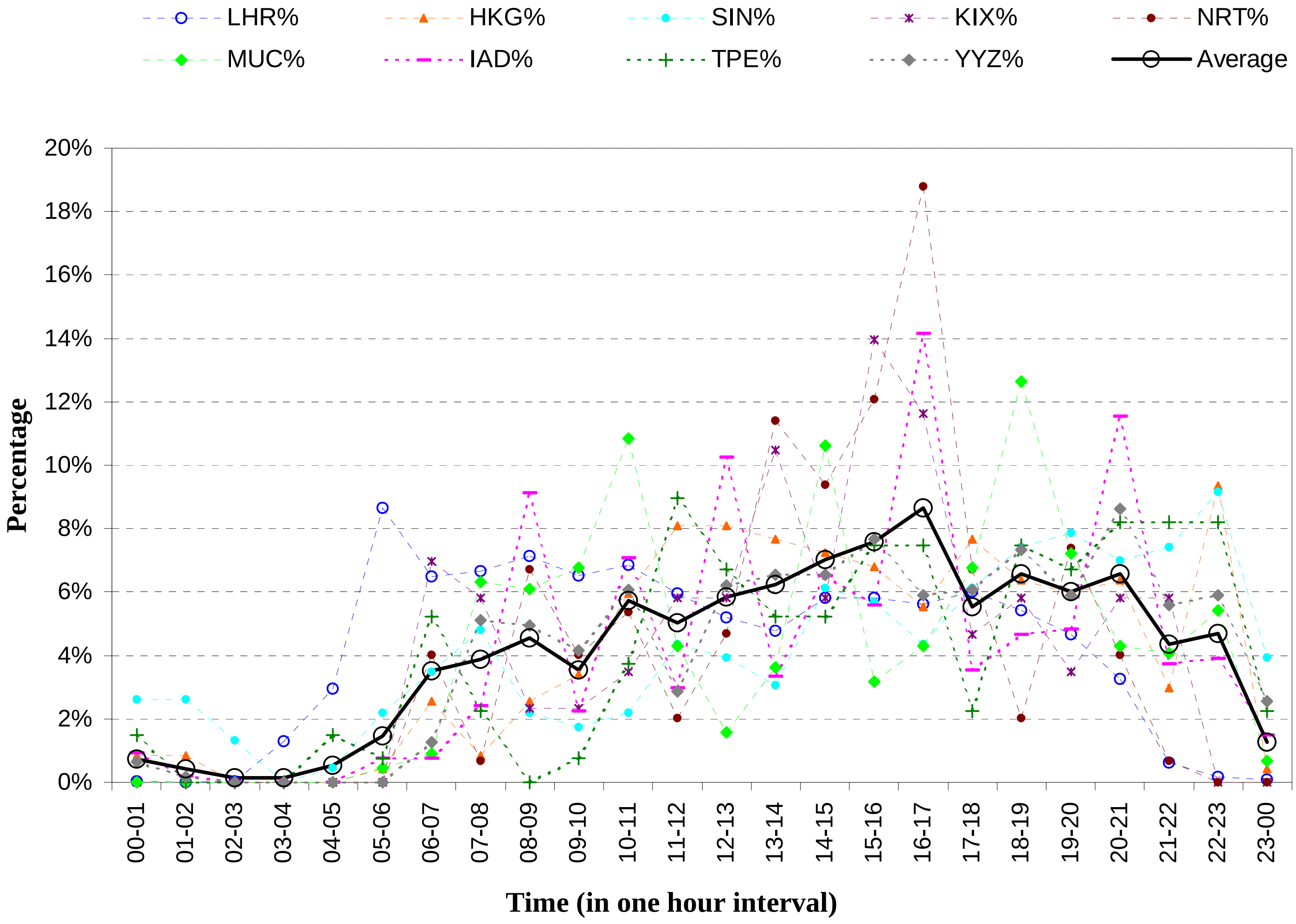


Figure 3.10 Arrival Hourly Distribution

3. Average Passengers per Aircraft (Batch Size). This study uses twelve wide-bodied aircraft and one narrow-body aircraft for arrivals in the simulation model. The proportion of wide-body and narrow-body aircraft obtained from the airport survey is shown in Figure 3.11. The wide-body part can be divided into twelve commercial aircraft types that are currently operating, based on their fleet share worldwide. The discrete empirical distribution will be adopted for the input of batch size for an arrival entity in the simulation model. The probability and average number of passengers per aircraft of each aircraft type are aggregated into six categories as shown in Table 3.24. The discrete empirical distribution can be expressed as $DISC(PAX_{AC1}, F_1, PAX_{AC2}, F_2, \dots)$.

Table 3.24 Average Number of Passengers per Aircraft

Aircraft Class	Passengers per Aircraft (PAX_{ACi})	Probability	Cumulative Probability (F_i)
W1 (200-220 pax)	208	8.83%	8.83%
W2 (220-230 pax)	223	20.33%	29.16%
W3 (230-250 pax)	236	18.03%	47.19%
W4 (250-300 pax)	277	3.91%	51.10%
W5 (over 300 pax)	322	31.71%	82.81%
N (narrow-body)	123	17.19%	100.00%

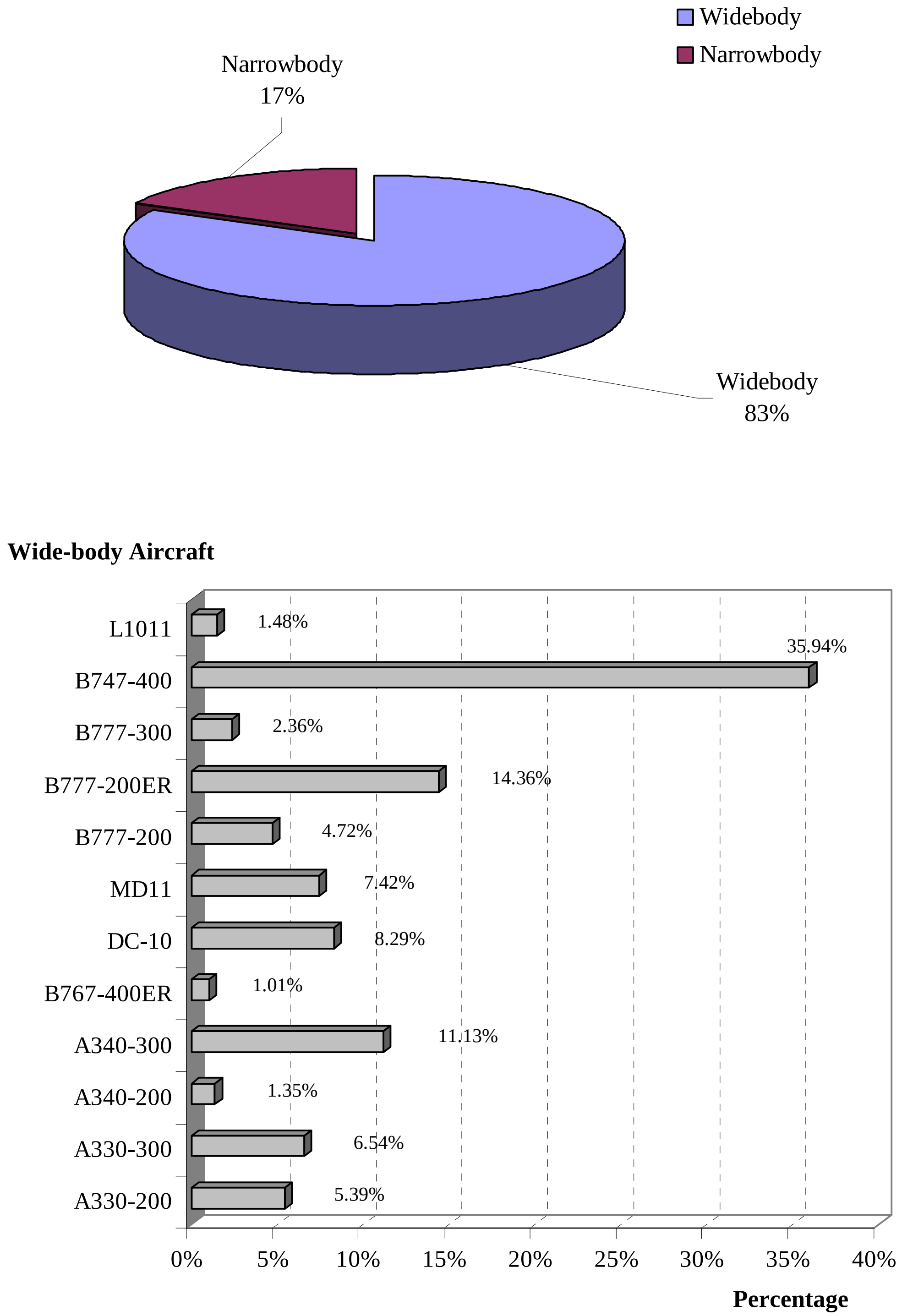


Figure3.11 Fleet Share of Wide-body Aircraft

CHAPTER 4. MODEL DEVELOPMENT AND VALIDATION

This Chapter describes the development of the integrated simulation model for arrival passenger flows and examines if the model is able to capture the operational pattern of a typical busy international terminal. Section 4.1 provides an overview of the integrated simulation model. Then, simulation results are briefly summarized in Section 4.2. Section 4.3 introduces Model validation to demonstrate the extent of agreement between model outputs and the corresponding data obtained in the real system. The model that gets good prediction of the real system can thus be utilized to analyze the NLA introduction scenarios. Due to the limitations of data collection for type II international arrival passenger flows, the integrated model will only be validated for type I passenger flows, at both linear and pier terminals.

4.1 MODEL DEVELOPMENT

After completing the estimations on arrival and service characteristics, one can determine the simulation cases for each terminal concept (linear and the other) which need to be simulated, simply by giving the number of gates. Eleven base cases have been evolved from the simulation model, including four linear terminals with 15, 20, 25, and 30 gates, as well as seven pier/satellite terminals with 20, 25, 30, 35, 40, 45, and 50 gates. The model inputs for service functions, listed in Table 4.1, can be estimated based on the methods described in Section 3.3. The estimations on immigration checks and customs examination, however, cannot represent the actual FIS operation. Some other factors, such as the actual number of personnel that the federal agencies can provide, will affect the service that the system can really provide. Therefore, some operational adjustment factors will be used in the simulation model input. These factors can be obtained by direct airport observations.

Table 4.1 Estimation on Passenger Processing Facilities Required for Base Year

Terminal Concept	Gate	Estimated Annual Passengers	Peak –hour Arrival Passengers	Daily Arrival Flights	Passport Checks[a]	Baggage Carousels	Customs[b]
PIER & SATELLITE	20	5,709,214	1,231	43	10	3	4
	25	9,935,757	2,142	75	17	5	8
	30	14,162,299	3,054	107	24	7	11
	35	18,388,842	3,965	139	31	9	14
	40	22,615,385	4,876	170	38	11	17
	45	26,841,927	5,788	202	46	13	17[c]
	50	31,068,470	6,699	234	53	15	17
LINEAR	15	7,327,134	1,580	55	12	4	6
	20	11,553,677	2,491	87	20	5	9
	25	15,780,220	3,402	119	27	8	12
	30	20,006,762	4,314	151	34	10	15

[a] FAA AC150/5360-13 shows that numbers of INS check booths and customs are 7, 12, and 17, when passengers per hours 800, 1400, and 2000.

[b] Default numbers for the secondary customs examination is 2, one for customs and one for agriculture.

[c] The maximum number of customs used in the model is 17.

The arrival generation function is developed by program language C++. Table 4.2 shows an output example of the arrival generation method for a 20-gate linear terminal. For example, the interarrival distribution is U(2,4) for gate 2 with the first arrival at the gate is the 6th hour. In this example the gate assignment designates gate 2 as capable of handling wide-bodied aircraft. Programs and related output/output examples are attached in Appendix D.

Table 4.2 Results of Arrival Generation Method for a 20-gate Linear Terminal

A. Percentage Distribution of Aircraft Interarrival Time and Gate Assignment

Interarrival time	$P_{i\ (j,\ k)}$, %	$G_{ai}{}^{a}$	Gate Assignment S_{Gi}
2 – 4 hours	72.41	14	2, 8, 15, 1, 10, 5, 19, 3, 6, 12, 16, 17, 14, 13
4 – 6 hours	13.49	3	7, 20, 4
6 – 8 hours	10.34	2	9, 18
Over 8 hours	3.46	1	11

B. Initial Aircraft Arrivals and Gate Assignment

Time i – i+1	$X_{i,\ i+1}$, %	$AC_{n(i,\ i+1)}$	Gate Assignment $S_{AC(i,\ i+1)}$
0 – 1	0.73	0	0
1 – 2	0.43	0	0
2 – 3	0.15	0	0
3 – 4	0.14	0	0
4 – 5	0.54	0	0
5 – 6	1.47	1	2
6 – 7	3.52	3	8, 15, 1
7 – 8	3.88	3	10, 5, 19
8 – 9	4.56	4	3, 6, 12, 16
9 – 10	3.55	3	17, 14, 13
10 – 11	5.73	5	7, 20, 4, 9, 18
11 – 12	5.04	5	11[b]

C. Gates for the Wide-bodied and the Narrow-bodied

Aircraft Type	Percentage %	Number of gates	Gate Assignment S_{Fw}
Wide-bodied	82.82	17	2,8,15,1,10,5,19,3,6 12,16,17,14,13,7,20,4
Narrow-bodied	17.19	3	9, 18,11

[a] $\sum G_{ai} = 20$

[b] After assigning gate 11, $\sum_{i=0}^{11} AC_{n(i,i+1)} = 20$, when j = the 11th hour. Each gate has been assigned with an interarrival distribution, the program is thus terminated. Therefore, within the 11-12 hour, only one gate is assigned.

The integrated simulation model is constructed under ARENA 3.0. The inputs of the model, which can be found in Appendix E, are demonstrated in detail with the model illustration and each related dialog for the example of a 20-gate linear terminal. The model divides the arriving passenger flow into four sequential processing segments: from gates to immigration check points, from immigration checks to baggage claim systems, from baggage claim systems to customs, from customs to the curbside, which represents the exit from the system. The first segment also includes the time spent in the concourses. Each processing segment is modeled as a steady-state First-Come-First-Serve (FCFS) queuing system, with probabilistic arrival and service distributions. The FCFS policy is a proper description for most of passenger processing facilities in the terminal. As for baggage claim systems, however, the FCFS policy no longer holds and the service pattern is totally random. In order to model the baggage claim system and the FCFS queuing network, an average service rate can be utilized. The average service rate is obtained by dividing total passengers processed by a carousel, by the operating time from the arrival of the first passenger until the departure of the last passenger. Using the average service rate, a baggage claim system can thus be viewed as a FCFS queue. In the simulation model, immigration checks and customs declaration are modeled as a pooled queue, baggage claim systems and secondary examination are considered to be separate.

4.2 MODEL OUTPUT

4.2.1 Confidence Intervals for terminating Simulation

Simulation outputs for the integrated model include total time spent in the system for arriving and transfer passengers, total number of observations, queuing time at each server, average queuing length of each server, busy period of each server. This study uses total time spent by passengers in the system for arriving passengers as the parameter to determine the number of replications needed. ARENA Output Analyzer can calculate the following: over-replications mean, half-width of a 95% confidence interval, minimum and maximum over the replications. Once the half-width (h) of a 95% confidence interval is less than 0.5, the simulation work can be terminated. The equation used to calculate of the half width is shown in Equation 4.1 [Kelton et al., 1998].

$$h = t_{n-1,1-\alpha/2} \frac{s}{\sqrt{n}} \tag{4.1}$$

where h: half width of the (1-α) confidence interval, $\alpha = 0.05$

s: standard deviation of total time in the system

n: number of replications

The simulation results of this study show that the half-width of a 95% confidence interval after the first replication varies from approximately 0.1 to 0.25, where the number of gates increases, which means that if the number of passenger observations increases, the half-width decreases. A small half-width represents the error in the point estimate of the mean is very low (less than 0.1% in this study) because of a very large number of total observations, as shown in Table 4.3.

Table 4.3 List of Total Observations (Base Year)

Simulation Cases	Total Arrival Observations
Linear 10 gates	12,581
Linear 20 gates	18,847
Linear 25 gates	22,781
Linear 30 gates	28,721
Pier 20 gates	9,977
Pier 25 gates	19,619
Pier 30 gates	26,488
Pier 35 gates	31,661
Pier 40 gates	35,423
Pier 45 gates	43,457
Pier 50 gates	47,858
Total Observations	297,413

4.2.2 Simulation Model Outputs

After running the eleven simulation base cases, the desired performance measures can be obtained, including total time in the system, waiting time at each server, as well as average and maximum queuing length. The average values for the base cases are listed in Table 4.4, for each performance measure. An output departure example of a 20-gate linear terminal is shown in Figure 4.1. The queuing length at each server is depicted in Figure 4.2.

Table 4.4 Major Performance Measures for the Base Cases

Performance Measures	Values
Total time in the system	33.91 minutes
Average deboarding time	6.63 minutes
Waiting time for immigration	16.30 minutes
Waiting time for baggage claim system	8.87 minutes
Waiting time for customs	4.18 minutes
Average queuing length for immigration	267 Pax
Maximum queuing length for immigration	1,671 Pax
Average queuing length for customs	61 Pax
Maximum queuing length for customs	243 Pax
Average number of daily passengers processed by a single baggage claim	4,398 Pax
Average number of peak-hour passengers processed by a single baggage claim	692 Pax

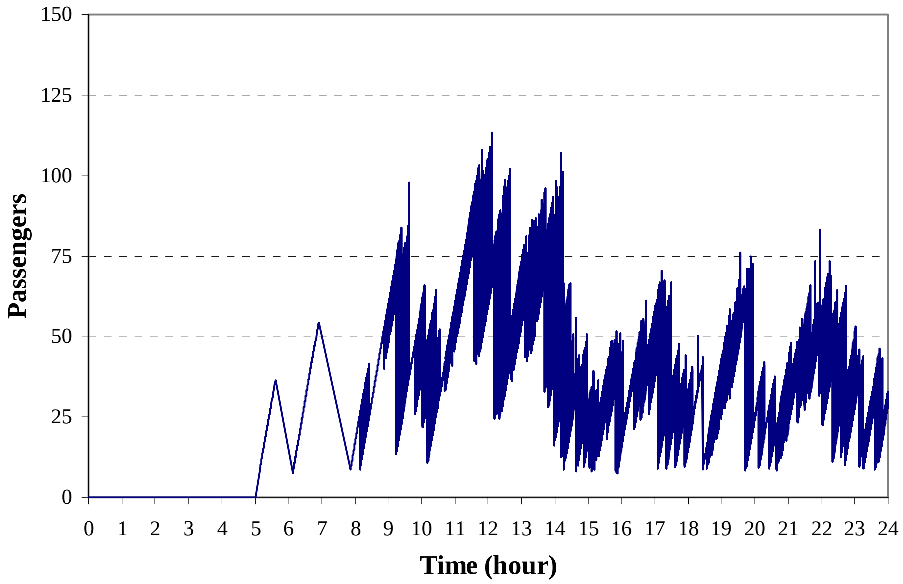
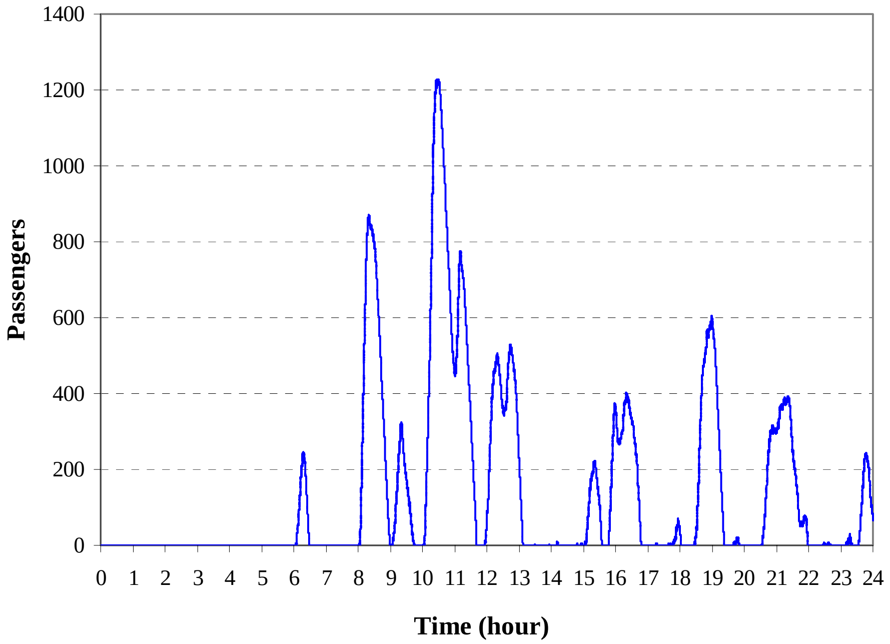
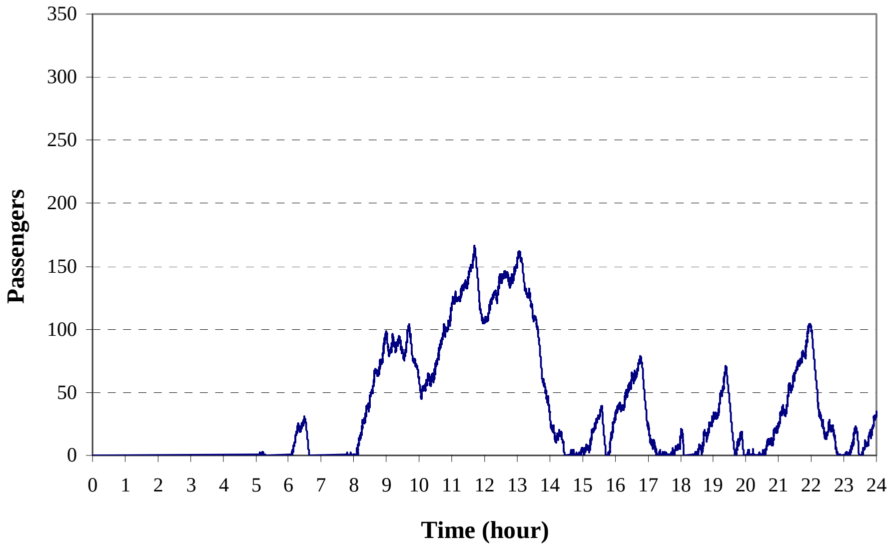


Figure 4.1 Daily Departures from the Terminal System (Base Year)

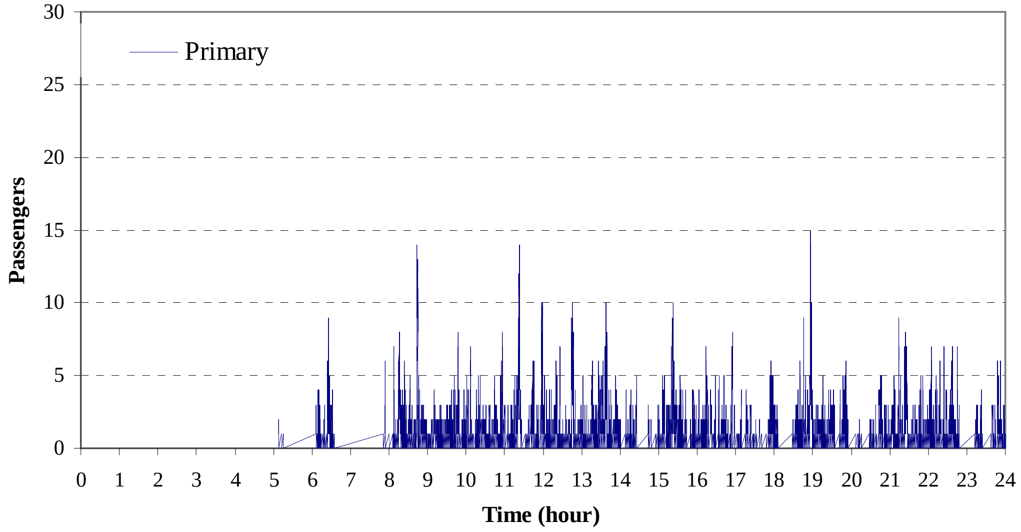


(a) Queuing Length at Immigration Checks

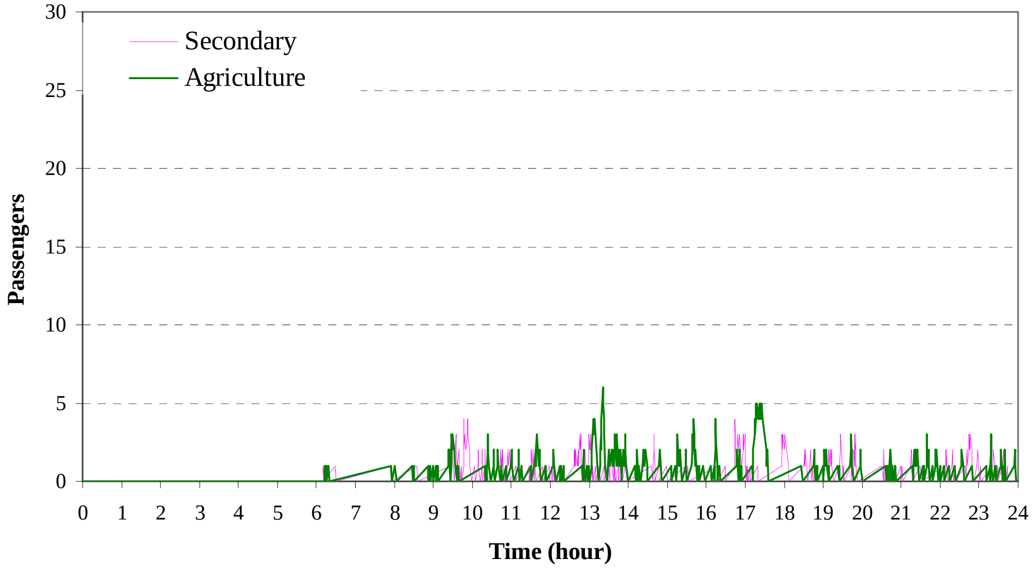


(b) Queuing Length at Baggage Claim Systems

Figure 4.2 Queuing Length at Each Server (Base Year)



(c) Queuing Length at Primary Customs



(d) Queuing Length at Secondary Customs and Agriculture Checks

Figure 4.2 (Cont.) Queuing Length at Each Server (Base Year)

4.3 MODEL VALIDATION

A simulation model is used as a surrogate for actually experimenting with an existing or proposed system. Since it is only an approximation of an actual system, it should be validated relative to the performance measures that will be used for evaluation. For the purpose of model validation with comparable data, this study proposes three major measurements: daily arriving passengers, average time spent in the terminal and its proportional distribution over sequential processing segments.

4.3.1 Daily Arriving Passengers

The number of daily arriving passengers was used to evaluate the arrival generation method embedded in the integrated model. First, each base case is simulated and the total number of passengers within 24 hours is obtained. Second, a goodness of fit test is conducted to compare the simulation outputs of each base case and the daily arrivals estimated from the regression model. Third, by formulating the relationship of the total number of daily arriving passengers (PAX_d) and the corresponding number of gates, and comparing it to the collected terminal information, a test of significance is performed. If there is no significant difference, the base cases can be considered as a good approximation to the 1999 demand. The hypothesis test used was the F test. The unrestricted models for the hypothesis test include two regression lines; one is from 1999 terminal data (4.2) and the other from simulation results (4.3).

$$Gate = 13.247 - 6.915\ TC + 0.0008662\ PAX_d,\ R^2 = 0.60 \qquad (4.2)$$
$$(4.915) \quad (-2.076) \quad (6.077)$$

$$Gate = 8.463 - 3.386\ TC + 0.0008404\ PAX_d,\ R^2 = 0.99 \qquad (4.3)$$
$$(10.659) \quad (-6.071) \quad (36.095)$$

The restricted model for the test is a regression model which combines the above two samples (4.4). The model validation for daily arriving passengers is shown in Table 4.5.

$$Gate = 13.648 - 6.696\ TC + 0.0007768\ PAX_d,\ R^2 = 0.68 \qquad (4.4)$$
$$(6.282) \quad (-2.656) \quad (8.349)$$

Table 4.5 Model Validation for Daily Arriving Passengers

	Unrestricted Model		Restricted Model	
Coefficients	Terminal Data (1999)	Simulation Results		F-test
Constant	13.247	8.463	13.648	Test statistic F
TC	-6.915	-3.386	-6.696	1.07
PAX_d	0.0008662	0.0008404	0.0007768	
R^2	0.60	0.99	0.68	Critical value F
ESS	2419.181	5.035	2550.907	3.23

The test results show that there was no significant difference between the unrestricted and restricted models. This implies that the simulation model is able to capture the arriving characteristics.

4.3.2 Total Time in the Terminal

The average time in the terminal, and its proportional distribution over the sequential processing segments, are the parameters used to assess if each formula used in the service functions appropriately replicates the supply function of a typical international airport. The average time spent by passengers in the terminal system comprises of service time of each processing facility, waiting time at each processor, and connection time between processors. It is defined as the average time per arriving passenger required to go from the gate to the curbside. In-cabin waiting time and deboarding time were excluded in model validation. Data were obtained from the global airport survey (Figure 4.3) showed a mean of 35.77 minutes, and a standard deviation of 10.96 minutes. The survey results also show that the average time in the terminal is independent from the number of gates, peak hour passenger volumes, and the terminal concepts. The mean obtained from simulation results is 33.98 minutes with a standard deviation of 13.40 minutes. A t-test was used to verify the hypothesis as shown in Equation 4.6.

The null hypothesis is used where there is no difference for total time in the terminal between results from airport survey and from simulation, by assuming that the distribution of total time spent by passengers in the terminal is normally distributed. The null hypothesis is:

H_0: $\mu_A - \mu_S = 0$

H_a: $\mu_A - \mu_S \neq 0$

$$t = \frac{[\overline{TT}_A - \overline{TT}_S] - (\mu_A - \mu_S)}{\sqrt{n_A \cdot S_A^2 + n_S \cdot S_S^2}} \cdot \sqrt{\frac{n_A \times n_S (n_A + n_S - 2)}{n_A + n_S}}$$

$$= 0.34 < t_{0.05,\,22} = 2.391 \qquad (4.6)$$

where $\overline{TT}_A, \overline{TT}_S$:Mean of total time in the terminal system obtained from airport survey and simulation, respectively.

n_A , n_S: Number of airports of survey and simulation, respectively.

S_A, S_S: Standard deviation

The hypothesis tests show that there is no significant difference. This suggests that the estimation procedure for the facility requirements is valid and that the associated distribution is a good projection of the service characteristics.

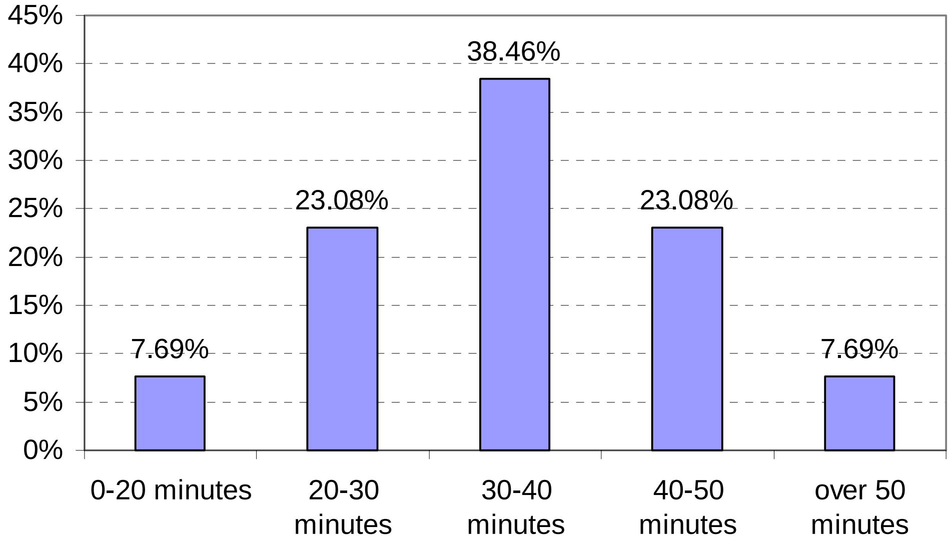


Figure 4.3 Total time distribution from airport survey

4.3.3 Time Proportional Distribution over Processing Segments

This distribution examines if the simulation model appropriately captures the movement characteristics of arriving passenger flow in a terminal. Arriving passenger flow is divided into four sequential processing segments in this study. (T_{GI}, T_{IB}, T_{BC}, and T_{CC}). One can calculate the proportion of time spent by passengers in individual segments over total time in the entire terminal and get the average proportional distribution. A Chi-square test was used to compare the average proportional distribution of time obtained from simulation outputs with the global airport survey. Results are shown in Table 4.6 and Figure 4.4. The outputs from simulation results are shown in Table 4.7 and Figure 4.5.

Figure 4.3 preliminarily shows that the simulation model projected well over processing segments, except the segment from baggage claim systems to customs. The Chi-square test value is 4.089, which is less than the critical value 7.815 corresponding to 3 degree of freedom and the given level of significance 0.05. This result implies that the null hypothesis is true when the level of significance is 5%, and that the simulation model is a good approximation of the entire passenger movements.

Both the global survey and the simulation results, it was noticed that if the proportion of time spent in immigration was longer, and that the proportion in baggage claim area was shorter. However, if someone spends a smaller amount of time in immigration, this same person will spend a greater amount of time in the baggage claim area. It is intuitive that the previous server seems to regularize the passenger flow. Time spent in the last server, i.e. customs, is likely to possess a lower proportion. The integrated simulation model can be viewed as a good approximation of the entire passenger movements.

Table 4.6 Time Proportional Distribution from Survey Results (%)

Airport	T_{GI}	T_{IB}	T_{BC}	T_{CC}
LAX	33.33	33.33	13.33	20.00
DFW	25.00	25.00	25.00	25.00
CDG	7.69	23.08	61.54	7.69
BOS	27.78	16.67	27.78	27.78
DTW	45.83	12.50	12.50	29.17
KIX	25.00	41.67	25.00	8.33
LHR	33.33	46.67	0.00	20.00
SFO	55.00	25.00	15.00	5.00
HKG	50.00	30.00	10.00	10.00
BKK	22.22	22.22	33.33	22.22
SYD	35.00	25.00	15.00	25.00
YYZ	58.33	25.00	8.33	8.33
OSL	60.00	20.00	0.00	20.00
AVERAGE	**37.29**	**25.99**	**18.64**	**18.08**

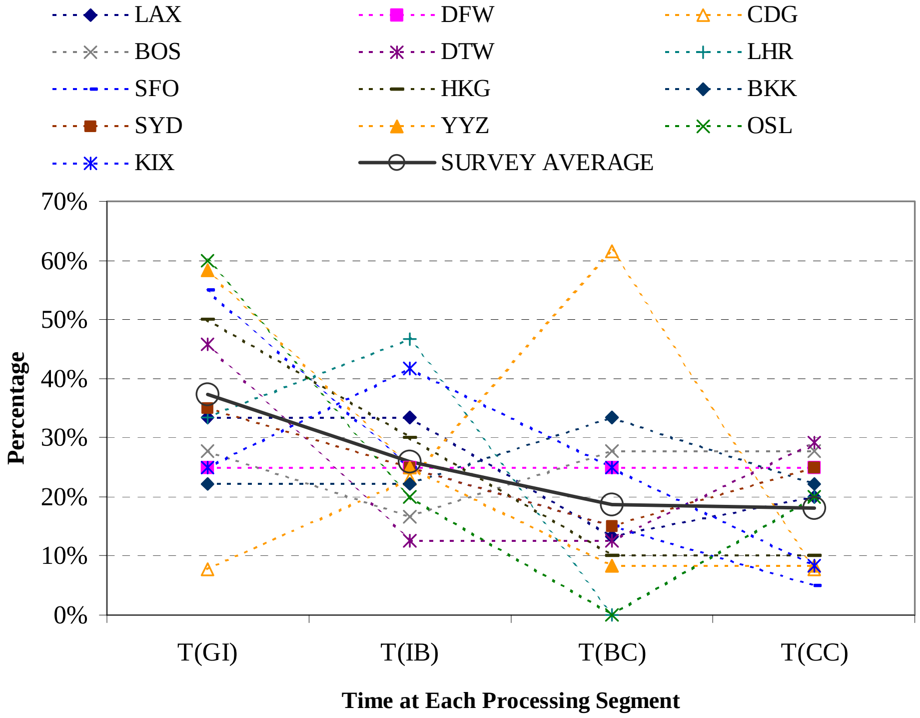


Figure 4.4 Time Proportional Distribution from Survey Results

Table 4.7 Proportional Distribution from Simulation Results (%)

Simulation Cases	T_{GI}	T_{IB}	T_{BC}	T_{CC}
Linear 15 Gates (L15)	46.80	10.97	19.02	23.21
Linear 20 Gates (L20)	39.85	37.55	0.19	22.42
Linear 25 Gates (L25)	37.22	25.43	0.48	36.87
Linear 30 Gates (L30)	29.88	35.23	0.68	34.22
Pier 20 Gates (P20)	32.08	28.56	30.71	8.65
Pier 25 Gates (P25)	53.88	35.59	0.30	10.23
Pier 30 Gates (P30)	47.89	25.07	0.83	26.21
Pier 35 Gates (P35)	36.03	39.89	0.77	23.32
Pier 40 Gates (P40)	23.09	48.92	3.78	24.21
Pier 45 Gates (P45)	31.42	25.56	22.93	20.09
Pier 50 Gates (P50)	33.04	20.07	20.40	26.48
AVERAGE	**38.35**	**30.67**	**11.12**	**19.87**
SURVEY	**37.29**	**25.99**	**18.64**	**18.08**

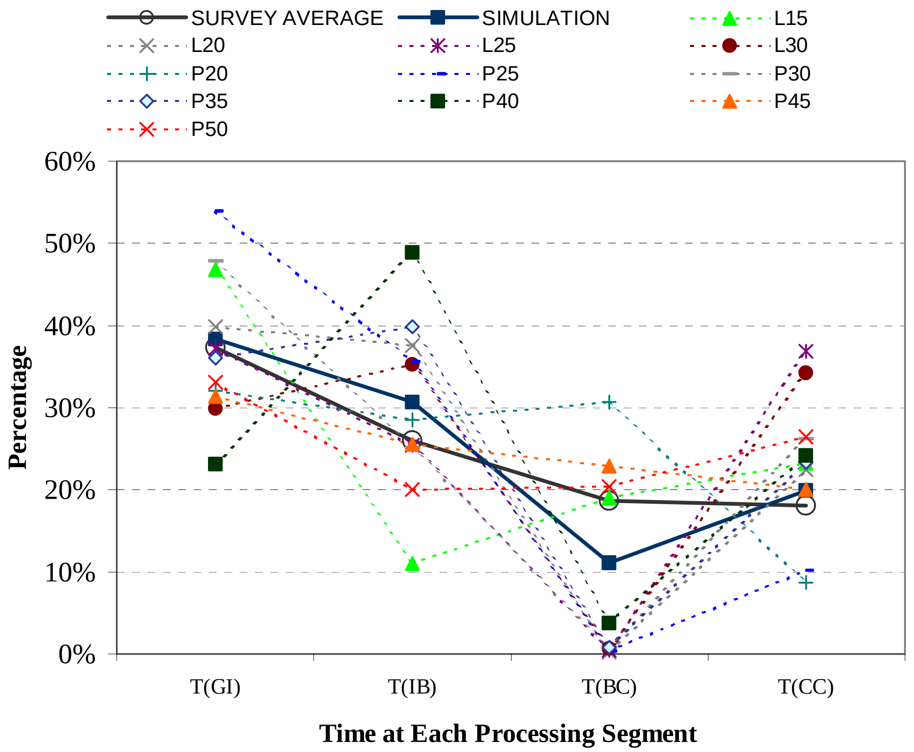


Figure 4.5 Time Proportional Distribution from Simulation Results

CHAPTER 5. MODEL APPLICATIONS – IMPACTS OF NEW LARGE AIRCRAFT

In this chapter, the potential impact of the NLA on arriving passenger flows is evaluated by using the integrated simulation model. In Section 5.1, the evaluation framework is introduced. An overview of the evaluation procedure employed in this study is provided. In Section 5.2, the results of the simulation model for the design year without taking into account NLA introduction will be presented. Simulation results taking into account NLA introduction will be demonstrated in Section 5.3. In addition, potential bottlenecks will also be discussed. Finally, operational strategies will be involved in model applications. The improvement of system performances will be shown in Section 5.4.

5.1 EVALUATION FRAMEWORK

A valid integrated simulation model can be applied to evaluate the impact of introducing the NLA by comparing before and after scenarios. The procedure is to first determine the design year and the average annual growth rate to be used in forecasting the future demand. Second, the model needs to be run without taking into consideration NLA operations in the design year. Finally, by adding various scenarios of NLA introduction, the model will provide results of how the introduction will modify the performance measures.

The basic assumption for simulating the terminal passenger flows in the design year is that the hourly distribution, the capacity of passenger processing facilities, and the fleet mix under 250 passengers all remain the same as in the base year. The average number of passengers per NLA is 444, where the load factor is assumed as 80%. The NLA only competes in the market with aircraft which have an average passenger load over 250. The evaluation procedure is described as follows.

1. Set up the design year

Since the first NLA is expected to enter commercial service in 2006, the design year of this study can be specified in the year after 2006. In this study, we used 2010 as the design year. At this point in time, the NLA will have been in operation for five years.

2. Determine the growth rate and forecast the passenger volume in the design year

This step serves to compare the global growth rates estimated by airframe manufacturers and aviation organizations, and to develop scenarios according to different forecasts of future passenger volume. Once the annual passenger volumes are obtained, the demand levels and supply requirements of the terminal can be derived by utilizing the parameters and related operation logic, as described in Section 3.1.2.

3. Run the simulation for the design year without accounting for NLA introduction

Using the same parameters and operation logic as those input for the base year (1999), a simulation is run for the design year (2010) without taking into consideration NLA introduction.

4. Re-run the simulation for the design year accounting for NLA introduction

The user simply changes the discrete distribution of the fleet mix. Due to the uncertainty about the actual market share of the NLA, different scenarios with various fleet mix distributions are developed, and their effects on the system are observed. Moreover, since the NLA will most likely be used in intercontinental routes, they will compete with B747s and B777s. This implies that the increase in the NLA will cause a decrease in the other two types of aircraft. In addition, we assume that the larger wide-body aircraft will hold the same share over the total wide-body aircraft market as in the base year.

5. Specify the significant changing point and potential bottlenecks

By comparing the primary performance measures, such as total time in the system, time spent by passengers in individual servers, and queuing length, before and after NLA introduction, the planner can determine the potential bottlenecks occurred in the arriving passenger flows.

6. Evaluate operating strategies

The last step consists of developing operating strategies to reduce the impact on bottleneck servers and re-run the simulation. These results will also be used to examine how airport authorities should accommodate the introduction of the NLA and to prepare the investment plans.

5.2 SIMULATION FOR THE DESIGN YEAR WITH NO NLA

This section contains simulation results of arriving passenger flows in the design year 2010 without introducing the NLA. First, different passenger forecasts will be reviewed. Second, three forecast scenarios will be performed and these scenarios taking into consideration NLA introduction will thus be simulated.

5.2.1 Major Aviation Traffic Forecasts

The major aviation agencies and airframe manufacturers have recently proposed aviation global market forecasts. Based on the figures in these major forecasts, we developed three scenarios for passenger volumes: pessimistic, moderate, and optimistic. The design year chosen was 2010. The major forecasts are summarized below.

1. **Federal Aviation Administration (FAA).** The latest aviation forecast published by the FAA was the 2001-2012 FAA Forecasts. It shows that, in the United States, the growth rate is expected to be 5.9% per year for international enplanements and 5.3% per year for total passengers. Other relevant factors are listed in Table 5.1. The forecasts also show that the average aircraft size will slightly increase at a rate of 0.53% from the year 2000 to 2012 [FAA, 2001].

Table 5.1 FAA Forecasts for International Operations

Items	1999	2012	Annual Growth Rate
Enplanements (millions)	53.3	108.4	5.9%
Total Passengers (millions)	131.3	258.8	5.3%
Average Aircraft Size (seats)	232.4	248.2	0.53%
Average Load Factor	73.9	76.3	0.23%

Sources: FAA, 2001

2. **International Air Transport Association (IATA).** The latest IATA forecast was a short-term forecast which covers the years 2000 to 2004 [IATA, 2001]. The results show that the scheduled international traffic will increase at an annual rate of 5.6% in terms of Revenue Passenger-Kilometer (PRK).

3. Airports Council International (ACI). In its latest forecast, ACI collected passenger data at airports all over the world and obtained an average global growth rate for traffic. The results show that international traffic will increase at a rate of 4.65% per year, domestic traffic 2.95%, and overall traffic 3.95% from 1997 through 2010, as shown in Table 5.2 [ACI, 2001].

Table 5.2 ACI Forecasts in Annual Growth Rates (%)

Regions	**International**	**Domestic**	**Overall**
Africa	4.38	4.04	4.29
Asia/Pacific	5.03	4.40	4.70
Europe	4.50	3.75	4.78
Latin America	5.10	4.65	4.82
Middle East	5.55	4.23	5.24
North America	4.64	2.38	2.88
World Average	**4.65**	**2.95**	**3.95**

Source: ACI, 2001

4. International Civil Aviation Organization (ICAO). The latest ICAO forecast was performed on the aviation market forecast for the years 1999 to 2010 [ICAO, 2001]. Their results show that, even though the GDP only increases by 2.5%, the air traffic will increase by 4.5% per year in terms of RPK, and by 3.5% in terms of passengers carried. For international passengers, the forecasts also present a higher projection than the overall growth rate. The expected growth is 5.5% in RPK and 5.0% in passengers.

5. Airbus Industrie. Airbus' latest released Global Market Forecast (GMF) for years 2000 to 2019 also demonstrated similar predictions [Airbus, 2001]. They estimated that the RPK would increase at an average of 5.2% per year from 2000 through 2009, and by 4.6% from 2010 to 2019, resulting in a twenty-year average annual growth rate in RPK of 4.88% from 2000 through 2019. For annual departures, they estimated that the growth rate will be 3.8% per year through 2009 and 2.7% from 2010 to 2019, resulting in an overall rate of 3.3% for the twenty-year period. Their load factor, however, was less than the forecasts for the United States. It varied from 70.3% in 1999 to 72.1% in 2009 and to 73.5% in 2019.

6. Boeing. Boeing's forecast indicates that, as the GDP increases at an average 3% per year for next two decades, passengers will increase at an average 4.7% per year in terms of RPK [Boeing, 2001]. The growth rate varied from 2.6% to 9.3% by region. Boeing also presents that they expect the share of large airplanes to decline from 7% to 5%.

In conclusion, the average growth rate in terms of RPK mostly varies from 4% to 6%, and 3% to 5% in number of passengers. Generally speaking, for developed regions, the growth rate is less than that of developing regions. This study uses an average growth rate of 3% for the conservative scenario, 4% for the moderate scenario, and 5% for the optimistic scenario to simulate the daily arriving passenger flow in 2010. The projected passenger volume and number of flights for all simulation cases are shown in Table 5.3. In this study, the average annual growth rate of the U.S. of 0.53% for the average seat capacity is used to derive the number of daily flights in 2010.

Table 5.3 Forecasts of Annual Passenger Volumes and Daily Flights in 2010

Scenarios	**Conservative (3%)**		**Moderate (4%)**		**Optimistic (5%)**	
Simulation Cases	**Annual PAX**	**Daily Flights**	**Annual PAX**	**Daily Flights**	**Annual PAX**	**Daily Flights**
Linear 15	10,142,468	72	11,279,787	80	12,531,886	89
Linear 20	15,992,991	114	17,786,355	127	19,760,709	141
Linear 25	21,843,515	156	24,292,923	173	26,989,531	192
Linear 30	27,694,038	197	30,799,492	219	34,218,353	244
Pier 20	7,902,887	56	8,789,072	63	9,764,693	70
Pier 25	13,753,411	98	15,295,641	109	16,993,515	121
Pier 30	19,603,934	140	21,802,209	155	24,222,338	172
Pier 35	25,454,458	181	28,308,777	202	31,451,160	224
Pier 40	31,304,981	223	34,815,346	248	38,679,982	275
Pier 45	37,155,505	265	41,321,914	294	45,908,805	327
Pier 50	43,006,028	306	47,828,482	341	53,137,627	378

5.2.2 Simulation Results with No NLA

As previously mentioned, three scenarios of future aviation demand for year 2010 were developed, including conservative, moderate, and optimistic, with annual growth rates of total passenger volumes of 3, 4, and 5%, respectively. The projected total passenger volume was used to estimate the daily arriving passengers and flights. The daily flights were entered into the simulation model by applying the arrival generation method described in Section 3.1.2. The simulation results demonstrate that passengers will spend approximately 10% more time at the terminal than in the base year, which increases the average from 48 to 54 minutes. In this case, the average time in the terminal includes in-cabin waiting and deplaning times. This implies that the capacity of passenger processing facilities can meet the demand in the design year without accounting for any NLAs. Simulation results in the design year show a higher proportion of time at the baggage claim area. There is no significant difference among the three scenarios in total time and time proportional distribution. Total arriving passenger observations for each scenario are listed in Table 5.4. The simulation results are summarized in Table 5.5.

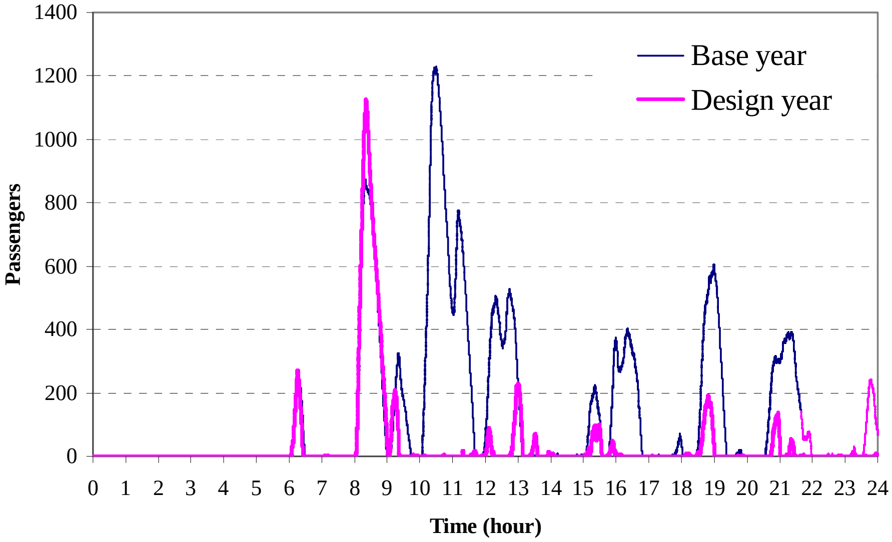
Table 5.4 List of Daily Arriving Passenger Observations (Design Year)

Simulation Cases	Conservative (3%)	Moderate (4%)	Optimistic (5%)
Linear 15 gates	14,991	19,521	19,283
Linear 20 gates	21,083	26,085	26,085
Linear 25 gates	26,522	35,860	35,860
Linear 30 gates	32,797	41,661	43,490
Pier 20 gates	13,681	14,633	17,478
Pier 25 gates	20,781	21,256	27,850
Pier 30 gates	29,485	29,906	38,892
Pier 35 gates	36,323	35,097	47,918
Pier 40 gates	39,719	42,108	53,932
Pier 45 gates	47,032	47,366	63,582
Pier 50 gates	52,464	52,223	69,270

Table 5.5 Major Performance Measures for the Design Year

Performance Measures	**Conservative**	**Moderate**	**Optimistic**
Total time in the system (min)	53.49	53.82	53.55
Average deboarding time (min)	7.03	7.03	7.03
Waiting time for immigration (min)	7.50	7.99	7.44
Waiting time for baggage systems (min)	25.45	25.76	24.95
Waiting time for customs (min)	0.92	1.07	1.09
Average queue length for immigration (PAX)	133	148	141
Maximum queue length for immigration (PAX)	1,169	1,456	1,351
Average queue length for customs (PAX)	35	42	42
Maximum queue length for customs (PAX)	110	130	127
Average number of daily passengers processed by a single baggage claim (PAX)	4,493	4,556	4,664
Average number of peak-hour passengers processed by a single baggage claim (PAX)	706	720	735

An output example of a linear terminal with 20 gates is shown in Figure 5.1. The maximum queuing length for immigration checks is about 1,100 PAX. The average queuing length (133 PAX) is smaller than that in the base year, since the assumption is that the immigration service operates at its full capacity (all checking booths operate at all times). The maximum queue at a single baggage carousel is about an average of 300 passengers. The queuing length for customs check is relatively small, which is under 10 passengers.



(a) Queuing Length at Immigration Checks (Design Year)

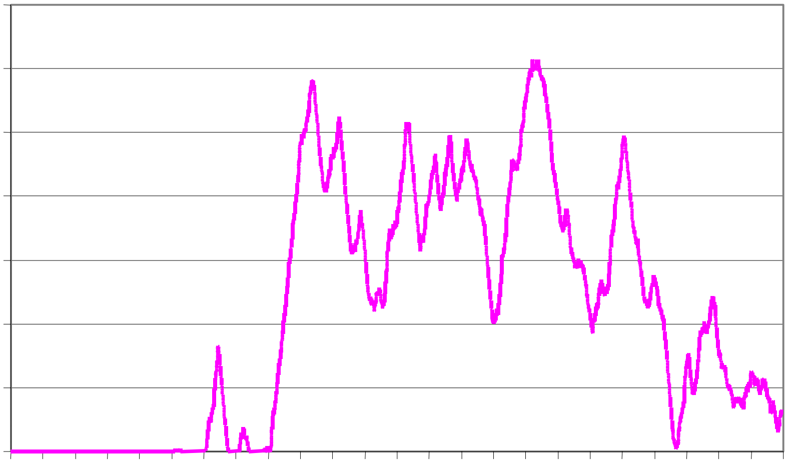
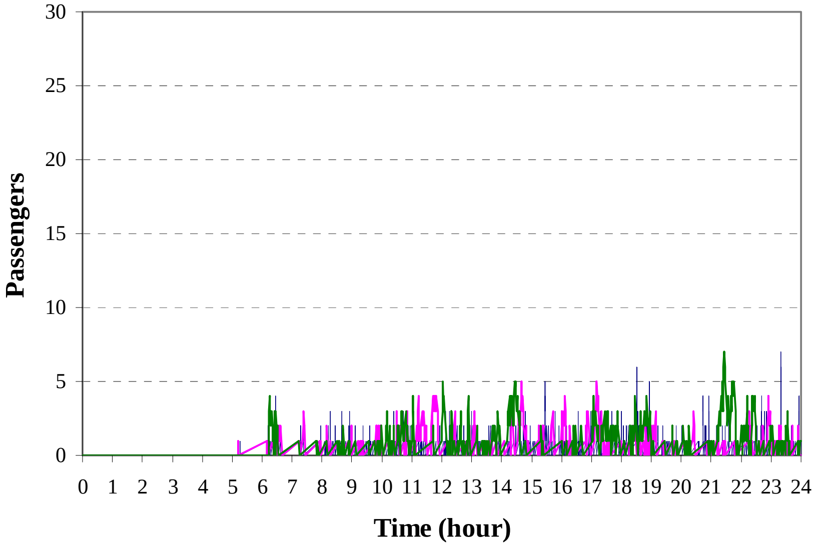
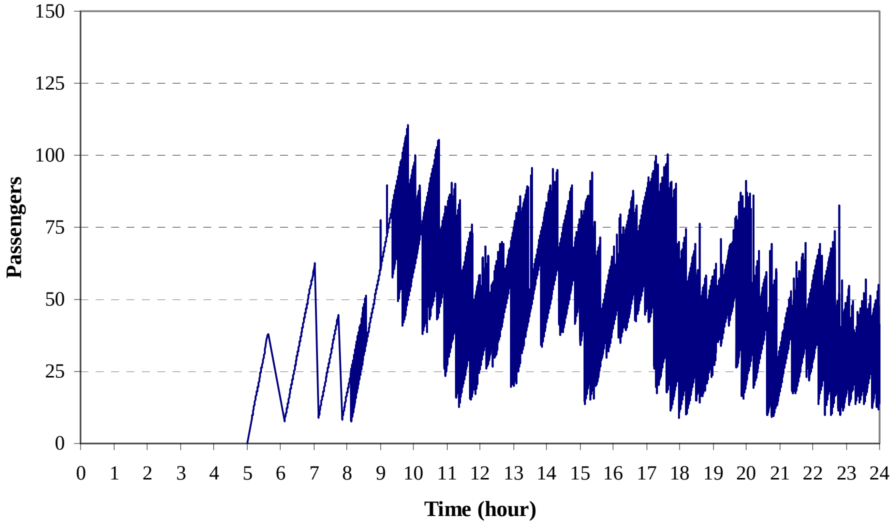


Figure 5.1 Queuing Length in a 20-gate Linear Terminal (2010)



(c) Queuing Length at Customs (Design Year)



(d) Daily Departure from the Terminal system
(Design Year)

Figure 5.1 (Cont.) Queuing Length in a 20-gate Linear Terminal (2010)

5.3 IMPACTS OF NEW LARGE AIRCRAFT

Next examples of the integrated model were used to evaluate the impact of NLA introduction on passenger flows at airport terminals. The examples use a conservative rate of 3% as the average annual growth rate to estimate demand in the design year, shown in Table 5.6. The proportion of the aircraft under 250 passengers remains unchanged. We consider two scenarios of gate utilization in simulation model applications. The first scenario is to assign gates for NLA operations only, and the second one is to assign gates for both NLA and other wide-bodied aircraft. The assumption for gate assignment policies is that when a gate is assigned for NLA operations, its adjacent gates will not operate the NLA, B747, and B777. In this study, the impacts on individual processing facilities are demonstrated by the increases in average waiting time and queuing length. Four terminal cases will be simulated and analyzed based on the queuing time, including linear terminals with 20 and 30 gates, and pier/finger terminals with 30 and 40 gates. The list of simulation scenarios and corresponding various NLA proportions is shown in Table 5.

Table 5.6 Estimated Traffic Demand in the Design Year (Growth Rate: 3%)

	Terminal Concept	No. of Gates	Annual PAX	Peak-Hour Arriving PAX	Daily Flights
1.	Linear	20	15,992,991	3,448	114
2.		30	27,694,038	5,971	197
3.	Pier	30	19,603,934	4,227	140
4.		40	31,304,981	6,750	223

Table 5.7 List of Simulation Scenarios and NLA Operational Cases

	Terminal	Scenarios	No. of Gates	Operational Cases (NLA Proportions for Each NLA Gate)
1.	Linear 20 gates	I. Gates for NLA only	1, 2	100%
		II. Multiple NLA gates with various NLA proportions	2, 4, 6	5~35%
2.	Linear 30 gates	I. Gates for NLA only	1, 2, 3	100%
		II. Multiple NLA gates with various NLA proportions	3, 6, 9	5~35%
3.	Pier 30 gates	I. Gates for NLA only	1, 2, 3	100%
		II. Multiple NLA gates with various NLA proportions	3, 6, 9	5~35%
4.	Pier 40 gates	I. Gates for NLA only	2, 4	100%
		II. Multiple NLA gates with various NLA proportions	4, 8, 12	5~35%

5.3.1 Linear Terminals

1. The 20-gate Linear Terminal

a. Scenario I: Gates for NLA Operations Only

Two cases were considered in this scenario, including one single NLA gate and two NLA gates. The simulation results show that there is no significant change in performance measures when only one gate is assigned for NLA operations. For the case of two NLA gates, the total time spent in the terminal consisting of the deplaning time increases 28%. Major effects occurred at the baggage claim area. The queuing time at the system increases from 23 minutes to 31 minutes (increase of 35%). The simulation results are listed in Table 5.8.

Table 5.8 Simulation Results for the 20-gate Linear Terminal: Scenario I

Cases	No NLA	Introduction of the NLA	
- Number of NLA gates	0	1	2
- Estimated Daily NLA Arrivals	0	6	12
Impacts of the NLA on Queuing Times			
- Daily Arriving Passengers	21,083	20,745	20,988
- Increase in PAX (%)	-	na[a]	0.43
- Total Queuing Time (min)	46.854	49.378	59.801
- Increase in Total Time (min)	-	2.524	12.947
- Increases in Total Time (%)	-	5.39	27.63
- Increases in Queuing Time (%)			
Immigration	-	17.76	34.67
Baggage Claim Area	-	7.68	34.52
Customs	-	na	na
- Percentage of Increases (%)			
ΔImmigration Time /ΔTotal Time	-	13.78	5.25
ΔBaggage Time/ΔTotal Time	-	71.16	62.37
ΔCustoms Time/ΔTotal Time	-	na	na

[a] Not applicable: the increase is less than 0.1%.

b. Scenario II: Multiple NLA Gates with Various NLA Proportions

In this scenario, three operational cases for the various numbers of the NLA gates were involved, 10%, 20%, and 30% over total gates (2, 4, and 6 NLA gates). The proportions of the NLA arrivals for each NLA gate were within the range of 5 to 35 percent. For a given NLA percentage, the proportions of aircraft classes W4 and W5, shown in Table 3.24, were revised according to the fleet share in the base year. The change in total time in the terminal system is shown in Table 5.9 and Figure 5.2. Based on the results, when the NLA arrivals reach some specific share of the fleet mix, the impacts will become significant. Obviously, a higher fleet share of the NLA will cause more NLA operations in the terminal. Due to more NLA operations, the terminal system will have a higher probability of closer NLA arrivals. Closer NLA arrivals will certainly result in congestion in the system.

Table 5.9 Change in Total Time in the 20-gate Linear Terminal

	Case I 2 NLA Gates		**Case II 4 NLA Gates**		**Case III 6 NLA Gates**	
NLA Arrivals (%)	**NLA Arrivals**	**Total Time**	**NLA Arrivals**	**Total Time**	**NLA Arrivals**	**Total Time**
No NLA	0	46.854	0	46.854	0	46.854
5%	1	46.854	1	48.241	2	52.461
10%	1	46.854	2	51.528	3	53.409
15%	2	46.854	3	51.528	5	53.409
20%	2	46.854	5	53.504	7	57.717
25%	3	46.854	6	54.412	9	57.529
30%	3	47.648	7	54.521	10	59.501
35%	4	47.648	8	56.899 [a]	12	63.574

[a] Total time in the terminal exceeds 10 minutes.

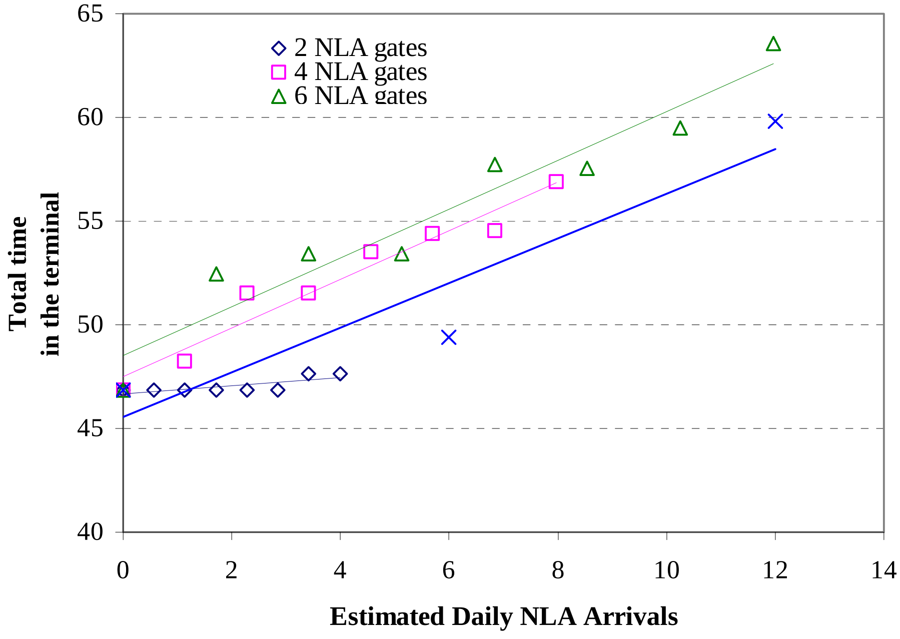


Figure 5.2 Increasing Trend of Total Time in the 20-gate Linear Terminal

According to the increasing trend shown in Figure 5.2, the terminal providing the gates for NLA operations only (Scenario I) is likely more compatible with NLA operations (Table 5.10), under the same level of NLA demand. In Scenario II, operational Cases II and III, with 4 and 6 NLA gates respectively, can be examined to determine if a terminal with fewer gates for NLA operations would have better system performance. The results of the hypothesis test shows that there is no significant difference between the compatibility of these two cases (Table 5.11).

Table 5.10 Comparisons of Scenarios I and II [a]

Coefficient [b]	**B**	**t-statistics**	**Significance**
Constant	45.850	60.755	.000
NLA Arrivals	1.492	10.841	.000
Dummy Variable [c]	-4.684	-2.743	.012

[a] R^2= 0.851
[b] Dependent Variable: Total Time in the Terminal
[c] Dummy Variable: Scenario I:1, Scenario II: 0

Table 5.11 Hypothesis Test for Operational Cases II and III [a]

Coefficient [b]	**B**	**t-statistics**	**Significance**
Constant	48.129	68.508	.000
NLA Arrivals	1.241	10.274	.000
Dummy Variable [c]	0.165	0.200	.845

[a] R^2= 0.916
[b] Dependent Variable: Total Time in the Terminal
[c] Dummy Variable: Case II (4 NLA gates): 0, Scenario III (6 NLA gates): 1

The results of queuing time analysis are listed in Table 5.12 and described below.

- With 2 of 20 gates assigned for NLA operations, the simulation results show that no significant changes were detected.
- With 4 of 20 gates capable of handling the NLA and with each NLA gate assigned 35% NLA arrivals, the impacts become obvious. The total time spent by

passengers in the terminal as well as at individual processing facilities increases over 10 minutes. The most affected facility is the baggage claim system. The queuing time at the baggage claim area increases from 23 to 32 minutes. It also suggests that the capacity of baggage claim systems derived from the IATA formulae might not be able to accommodate the demand efficiently.

- With 30% of total gates capable of handling the NLA (6 NLA gates) and each NLA gate assigned 20% of the NLA arrivals, significant changes would occur. Similarly, the impact on the baggage claim system is obvious (increase of 42%).

In comparison with changes in queuing times of individual facilities over total changes, the baggage claim system also makes up the largest part of the total change. In this scenario, with 6 NLA gates operating the NLA and each NLA gate assigned 20% NLA arrivals, the change in queuing times at the baggage claim system of the total change is about 90%. The baggage claim system undoubtedly is the greatest issue and has the largest impact on terminal operations for arriving passengers.

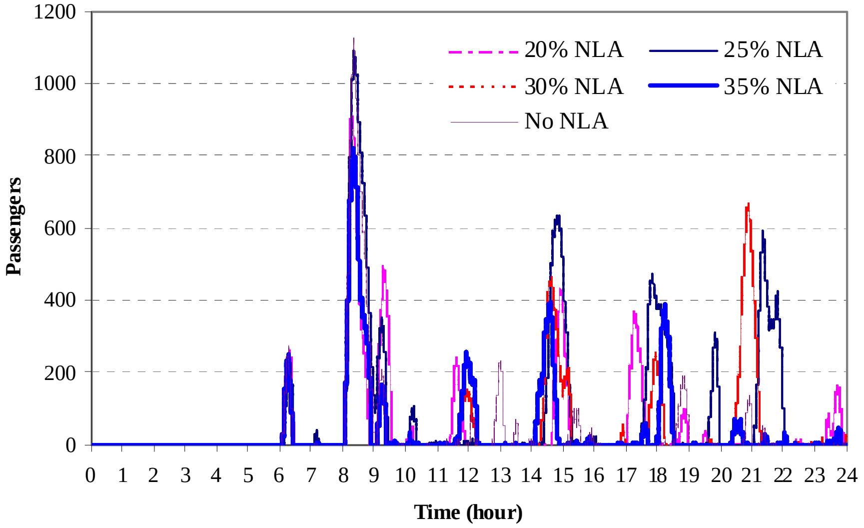
Another reason for the significant impacts on the baggage claim system might be the original pattern of passenger flows. For the 20-gate linear terminal, the simulation results for the design year with no NLA indicate that passengers spend less time for immigration checks (2 minutes) and much more time at baggage claim systems (23 minutes). Intuitively, the facility that originally performed with congestion would be impacted more due to the increasing arrivals. The queuing length at immigration checks and baggage claim systems for operational Case III are depicted in Figure 5.3.

Arriving passengers of the NLA would also be facing longer in-cabin waiting time for deboarding. The increase in deboarding time is shown in Figure 5.4. The deboarding time used in this analysis is exclusive of the time between the aircraft arriving at the gate and the first passenger leaving the boarding bridge. The maximum deboarding time for the 555-seat NLA will increase up to 30 minutes, which is longer than that for the current B747-400 (23 minutes).

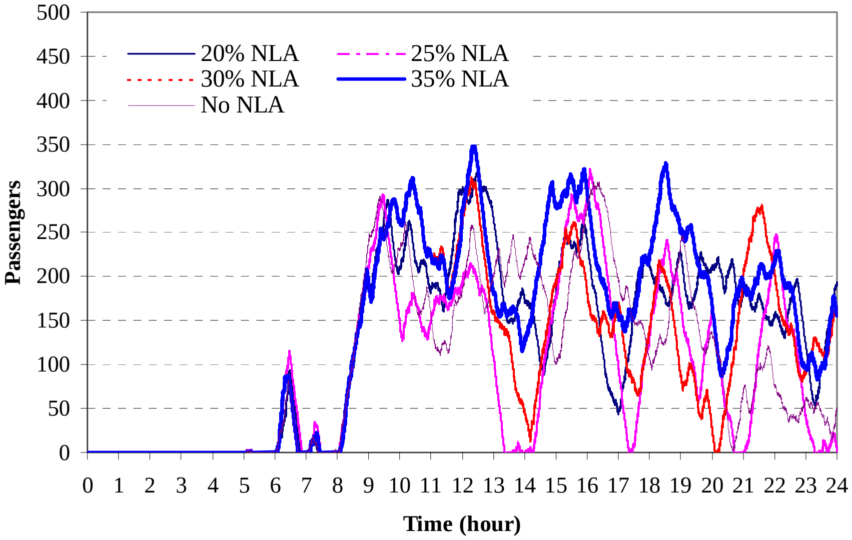
Table 5.12 Simulation Results for the 20-gate Linear Terminal: Scenario II

Cases	No NLA	Introduction of the NLA		
- Percentage of the NLA gates	0	10%	20%	30%
- Number of NLA gates	0	2	4	6
Impacts of the NLA on Queuing Times				
- Critical Percentage[a] of NLA arrivals for each gate (%)	0	35	35	20
- Daily Arriving Passengers	21,083	20,918	20,855	20,582
- Increase in PAX (%)	-	na	na	na
- Total Queuing Time (min)	46.854	47.648	56.899	57.717
- Increase in Total Time (min)	-	0.794	10.045	10.863
- Increases in Total Time (%)	-	1.69	21.44	23.18
- Increases in Queuing Time (%)				
Immigration	-	na[b]	52.96	41.98
Baggage Claim Area	-	3.56	37.39	41.81
Customs	-	na	na	3.10
- Percentage of Increases (%)				
ΔImmigration Time /ΔTotal Time	-	na	8.32	7.57
ΔBaggage Time/ΔTotal Time	-	na	88.67	90.03
ΔCustoms Time/ΔTotal Time	-	na	na	na
Comparisons among Various Cases with a fixed NLA Percentage				
- Percentage of NLA arrivals for each gate	0	35	35	35
- Daily Arriving Passengers	21,083	21,918	20,855	21,097
- Increase in PAX (%)	-	na	na	na
- Total Queuing Time (min)	46.854	47.648	56.899	63.574
- Increase in Total Time (min)	-	0.794	10.045	16.72
- Increases in Total Time (%)	-	1.69	21.44	35.68
- Increases in Queuing Time (%)				
Immigration	-	na	52.96	5.1
Baggage Claim Area	-	3.56	37.39	68.11
Customs	-	na	na	na
- Percentage of Increases (%)				
ΔImmigration Time /ΔTotal Time	-	na	8.32	0.6
ΔBaggage Time/ΔTotal Time	-	na	88.67	95.30
ΔCustoms Time/ΔTotal Time	-	na	na	na

[a] The increase in total time exceeds 10 minutes. [b] Not applicable: the increase is less than 0.1%.



(a) Change in Queuing Length at Immigration Checks with Various NLA Proportions



(b) Change in Queuing Length at Baggage Carousels with Various NLA Proportions

Figure 5.3 Changes in Queuing Length with Various NLA Proportions

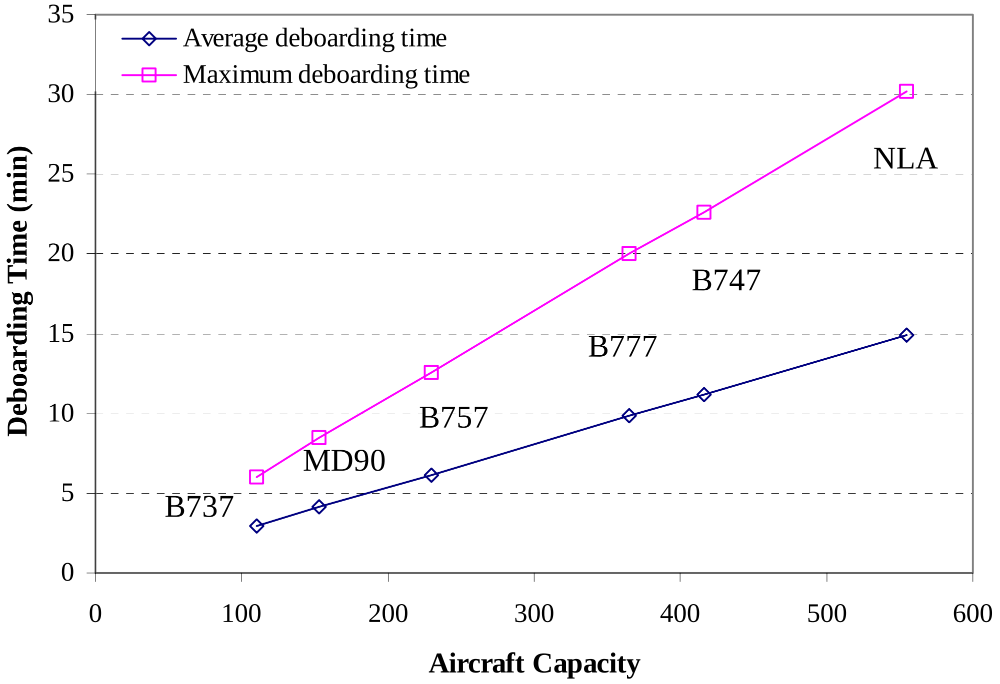


Figure 5.4 Performance of Passenger Deplaning

2. The 30-gate Linear Terminal

a. Scenario I: Gates for NLA Operations Only

For a 30-gate terminal, three cases of NLA introduction were considered, with one, two, or three NLA gates. The simulation results show that there is no major effect when three gates are assigned for NLA operations. For the utilization of three NLA gates, the total time spent in the terminal increases from 25 minutes to 30 minutes (increase of 17%). Therefore, the impact of NLA introduction on the 30-gate linear terminal is not significant. The simulation results are summarized in Table 5.13.

Table 5.13 Simulation Results for the 30-gate Linear Terminal: Scenario I

Cases	No NLA	Introduction of the NLA		
- Number of NLA gates	0	1	2	3
- Estimated Daily NLA Arrivals	0	7	13	20
Impacts of the NLA on Queuing Times				
- Daily Arriving Passengers	30,586	32,797	32,537	32,288
- Increase in PAX (%)	-	7.23	6.38	5.56
- Total Queuing Time (min)	25.143	26.955	27.816	29.487
- Increase in Total Time (min)	-	1.812	2.673	4.344
- Increases in Total Time (%)	-	7.21	10.63	17.28
- Increases in Queuing Time (%)				
Immigration	-	2.19	48.55	126.28 [a]
Baggage Claim Area	-	38.97	51.28	90.66
Customs	-	14.07	66.33	52.11
- Percentage of Increases (%)				
ΔImmigration Time /ΔTotal Time	-	7.46	15.36	8.71
ΔBaggage Time/ΔTotal Time	-	64.34	61.14	62.24
ΔCustoms Time/ΔTotal Time	-	1.55	4.73	3.89

[a] Average queuing time is 1.64 minutes. The impact is considered as insignificance.

b. Scenario II: Multiple NLA Gates with Various NLA Proportions

The simulation results also demonstrate a smaller impact on the terminal system, as shown in Table 5.14 and Figure 5.5. There is no sufficient evidence to show that the terminal providing some gates dedicated for NLA operations or fewer NLA gates would have better system performance. The analysis of queuing time at each server is listed in Table 5.15 and described as follows.

- With 10% of total gates capable of handling the NLA and with each gate assigned 35% of NLA arrivals, the queuing time at the baggage claim area increases 39%.
- With 20% NLA gates and when the percentage of NLA for each NLA gate reaches 35%, the total time increases 11% and the queuing time at the baggage claim area increases 51%.
- With 30% NLA gates and when the percentage of NLA is 35%, the increased rate of total time is also 17%. In comparison with queuing times of 35% NLA arrivals for all scenarios, the increases in the 30-gate terminal are less than in the 20-gate terminal. Since the 30-gate terminal possesses higher processing capacity, the impacts in total

time derived from the introduction of the NLA will tend to be less. This implies that a bigger terminal is likely to be more compatible with the NLA, if its determination of the facility capacity is derived from the IATA Reference Manual.

Moreover, the pattern of passenger flows in this simulation case shows that the queuing times for immigration checks and for baggage pick-up are closer than that in the 20-gate terminal. One may therefore find out that individual processing facilities are affected more evenly.

Table 5.14 Change in Total Time in the 30-gate Linear Terminal

	Case I 3 NLA Gates		**Case II 6 NLA Gates**		**Case III 9 NLA Gates**	
NLA Arrivals (%)	**NLA Arrivals**	**Total Time**	**NLA Arrivals**	**Total Time**	**NLA Arrivals**	**Total Time**
No NLA	0	25.143	0	25.143	0	25.143
5%	1	25.143	2	27.134	3	27.001
10%	2	26.349	4	27.722	6	27.294
15%	3	26.357	6	27.368	9	27.37
20%	4	25.783	8	27.428	12	27.492
25%	5	25.784	10	27.404	15	28.333
30%	6	27.287	12	27.972	18	29.352
35%	7	27.298	14	28.482	21	29.435

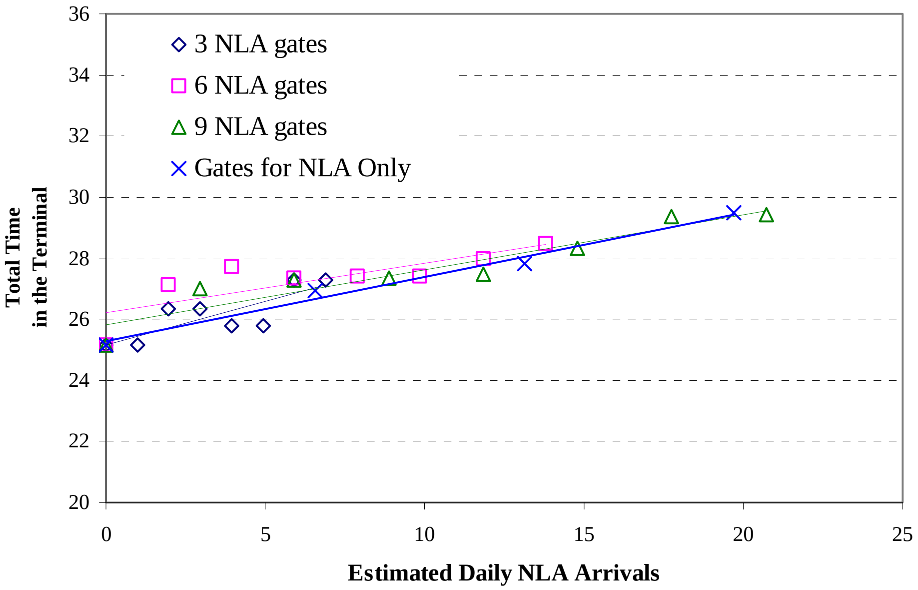


Figure 5.5 Increasing Trend of Total Time in the 30-gate Linear Terminal

Table 5.15 Simulation Results for the 30-gate Linear Terminal

Scenarios	No NLA	Introduction of the NLA		
- Percentage of the NLA gates	0	10%	20%	30%
- Number of NLA gates	0	3	6	9
Impacts of the NLA on Queuing Times				
- Critical Percentage of NLA arrivals for each gate (%)	0	35	35	35
- Daily Arriving Passengers	30,586	32,757	31,952	33,258
- Increase in PAX (%)	-	7.09	4.47	8.74
- Total Queuing Time (min)	25.143	27.298	28.482	29.435
- Increase in Total Time (min)	-	2.155	3.339	4.292
- Increases in Total Time (%)	-	8.57	13.28	17.07
- Increases in Queuing Time (%)				
Immigration	-	22.20	70.80	89.88
Baggage Claim Area	-	44.33	65.27	84.58
Customs	-	14.07	66.33	87.45
- Percentage of Increases (%)				
ΔImmigration Time /ΔTotal Time	-	7.46	15.36	15.17
ΔBaggage Time/ΔTotal Time	-	64.34	61.14	61.63
ΔCustoms Time/ΔTotal Time	-	1.55	4.73	4.85

5.3.2 Pier/Finger Terminals

1. The 30-gate Pier Terminal

a. Scenario I: Gates for NLA Operations Only

Similar to linear terminals, three operational cases were considered in the simulation model applications. The simulation results show that when three gates are assigned for NLA operations only, the impact will become significant, as shown in Table 5.16.

Table 5.16 Simulation Results for the 30-gate Pier Terminal: Scenario I

Cases	**No NLA**	**Introduction of the NLA**		
- Number of NLA gates	0	1	2	3
- Estimated Daily NLA Arrivals	0	5	9	14
Impacts of the NLA on Queuing Times				
- Daily Arriving Passengers	29,485	29,593	29,377	29,457
- Increase in PAX (%)	-	0.36	na[a]	na
- Total Queuing Time (min)	45.814	47.402	49.779	55.057
- Increase in Total Time (min)	-	1.588	3.965	9.243
- Increases in Total Time (%)	-	3.47	8.65	20.18
- Increases in Queuing Time (%)				
Immigration	-	30.26	3.78	34.26
Baggage Claim Area	-	na	31.88	38.11
Customs	-	na	na	na
- Percentage of Increases (%)				
ΔImmigration Time /ΔTotal Time	-	>100.00	11.75	45.69
ΔBaggage Time/ΔTotal Time	-	na	94.82	49.40
ΔCustoms Time/ΔTotal Time	-	na	na	na

[a] Not applicable

b. Scenario II: Multiple NLA Gates with Various NLA Proportions

The simulation results are listed in Table 5.17 and depicted in Figure 5.6. Significant impacts are detected when the NLA reaches a higher fleet share. The hypothesis test demonstrates that Scenario I can operate NLA more efficiently (Table 5.18). The analysis of queuing time at each server is shown in Table 5.18 and described below.

- With 3 of 30 gates assigned for NLA operations, there is no significant change in performance measures.
- With 6 of 30 gates capable of handling the NLA and with each NLA gate assigned 35% NLA arrivals, the impacts become obvious (increase of 16%). The affected facilities include the baggage claim system and immigration checks. The queuing time at the baggage claim area increases from 12 to 16 minutes.
- With 30% of total gates capable of handling the NLA (9 NLA gates) and each NLA gate assigned 25% of the NLA arrivals, significant changes would occur. The impact on the baggage claim system is an increase of 80%. The change in queuing times at baggage claim systems is the major part over the total change. In this case, the queuing time for immigration checks increase significantly (41%) with 6 gates operating the NLA and each NLA gate assigned 35% NLA arrivals. For the case of 9 gates operating the NLA, the increase in immigration queuing times is about 34% when each NLA gate is assigned 20% NLA arrivals.

Table 5.17 Change in Total Time in the 30-gate Pier Terminal

	Case I 3 NLA Gates		**Case II 6 NLA Gates**		**Case III 9 NLA Gates**	
NLA Arrivals (%)	**NLA Arrivals**	**Total Time**	**NLA Arrivals**	**Total Time**	**NLA Arrivals**	**Total Time**
No NLA	0	45.814	0	45.814	0	45.814
5%	1	44.696	1	48.908	2	49.133
10%	1	46.318	3	48.853	4	49.092
15%	2	46.318	4	49.965	6	51.021
20%	3	46.773	6	51.160	8	54.461
25%	3	46.773	7	51.379	10	56.909
30%	4	47.455	8	52.897	13	57.148
35%	5	49.012	10	53.322	15	59.886

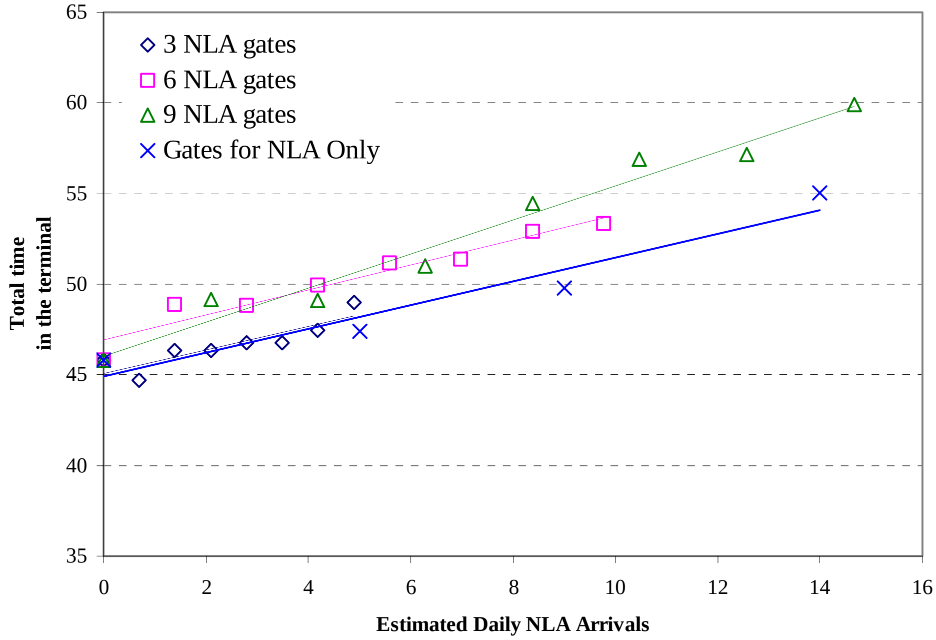


Figure 5.6 Increasing Trend of Total Time in the 30-gate Pier Terminal

Table 5.18 Hypothesis Test for Scenarios I and II (30-gate Pier Terminal) [a]

Coefficient [b]	B	t-statistics	Significance
Constant	45.366	106.420	.000
NLA Arrivals	0.942	14.855	.000
Dummy Variable [c]	-3.410	-4.231	.000

[a] R^2= 0.909

[b] Dependent Variable: Total Time in the Terminal

[c] Dummy Variable: Scenario I:1, Scenario II: 0

Table 5.19 Simulation Results for the 30-gate Pier Terminal: Scenario II

Scenarios	No NLA	Introduction of the NLA		
- Percentage of the NLA gates	0	10%	20%	30%
- Number of NLA gates	0	3	6	9
Impacts of the NLA on Queuing Times				
- Critical Percentage of NLA arrivals for each gate[a] (%)	0	35	35	25
- Daily Arriving Passengers	29,485	28,780	29,525	29,541
- Increase in PAX (%)	-	na	0.13	0.19
- Total Queuing Time (min)	45.814	49.012	53.332	56.909
- Increase in Total Time (min)	-	3.198	7.508	11.095
- Increases in Total Time (%)	-	6.98	16.39	24.22
- Increases in Queuing Time (%)				
Immigration	-	na[b]	24.92	8.86
Baggage Claim Area	-	25.48	32.84	79.85
Customs	-	na	na	na
- Percentage of Increases (%)				
ΔImmigration Time /ΔTotal Time	-	na	40.92	9.85
ΔBaggage Time/ΔTotal Time	-	95.47	52.40	86.22
ΔCustoms Time/ΔTotal Time	-	na	na	na
Comparisons among Various Scenarios with a fixed NLA Percentage				
- Percentage of NLA arrivals for each gate	0	35	35	35
- Daily Arriving Passengers	29,485	28,780	29,525	29,544
- Increase in PAX (%)	-	na	0.13	0.20
- Total Queuing Time (min)	45.814	49.012	53.332	59.886
- Increase in Total Time (min)	-	3.198	7.508	14.072
- Increases in Total Time (%)	-	6.98	16.39	30.72
- Increases in Queuing Time (%)				
Immigration	-	na[b]	24.92	40.85
Baggage Claim Area	-	25.48	32.84	67.67
Customs	-	na	na	na
- Percentage of Increases (%)				
ΔImmigration Time /ΔTotal Time	-	na	40.92	35.79
ΔBaggage Time/ΔTotal Time	-	95.47	52.40	57.61
ΔCustoms Time/ΔTotal Time	-	na	na	na

[a] Under the critical percentage, the impacts on the system are not significant.

[b] Not applicable: the increase is less than 0.1%.

2. The 40-gate Pier Terminal

a. Scenario I: Gates for NLA Operations Only

Two operational cases were considered in the simulation model applications, including two and four NLA gates. The simulation results show that the impacts derived from NLA introduction are not significant, as shown in Table 5.20.

Table 5.20 Simulation Results for the 40-gate Pier Terminal: Scenario I

Cases	No NLA	Introduction of the NLA	
- Number of NLA gates	0	2	4
- Estimated Daily NLA Arrivals	0	11	22
Impacts of the NLA on Queuing Times			
- Daily Arriving Passengers	39,719	41,649	42,582
- Increase in PAX (%)	-	4.40	7.21
- Total Queuing Time (min)	31.119	32.793	34.781
- Increase in Total Time (min)	-	1.674	23.141
- Increases in Total Time (%)	-	5.38	11.77
- Increases in Queuing Time (%)			
Immigration	-	22.26	29.95
Baggage Claim Area	-	na[a]	12.97
Customs	-	43.99	na
- Percentage of Increases (%)			
ΔImmigration Time /ΔTotal Time	-	56.36	34.65
ΔBaggage Time/ΔTotal Time	-	na	13.63
ΔCustoms Time/ΔTotal Time	-	58.74	29.15

[a] Not applicable: the increase is less than 0.1%.

b. Scenario II: Multiple NLA Gates with Various NLA Proportions

The simulation results are listed in Table 5.21 and depicted in Figure 5.7. Significant impacts are detected when the NLA reaches a higher fleet share. The hypothesis test also demonstrates that scenario I can operate NLA more efficiently (Table 5.22). The analysis of queuing time at each server is shown in Table 5.23 and described below.

- With 4 of 40 gates assigned for NLA operations, there is no significant change in performance measures.

Table 5.21 Change in Total Time in the 40-gate Pier Terminal

NLA Arrivals (%)	Case I 4 NLA Gates		Case II 8 NLA Gates		Case III 12 NLA Gates	
	NLA Arrivals	Total Time	NLA Arrivals	Total Time	NLA Arrivals	Total Time
No NLA	0	31.119	0	31.119	0	31.119
5%	1	33.345	2	33.512	3	34.086
10%	2	33.375	4	34.543	7	34.563
15%	3	33.006	7	34.429	10	35.657
20%	4	33.391	9	34.840	13	36.174
25%	6	33.102	11	35.568	17	36.453
30%	7	33.533	13	35.833	20	36.907
35%	8	33.395	16	36.507	23	37.906

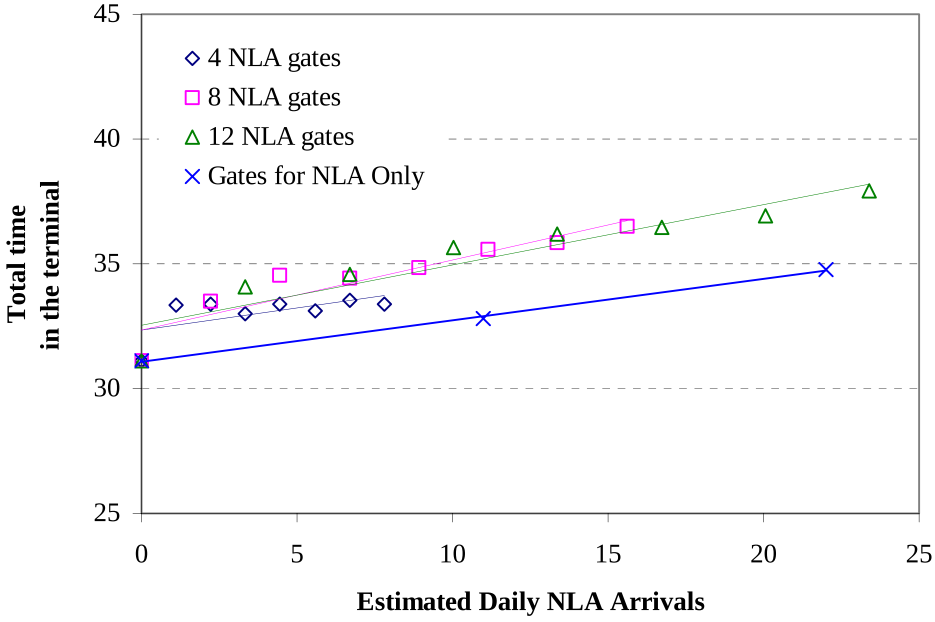


Figure 5.7 Increasing Trend of Total Time in the 30-gate Pier Terminal

Table 5.22 Hypothesis Test for Scenarios I and II (40-gate Pier Terminal) [a]

Coefficient [b]	B	t-statistics	Significance
Constant	32.903	169.050	.000
NLA Arrivals	0.220	12.009	.000
Dummy Variable [c]	-2.748	-6.336	.000

[a] R^2= 0.877

[b] Dependent Variable: Total Time in the Terminal

[c] Dummy Variable: Scenario I:1, Scenario II: 0

- With 8 of 40 gates capable of handling the NLA and with each NLA gate assigned 35% NLA arrivals, an increase of 17% in total time is obtained. The impacted facilities include immigration checks and baggage claim systems. The immigration check is the most affected facility in this case. In comparison with changes in queuing times of individual facilities of total changes, the immigration check also possesses the largest part of the total change. Since the 40-gate pier terminal provides sufficient facilities to process passengers, the impact of NLA introduction is not tremendous.
- With 12 of total gates capable of handling the NLA and each NLA gate assigned 35% of the NLA arrivals, an increase of 22% in total time would occur. The most affected area is the immigration check. Since the 40-gate pier terminal provides sufficient facilities to process arriving passengers, the impact of NLA introduction in the 40-gate pier terminal is less than in the 30-gate pier terminal.

Table 5.23 Simulation Results for the 40-gate Pier Terminal: Scenario II

Scenarios	No NLA	Introduction of the NLA		
- Percentage of the NLA gates	0	10%	20%	30%
- Number of NLA gates	0	4	8	12
Impacts of the NLA on Queuing Times				
- Critical Percentage of NLA arrivals for each gate[a] (%)	0	35	35	35
- Daily Arriving Passengers	39,719	42,252	41,855	43,160
- Increase in PAX (%)	-	6.38	5.38	8.66
- Total Queuing Time (min)	31.119	33.395	36.506	37.906
- Increase in Total Time (min)	-	2.276	5.387	6.787
- Increases in Total Time (%)	-	7.31	17.31	21.81
- Increases in Queuing Time (%)				
Immigration	-	12.21	57.41	61.55
Baggage Claim Area	-	4.46	33.33	49.70
Customs	-	55.23	37.56	65.79
- Percentage of Increases (%)				
ΔImmigration Time /ΔTotal Time	-	22.73	45.15	38.43
ΔBaggage Time/ΔTotal Time	-	7.54	23.82	28.19
ΔCustoms Time/ΔTotal Time	-	54.25	15.58	21.67

[a] Under the critical percentage, the impacts on the system are not significant.

[b] Not applicable: the increase is less than 0.1%.

5.3.3 Summary

This study presented an integrated simulation method for evaluating the impacts of the NLA on terminal operations. This method used several approaches to achieve the evaluation under uncertain operating characteristics of the NLA, including establishing a generic international airport for simulation purpose, generating arriving passengers, and estimating the proper facility requirements and associated service distributions. Through a statistical comparison with survey data from fifteen international airports, the simulation model was validated. The integrated simulation model was able to accurately capture the operational characteristics of an active international airport.

Simulation results explicitly demonstrated that, for arriving passengers, all processing facilities would be affected. The most affected area is the baggage claim system when the NLA arrivals reach some specific share of fleet mix. As expected, the linear and pier/finger terminal analyses indicated that the larger terminal providing more processing facilities is more compatible with the NLA. According to the results of hypothesis test, a terminal providing fewer gates for NLA only is capable of handling NLA operations more efficiently than providing more gates with partial NLA operations. The degree of impacts was also affected by the original pattern of terminal passenger flows. If the original queuing times at sequential servers were closer before NLA introduction, the impacts would be spread on each terminal facility more evenly. When a specific server performs with a higher queuing time, it would be affected more significantly by the increased demand derived from the introduction of the NLA.

5.4 EVALUATION OF OPERATIONAL STRATEGIES

Section 5.3 described the impact analysis of four terminal cases and indicated that the baggage claim system would be the most affected area in the terminal by the introduction of the NLA. In this section, the alternative of improving the performance at baggage claim systems will be simulated and investigated. In addition, the deboarding performance accounting for the double-deck boarding bridge will also be evaluated. Finally, suggestions for existing airports will be proposed.

5.4.1 Operational Strategies for Baggage Claim Systems

The strategy for improving the performance of the baggage claim system in this study is increasing its processing capacity. The simulation results suggest that the 20-gate linear terminal and the 30-gate pier terminal would need more capacity for baggage processing. The procedure to evaluate the alternative is first to add one more baggage carousel to the system. Second, the simulation model is re-run for the specific scenarios that performed with significant longer queuing times in the previous section. The simulation outputs will then be analyzed and evaluated. If the improvement is acceptable, that number of carousels will be the minimum requirement to accommodate future NLA operations under such conditions of demand. If the performance is not improved significantly, then the model will be modified by adding more baggage processing capacity. The evaluation flow chart is depicted in Figure 5.8.

1. The 20-gate Linear Terminal

a. Queuing Time Analysis

In this alternative, the number of baggage carousels is increased from 5 to 6. The simulation results show that the performance of baggage claim systems is improved, as listed in Table 5.24 Since the capacity of immigration checks and customs remain the same, queuing times at immigration checks and customs in the terminal are not significantly affected by the increase of the baggage processing capacity. Total time in the terminal decreases about 20 to 24 minutes. The analysis results explicitly show that the primary time saving comes from the baggage claim area (19 to 23 minutes).

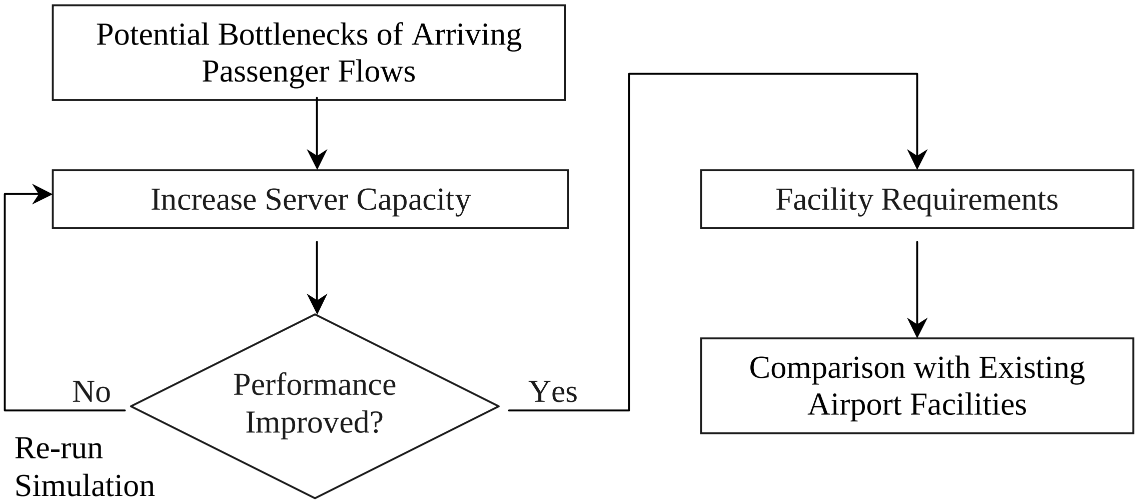


Figure 5.8 Flow Chart of Operational Strategies Evaluation

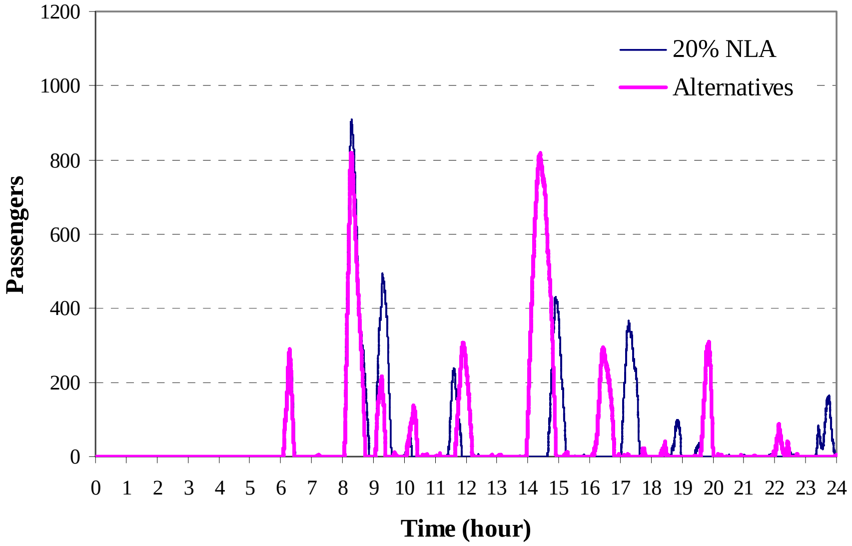
Table 5.24 Evaluation of Baggage Operating Strategies (Linear, 20-gate)

Items	**6 NLA Gates**			
- Percentage of NLA arrivals for each gate (%)	20	25	30	35
- Estimated Daily NLA Arrivals	7	9	10	12
- Total Time[a] (min)				
NLA Introduction	57.717	57.529	59.501	63.574
Alternatives	34.878	37.07	37.07	39.842
Time Saving	22.839	20.459	22.431	23.732
Decrease Rate (%)	39.57	35.56	37.70	37.33
- Decreases in Queuing Time at Baggage Claim Systems (min)				
NLA Introduction	33.174	32.083	34.397	39.328
Alternatives	11.643	12.991	12.991	15.942
Time Saving	21.531	19.091	21.406	23.386
Decrease Rate (%)	64.90	59.51	62.23	59.46

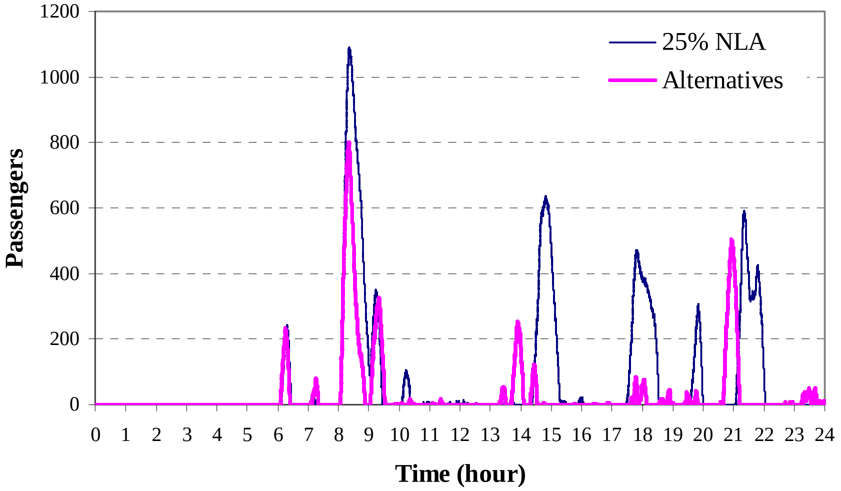
[a] Total time in the terminal includes average passenger deboarding time(about 7 minutes).

b. Queuing Length Analysis

According to the queuing length analysis at each server, the maximum queuing length at baggage claim systems decreases significantly (approximately from 300 to 200 passengers). No significant change is detected in immigration checks. The queuing length for customs examination is slightly increased. The simulation results are plotted in Figure 5.9 through 5.11. The queuing time and length analyses demonstrate that adding one more baggage carousel can significantly improve the terminal performance. With the sufficient baggage processing capability, the terminal can accommodate future NLA operations.

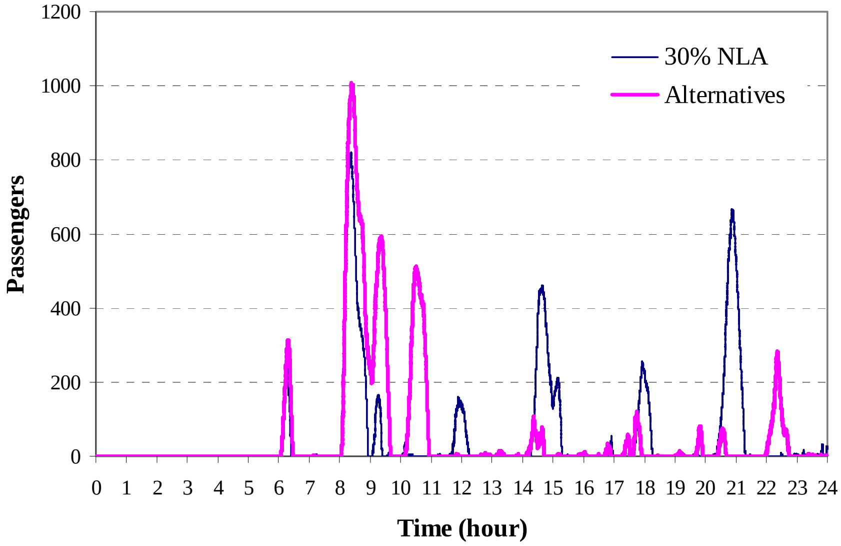


(a) Change in Queuing Length at Immigration Checks (20% NLA)

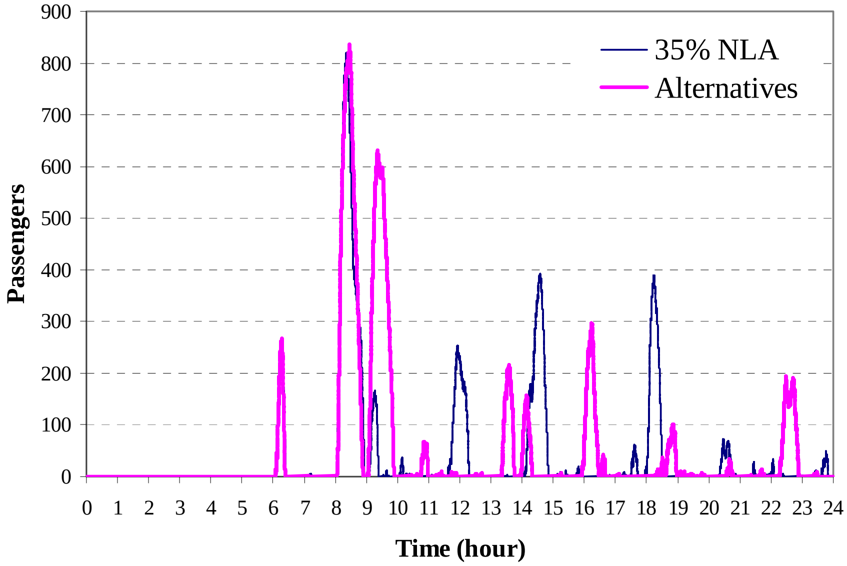


(b) Change in Queuing Length at Immigration Checks (25% NLA)

Figure 5.9 Queuing Length at Immigration Checks (Linear, 20-gate)

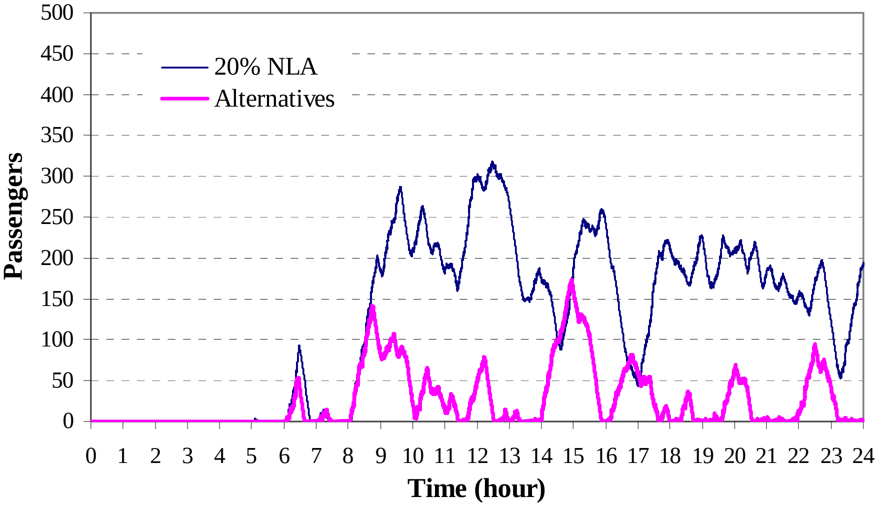


(c) Change in Queuing Length at Immigration Checks (30% NLA)

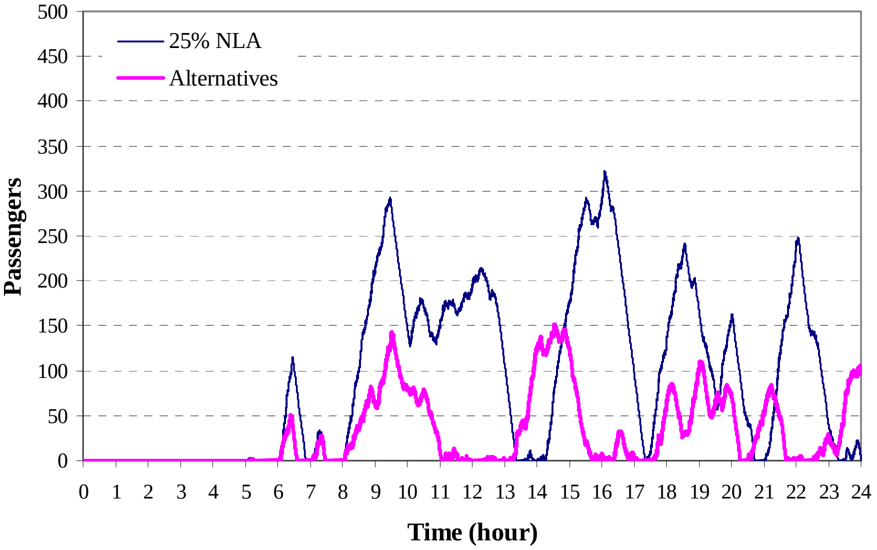


(d) Change in Queuing Length at Immigration Checks (35% NLA)

Figure 5.9 (Cont.) Queuing Length at Immigration Checks (Linear, 20-gate)

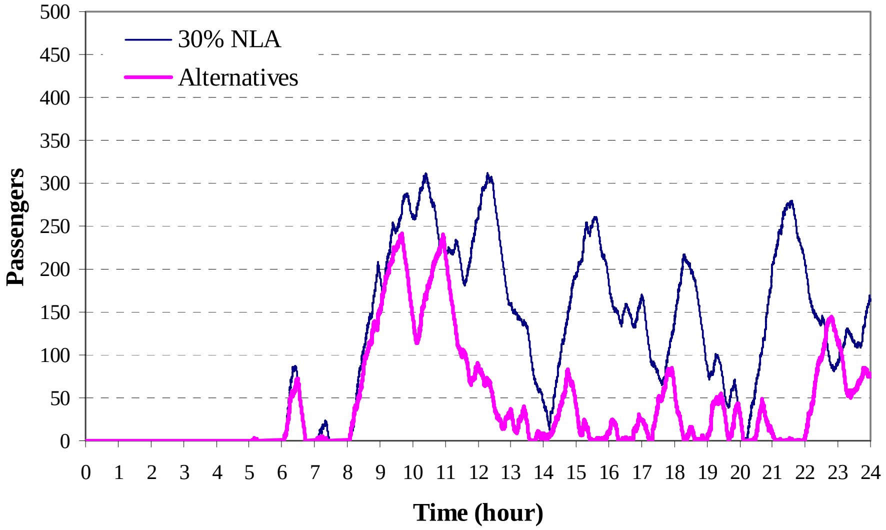


(a) Change in Queuing Length at Baggage Carousels (20% NLA)

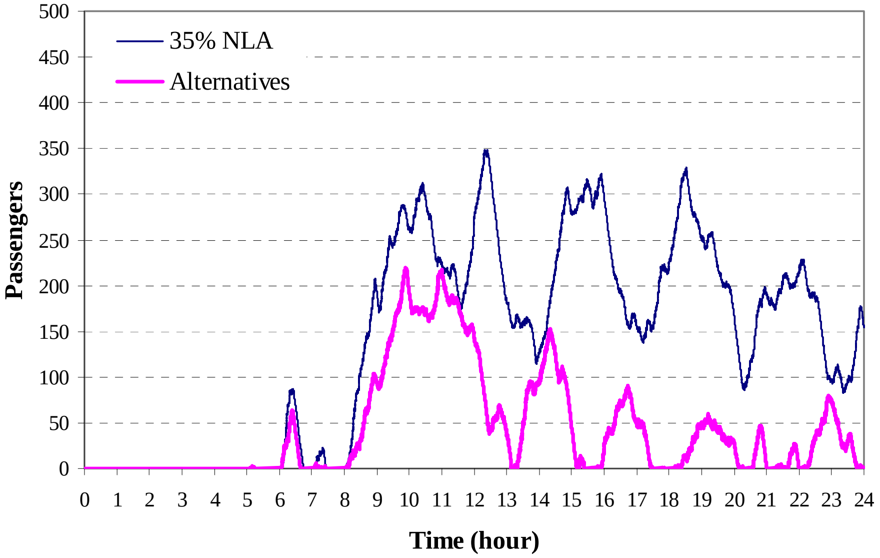


(b) Change in Queuing Length at Baggage Carousels (25% NLA)

Figure 5.10 Queuing Length at Baggage Areas (Linear, 20-gate)

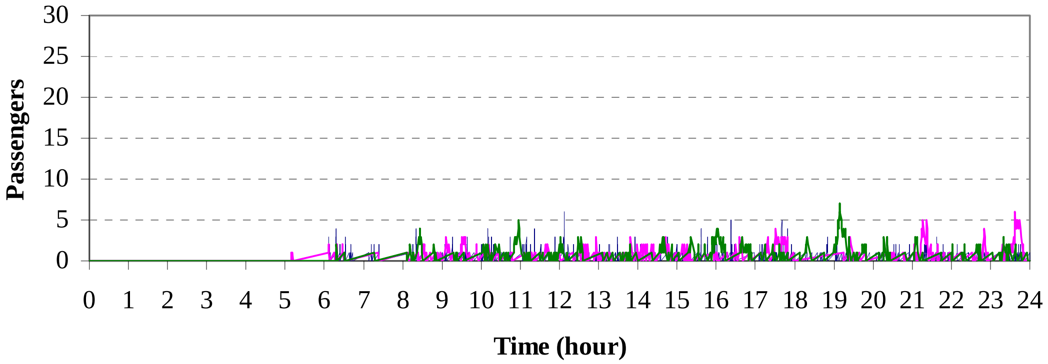


(c) Change in Queuing Length at Baggage Carousels
(30% NLA)

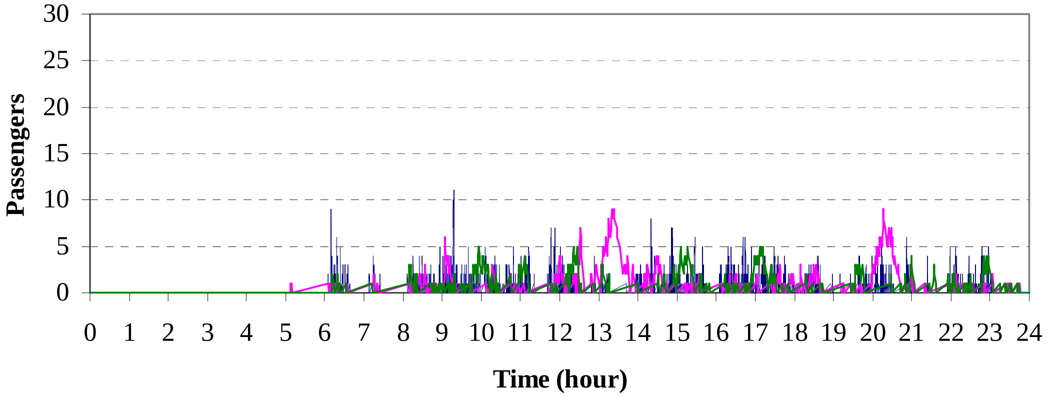


(d) Change in Queuing Length at Baggage Carousels
(35% NLA)

Figure 5.10 (Cont.) Queuing Length at Baggage Areas (Linear, 20-gate)

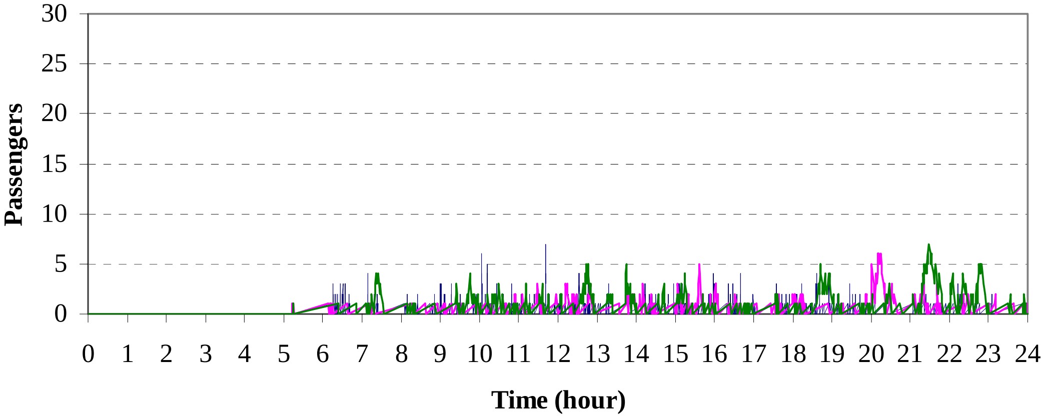


(a) Queuing Length at Customs (20% NLA)

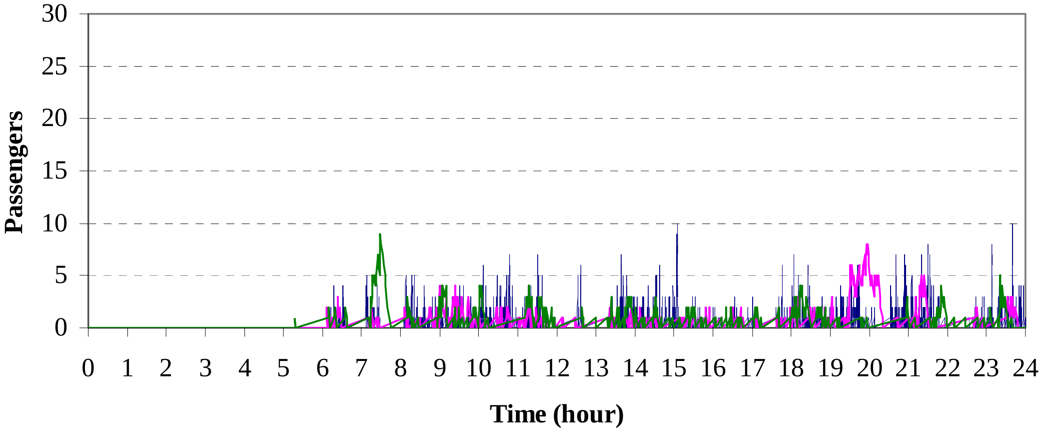


Queuing Length at Customs (20% NLA Alternatives)

Figure 5.11 Queuing Length at Customs (Linear, 20-gate)

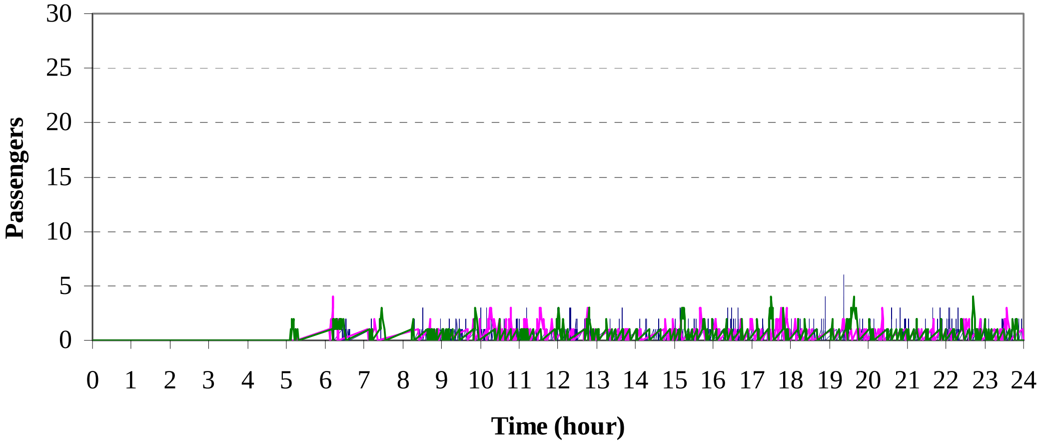


(b) Queuing Length at Customs (25% NLA)

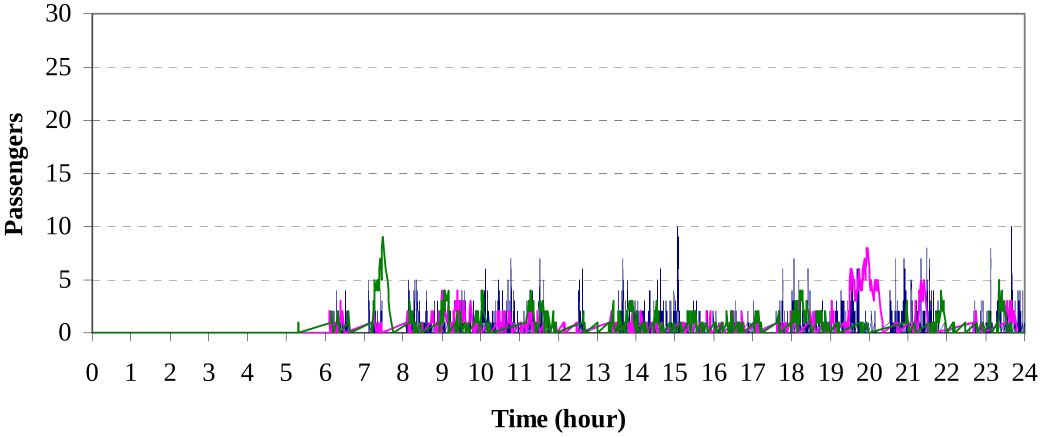


Queuing Length at Customs (25% NLA Alternatives)

Figure 5.11 (Cont.) Queuing Length at Customs (Linear, 20-gate)

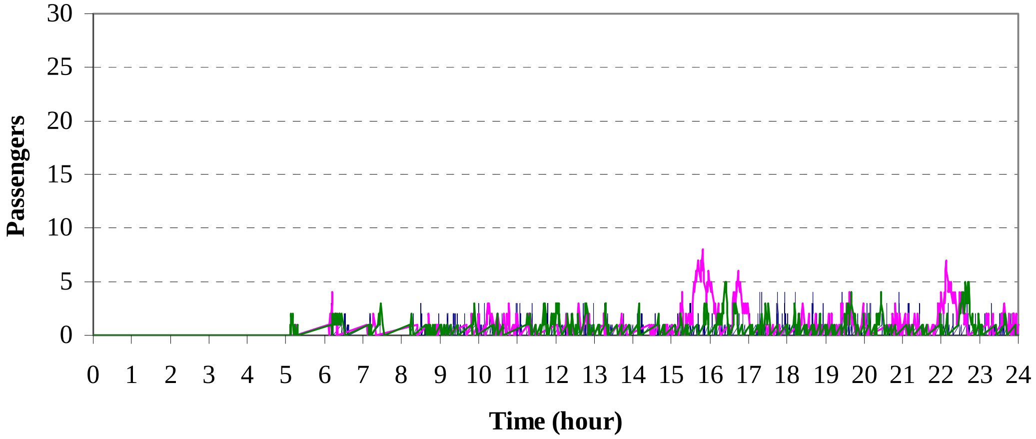


(c) Queuing Length at Customs (30% NLA)

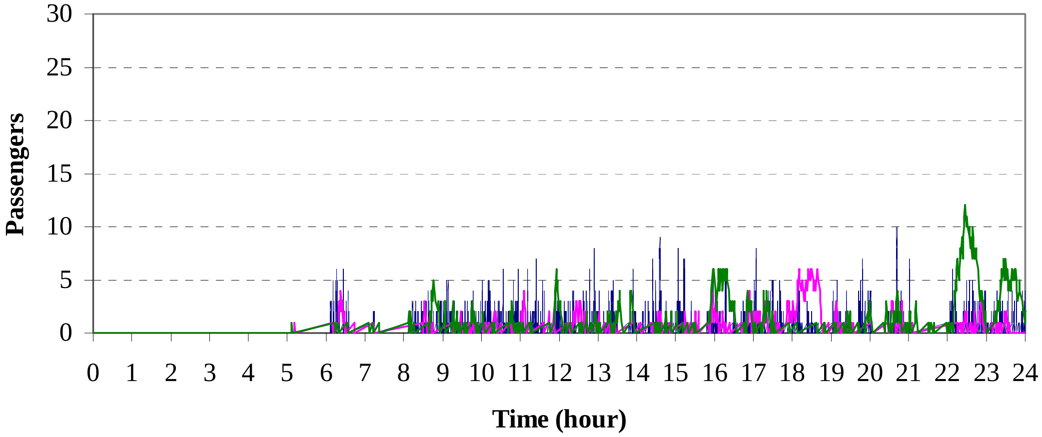


Queuing Length at Customs (30% NLA Alternatives)

Figure 5.11 (Cont.) Queuing Length at Customs (Linear, 20-gate)



(d) Queuing Length at Customs (35% NLA)



Queuing Length at Customs (35% NLA Alternatives)

Figure 5.11 (Cont.) Queuing Length at Customs (Linear, 20-gate)

2. The 30-gate Pier/Finger Terminal. The strategy for this terminal is to increase the number of baggage carousels from 7 to 8. The queuing time analysis demonstrates a significant improvement at baggage claim systems, as listed in Table 5.25. Total time spent by passengers in the terminal decreases about 20 minute, where the time saving at baggage claim systems is 18.5 minutes on average. In this alternative, passengers would have a very small queuing time at baggage claim systems. This implies that passengers do not need to wait for the arrival of their bags because bags have arrived at carousels and been processed. With respect to the queuing length at baggage claim systems, the results are similar to the 20-gate linear terminal case. The maximum queuing length decreases by half, from 100 to 50 passengers (Figure 5.12).

Table 5.25 Evaluation of Baggage Operating Strategies (Pier, 30-gate)

Items	6 NLA Gates		
- Percentage of NLA arrivals for each gate (%)	25	30	35
- Estimated Daily NLA Arrivals	9	10	12
- Total Time[a] (min)			
NLA Introduction	56.909	57.148	59.886
Alternatives	39.31	38.608	39.474
Time Saving	17.599	18.54	20.412
Decrease Rate (%)	30.92	32.44	34.08
- Queuing Time at Immigration Checks (min)			
NLA Introduction	13.420	15.596	17.363
Alternatives	15.720	15.499	15.693
- Decreases in Queuing Time at Baggage Claim Systems (min)			
NLA Introduction	21.546	18.111	20.087
Alternatives	1.327	1.442	1.335
Time Saving	20.219	16.669	18.752
Decrease Rate (%)	93.84	92.04	93.35

[a] Total time in the terminal includes average passenger deboarding time (about 7 minutes).

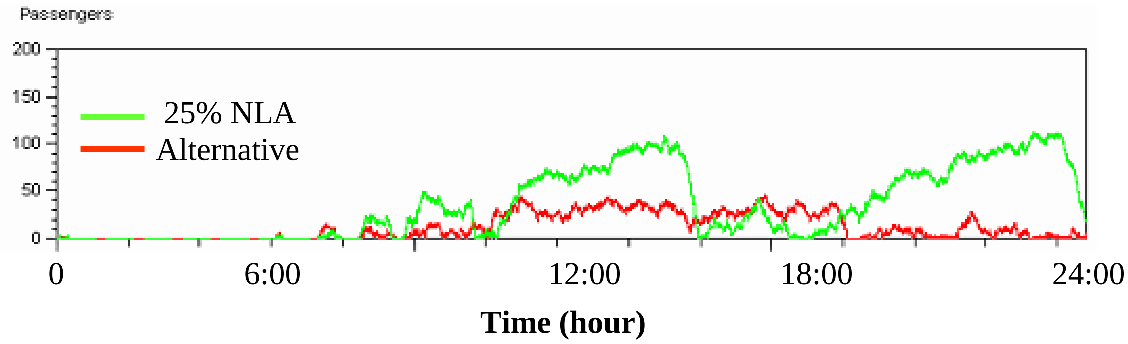


Figure 5.12 Queuing Length at Baggage Claim systems (Pier, 30-gate)

5.4.2 Operational Strategies for Boarding Bridges

The boarding bridge is one of the major facilities being impacted by NLA introduction. The strategy for accommodating 555 passengers arriving at the same time is to introduce the double-deck boarding facility. The arrival inputs for the NLA in the simulation model can thus be modified as two 277-seaters (B767-400ER) arriving at the same time. The simulation results show that the average deboarding time decreases from 15 to 7.5 minutes, as listed in Table 5.26. Similarly, the maximum deboarding time decreases by half (from 30 to 15 minutes) once the double-deck boarding bridge is utilized

Table 5.26 Evaluation of Operational Strategies for NLA Boarding Facilities

Strategies	Average Deboarding Time (min)	Miximum Deboarding Time (min)	Observations
Existing Facilities	14.94	30.21	41,458
Double-deck Bridges	7.48	15.21	93,242

5.4.3 Applications to Existing Airport Terminals

The impact analyses in this study suggested that the baggage claim system would be the most affected facilities for terminal operations by the NLA. The alternatives of increasing the baggage processing capacity were evaluated based on the queuing time analysis. The simulation results show that adding one more carousel can improve the system performance significantly. Therefore, the minimum capacity requirements of baggage claim systems for accommodating NLA operations can be induced, as listed in Table 5.27.

Table 5.27 Capacity Requirements of Baggage Claim Systems [a]

No. of Gates	Peak-hour Arriving Passenger (1999)	Peak-hour Arriving Passenger (2010)	No. of Baggage Carousels (2010)	Gate Utilization Alternatives	Minimum Capability of Operating the NLA[b] (AC/day)
20	2,500	3,500	6	- 2 gates for NLA only - 6 gates capable of operating the NLA	12
30	3,000	4,200	8	- 3 gates for NLA only - 9 gates capable of operating the NLA	15
	4,300	6,000	10	- 3 gates for NLA only - 9 gates capable of operating the NLA	21
40	5,000	6,800	11	- 4 gates for NLA only - 12 gates capable of operating the NLA	23

[a] Base Year:1999, Design Year: 2010, Annual Growth Rate: 3%.
[b] The fleet share of the NLA over total flights is about 10%.

The current numbers of baggage carousels obtained from the airport survey conducted by this study are listed in Table 5.28. The relationship between peak-hour arriving passengers and the number of baggage carousels is depicted in Figure 5.13. In comparisons with IATA formulae used in this study, the regression line obtained from the airport data worldwide shows that higher baggage processing capacity is being provided, under the level of demand in 1999. According to the relationship, IATA formulae are likely to underestimate the requirements of baggage carousels if the peak-hour arriving passenger volume is smaller than 1,000. The application of Table 5.27 is described below.

- A 20-gate terminal with a peak-hour arriving passenger volume of 2,500 in 1999 and providing 6 baggage carousels can accommodate NLA operations of at least 12 flights per day with a peak-hour arriving demand of 3,500 passengers in 2010.
- A 30-gate terminal with a peak-hour arriving passenger volume of 3,000 in 1999 and providing 8 baggage carousels can accommodate NLA operations of at least 15 flights per day with a peak-hour arriving demand of 4,200 passengers in 2010. With a peak-hour demand level of 6,000 passengers in 2010 and providing 10 baggage carousels, the terminal can accommodate at least 21 daily NLA flights with no major impacts on terminal facilities.
- A 40-gate terminal with a peak-hour arriving passenger volume of 5,000 in 1999 and providing 11 baggage carousels can accommodate NLA operations of at least 23 flights per day with a peak-hour arriving demand of 6,800 passengers in 2010.

Table 5.27 proposes a basis for airport operators to examine the compatibility of their current baggage facilities and provides the information to assist airport operators in preparing the future development plan.

Table 5.28 Baggage Facilities at Airport Terminals (1999)

Airport	**No. of Gates**	**Peak-hour Arriving PAX**	**No. of Baggage Carousels**
BOS	7	227	4
CDG2A[a]	15	813	4
CDG2C[b]	12	1,231	4
DFW_B	6	487	3
HKG	48	4,000	12
LAX_INTL	13	2,450	9
LHRT2	16	1,702	4
LHRT3	30	4,366	11
LHRT4	21	4,163	7
MUC	18	3,553	10
NRT	41	5,557	19
SFO_INTL	26	3,400	12
SYD	28	5,161	11

[a] The total number of 1999 peak-hour arriving passengers is 10,106. The annual passenger volume is 43,597,194. The estimated peak-hour arriving passenger volume for Terminal 2A at CDG is derived from terminal annual passenger volume (3,508,198) multiplying by the peak-hour factor (10,106/43,597,194).

[b] Same as CDG 2A. The annual passenger volume for Terminal 2C at CDG is 5,309,598.

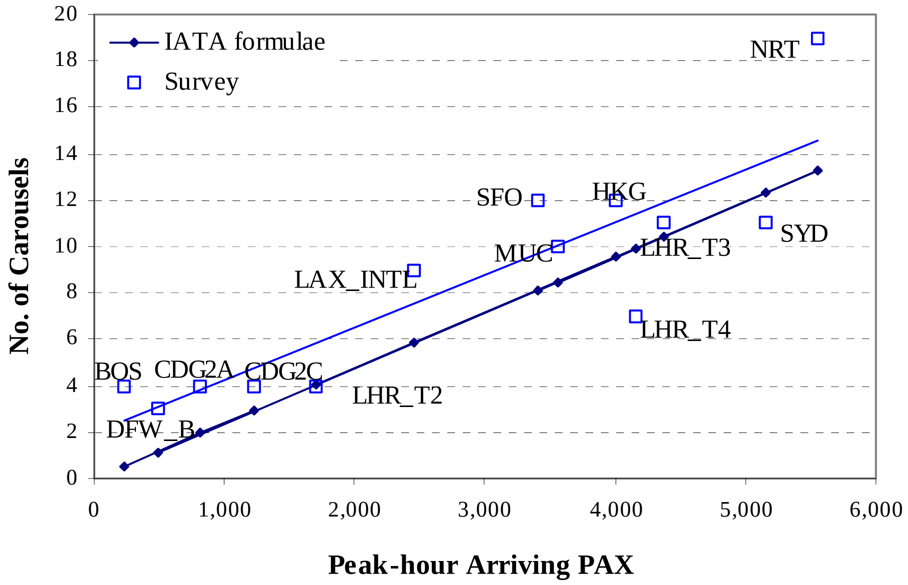


Figure 5.13 IATA Formulae and Airport Data for Baggage Claim Systems

CHAPTER 6. CONCLUSIONS

6.1 SUMMARY OF FINDINGS

This study developed an integrated simulation method for evaluating the impacts of the NLA on terminal operations. The method developed several approaches to achieve the evaluation under uncertain operating characteristics of the NLA, including establishing a generic international airport for simulation purpose, generating arriving passengers, and estimating the proper facility requirements and associated service distributions.

Through a statistical comparison with survey data from fifteen international airports, the simulation model was validated. The validation covers three major measurements:

- Daily arriving passenger volumes
- Average time in the terminal
- Time spent by passengers from gates to immigration, from immigration to baggage claim, from baggage claim to customs, and from customs to curbside.

Since there is no specific terminal to observe the actual passenger flow, the comparison bases for these three measurements are obtained from the airport survey.

In this study, the impacts of NLA introduction were evaluated in a before and after context. Three scenarios for demand forecasts, including conservative (3%), moderate (4%), and optimistic (5%) were developed. Using the conservative scenario at a growth rate of 3%, the study estimated the demand in the design year 2010 to simulate the terminal passenger flows before and after NLA introduction. In order to examine the impact of NLA introduction, two scenarios of gate utilization were considered in simulation model applications. The first scenario is to assign gates for NLA operations only, and the second one is to assign gates as for both NLA and other wide-body aircraft. The main assumption for gate assignment policies is that when a gate is assigned for NLA operations, its adjacent gates will not operate the NLA, B747, and B777. Four terminal cases were simulated and analyzed based on the queuing time, including linear terminals with 20 and 30 gates, and pier/finger terminals with 30 and 40 gates. The findings of the study are summarized as follows.

1. Results of model validation in this study show that the integrated model is an accurate approximation of an average of a sample of the actual international terminal, in addition to real-world observations, airport operators' responses can also be considered as a source for simulation validation.
2. Results of the impact analysis demonstrate that the terminal providing the gates for NLA operations only (Scenario I) is more compatible with NLA operations than Scenario II, under the same level of NLA demand.
3. The analysis of simulation results demonstrated that all processing facilities would be affected, in terms of the average queuing time. The most affected area is the baggage claim system when the NLA arrivals reach some specific share of the fleet mix. The higher fleet share of the NLA implies that there are probably more NLA operations in the terminal. Due to more NLA operations, the system will have higher probability of closer NLA arrivals. More closer arrivals would result in congestion at the baggage claim area.
4. The impact analysis indicates that larger terminals are more compatible with the NLA. Since larger terminals possess higher processing capacity, based on the IATA formulae, the impacts derived from the NLA introduction will be less.
5. The pattern of passenger flows in the terminal before NLA introduction has been found as one the factors determining how the terminal system would be affected by the NLA. The passenger processing facility that originally performed with congestion would be impacted more due to the increasing arrival derived from the introduction of the NLA.
6. The in-cabin waiting time for deboarding is another issue once the NLA is introduced. Passengers arriving by the NLA will have a longer queuing time in the cabin. The maximum deboarding time for the 555-seat NLA will increase up to 30 minutes, which is longer than that for the current B747-400 (23 minutes).
7. With respect to the improvement of the potential bottlenecks in the terminal, alternative operational strategies have been considered in this study, including increasing the baggage processing capacity and introducing double-deck boarding bridges. The analysis of simulation results demonstrates that the NLA arrivals can be viewed as two B767 arriving at the same time once the double-deck boarding facility is employed. It also shows that the

system performance of baggage facilities is significantly improved. The minimum capacity requirements for baggage claim systems can thus be obtained.

- A terminal providing 6 baggage carousels can accommodate NLA operations of at least 12 flights per day with the peak-hour arriving demand of 3,500 passengers in 2010.
- A terminal providing 8 baggage carousels can accommodate NLA operations of at least 15 flights per day with the peak-hour arriving demand of 4,200 passengers in 2010. With the peak-hour demand level of 6,000 passengers in 2010 and providing 10 baggage carousels, the terminal can operate of at least 21 daily NLA flights with no major impacts on terminal facilities.
- A terminal providing 11 baggage carousels can accommodate NLA operations of at least 23 flights per day with the peak-hour arriving demand of 6,800 passengers in 2010.

The minimum capacity requirements can be considered as the evaluation basis for airport operators to investigate the compatibility of their current baggage facilities and to assist airport operators in preparing the future development plan.

6.2 RECOMMEDATIONS

The recommendations for further research on the compatibility analysis of the NLA using simulation technology are presented in this section. The first two are with respect to modeling an active international terminal, while the rest are extensions of NLA research.

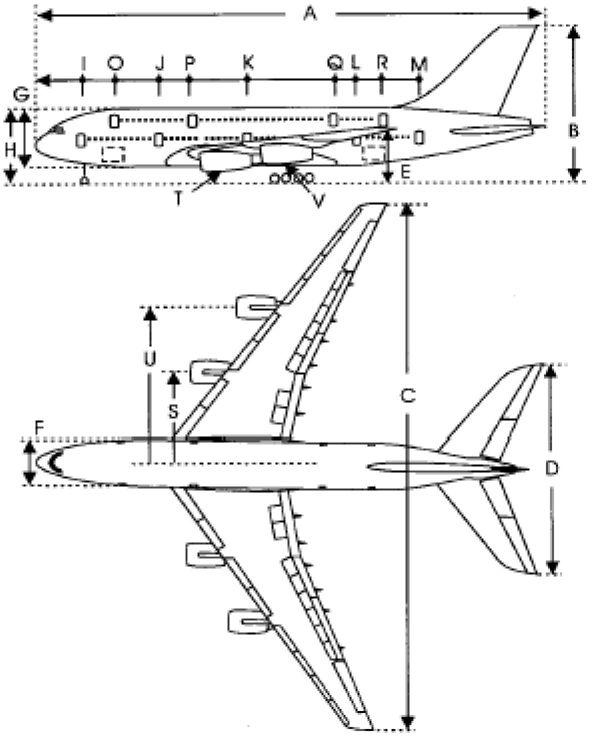
1. More passenger processing facilities can be involved in the integrated simulation model. For example, the terminal concourse is considered as one single server with a service probability distribution in the model. It can further be divided into more detailed segments, including walkways, escalators, people mover systems, etc. Immigration checks are modeled as a pooled queue in this study. More queuing formations can be involved, including separate services for citizens and for visitors.
2. The IATA formulae are capable of providing a standardized basis for the impact analysis in a before and after context. For baggage claim devices, the output derived from the formulae is the number of baggage carousels. In modeling arriving passenger flows, the formulae can better replicate the real baggage claim system by utilizing total length of baggage carousels.

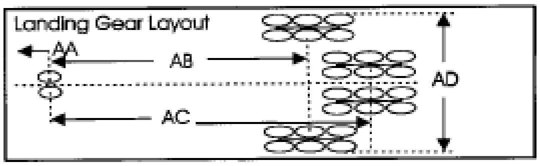
3. The fleet share of the NLA considered in this study is up to 10%. If the future market share of the 500-more-seater is less than 10%, existing terminals at most larger airports will not be significantly affected by NLA introduction. However, if an airport is expected to operate over 10% NLA of total daily flights, more simulation work will be needed. Moreover, the 555-seater is the first generation of the NLA derivatives. The impacts of larger NLA with seat capacity between 600 and 1,000 passengers can also be investigated.
4. Aircraft upgauging has been viewed as one of the significant airport delay mitigation strategies in both international and domestic operations. The conceptual framework can also be used in the impacts of increasing aircraft size on terminal facilities for domestic applications.
5. The impacts of departing passenger flows can be further investigated. In general, departing passengers arrive at the terminal between 2 and 3 hours before departure. The peak period would occur when passengers are boarding. The impacts on security checks that might be expected to perform with congestion will need further examination.
6. Airport operators may further integrate the impact investigation with cost analyses for pricing the NLA.

This Report has established a conceptual framework and a simulation method to analyze the impacts of aircraft with greater seat capacity on terminal facilities under uncertain operating characteristics. The integrated simulation model providing the input flexibility of seat capacity and fleet share, can be used to investigate the impacts of aircraft upgauging strategies in the future.

APPENDIX A. GENERAL SPECIFICATIONS OF THE NLA

A.1 PRELIMANRY SEPCIFICATIONS OF A3XX-100





QUICK REFERENCE	
Wingspan:	259' 2"
Length:	232' 4"
Height:	79' 8"
Passenger Capacity:	555
Maximum Takeoff Weight:	1,124,357
Airport Reference Code (ARC):	D-VI

	General Dimensions:	Feet	Inches
A	Length (Overall)	232	4
B	Height (Overall)	79	8
C	Wingspan	259	2
D	Tailspan	103	4
E	Wing Tip Ground Clearance	29	2
	Fuselage Dimensions:		
F	Fuselage Width	22	10
G	Fuselage Height	27	9
H	Top of Fuselage to Ground	-	-
	Door Sill Heights:		
	1st Passenger Door	17	4
	2nd Passenger Door	17	4
	3rd Passenger Door	17	5
	4th Passenger Door	17	6
	5th Passenger Door	17	6
	6th Passenger Door	-	-
	2nd Level, 1st Pass. Door	26	6
	2nd Level, 2nd Pass. Door	26	6
	2nd Level, 3rd Pass. Door	26	7
	2nd Level, 4th Pass. Door	26	7
	Landing Gear Dimensions:		
AA	Nose to Nose Gear Post	17	1
AB	Nose Gear Post to Forward Main Gear Post	88	11
AC	Nose Gear Post to Rearward Main Gear Post	98	5
AD	Maximum Main Gear Width (Outside Tire Edge)	50	8
	Door Locations:		
I	1st Passenger Door	20	4
J	2nd Passenger Door	49	2
K	3rd Passenger Door	88	3
L	4th Passenger Door	208	1
M	5th Passenger Door	172	9
N	6th Passenger Door	-	-
O	2nd Level, 1st Pass. Door	34	8
P	2nd Level, 2nd Pass. Door	64	5
Q	2nd Level, 3rd Pass. Door	127	4
R	2nd Level, 4th Pass. Door	157	7
	Engine Dimensions:		
S	Engine to Centerline (In)	44	6
T	Ground Clearance (In)	4	1
U	Engine to Centerline (Out)	77	1
V	Ground Clearance (Out)	8	1

General Specifications:	
Passenger Capacity	555
Cargo Capacity (Lbs.)	187,000
Fuel Capacity (Lbs.)	705,000
Empty Weight (Lbs.)	575,406
Max Takeoff Weight (Lbs.)	1,124,357
Max Landing Weight (Lbs.)	831,142
Runway Length Required (Ft.)	11,000
Service Turn-Around Time (Min.)	120
Approach Speed (Knots)	150
Takeoff Speed (Knots)	-
Pavement Reqired for 180 Degree Turn (Ft.)	197
Turning Radius of Nose Gear (Ft.)	170
Wingtip Clearance Radii (Ft)	-
Noise Level (Stage Level)	Below 3
Number of Engines	4
Maximum Thrust Per Engine	72,000

[Source: FAA, 1998]

A.2 SPECIFICATIONS OF A380

Aircraft dimensions		
- Overall Length		239ft 3in (73m)
- Cabin Length		166ft 3in (50.68m)
- Fuselage Diameter		23ft 5in (7.14m)
- Max. Cabin Width	main deck 5.58 m	21ft 7in
	upper deck 5.92 m	19ft 5in
- Height		79ft 7in (24.1m)
- Wheelbase		99ft 8in (30.4m)
- Track		46ft 11in (14.3m)
Wing dimensions		
- Wing Span (geometric)		261ft 8in (79.8m)
- Wing Area (reference)		9 100ft^2 (845 m^2)
- Sweep (25% chord)		33.5 degrees
Design weights		
- Max. Ramp Weight	lb x 1 000	1239
	tonnes	562
- Max. Take-off Weight	lb x 1 000	1235
	tonnes	560
- Max. Landing Weight	lb x 1 000	851
	tonnes	386
- Max. Zero Fuel Weight	lb x 1 000	796
	tonnes	361
- Max. Fuel Capacity	USg	81 890
	litres	310 000
- Typical Operating Weight Empty	lb x 1 000	608.4
	tonnes	276.8
- Typical Volumetric Payload	lb x 1 000	145.5
	tonnes	66.4
Basic operating data		
- Powerplants		Trent 900/GP 7000
- Thrust Range	lb slst	70 000
- Typical Seating		555
- Range (with Max. Passengers)	nm	8 000
	km	14 800
- Max. Operating Mach No. (Mmo)		M0.89

Source: Airbus, 2002

APPENDIX B. AIRPORT SURVEY QUESTIONNAIRE

**** For your convenience, there is an electronic version of the survey form. The web site is: http://www.ce.utexas.edu/stu/chiuc/surveyform1.html**

Name of Airport ____________________________________ Airport Code __________

PART I. AIRPORT CONFIGURATION AND TERMINAL FACILITIES

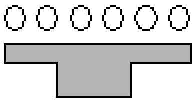
1. Number of terminals in the airport

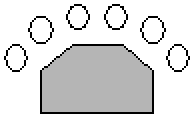
A. How many terminals for INTERNATIONAL travel only? (If zero, please go to question B.)
1 2 3 4 5 or more

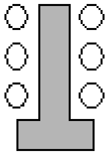
B. How many terminals with INTERNATIONAL GATES?
1 2 3 4 5 or more

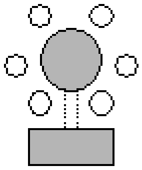
2. What concept is the best description of the international terminals?

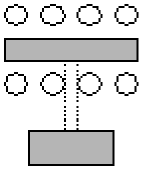
If more than THREE terminals, please only list THREE of them.


Linear


Compact


Pier/finger


Satellite


Island

Example: *London Heathrow Terminal 3: PIER/FINGER*
Dallas/Fort Worth American Airlines: LINEAR

Terminal 1 __________________________Concept Linear Number of Gates ___
Compact
Pier/finger
Satellite
Island

Terminal 2 __________________________Concept Linear Number of Gates ___
Compact
Pier/finger
Satellite
Island

Terminal 3 ___________________________Concept Linear Number of Gates ___
Compact
Pier/finger
Satellite
Island

3. Passenger Volumes

A. 1999 Annual total passenger volumes ___________________________________

B. Proportion of international passengers

less than 10 %
10 % - 20 %
20 % - 30 %
30 % - 40 %
40 % - 50 %
50 % - 60 %
60 % - 70 %
70 % - 80 %
80 % - 90 %
90 % - 100 %

C. Proportion of transfer passengers

less than 10 %
10 % - 20 %
20 % - 30 %
30 % - 40 %
40 % - 50 %
50 % - 60 %
60 % - 70 %
70 % - 80 %
80 % - 90 %
90 % - 100 %

D. Proportion of international/domestic transfer passengers

less than 10 %
10 % - 20 %
20 % - 30 %
30 % - 40 %
40 % - 50 %
50 % - 60 %
60 % - 70 %
70 % - 80 %
80 % - 90 %
90 % - 100 %

E. 1999 number of peak hour arrival (terminating) passengers _________________________

F. Proportion of passengers arriving by wide-body aircraft

less than 10 %
10 % - 20 %
20 % - 30 %
30 % - 40 %
40 % - 50 %
50 % - 60 %
60 % - 70 %
70 % - 80 %
80 % - 90 %
90 % - 100 %

(*IATA example: 80%, REF: 1995 IATA Manual*[*] *page 38)*

4. Baggage Claim Systems

A. How many baggage claim devices in the international terminal(s)?

---

[*] IATA, Airport Development Reference Manual, 8th edition, April, 1995.

If more than THREE terminals, please only list THREE of them.

Terminal 1 ______________________________Number of baggage claim devices ________

Terminal 2 ______________________________Number of baggage claim devices ________

Terminal 3 ______________________________Number of baggage claim devices ________

B. Average ***Time Estimate*** between aircraft arrival and the first bag getting to the claim

0 – 5 minutes	15 – 20 minutes
5 – 10 minutes	20 – 25 minutes
10 – 15 minutes	25 – 30 minutes

5. Average *Processing Time Estimates* for serving one passenger

A. Passport checks

0 – 2 minutes	6 – 8 minutes
2 – 4 minutes	8 – 10 minutes
4 – 6 minutes	over 10 minutes

(IATA example: 0.5 minutes, REF: 1995 IATA Manual page 36.)

B. Customs

0 – 2 minutes	6 – 8 minutes
2 – 4 minutes	8 – 10 minutes
4 – 6 minutes	over 10 minutes

(IATA example: 2.0 minutes, REF: 1995 IATA Manual page 40.)

PART II. PERFORMANCE MEASURES OF SERVICES

- *The information will not be used to compare airports or specific terminals but to facilitate better estimates of various input requirements of simulation models.*
- *All the measures will be estimated values based on experiences and expert knowledge.*

1. Select one terminal from among the terminals listed in question 2 of PART I.

Terminal 1 Terminal 2 Terminal 3

2. Total floor space area of the terminal: __________________ *M^2* **or**

__________________ *Ft^2*

3. Total time spent in the terminal for individual arrival passenger:

From GATE to CURBSIDE only, ***excluding*** *time spent in parking area or waiting for ground transportation.*

0 – 20 minutes
20 – 30 minutes
30 – 40 minutes
40 – 50 minutes
50 – 60 minutes
over 60 minutes

4. Average time from Gate to Passport Checks *(including service time)*:

0 – 5 minutes
5 – 10 minutes
10 – 15 minutes
15 – 20 minutes
20 – 25 minutes
25 – 30 minutes

5. Average time from Passport Checks to Baggage Claim *(including service time)*:

0 – 5 minutes
5 – 10 minutes
10 – 15 minutes
15 – 20 minutes
20 – 25 minutes
25 – 30 minutes

(IATA assumption: average occupancy time per passenger over baggage claim area: 30 minutes, REF: 1995 IATA Manual page 37.)

6. Average time from Baggage Claim to Customs *(including service time)*:

0 – 5 minutes
5 – 10 minutes
10 – 15 minutes
15 – 20 minutes
20 – 25 minutes
25 – 30 minutes

7. Average time from Customs to Curbside *(including time spent in arrival lounge)*:

0 – 5 minutes
5 – 10 minutes
10 – 15 minutes
15 – 20 minutes
20 – 25 minutes
25 – 30 minutes

(IATA assumption: average time per passenger spent in arrival lounge: 15 minutes, REF: 1995 IATA Manual page 41.)

PART III. AIRLINES OPERATIONS

- *Use the selected terminal of PART II.*
- *All the measures will be estimated values, based on experiences and expert knowledge.*

1. What are current international routes in the terminal? *(Multiple)*

North America ↔ Europe
North America ↔ Asia/Pacific
North America ↔ Latin America
North America ↔ Middle East/South Asia
Europe ↔ Asia/Pacific
Europe ↔ Latin America
Europe ↔ Middle East/ South Asia
Asia/Pacific ↔ Middle East/ South Asia
Asia/Pacific ↔ Latin America
Middle East/ South Asia ↔ Latin America

2. Average estimated inter-arrival time

- *The time between two consecutive international arrivals using the same gate.*
- *Example: TWO daily flights from Asia/Pacific to North America and TWO to South Asia arrive at a specific gate, the estimated interarrival time of the gate will be 6 – 8 hours.*
- *If more than THREE routes, please only list THREE of them.*

GATE 1 route(s)____________________↔___________________

0 – 4 hours
4 – 6 hours
6 – 8 hours
8 – 10 hours
10 – 12 hours
12 – 14 hours
14 – 16 hours
16 – 18 hours
18 – 20 hours
20 – 22 hours
22 – 24 hours
over 24 hours

GATE 2 route(s)____________________↔___________________

0 – 4 hours
4 – 6 hours
6 – 8 hours
8 – 10 hours
10 – 12 hours
12 – 14 hours
14 – 16 hours
16 – 18 hours
18 – 20 hours
20 – 22 hours
22 – 24 hours
over 24 hours

GATE 3 route(s)____________________↔___________________

0 – 4 hours
4 – 6 hours
6 – 8 hours
8 – 10 hours
10 – 12 hours
12 – 14 hours
14 – 16 hours
16 – 18 hours
18 – 20 hours
20 – 22 hours
22 – 24 hours
over 24 hours

COMMENTS:

____

____

____

Thank you for your assistance.

Dr. C. Michael Walton
Ernest H. Cockrell Centennial Chair in Engineering
Transportation Program
Department of Civil Engineering
University of Texas at Austin
Austin, TX 78712
USA
(Phone)512-471-1414
(Fax) 512-471-7995
cmwalton@mail.utexas.edu

Chiung-yu Chiu
PhD Candidate
Transportation Program
Department of Civil Engineering
University of Texas at Austin
Austin, TX 78712
USA
(Phone)512-232-4251, 4253, 4255
ccy@mail.utexas.edu

Last update 12.06.2000

APPENDIX C. SUMMARY OF AIRPORT SURVEY RESULTS

The survey results presented in this study can only be used for simulation model validation purpose.

C.1 LINEAR/COMPACT TERMINALS

Participant Airports: Los Angeles International Airport (LAX)
Dallas/Fort Worth International Airport (DFW)
Paris Charles de Gaulle International Airport (CDG)
Boston Logan International Airports (BOS)
Detroit Metro Airport (DTW)
Munich International Airport (MUC)

Part 1 Airport Configuration and Terminal Facilities

Airport	**LAX**	**DFW**	**CDG**	**BOS**
No. of Int’l Gates	13[a]	29	135[b]	7
Total Passengers (’99)	64,279,571	60,000,127	43,597,194	27,052,078
International Pax %	20-30%	<10% (6%)	80-90%	10-20%
Approx. Int’l Pax	8,430,000*	3,900,000	37,100,000	4,100,000
Transfer %	30-40%	50-60%	30-40%	<10%
Int’l/Domestic Transfer %	10-20%	<10%	10-20%	<10%
Peak Hour Arr. Pax (’99)	7,000	7,500	10,106	1,500
Approx. Int’l Peak Hour Arr. Pax	2,450[d]	487	8,600	227
Wide-body %	30-40%	<10%	30-40%	--
Wide-body Pax	22,500,000	3,000,000	15,300,000	--
Wide-body peak Hour Pax	2,450	375	3,546	--
No. of baggage Claims	9	10	12	4
Time (arrival – first bag), min	10-15	5-10	15-20	10-15
Processing time, min				
Immigration	2-4	0-2	0-2	2-4
Customs	2-4	2-4	0-2	2-4

[a] Only number of international terminal (Total international passenger volume is 15.1 millions)

[b] No terminal passenger volume available (CDG1:Satellite, CDG2A-2D, Linear, and CDG 2F: Pier/finger)

[c] Total 90 gates in five modules for arriving passengers. Each of these modules functions as a terminal.

[d] Approximate international peak hour passenger = (Peak hour passenger / Total passenger) × Approximate International Passenger

Part 1 Airport Configuration and Terminal Facilities (Cont.)

Airport	**DTW**	**MUC**
No. of Int’l Gates	6	18[c]
Total Passengers (’99)	34,038,381	21,282,906
International Pax %	<10%	60-70%
Approx. Int’l Pax	1,700,000	13,800,000 (13,479,000)
Transfer %	40-50%	20-30%
Int’l/Domestic Transfer %	--	20-30%
Peak Hour Arr. Pax (’99)	--	5,633
Approx. Int’l Peak Hour Arr. Pax	--	3,653
Wide-body %	<10%	10-20%
Wide-body Pax	--	3,200,000
Wide-body peak Hour Pax	--	847
No. of baggage Claims	3	10
Time (arrival – first bag), min	--	10-15
Processing time, min		
Immigration	--	0-2
Customs	--	0-2

Part II Performance Measures of Services

Airport	LAX	DFW	CDG	BOS
Total Space Floor Area (ft^2)	1,000,000	637,000	96,878	97,900
Total time in the terminal	30-40	20-30	30-40	30-40
Time (gate-immigration)	10-15	0-5	0-5	10-15
Time (immigration-baggage)	10-15	0-5	5-10	5-10
Time (bag-customs)	5-10	0-5	20-25	10-15
Time (customs-curbside)	5-10	0-5	0-5	10-15

Part II Performance Measures of Services (Cont.)

Airport	DTW	MUC
Total Space Floor Area (ft^2)	--	1,894,510
Total time in the terminal	>60	40-50
Time (gate-immigration)	25-30	0-5
Time (immigration-baggage)	5-10	15-20
Time (bag-customs)	5-10	0-5
Time (customs-curbside)	15-20	15-20

Part III Airlines Operations

Airport	LAX	DFW	CDG	BOS
Current Routes[e]	NA ←→ EU NA ←→ AP NA ←→ LA NA ←→ ME/SA	NA ←→ EU NA ←→ AP NA ←→ LA	NA ←→ EU EU ←→ LA EU ←→ ME/SA	NA ←→ EU NA ←→ AP NA ←→ LA
Interarrival Times, hrs[f]	G1:0-4 G2:0-4 G3:0-4	G1:0-4 G2:4-6	G1:0-4 G2:0-4 G3:0-4	G1:0-4 G2:0-4 G3:0-4

[e] NA: North America, EU: Europe, AP: Asia/Pacific, LA: Latin America, ME/SA: Middle East/ South Asia

[f] Most aircraft have dwell times on gate of at most 4 hours

Part III Airlines Operations (Cont.)

Airport	DTW	MUC
Current Routes	NA ←→ EU NA ←→ AP NA ←→ LA	NA ←→ EU EU ←→ AP EU ←→ LA EU ←→ ME/SA
Interarrival Times, hrs	--	--

C.2 PIER/FINGER TERMINALS

Participant Airports: London Heathrow International Airport (LHR)
San Francisco International Airport (SFO)
Hong Kong International Airports (HKG)
Bangkok International Airport (BKK)
Sydney International Airport, (SYD)
Toronto Lester B. Pearson International Airport (YYZ)
Kansai International Airport (KIX)
Oslo International Airport (OSL)

Part 1 Airport Configuration and Terminal Facilities

Airport	LHR	SFO	HKG	BKK
No. of Int'l Gates	67	10[a]	48	76
Total Passengers ('99)	62,623,365	40,101,387	29,728,145	27,287,847
International Pax %	80-90%	10-20%	90-100%	70-80
Approx. Int'l Pax	54,800,000	6,000,000	29,000,000	20,500,000
Transfer %	20-30%	20-30%	20-30%	<10%
Int'l/Domestic Transfer %	30-40%	30-40%	20-30%	<10%
Peak Hour Arr. Pax ('99)	10,848	--	4,000	6,821
Approx. Int'l Peak Hour Arr. Pax	9,493	3,400[b]	4,000	4,380
Wide-body %	50-60%	90-100%[c]	70-80%	30-40%
Wide-body Pax	34,400,000	6,000,000[b]	21,800,000	9,550,000
Wide-body peak Hour Pax	5,215	3,230 [b]	2,933	1,532
No. of baggage Claims	22	12	12	14
Time (arrival – first bag), min	10-15	5-10	10-15	5-10
Processing time, min				
Immigration	0-2	0-2	0-2	0-2
Customs	0-2	0-2	0-2	0-2

[a] Number of gates of old international terminal, the current one is with 26 gates.
[b] International only.
[c] Most of international operations are with B767, B777, A340, MD11, or B747.

Part 1 Airport Configuration and Terminal Facilities (Cont.)

Airport	SYD	YYZ	KIX	OSL
No. of Int’l Gates	28	85 (total)	40	34
Total Passengers (’99)	21,800,000	27,779,675	19,890,350	14,121,154
International Pax %	30-40%	50-60%	50-60%	40-50%
Approx. Int’l Pax	7,630,000	15,300,000	11,934,210	7,000,000 (6,462,000)
Transfer %	10-20%	20-30%	<10%	10-20%
Int’l/Domestic Transfer %	10-20%	<10%	10-20%	10-20%
Peak Hour Arr. Pax (’99)	5,161	4,400	4,306	1,750
Approx. Int’l Peak Hour Arr. Pax	1,806	2,423	2,584	875
Wide-body %	60-70%	20-30%	30-40%	<10%
Wide-body Pax	14,200,000	6,900,000	6,961,623	700,000
Wide-body peak Hour Pax	3,361	1,093	1,507	e
No. of baggage Claims	11	15	8	3
Time (arrival – first bag), min	15-20	10-15	15-20	10-15
Processing time, min				
Immigration	0-2	0-2	0-2	0-2
Customs	0-2	2-4	0-2	0-2

[e] Less than 100.

Part II Performance Measures of Services

Airport	LHR	SFO	HKG	BKK
Total Space Floor Area (ft^2)	1,892,939	2,500,000	5,920,344	2,121,636
Total time in the terminal	40-50	40-50	20-30	20-30
Time (gate-immigration)	10-15	25-30	10-15	0-5
Time (immigration-baggage)	15-20	10-15	5-10	0-5
Time (bag-customs)	0-5	5-10	0-5	5-10
Time (customs-curbside)	5-10	0-5	0-5	0-5

Part II Performance Measures of Services (Cont.)

Airport	SYD	YYZ	KIX	OSL
Total Space Floor Area (ft^2)	2,368,138	1,400,000	3,245,124	1,496,233
Total time in the terminal	40-50	30-40	30-40	0-20
Time (gate-immigration)	15-20	15-20	5-10	5-10
Time (immigration-baggage)	10-15	5-10	10-15	0-5
Time (bag-customs)	5-10	0-5	5-10	0-5
Time (customs-curbside)	10-15	0-5	0-5	0-5

Part III Airlines Operations

Airport	LHR	SFO	HKG	BKK
Current Routes	NA ←→ EU EU ←→ AP EU ←→ LA EU ←→ ME/SA	NA ←→ EU NA ←→ AP NA ←→ LA NA ←→ ME/SA	NA ←→ AP EU ←→ AP AP ←→ ME/SA	AP ←→ EU AP ←→ ME/SA
Interarrival Times, hrs	G1: 0-4 G2: 0-4 G3: 0-4	G1:0-4[d] G2: 0-4 G3: 0-4	G1: 4-6 G2: 4-6 G3: 4-6	G1:0-4 G2:0-4

---

[d] Average gate time is approximately 2.0 –2.5 hours, that is turn around time with a 15-20 minute separation time before the next arrival

Part III Airlines Operations (Cont.)

Airport	SYD	YYZ	KIX	OSL
Current Routes	NA ←→ AP EU ←→ AP AP ←→ ME/SA AP ←→ LA	NA ←→ EU NA ←→ AP NA ←→ LA NA ←→ ME/SA	NA ←→ AP EU ←→ AP APU ←→ ME/SA	NA ←→ EU
Interarrival Times, hrs	G1: 6-8 G2: 6-8 G3: 6-8	G1:0-4 G2:0-4 G3:0-4	--	G1:18-20

C.3 SATELLITE/ISLAND TERMINALS

Participant Airports: Tokyo Narita International Airport (NRT)

Part 1 Airport Configuration and Terminal Facilities

Airport	NRT
No. of Int'l Gates	41
Total Passengers ('99)	25,667,634
International Pax %	90-100%
Approx. Int'l Pax	25,667,634
Transfer %	<10%
Int'l/Domestic Transfer %	--
Peak Hour Arr. Pax ('99)	5,557
Approx. Int'l Peak Hour Arr. Pax	5,557
Wide-body %	90-100%
Wide-body Pax	25,667,634
Wide-body peak Hour Pax	5,557
No. of baggage Claims	19
Time (arrival – first bag), min	25-30
Processing time, min	
Immigration	0-2
Customs	0-2

Part II Performance Measures of Services

Airport	NRT
Total Space Floor Area (ft^2)	3,065,662
Total time in the terminal	40-50
Time (gate-immigration)	--
Time (immigration-baggage)	--
Time (bag-customs)	--
Time (customs-curbside)	10-15

Part III Airlines Operations

Airport	NRT
Current Routes[a]	NA ↔ AP EU ↔ AP AP ↔ LA AP ↔ ME/SA
Interarrival Times, hrs	--

APPENDIX D. ARRIVAL GENERATION METHODS

D.1 Aircraft Arrival Generation

1. Random Number Generator for Aircraft Arrival Generation

// RandChiu.cpp : Defines the entry point for the console
// application

```
// This program is used to assign interarrival distributions to
// gates by using the random number generator

#include <cstdio>
#include <cmath>
#include <iostream>
#include <fstream>
#include <cstdlib>
#include <algorithm>
#include <vector>
#include <numeric>
#include <functional>
#include <string>
#include <stdlib.h>

using namespace std;
class RandAssign {
public:
      RandAssign();
      ~RandAssign(){}
      void ReadInput(string inputFile, string outputFile);
      void Assign(int seed = 0);
private:
      vector<int> Mark;
      vector<float> P;
      int N, Size_P;
      ifstream fin;
      ofstream fout;
};

RandAssign::RandAssign(){
      P.resize(40);
      Size_P = 0;
      return;
}

void RandAssign::ReadInput(string inputFile, string outputFile)
{
      int n = 0, m = 0, p = 0;
      cout<<"\n*** Welcome to Aircraft Arrival Random Number
            Generator ***\n"<<endl;

      while(n <= 0) {
            cout<<"Please enter Number of Gates (N)"<<endl;
            cin>>n;
```

```
            N = n;
            cout<<"\n*** N = "<<N<<endl;
            if(N > 0){
                  Mark.resize(N+1);
                  break;
            }
            else {
                  cout<<"N must be > 0 "<<endl;
                  cout<<"Please try again"<<endl;
            }
      }

      cout<<"inputFilename = "<< inputFile.data() <<endl;
      cout<<"outputFilename = "<< outputFile.data() <<endl;

      fin.open(inputFile.data());
      fout.open(outputFile.data());

      fout<<"input file: "<<inputFile.data()<<endl;

      float pcts;
      int l = 0;
      while(!fin.eof()){
            l++;
            if(l >= P.size()){
                  int curSize = P.size();
                  P.resize(curSize+20);
            }

            fin>>pcts;
            P[l] = 0.01*pcts*(float)N;
            cout<<"NP["<<l<<"] = "<<P[l]<<endl;
      }
      Size_P = l;
      // check P[i] here
}

void RandAssign::Assign(int seed){
      // initiate Mark array to zero first
      Mark.resize(N+1);
      for(int i = 0; i <= Mark.size(); i++)
            Mark[i] = 0;

      int sum = 0;
      cout<<"random seed = "<<seed<<endl;
      fout<<"random seed = "<<seed<<endl;

      srand(seed);

      while(sum < N){
            for(int j = 1; j <= Size_P; j++){
                  int rand_cap = 0;
                  int rand_limit = 0;
                  if(P[j]-floor(P[j]) >0.5 )
                        rand_limit = floor(P[j]) + 1;
                  else
                        rand_limit = floor(P[j]);
```

```
                  if(j == Size_P)
                        rand_limit = N - sum;

                  cout<<"NP["<<j<<"]="<<P[j]<<", Random Assign: ( ";
                  fout<<"NP["<<j<<"]="<<P[j]<<", Random Assign: ( ";

                  while(rand_cap < rand_limit ){

                        int new_rand = 0;
                        // generate an unduplicated random number
                        do {
                              new_rand = ( rand()% N )+ 1;
                        } while(Mark[new_rand] != 0);

                        // An unduplicated random number is obtained
                        Mark[new_rand] = 1;
                        rand_cap++;
                        sum++;
                        if(sum == N){
                              cout<<new_rand;
                              fout<<new_rand;
                              break;
                        }

                        if(rand_cap == rand_limit){
                              cout<<new_rand;
                              fout<<new_rand;
                        }
                        else {
                              cout<<new_rand<<" , ";
                              fout<<new_rand<<" , ";
                        }
                  }
                  cout<<" )"<<endl;
                  fout<<" )"<<endl;
            }
      }
}

void main(int argc, char* argv[])
{
      RandAssign myRand;

      cout<<"Hookem Horns!\n"<<endl;
      switch(argc){
      case 1:
                  myRand.ReadInput("input.txt","output.txt");
                  myRand.Assign();
                  break;
      case 2:
                  myRand.ReadInput(argv[1],"output.txt");
                  myRand.Assign();
                  break;
      case 3:
                  myRand.ReadInput(argv[1],argv[2]);
                  myRand.Assign();
```

```
            break;
    default:
            myRand.ReadInput(argv[1],argv[2]);
            myRand.Assign(atoi(argv[3]));
    }

    exit(0);
    return;
}
```

2. Input Example

```
72.63
13.53
10.37
3.47
seed = 0
```

3. Output Example

```
input file: input.txt
random seed = 0
NP[1]=14.526, Random Assign: ( 19 , 20 , 18 , 16 , 6 , 11 , 13 ,14 ,  1 , 3
                                , 2 , 17 , 12 , 7 , 4 )
NP[2]=2.706, Random Assign: ( 8 , 5 , 10 )
NP[3]=2.074, Random Assign: ( 9 , 15 )
NP[4]=0.694, Random Assign: (  )
```

D.2 INITIAL GATE ASSIGNMENT

1. Random Number Generator for Initial Gate Assignment

```
// URandGen.cpp : Defines the entry point for the console
// application

// This program is used to determine the first aircraft arrival
// at each gate by using random number generator

#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <iostream>
#include <fstream>
#include <vector>

#define MAX 101
using namespace std;

class URandGen {
private:
      int N, M, P, MP;
      vector<int> Mark;
      vector<float> MPArray;
      ifstream fin;
      ofstream fout;

public:
      URandGen(){}
      ~URandGen(){}
      void ReadInput(string inputFile, string outputFile);
      void Gen(int seed);
      void close();
};


void URandGen::close(){
      fin.close();
      fout.close();
}

void URandGen::ReadInput(string inputFile, string outputFile)
{
      int n = 0, m = 0, p = 0;
      cout<<"\n\n\n*** Welcome to Initial Aircraft Arrival Random
             Number Generator ***\n"<<endl;
      do {
            cout<<"Please enter Number of Gates (N)"<<endl;
            cin>>n;
            cout<<"Please enter Number of daily flights (M)"<<endl;
            cin>>m;

            N = n;
            M = m;
```

```
            cout<<"\n\n\n*** N = "<<N<<endl;
            cout<<"*** M = "<<M<<endl;

            if(N > 0)
                  Mark.resize(N);
            else {
                  cout<<"N must be greater than 0 "<<endl;
                  cout<<"Please try again"<<endl;
            }
      } while(N <=0);

      for(int i = 0; i <= N; i++)
            Mark[i] = 0;

      cout<<"inputFilename = "<< inputFile.data() <<endl;
      cout<<"outputFilename = "<< outputFile.data() <<endl;

      fin.open(inputFile.data());
      fout.open(outputFile.data());


      int min;
      float pcts;

      int l = 0;
      while(!fin.eof()){
            l++;
            if(l >= MPArray.size())
                  MPArray.resize(l+50);

            fin>>min>>pcts;
            MPArray[l] = 0.01*pcts*(float)M;
            cout<<"read line: "<<l<<" ,min: "<<min<<" ,MP:
"<<MPArray[l]<<endl;
      }

}

void URandGen::Gen(int seed)
{
      int n = 0, i = 1, m = 0, l = 1;;
      int t = 0;
      srand(seed);
      while(n < N){
            cout<<"**"<<i<<" hourly flights="<<MPArray[l]<<" set( ";
            fout<<"**"<<i<<" hourly flights="<<MPArray[l]<<" set( ";

            MP = (int) MPArray[l];
            while(m < MP){
                  do {
                        t = rand();
                        t = (t % N) + 1;  // Now t is between 1 to N
                  } while ( Mark[t] != 0 );

                  if( Mark[t] == 0 ){
                        m++;
                        n++;
```

```
                        Mark[t] = 1;
                        cout<<" "<<t;
                        fout<<" "<<t;

                        if( m == MP){
                              break;
                        }
                        else {
                              if( n >= N )
                                    break;
                              else {
                                    cout<<",";
                                    fout<<",";
                              }
                        }

                        if( n >= N ){
                              cout<<" )"<<endl;
                              fout<<" )"<<endl;
                              return;
                        }
                  }
            }
            cout<<" )"<<endl;
            fout<<" )"<<endl;
            m = 0;
            i++;
            l++;
      }
}


int main(int argc, char* argv[])
{
      cout<<"Hookem Horns!"<<endl;
      URandGen myRand;
      int seed = 1;

      switch(argc){
      case 1:
                  myRand.ReadInput("input.txt","output.txt");
                  break;
      case 2:
                  myRand.ReadInput(argv[1],"output.txt");
                  break;
      case 3:
                  myRand.ReadInput(argv[1],argv[2]);
                  break;
      default:
                  myRand.ReadInput("input.txt","output.txt");
                  seed = atoi(argv[3]);
      }

      myRand.Gen(seed);
      myRand.close();

      exit(0);
```

```
      return 0;
}
```

2. Input Example

```
   1 0.73
   2 0.43
   3 0.15
   4 0.14
   5 0.54
   6 1.47
   7 3.52
   8 3.88
   9 4.56
   10 3.55
   11 5.73
   12 5.04
   13 5.83
   14 6.23
   15 7.03
   16 7.58
   17 8.64
   18 5.53
   19 6.57
   20 6.00
   21 6.57
   22 4.34
   23 4.68
   24 1.27
   Default seed number = 1
```

3. Output Example

```
**1 hourly flights=0.6351 set(  )
**2 hourly flights=0.3741 set(  )
**3 hourly flights=0.1305 set(  )
**4 hourly flights=0.1218 set(  )
**5 hourly flights=0.4698 set(  )
**6 hourly flights=1.2789 set(  2 )
**7 hourly flights=3.0624 set(  8, 15, 1 )
**8 hourly flights=3.3756 set(  10, 5, 19 )
**9 hourly flights=3.9672 set(  3, 6, 12 )
**10 hourly flights=3.0885 set(  16, 17, 14 )
**11 hourly flights=4.9851 set(  13, 7, 20, 4 )
**12 hourly flights=4.3848 set(  9, 18, 11 )
```

APPENDIX E. AN EXAMPLE OF A 20-GATE LINEAR TERMINAL

1. Aircraft Arrival Dialog

The aircraft Arrival Dialog includes all the information relative to aircraft arrival distribution, empirical distribution of average number of passengers per aircraft, first arrival time, and the connected server (Gate) that the entity is about to enter next. “Mark Time Attribute” is entered with arrival time for calculating total time spent in the entire system.

The batch size for this gate in the base year is a discrete empirical distribution, expressed as *DISC(0.0883, 208, 0.2916, 223, 0.4719,236, 0.511, 277, 0.8281, 322, 1, 123)*. The first creation is the time required to generate the initial arrival for this gate, which is 360 minutes after the simulation starts. The interarrival time distribution is *U(120,240)*, which is shown in minutes). The distributions of the batch size in the design year for the NLA gate and its adjacent gates are listed as Table E.1.

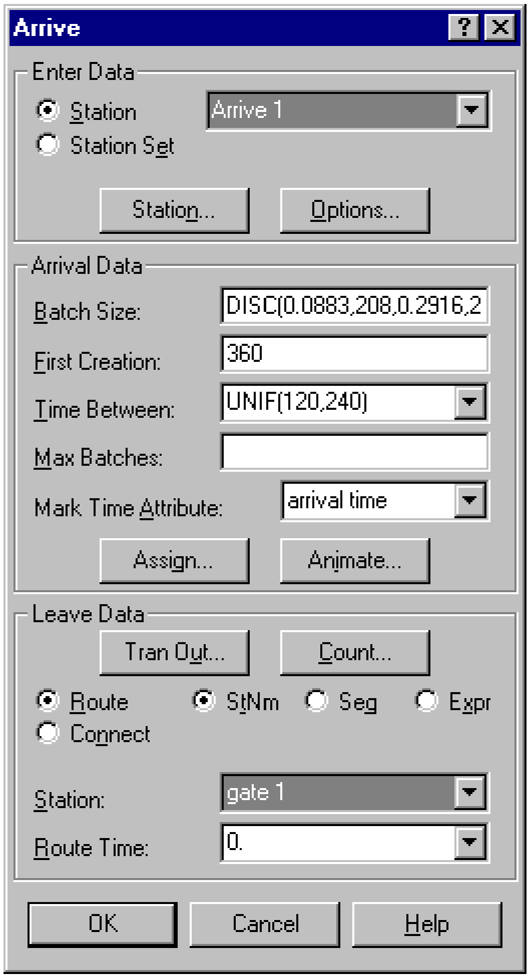
Table E.1 Empirical Distributions of the Batch Size for the Design Year

Aircraft Class	**NLA %**	**Distribution of Batch Size**[a]
W1~W3	--	*DISC(0.1371, 218, 0.4529, 235, 0.7330, 248, 1, 129)*
W4~W5, NLA	5[b]	*DISC(0.1043, 292, 0.8457, 339, 1, 444)*
	10	*DISC(0.939, 292, 0.8061, 339, 1, 444)*
	15	*DISC(0.887, 292, 0.7613, 339, 1, 444)*
	20	*DISC(0.834, 292, 0.7106, 339, 1, 444)*
	25	*DISC(0.782, 292, 0.6718, 339, 1, 444)*
	30	*DISC(0.731, 292, 0.6269, 339, 1, 444)*
	35	*DISC(0.678, 292, 0.5822, 339, 1, 444)*

[a] Use 80% Load Factor for the average number of passengers per aircraft

[b] The proportion of the NLA over all aircraft classes (W1~W5 and NLA)

The Aircraft Arrival Dialog is shown as below.



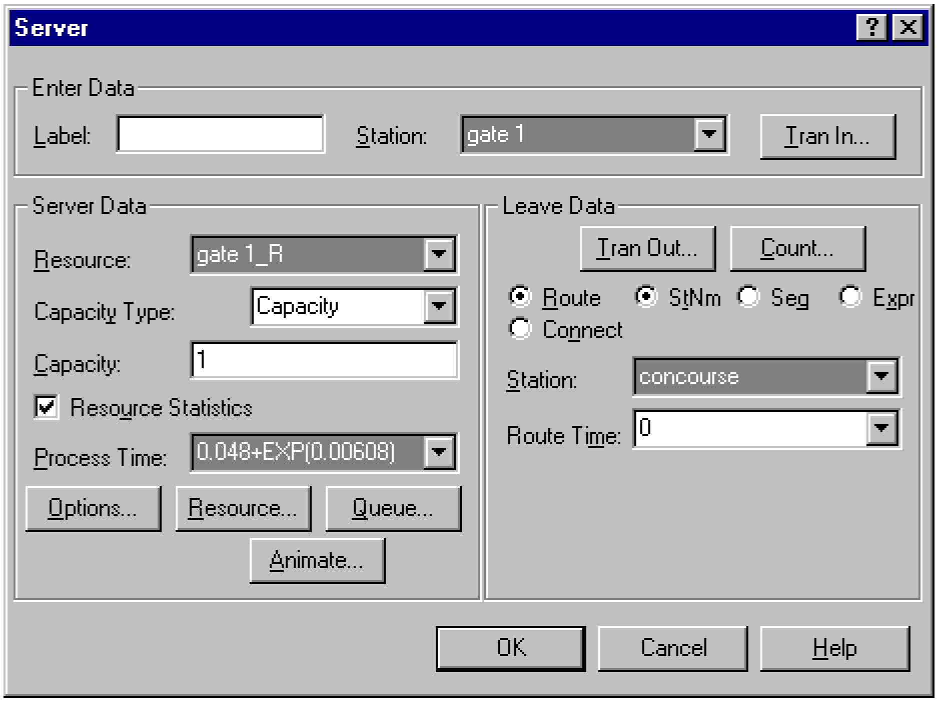
● Station
○ Station Set
Arrive 1

Batch Size: DISC(0.0883,208,0.2916,2
First Creation: 360
Time Between: UNIF(120,240)
Max Batches:
Mark Time Attribute: arrival time

● Route
○ Connect
● StNm ○ Seg ○ Expr
Station: gate 1
Route Time: 0.

2. *Gate Dialog*

Gate inputs use a “server” dialog. They include the capacity of the server, service time distribution, and the next server (Concourse). The service time distribution is actually derived from unloading rates.



Label:

Station: gate 1

Resource: gate 1_R

Capacity Type: Capacity

Capacity: 1

☑ Resource Statistics

Process Time: 0.048+EXP(0.00608)

● Route ● StNm ○ Seg ○ Expr

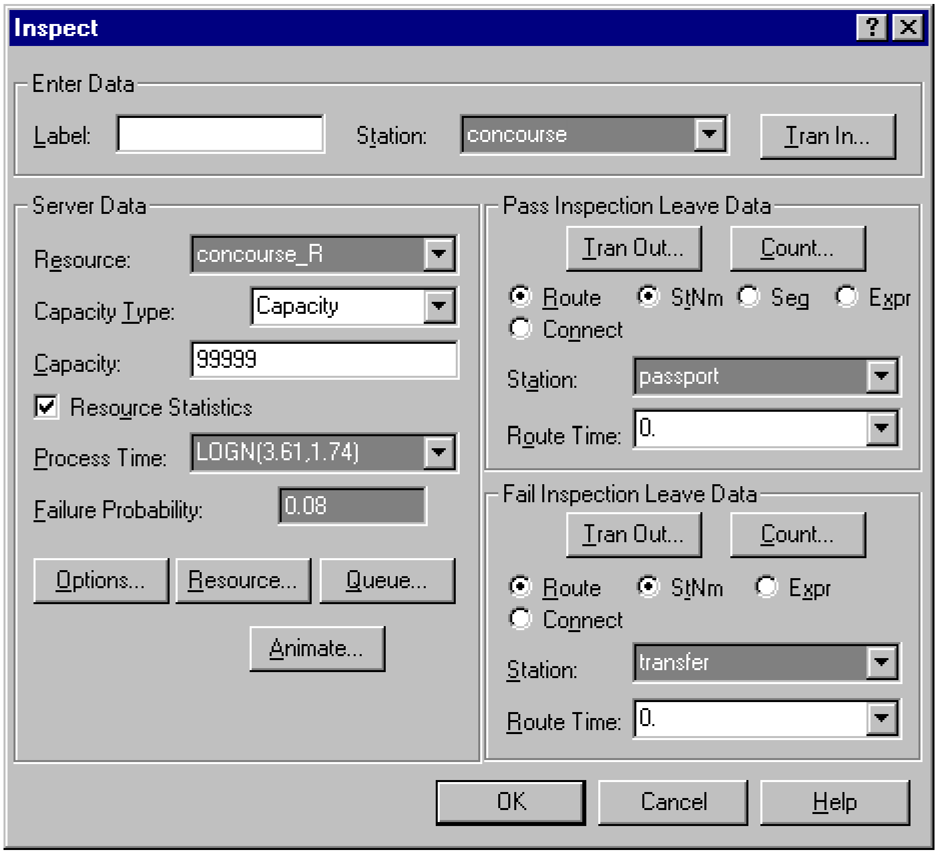
○ Connect

Station: concourse

Route Time: 0

3. Concourse Dialog

The Concourse information uses an “inspect” dialog. All passengers are split into passport-checked arrival and non-passport-checked transfer. These data are used to set up the time distribution for time spent by passengers in the concourse. The input requirements contain capacity (entered with a very large number), percentage of non-passport-checked passengers (shown in “Failure Probability, FP), and the next servers. The very large capacity is used to model the concourse as a FCFS queue with infinite servers. The concourse actually processes passengers simultaneously. For an inspect-type dialog there are two kinds of leave data. According to the user-defined probability (FP), (1-FP) will be entered in the “pass inspection” station (Passport) and FP in the “fail inspection” station (transfer).



Enter Data
Label:
Station: concourse

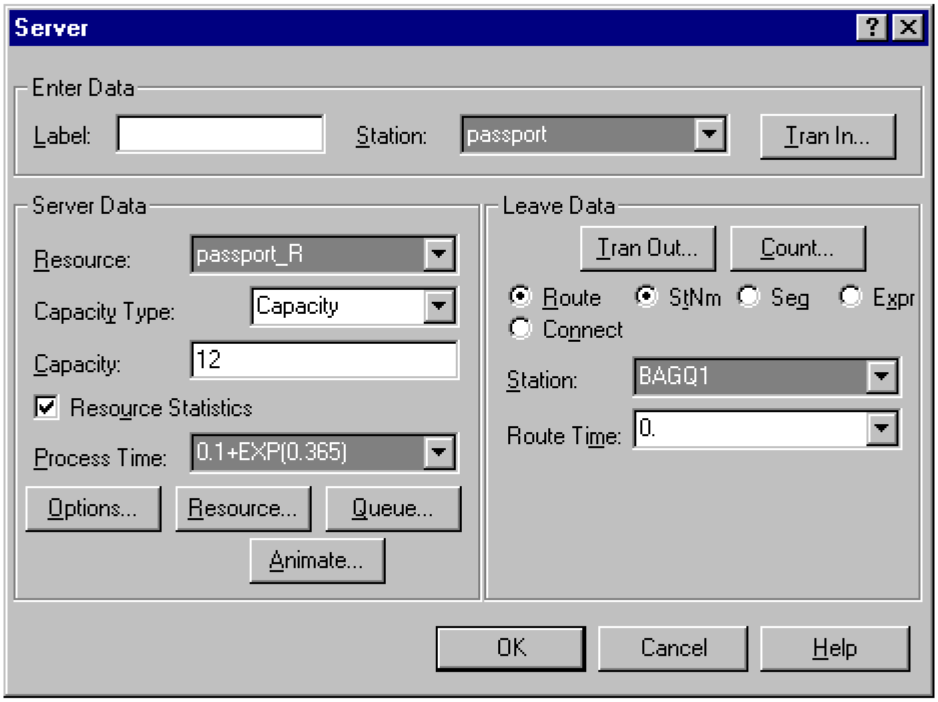
Server Data
Resource: concourse_R
Capacity Type: Capacity
Capacity: 99999
☑ Resource Statistics
Process Time: LOGN(3.61,1.74)
Failure Probability: 0.08

Pass Inspection Leave Data
● Route ○ Connect
● StNm ○ Seg ○ Expr
Station: passport
Route Time: 0.

Fail Inspection Leave Data
● Route ○ Connect
● StNm ○ Expr
Station: transfer
Route Time: 0.

4. Passport Dialog

Except for international transfer passengers, all passengers undergo immigration checks when arriving at airport terminals. Passport, by using a “server” dialog, is modeled as a pooled multi-channel queue system. The input requirements contain total number of check positions (shown in capacity), service time distribution, and the next server (BAGQ1). The operational adjustment factor, obtained by the airport observation, was found to be 0.6.



Label:

Station: passport

Resource: passport_R

Capacity Type: Capacity

Capacity: 12

☑ Resource Statistics

Process Time: 0.1+EXP(0.365)

● Route ● StNm ○ Seg ○ Expr

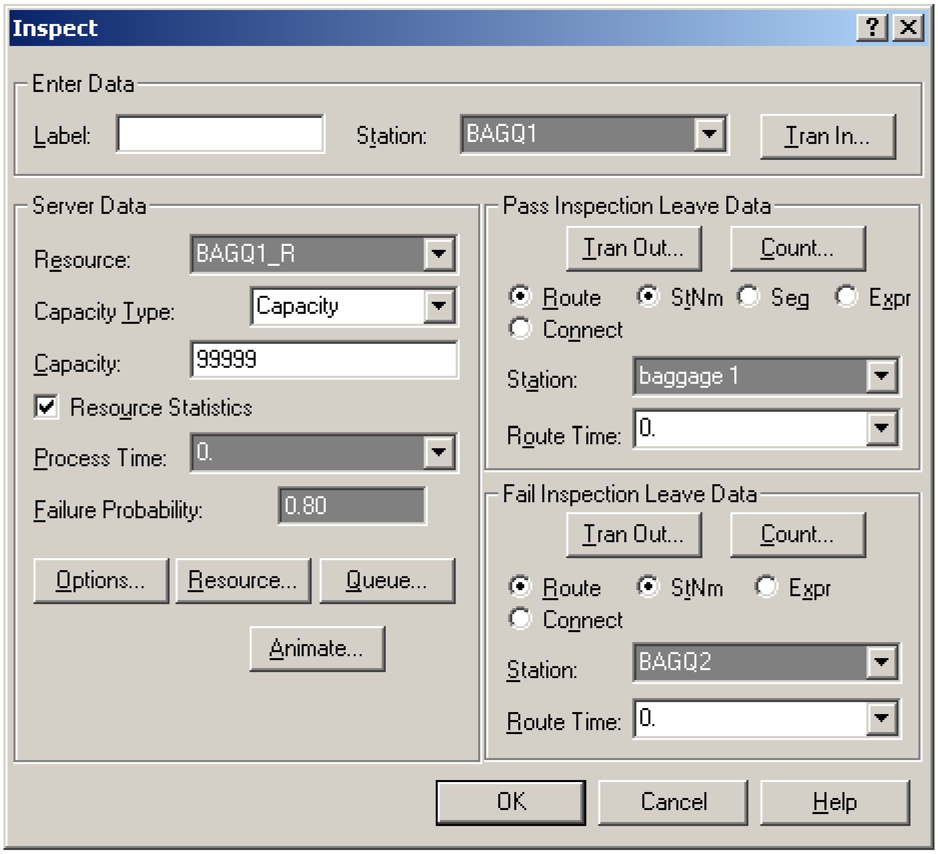
○ Connect

Station: BAGQ1

Route Time: 0.

4. *BAGQ1 Dialog*

This is a pseudo station. Its objective is to model a baggage claim system as separate queues and to split passengers after passport control into each baggage carousel. The percentage information shows the proportion of passengers processed by the first carousels and the others. For a pseudo station, capacity is close to infinity and all processing times are set to zero. This study assumed that the probability of each baggage carousel occupied is the same. For example, if there were *N* baggage carousels operated simultaneously in the terminal, one would need to build (*N*-1) pseudo stations by using an “inspect” dialog. Based on this assumption, *1/N* (in this case, 20%) enter the first carousel (baggage 1) and (1-*1/N*) enter the next pseudo station (BAGQ2) to assign an entity to the second carousel.



Enter Data
Label:
Station: BAGQ1

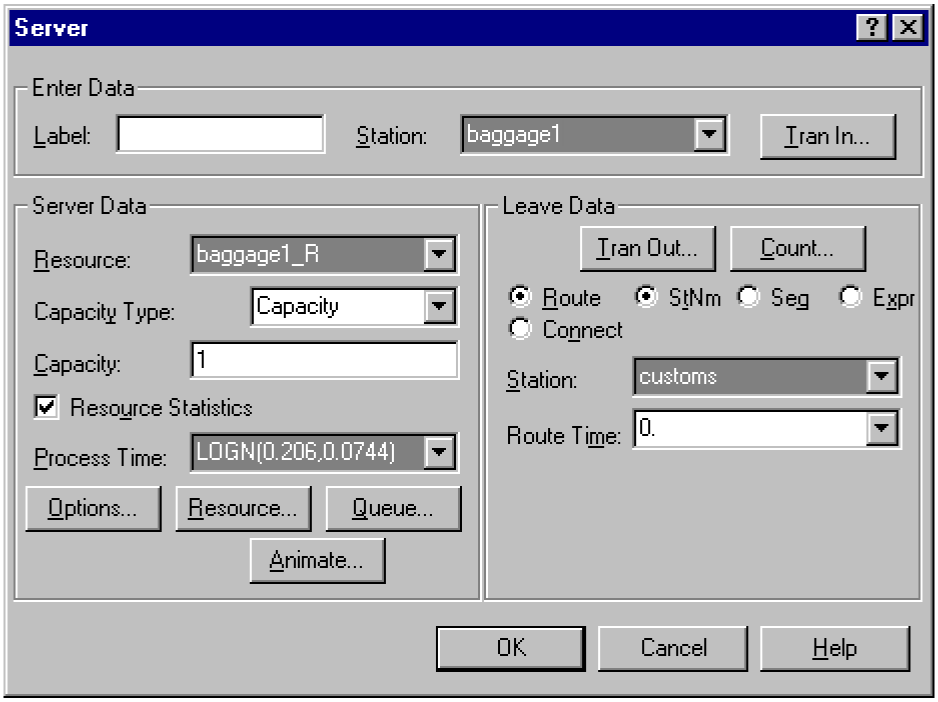
Server Data
Resource: BAGQ1_R
Capacity Type: Capacity
Capacity: 99999
☑ Resource Statistics
Process Time: 0.
Failure Probability: 0.80

Pass Inspection Leave Data
● Route ● StNm ○ Seg ○ Expr
○ Connect
Station: baggage 1
Route Time: 0.

Fail Inspection Leave Data
● Route ● StNm ○ Expr
○ Connect
Station: BAGQ2
Route Time: 0.

5. *Baggage Dialog*

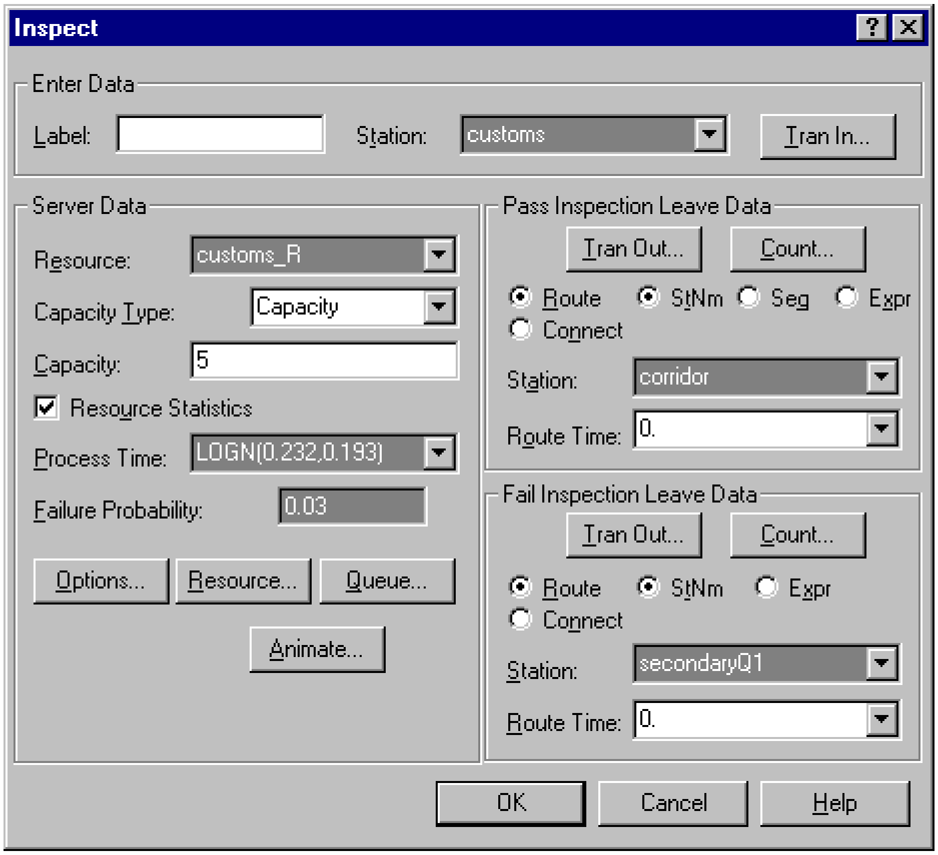
Since all international passengers undergo customs declaration, a “server” dialog is employed. This information includes average service time distribution of baggage carousel, and the next server (Customs). At this stage, passenger flow has been processed by the preceding pseudo stations. The calculation of queuing length and waiting time is based on separate queues. The operational adjustment factor for baggage claim system was found to be 0.8.



Label:
Station: baggage1
Resource: baggage1_R
Capacity Type: Capacity
Capacity: 1
☑ Resource Statistics
Process Time: LOGN(0.206,0.0744)
● Route ● StNm ○ Seg ○ Expr
○ Connect
Station: customs
Route Time: 0.

6. *Customs Dialog*

In the integrated simulation model, customs check is modeled as an inspection module involving the secondary examination in order to better approximate real-system operations. It is also considered as a pooled multi-channel queuing system. The probability information refers to the proportion of passengers to be secondarily checked. This probability information was obtained by interview with US Customs personnel. This study conducted an observation at DFW international airport. Other passengers are entering the next server (Corridor). The operational adjustment factor for the primary customs examination was found to be 0.8.



Inspect

Enter Data

Label:

Station: customs

Server Data

Resource: customs_R

Capacity Type: Capacity

Capacity: 5

☑ Resource Statistics

Process Time: LOGN(0.232,0.193)

Failure Probability: 0.03

Pass Inspection Leave Data

● Route ● StNm ○ Seg ○ Expr

○ Connect

Station: corridor

Route Time: 0.

Fail Inspection Leave Data

● Route ● StNm ○ Expr

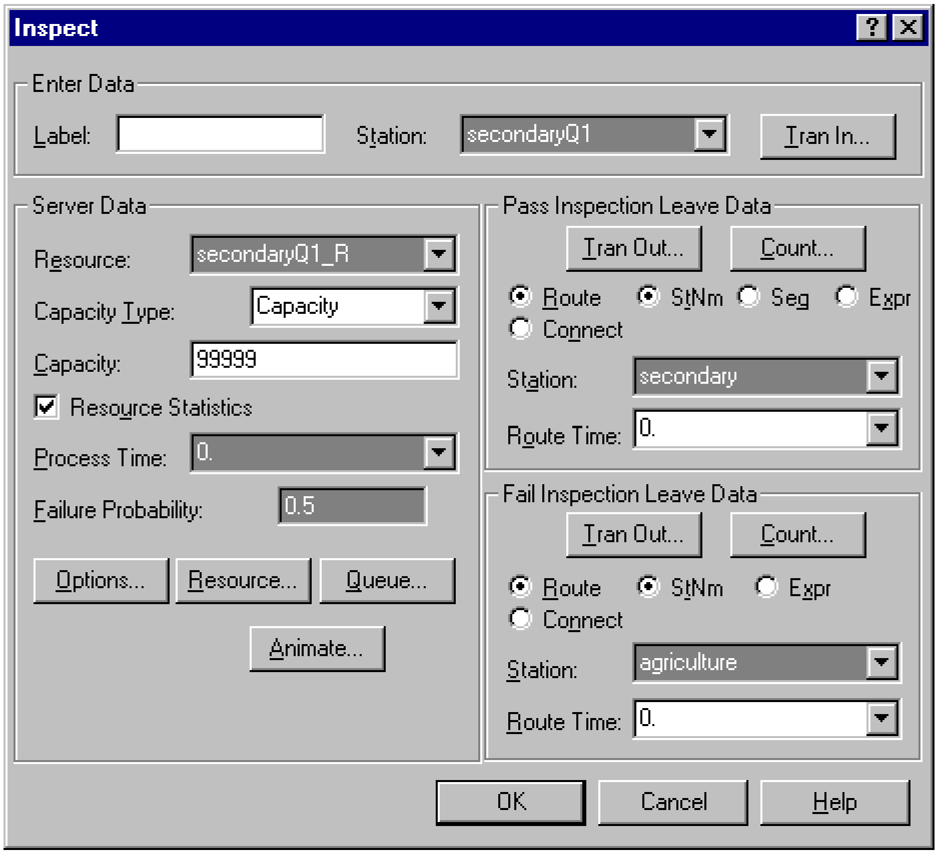
○ Connect

Station: secondaryQ1

Route Time: 0.

7. *SecondaryQ1 Dialog*

This step is also a pseudo station that splits the passengers into secondary customs check and agriculture examination evenly. This station simply serves model secondary checks as separate queues, which can better reflect real operations.



Enter Data

Label:

Station: secondaryQ1

Server Data

Resource: secondaryQ1_R

Capacity Type: Capacity

Capacity: 99999

☑ Resource Statistics

Process Time: 0.

Failure Probability: 0.5

Pass Inspection Leave Data

● Route ● StNm ○ Seg ○ Expr
○ Connect

Station: secondary

Route Time: 0.

Fail Inspection Leave Data

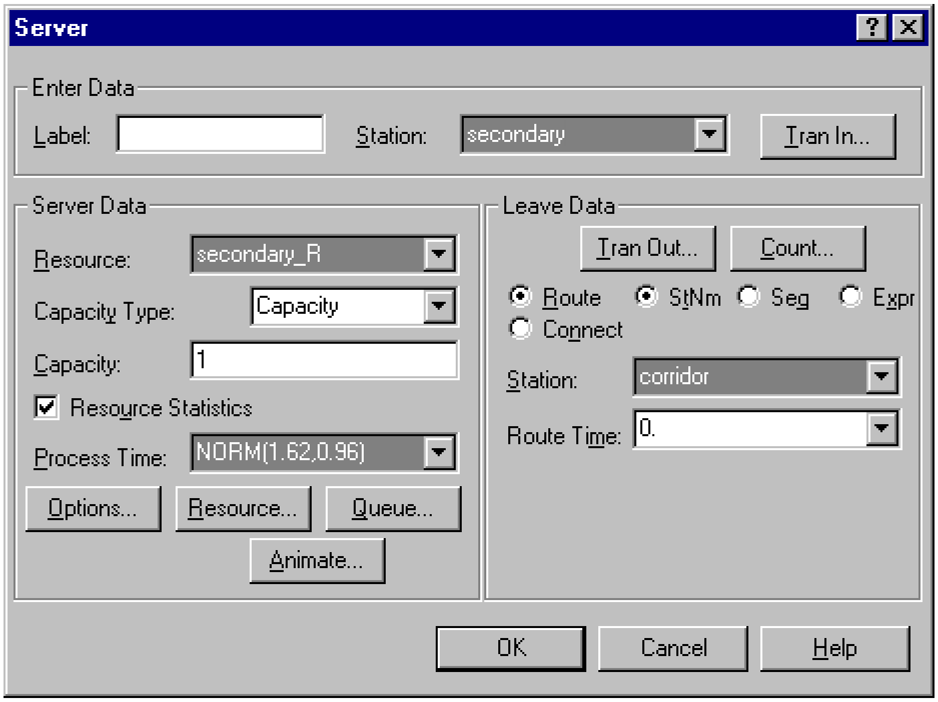
● Route ● StNm ○ Expr
○ Connect

Station: agriculture

Route Time: 0.

8. *Secondary Dialog*

This step demonstrates the service time distribution for secondary customs check. The other server named “Agriculture” has the same attributes as this server.



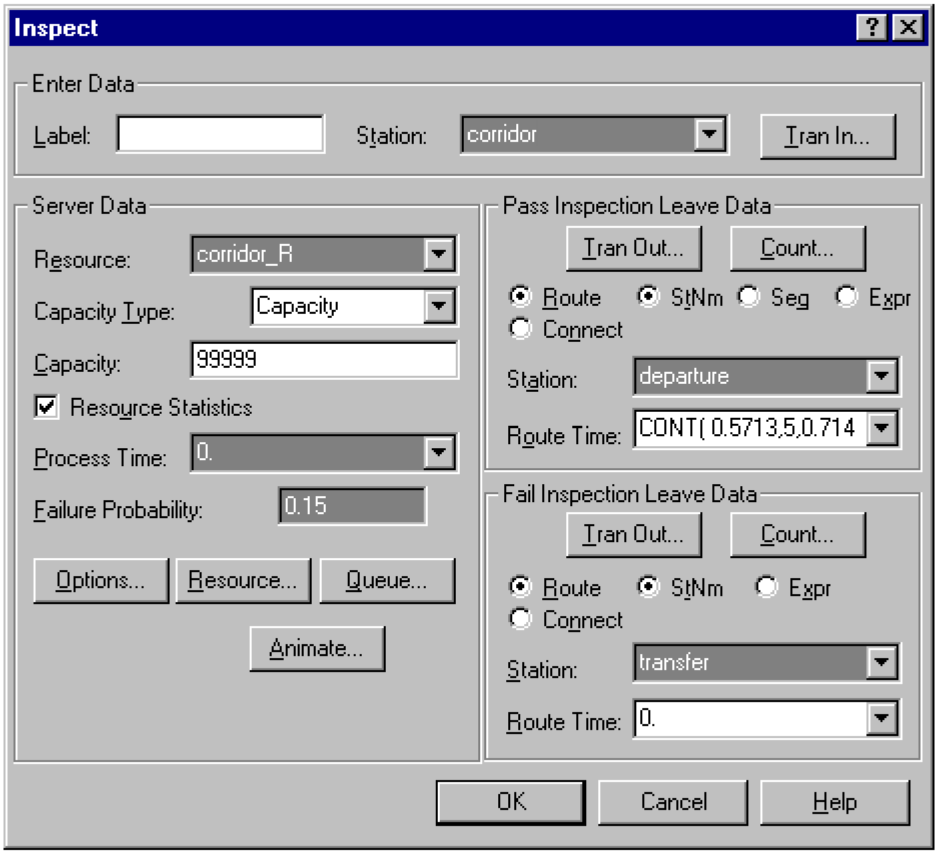
Label:
Station: secondary

Resource: secondary_R
Capacity Type: Capacity
Capacity: 1
☑ Resource Statistics
Process Time: NORM(1.62,0.96)

● Route ● StNm ○ Seg ○ Expr
○ Connect
Station: corridor
Route Time: 0.

9. *Corridor Dialog*

This server is used to set the proportion of baggage-rechecked transfer (mostly international-domestic transfer) passengers, and the lobby time distribution that shows a continuous empirical distribution. The expression of the continuous empirical distribution is *CONT(0.5713, 5, 0.714, 10, 0.8571, 15, 1, 20)*. Non-transfer passengers enter the next station (Departure) and leave the system.



Inspect

Enter Data

Label:

Station: corridor

Server Data

Resource: corridor_R

Capacity Type: Capacity

Capacity: 99999

☑ Resource Statistics

Process Time: 0.

Failure Probability: 0.15

Pass Inspection Leave Data

● Route ● StNm ○ Seg ○ Expr

○ Connect

Station: departure

Route Time: CONT(0.5713,5,0.714

Fail Inspection Leave Data

● Route ● StNm ○ Expr

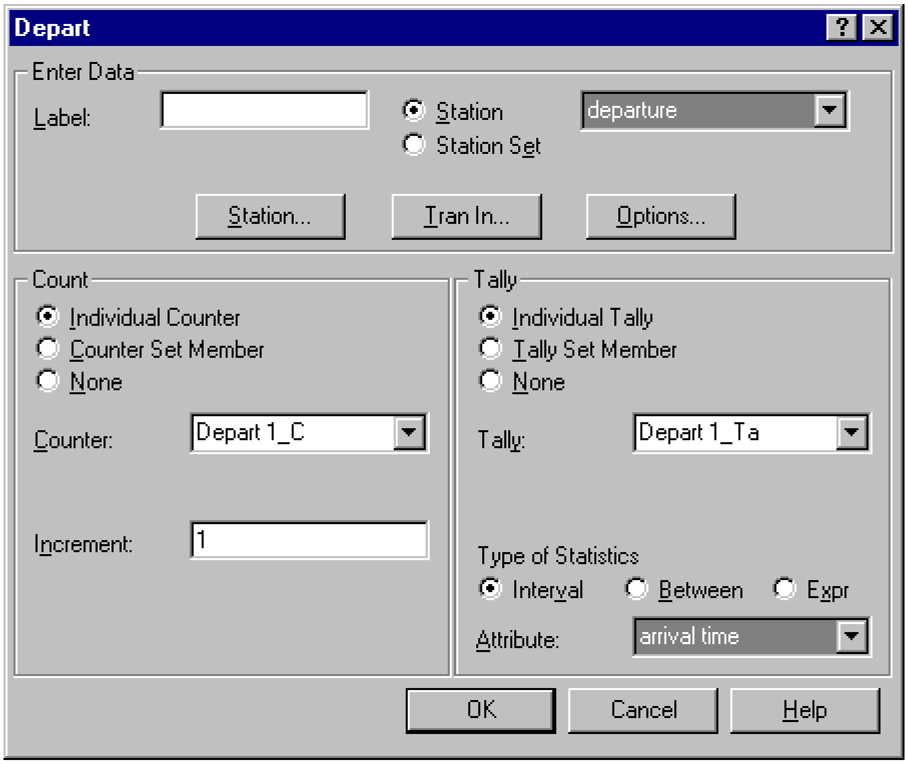
○ Connect

Station: transfer

Route Time: 0.

10. Departure Dialog

Departure, as well as transfer, is modeled by "depart" dialog and defines the end of the system and the statistical information the system is to provide, including entity counter and total time spent in the system (Tally).



Label:
● Station: departure
○ Station Set

Count:
● Individual Counter
○ Counter Set Member
○ None

Counter: Depart 1_C
Increment: 1

Tally:
● Individual Tally
○ Tally Set Member
○ None

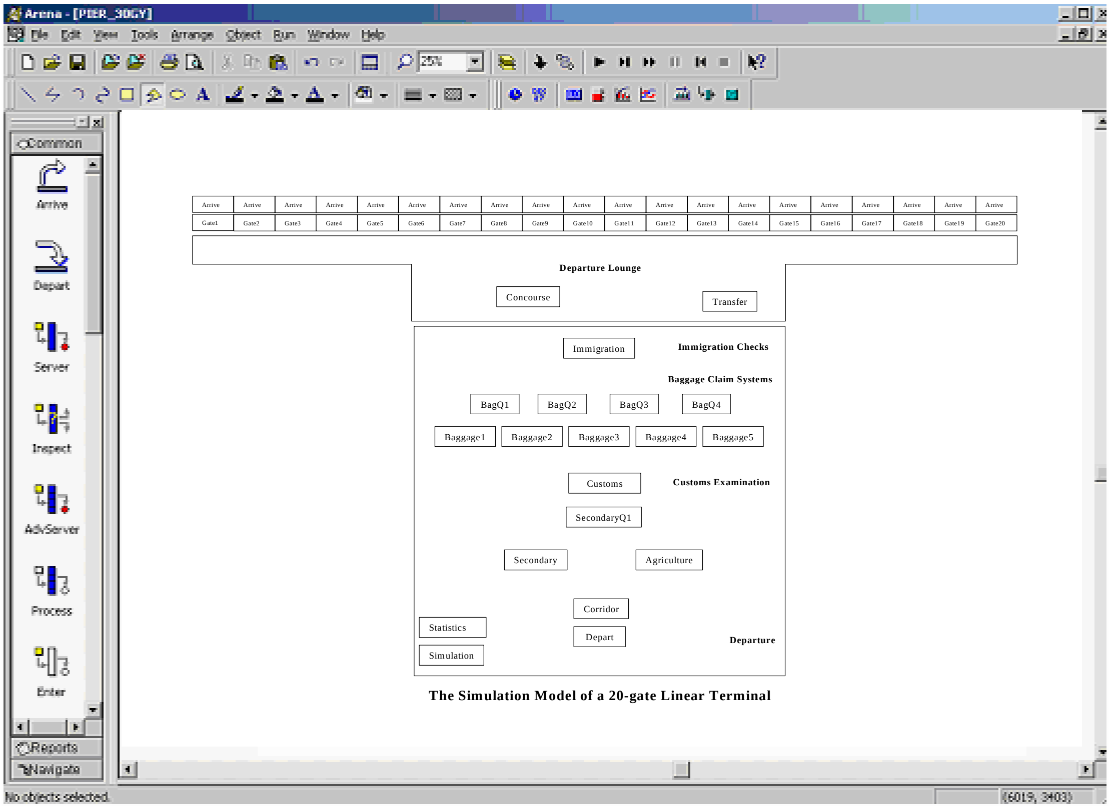
Tally: Depart 1_Ta

Type of Statistics
● Interval ○ Between ○ Expr

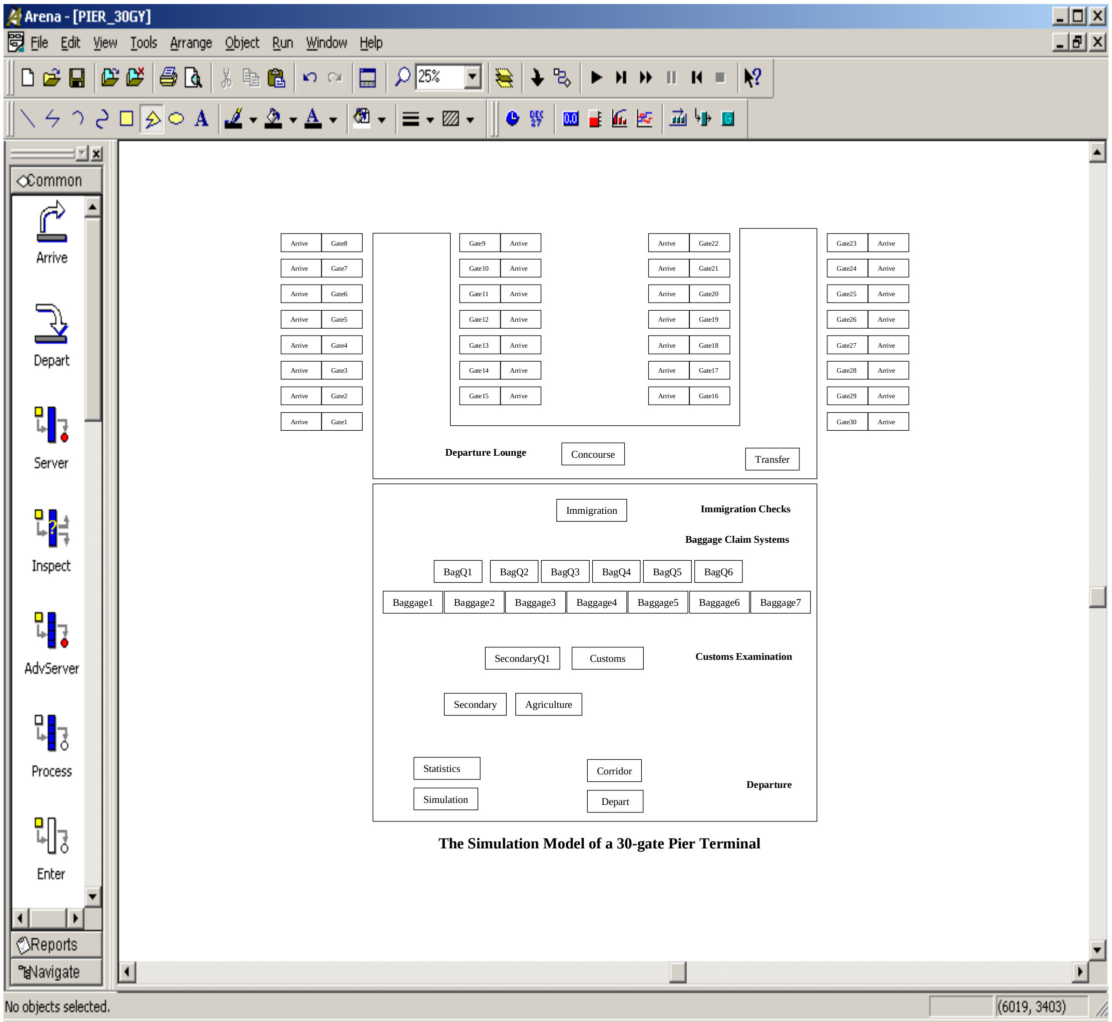
Attribute: arrival time

In conclusion, this model can simulate arrival passenger flow at a specific airport terminal by modifying the relative input parameters. In terms of integrated modeling, the parameters can be enhanced by more comprehensive surveys.

11. The Simulation Model of a 20-gate Linear Terminal



12. The Simulation Model of a 30-gate Pier Terminal



No objects selected.

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