Simulation and GA-optimisation for modeling the operation of airport passenger terminals

By Doina Olaru[•] and Stephen Emery - The University of Western Australia

Abstract

The continuous increase of air traffic and new security measures, introduced to protect commercial aviation, challenge numerous airports in terms of their capacity and their performance indicators.

Simulation represents a "standard tool" for modelling stochastic queuing systems, but in very rare situations hybridising simulation with optimisation occurs for enhancing the modelling results (Van Dijk et al., 2006). This paper reports on such a combined model developed for the landside of a passenger terminal, in order to evaluate the performance of the terminal, and potential implications of changes in the operation (Andreatta et al., 2007). These changes include modified airplanes' schedule; introduction of checked baggage screening; and changes from dedicated to multi-airline check-in desks.

The discrete event simulation model is built using Extend V.6 platform (ImagineThat) and includes all passenger operations required for departure of aircraft (arrival of passengers from carpark area/tour buses, check-in, security screening, waiting in the gate lounges or commercial/recreational area, and boarding). There are numerous airlines operating and currently they have dedicated check-in points. This is likely to be less efficient especially when the time between departing flights is reduced. The delay affects aircraft departures, passengers' waiting time and service levels. Similarly, security screening (X-ray and walk-through detecting equipment, followed by explosive trace detecting) can represent a bottleneck in the system if the scheduled departures of the aircrafts become too close to each other.

The model captures the underlying queuing processes and displays detailed results on any queue in the terminal and on the level of service (LOS) at any minute. For optimisation purposes, the model applies the valuation of waiting time recommended by IATA ($40/min). The model signals situations when LOS is lower or equal to IATA level C during the peak times operation and it also provides assistance on how to alleviate such situations using a GA-optimiser (e.g., given a certain schedule of departures, it opens/closes facilities to reduce delays).

The model can assist management to evaluate the efficiency of the entire complex of operations in the terminal – departure area. Verification and validation of the model has been achieved via consultation with airport management and data collection done on two occasions.

Key words: airport operation, optimisation, simulation

[•] Contact author
School of Economics and Commerce - UWA
M261
35 Stirling Highway, Crawley, 6009, W.A.
Phone: 61 (08) 6488 3908
Fax: 61 (08) 6488 1055
Email: doina.olaru@uwa.edu.au

1 Introduction

A general objective of airport planning and scheduling activities is to optimise the use of infrastructure and the cost of operation (Zografos and Madas, 2006; Madas and Zografos, 2008). Therefore, algorithms and solutions to avoid inefficient functioning are of great value for airport terminals.

Traditionally, operations research (OR) was asked to offer answers to the planning operation, and the problem decomposition was a successful solution strategy when coupled with very fast and efficient algorithms. Yan and Tang (2007) investigated gate assignment as result of stochastic delays using integer programming with three heuristic methods. Chu (2007) used goal programming for crew rostering in Hong Kong airport and Bäuerle et al. (2007) applied queuing models for the analysis of waiting time of arriving aircrafts and the relation with capacity in airports with one or two runways. However, repeated 'what–if' analyses, that enhance the understanding of how variations in the 'slow' dynamics systems affect the solutions of the 'fast' systems, were addressed by using simulation (Banks, 1998; Roanes-Lozano et al, 2004; Van Dijk et al. 2006; Andreatta et al., 2007). Simulation studies either:

- focus on particular sub-systems in the airport operation (traffic control, passenger vs baggage flows, modelling of airspace, airfield, or terminal operations) - Kaltenhäuser, 2003; Van Landeghem and Beuselinck, 2002);
- or treat the whole airport as an entity (Offerman, 2001; Assa and Thomet, 2004; Andreatta et al., 2007).

This research addresses the operation of a departure terminal using simulation combined with optimisation with genetic algorithms. Simulation modelling is popular because of the visualisation of each system and its interactions, ability to compress or expand time for thorough investigation, relative simplicity in understanding and interpreting (Banks, 1998).

In recent years, there has been a concerted push toward developing scheduling methods with greater mathematical capabilities. One such method involves the use of genetic algorithms (GAs), which are a form of heuristic, that have begun to gain prominence in the transport industry. GAs were originally developed to mimic the processes involved in evolution and natural selection (Holland, 1975; Davis, 1991). These algorithms were based on the need for each species in nature to adapt to a complicated and changing environment in order to maximise their likelihood of survival. The metaphysical improvement of each species is encoded in its chromosomes that are transformed as reproduction occurs. Over time, these transformations result in species that have greater chance of survival in a given environment and are therefore more likely to pass these genetic characteristics onto future generations.

A review of the publications in airport modelling however reveals very few hybrid applications (Van Dijk and van der Sluis, 2006) on how to improve airport terminal performance, despite its importance. The combination of simulation and optimisation is expected to enhance the modelling results by taking advantage of both methodologies' benefits.

1.1 Airport terminal operation – brief overview

Jim and Chang (1998) and Correia et al. (2007) present airport as the interface between ground and air transport, comprised of airspace, airfield, and passenger terminal. Each area has its own specific flows and requires different infrastructure and supplied services – e.g., aircrafts and runway, taxiway, and apron systems, ground handling equipment, facilities and personnel for passengers and baggage, etc.

The terminal area focuses on the ground operations necessary for departure, arrival, and transit of passengers. Again, three main functional areas are identified (Correia et al., 2007):

- *Access interface* – serving for passenger transfer from access transport mode to airport's passenger functional area (it includes circulation, parking, and curbside loading and unloading of passengers);
- *Processing* – refers to operations before or after travel time in the airplane (ticketing, baggage check-in, baggage claim, seat assignment, customs, services and security);
- *Flight interface* – where the passenger transfers from the processing functional area to the aircraft (aircraft boarding/unloading and walking on the corridors).

With the increase of air transport demand and new security measures, numerous operations are affected by limited equipment and/or human agents, which affect the performance of the terminal and passengers' perception of quality of services. Level of service (LOS) in terminals is traditionally measured by the amount of space per passenger in different areas (check-in, baggage claim, corridors, etc.). IATA has five levels of service (A – the best to F – unacceptable) and recommends for comfort values between 1.4 (generic area) to 2.7 (holding area) m^2/passenger for an A level of service. However, this indicator has been criticised by airport professionals (Yeh and Kuo, 2003; Correia et al., 2007) for its linearity between space and LOS, for not being consistent to customers perceived standards of service (customers have different evaluations of processing time vs waiting time, and the second significant indicator of service after processing is the provision of various facilities in the terminal) and for not including subjective/soft elements of service such as comfort, ambience, courtesy of staff.

Yeh and Kuo (2003) used a fuzzy multi-attribute decision making approach for evaluating passenger service quality in Asia-Pacific international airports and Correia et al. (2007) applied regression analysis to evaluate the weights for LOS of different compartment areas of the terminal airport. Their findings show that concessions are extremely important in the airport and access can sometimes overshadow check-in or screening waiting times.

2 Empirical setting

The simulation model is built for Broome International Airport departures system. Broome International Airport (BIA) serves the Broome Town, Broome Shire, and surrounding area in the Kimberley. BIA had one of the highest numbers of passengers across the regional airports in Western Australia, accounting for 346,930 passengers in 2006. Traffic at Broome grew significantly in the last 5 years with a growth rate of 13% per annum. In terms of origins of passengers, 60% come from Perth, and around 60% of passengers are associated with tourism.

It is expected that significant growth in oil and gas exploration would occur off the Kimberley coast and be substantially serviced by BIA which would continue as a hub for destinations in Kimberley region. Similarly, future growth in traffic at BIA is expected to be linked to tourism, although limited by the capacity of tourist accommodation.

In 2007 a number of more than 379,000 passengers are expected to be served, and Kubu Australia Pty Ltd (2007) forecasted 817,000 passengers for 2025, which is similar to growth forecasted for similar airports such as Sunshine Coast Airport in Queensland (Maroochy Council, 2007). There is a strong seasonal, weekly, and daily variation of traffic, with June and July the highest level (double the demand of February when the traffic is minimum). Weekly and daily peaks depend on the airlines schedule (Qantas, Virgin, SkyWest, and smaller carriers) which is variable through the year. Sunday is typically the busiest day of the week and in 2006 there was typically a single main peak at lunchtime. For planning purposes, level of service is determined for the peak period on the 30th busiest day. The peak period at Broome is slightly more than an hour long, since the aircrafts tend to depart/arrive within a

60-90 minute block (in 2006, during the 30th busiest day peak period, 412 passengers departed the airport).

Broome International Airport departure terminal has an area of 1,638 m^2, including check-in desks, security, offices, waiting lounge, a bar/café and gift shop, and departure gates. Of this, 288 m^2 is available for check-in and security queuing/corridors. The simulation model starts with the carpark and includes all these facilities until departure of the aircraft. The model does not address the potential bottlenecks in the air traffic route or ground airfield operations and considers them as exogenous influences on the terminal functioning. As indicated, the model focuses currently on departures considered by BIA management as priority area of investigation, and the operation of the arrival module will follow shortly.

3 Simulation model

The simulation model for Broome International Airport departures system includes a series of hierarchical blocks such as: arrival passengers in the terminal, queuing in the check-in area, check-in, security screening, waiting in the departure lounge (including shopping and dining), boarding of aircrafts and departure (Figure 1). Each of these blocks include numerous building blocks of the software with different functionality (generators or programs, blocks setting the parameters of the processes or attributes of the passengers or airline, blocks performing a service, queues, blocks performing mathematical of logical operations, and blocks displaying information about the processes). Information comes into a block and is processed by the program in the block. As convention, green border is identifying input blocks, blue processing blocks, and red border either information of output blocks. Blocks linked through thick connection lines move physical items (e.g., passengers, baggage) and blocks with single/thin connection lines are responsible for information flows only.

The capability of grouping blocks hierarchically is appealing for its simplified view of the model. Each hierarchical block has a ‘unique theme’ and therefore, the investigation of that particular process requires observation to be made on only one level. Each of the hierarchical blocks enumerated above will be described in greater detail in the following.

3.1 Arrival passengers

Figure 2 shows the structure of the block of arrivals. Arrivals in the departures terminal are expected between 90 to 30 min prior to departure of the aircraft. A number of passengers are considered to be already in the airport before the 90 min interval for the morning flights – in general tourists who check-out in the morning and come directly to the airport. Passengers come by taxi, rented or private cars or tourist buses (see Figure 8). In the model each person entering the departures terminal has a number of attributes: their flight, if they are passengers or just accompanying passengers to the airport, size of the group/family departing from Broome (Figure 2). Party size depends on the purpose of the trip, and 60% of the passengers are associated with tourism (couples and families). For departures of a particular airline and flight, a number of passengers equal to the capacity of the aircraft multiplied by the occupancy (load factor) is generated. Visitors represent 20% of the total number of persons coming into the terminal.

Data from July 2007 and November 2007 was used to calibrate the distribution of arrivals: exponential distribution with inter-arrival time of 0.45 to 0.5 min for passengers in cars and a number of scheduled buses (2-4) at 10 min interval (with variable number of passengers from 8 to 20 using an empirical distribution estimated from data using BestFit software, Palisade Corporation).

3.2 Queuing before check-in

Depending on the airline, passengers currently queue in two main areas: Qantas (on the right of the main entrance, closer to security) and Virgin and Sky-West (left of the main entrance and in the vicinity of airport offices) (Figure 3). A random uniform distribution with average of 0.25 min is established for walking in the terminal towards the check-in points. Only passengers are considered to stand in line before the check-in desks, visitors accompanying them do not affect the LOS.

The areas for queuing are 30 and 42 m^2 and they were used for assessing the level of service in the check-in area of the terminal (Figure 4). IATA's criteria are presented in Table 1 for all airport service areas. The level of service decreases from A (excellent) to E (very poor) or F (unacceptable – not shown in the table).

Table 1 Level of service (LOS) in airports

LOS	**Unit**	**A**	**B**	**C**	**D**	**E**
Baggage claim	(m^2)	2.00	1.80	1.60	1.40	1.20
Flow-space	(passengers m^2)	20.00	25.00	40.00	57.00	75.00
Check-in area	(m^2)	1.80	1.60	1.40	1.20	1.00
Holding area	(m^2)	2.70	2.30	1.90	1.50	1.00
Generic area	(m^2)	1.40	1.20	1.00	0.80	0.60

For example, if in the check-in area there is an average secured space of 1.6 m^2/passenger, this suggests the area operates at service level B - high LOS and comfortable for passengers. Usually, level C is recommended as a minimum and level D is considered acceptable for very short peak periods.

3.3 Check-in operations

Broome International Airport (BIA) has dedicated check-in points for all airlines (Figure 5). In general 3-5 check-in counters open 90 min before the departure and close 30 min before the departure of the aircraft. For a more efficient operation, the model allows for opening of additional check-in points depending on the length of the queue (e.g., above 25 passengers). Online check-in has also been considered, but data collected has shown that only 8-10% of passengers used it in July and November 2007.

Triangular distributions were used for the check-in time depending on the purpose of the trip and if the passenger has already the boarding pass. For example, groups who spent their holiday in Broome are likely to have more luggage and in consequence higher service rate. Check-in desks have also slightly differentiated service characteristics accounting for the human factor. In average the service time has as parameters: 0.5 (min), 1.1 (most likely), and 1.5 (max) min/person.

After collection of boarding pass and/or baggage drop, passengers walk to the security screening area located on the right of the main entrance in the departure terminal (a random distribution with values between 0.1 and 0.2 min is used for walking).

3.4 Security screening

Currently BIA security screening involves X-ray of all hand luggage (passengers deposit in separate trays laptops, personal items, liquids, along with their cabin luggage for scanning on only one band and tunnel) and walk of each person through the magnetometer, followed by random explosive trace detecting on about 15% of all passengers.

The screening lasts for a couple of seconds to 0.5 min with an average of 12 seconds/person (Figure 6). When necessary passengers and visitors have to walk more than once through the detection equipment and this may increase the service time. Similarly, a carry-on item may be scanned twice if the first screening is not conclusive. Having only one X-ray machine and one arch-shaped magnetometer, when departures of aircrafts are close to each other, the area becomes a bottleneck for the BIA airport operation.

As the Australian Government will spend $114 million on a dramatic expansion of the aviation security regime (http://www.dotars.gov.au/transport/security/aviation/index.aspx), new security measures such as baggage screening before check-in are expected. They are discussed at BIA and the model has inserted them as potential options.

3.5 Operations before boarding

Once passengers and visitors have passed through the security operations, they arrive in the 998 m^2 departure area where they can choose from the existing facilities or head directly to the gates (Figure 8 shows the blocks used to model the operations and Figure 10 presents the layout of the area). The departure lounge includes: a fountain surrounded by tropical vegetation in the middle, recreation area with a bar/café and a souvenirs shop (on the right), and two gate lounges with Internet access (on the left). The departure area accommodates seating for 180 passengers with a number of 36 tables and 12 benches spread in the area and has facilities such as rest rooms and showers, and Internet booths in the gate 1 lounge.

3.6 Boarding and departure aircrafts

Boarding starts 20 to 15 mins before the scheduled departure (Figure 7). At any one moment a maximum of two Boeing 737 class airplanes can be departing. The flight schedule is considered as main input in the model (the demand placed on the terminal) and any delays caused by time variability of the schedule impacts upon the service of the terminal operations.

The characteristics included in the model are: airline/flight, type of aircraft, capacity/# of PAX, load factor (utilisation rate). For example, a Qantas 737-800 (flight QF1930) has 177 seats and load factor up to 100%).

3.7 Assumptions

The aim of this study is to assess the level of service (impact on passenger's service quality) provided in the departure terminal of BIA and investigate the possibility to adjust to a growing number of passengers, changes in air flight schedules, and modifications in the terminal operation:

- reduction of interval between airplane departures;
- "peak-spread" or slot management to avoid sharp increases in waiting times for various operations; traffic peaks are considered to be due to airline scheduling practices and also

preferences/needs of passengers to travel at certain times of the day, or certain days of the week;
- additional baggage screening;
- increase of the departure terminal size.

Currently, the simulation model considers the following operation assumptions:
- check-in desks are available for additional traffic – via common-use of the counters between different carriers;
- all equipment is expected to perform continuously without breakdowns;
- service time distributions are independent of time of day and workload at the check-in point; however, these distributions differ from one facility to the next depending on the experience of the personnel;
- passengers proceed directly from facility to facility (e.g., no passenger goes outside of the terminal to eat in the “city” after his/her check-in, then returns to the terminal before departure);
- the schedule of flights is known (times are needed to generate all simulated passengers);
- if required, a new check-in counter is allocated to an airline until 15 min before scheduled departure of the aircraft.

Statistical analysis has been undertaken to determine the distribution for all processes performed in the departure terminal.

The simulation time has been set for the peak period and the model was “calibrated” to mimic the current situation. The simulation was run 100 times and used a predetermined generator random seed. The results were compared with the observed/recorded data (September 2006, July and November 2007) to validate the model and then several scenarios examined.

A second variation of the model includes an optimiser where the opening of the check-in counters is determined by the model globally instead of using local decision rules. The objective function that is minimised regards the total cost experienced by BIA and passengers for service and waiting. The model applies the valuation of waiting time recommended by IATA ($40/min) and the costs provided by BIA for opening new check-in desks ($150/hour). The constraints we imposed regard level C service in the check-in and security area.

4 Results

Results from simulation can be seen via animation and summary reports. Through animation, the entities, flows can be viewed and the areas of congestion can be located, hence experiments can be designed to assess compliance with changing environment conditions. Through summary reports and plots (Figures 10 and 11 provide two examples of possible output obtained from the model), the details of bottlenecks can be examined, and the performance of various compartments in different conditions observed over time (main outputs are the optimal operation of check-in points and different solutions to ‘what–if’ scenarios). Therefore, simulation assists to check the feasibility of timetables, develop/select and validate new strategies for BIA, providing early feedback on possible impacts of changes for the airport system (Offerman, 2001).

Table 2 presents findings from several scenarios investigated by BIA for their current and future operation.

The optimal allocation of the check-in counters has identified the need for 13 desks and two screening lines in order to provide level C service for passengers for conditions described in scenarios 5 and 6.

Table 2 Results simulations

Scenario	Conditions	#PAX	Queuing time check-in (mean, max)	Queue length check-in (mean, max)	Queuing time screening (mean, max)	Queue length screening (mean, max)	LOS (check-in, security)
1 Busy period Sunday	4 planes – 3 Qantas, 1 Virgin Blue/ SkyWest (interval between departures 30, 15, 15 min)	385 Qantas	4.67', 21.93'	5.99, 49	1.36', 6.01'	2.63, 38	4.4% of the time level below B, A at all times
	5 Qantas + 3 SkyWest & Virgin check-in desks open	144 Virgin Blue and Sky West	5.78', 12.55'	2.77, 32			A at all times, A at all times
2 & 3 Reduced interval between flights	Interval between departures 15 min 5 + 5 check-in desks open	385 Qantas	9.2', 46.34'	12.12', 85	2.38', 8.91'	4.67, 56	11.3% of the time below level D, 8.5% of time level C
		144 Virgin Blue and Sky West	1.93', 5.09'	0.92, 22			A at all times, 8.5% of time level C
	Common-use of check-in points (6 + 4 check-in desks open)	385 Qantas	4.47', 27.09'	5.88', 55	2.52', 8.77'	4.94, 55	4.8% of the time at level C, 8.8% of the time level C
		144 Virgin Blue and Sky West	1.97', 5.87'	0.95, 21			A at all times, 8.8% of the time level C
4 Increased demand	Six flights with departures at 30 min interval	385 Qantas	4.27', 13.91'	3.03, 37	0.64', 2.59'	0.97, 16	A at all times, A at all times
		385 Virgin Blue and Sky West	5.67', 16.12'	3.39, 44			A at all times, A at all times
5 Increased number of passengers due to operation of wide body aircrafts	Same as Busy period Sunday Change of #pax/aircraft from a max of 177 to 350 (e.g., Airbus A330-300) 8 Qantas + 4 SkyWest & Virgin Blue desks open	700 Qantas	34.2', 56.3'	Terminal blocked	11.34', 29.24'	Terminal blocked	41% of the time below level D, 37% of the time below level D
		288 Virgin Blue and Sky West	4.57', 29.3'	4.39, 60			1.3% of the time level below B, 37% of the time below level D
6 Peak-spread	Same as Busy period Sunday Interval between aircraft departures 45 min	700 Qantas	17.9', 30,75'	Terminal blocked	4.4', 16.8'	Terminal blocked	34% of the time below level D, 32% of the time below

Scenario	Conditions	#PAX	Queuing time check-in (mean, max)	Queue length check-in (mean, max)	Queuing time screening (mean, max)	Queue length screening (mean, max)	LOS (check-in, security)
							level D
		288 Virgin Blue and Sky West	1.67’, 5.43’	1.73, 20			A at all times, 32% of the time below level D
7 Additional baggage screening	Same as Busy period Sunday	354 Qantas	2.16’, 8,68’	2.77, 31	0.69’, 2.98’	1.35’, 18	A at all times, A at all times
		288 Virgin Blue and Sky West	1.24’, 5,25’	0.59, 22			A at all times, A at all times
8 Increase of waiting area from 72 to 106 m^2 and change in type aircrafts/airline	4 planes – 2 Qantas, 1 Virgin Blue and 1 SkyWest (interval between departures 30, 15, 15 min) 6 Qantas + 4 SkyWest & Virgin Blue check-in desks open	354 Qantas	2.49’, 6.99’	2.96, 35	3.49’, 8.57’	8.09, 57	7.8% of the time level below C, 48% of the time below level C
		288 Virgin Blue and Sky West	4.57’, 29.3’	4.39, 60			1.3% of the time level below B, 48% of the time below level C

5 Conclusions and recommendations

We used simulation and optimisation as a process of organisational change to assess the efficiency of the airport operation and impacts of infrastructure and operation changes. The optimisation was embedded in the simulation model and focused on: minimising the cost of keeping check-in desks and waiting time for customers. The 'most' limiting resources in the terminal are: the space, number of check-in desks, and the number of security screening lines.

The simulation model was then used to test different scenarios suggested by BIA's management, and observe their impacts. As the model has the possibility to study the fundamental trade-off between the cost of providing service and waiting cost for customers, the investigation of infrastructure effects (e.g., increased floor space or new baggage screening equipment) on the performance of operation (measured as IATA level of service) is possible. Results showed that flexible (common-use) check-in points is an option to optimise costs for both airport and customers when demand increases or it concentrates in a short time interval.

Optimisation has shown that departures at 15 min or increased demand (by including aircrafts of high capacity, e.g. Airbus A330-300 in the current schedule) require more check-in counters and two screening lines (with associated increase in floor space) in order to ensure a minim level C of service in the terminal.

REFERENCES

- Andreatta, G., Brunetta, L., and Righi, L. (2007) Evaluating terminal management performances using SLAM: The case of Athens International Airport, *Computers & Operations Research*, 34, 1532–1550.
- Assa, O. and Thomet, M. (2004) *The Virtual Airport*, Bechtel Corporation, Working Paper, ACI Europe Communiqué Airport Business.
- Banks, J. (ed.). (1998), *The Handbook of Simulation*, J. Wiley & Sons, Canada.
- Bäuerle, N., Engelhardt-Funke, O., and Kolonko, M. (2007) On the waiting time of arriving aircrafts and the capacity of airports with one or two runways, *European Journal of Operational Research*, 177(2), 1180-1196.
- Chu, S.C.K. (2007) Generating, scheduling and rostering of shift crew-duties: Applications at the Hong Kong International Airport, *European Journal of Operational Research*, 177(3), 1764-1778.
- Correia, A.R., Wirasinghe, S.C., and de Barros, A.G. (2007) A global index for level of service evaluation at airport passenger terminals, *Transportation Research Part E: Logistics and Transportation Review*, doi:10.1016/j.tre.2007.05.009.
- Davis, L. D. (1991), *Handbook of Genetic Algorithms*, Van Nostrand, New York.
- Holland, J. H. (1975), *Adaptation in Natural and Artificial Systems*, University of Michigan Press, Ann Arbor, USA.
- Jim, H.K. and Chang, Z.Y. (1998) An airport passenger terminal simulator: A planning and design tool, *Simulation Practice and Theory*, 6, 387-396.
- Kaltenhäuser, S. (2003) Tower and airport simulation: flexibility as a premise for successful research, *Simulation Modelling Practice and Theory*, 11, 187-196.
- Leone, K. and Liu, R. (2005) The key design parameters of checked baggage security screening systems in airports, *Journal of Air Transport Management*, 11, 69–78.
- Madas, M.A. and Zografos, K.G. (2008) Airport capacity vs. demand: Mismatch or mismanagement?, *Transportation Research Part A: Policy and Practice*, 42(1), 203-226.
- Maroochy Council (2007) Sunshine Coast Airport Master Plan, Maroochydore,

- Offerman, H. (2001) Simulation to Support the Airport Stakeholder Decision-Making Process, *Air & Space Europe*, 3(1/2), 60-67.
- Ray, C. and Claramunt, C. (2003) A distributed system for the simulation of people flows in an airport terminal, *Knowledge-Based Systems*, 16, 191–203.
- Roanes-Lozano, E. Laita, L.M., and Roanes-Macías, E. (2004) An accelerated-time simulation of departing passengers’flow in airport terminals, *Mathematics and Computers in Simulation*, 67, 163–172.
- Van Dijk, N.M. and van der Sluis, R. (2006) Check-in computation and optimization by simulation and IP in combination, *European Journal of Operational Research*, 171, 1152–1168.
- Van Landeghem, H. and Beuselinck, A. (2002) Reducing passenger boarding time in airplanes: A simulation based approach, *European Journal of Operational Research*, 142(2), 294-308.
- Yan, S. and Tang, C.-H. (2007) A heuristic approach for airport gate assignments for stochastic flight delays, *European Journal of Operational Research*, 180(2), 547-567.
- Yeh, C.-H. and Kuo, Y.-L. (2003) Evaluating passenger services of Asia-Pacific international airports, *Transportation Research Part E: Logistics and Transportation Review*, 39(1), 35-48.
- Zografos, K.G. and Madas, M.A. (2006) Development and demonstration of an integrated decision support system for airport performance analysis, *Transportation Research Part C: Emerging Technologies*, 14(1), 1-17.

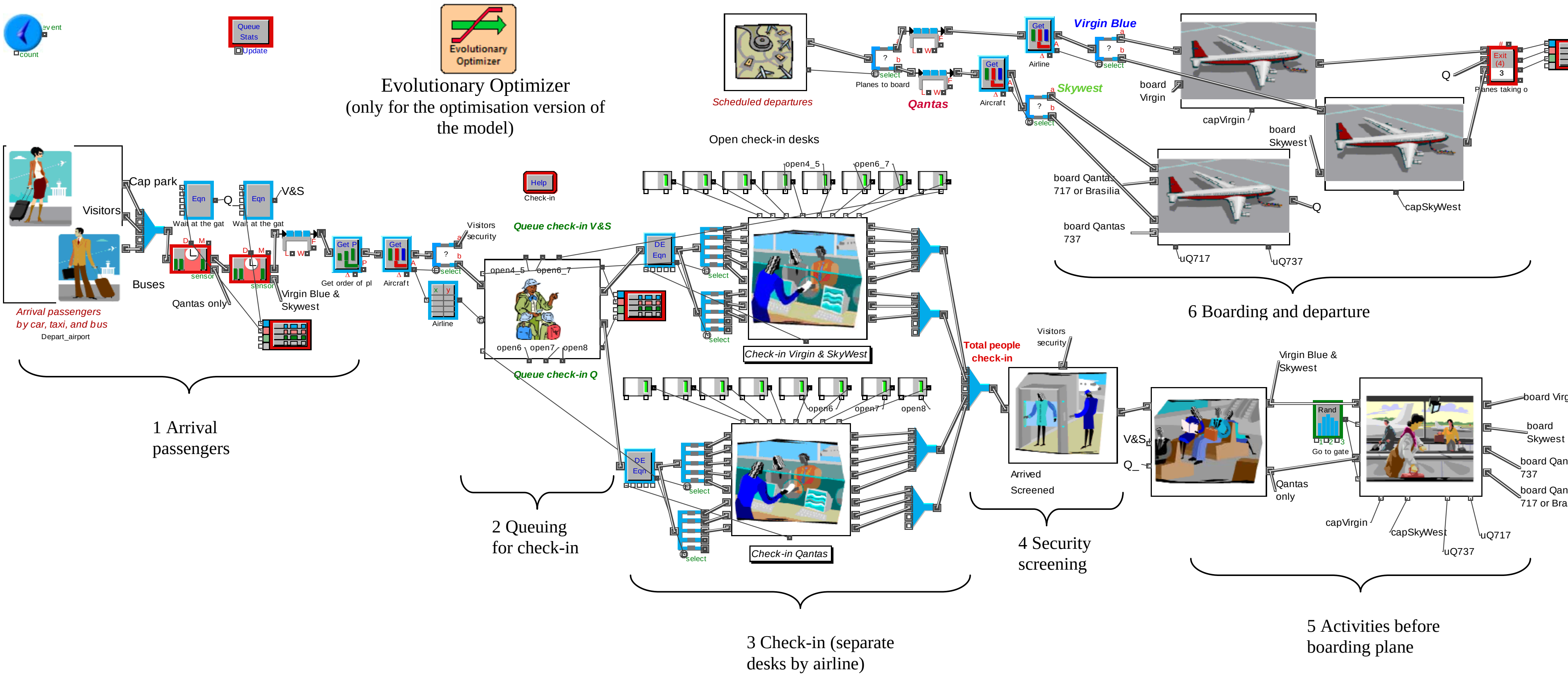

Figure 1 Overall structure of the model

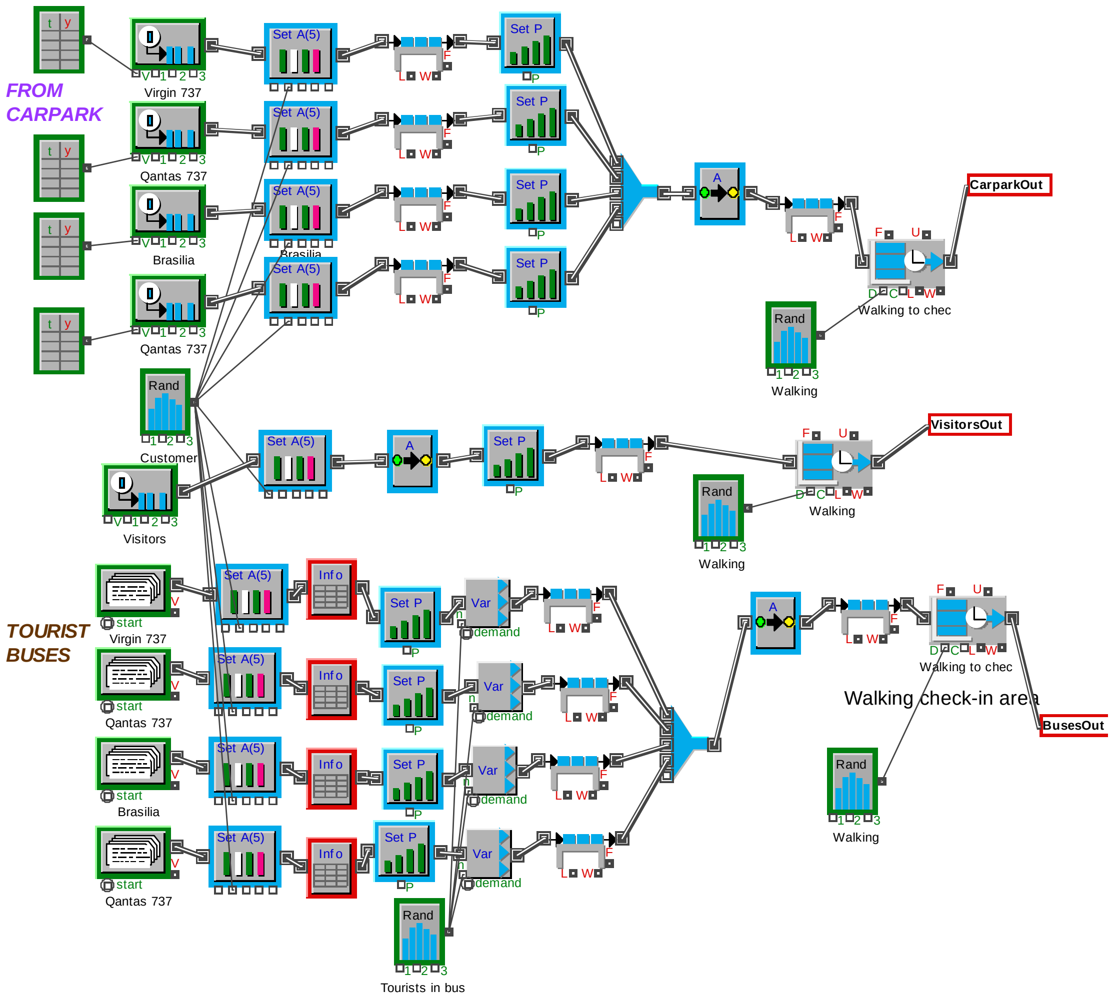

Figure 2 Structure of the hierarchical block "Arrival passengers" in the terminal

Figure 3 Queuing area in departure terminal

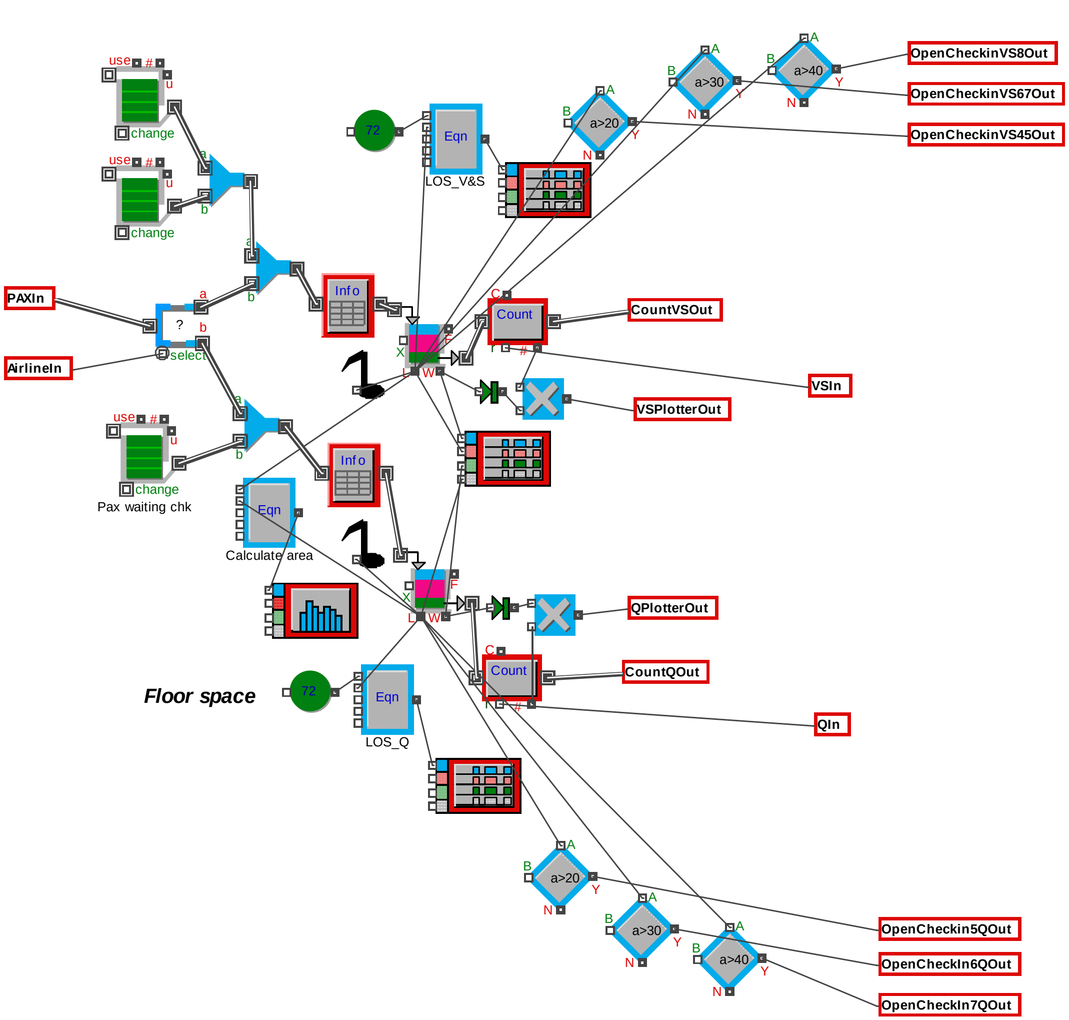

Figure 4 Structure of the hierarchical block “Queuing for check-in”

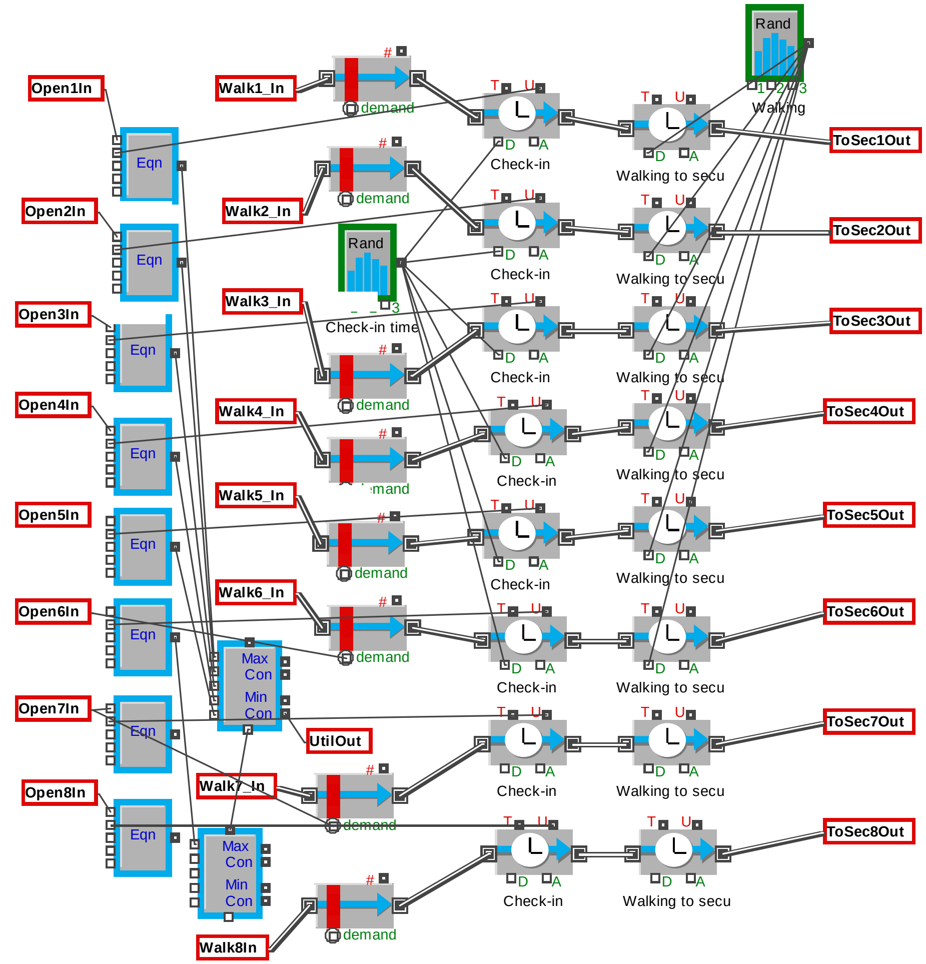

Figure 5 Structure of the hierarchical blocks “Check-in” (airline specific)

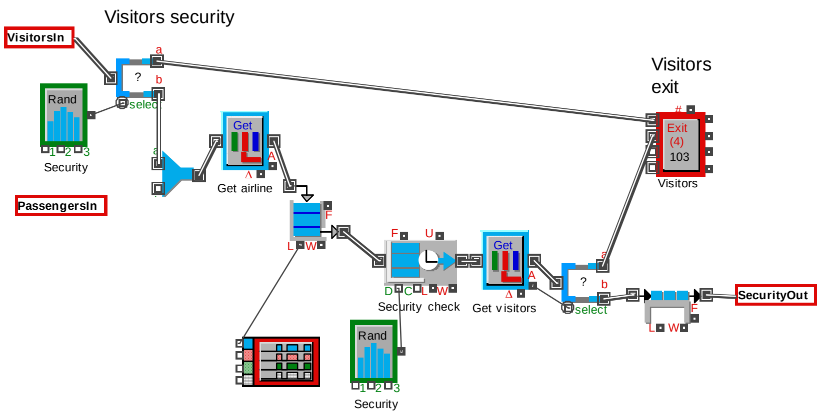

Figure 6 Structure of the hierarchical block “Security”

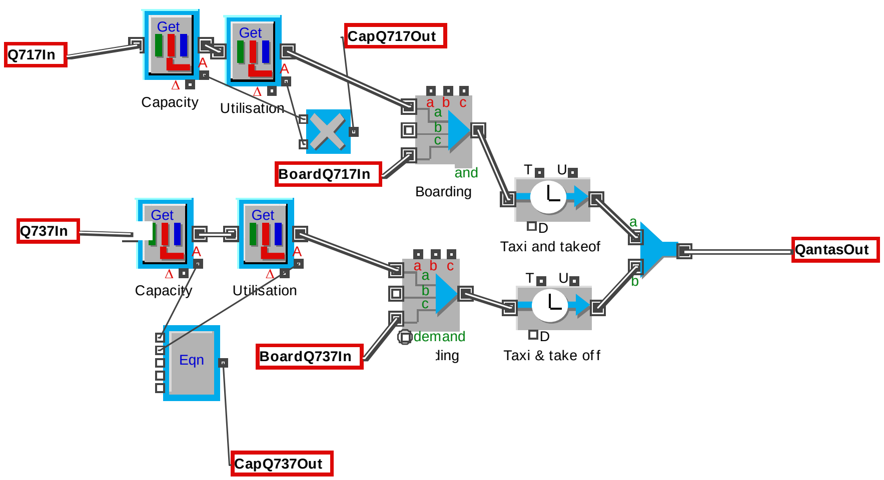

Figure 7 Structure of the hierarchical blocks “Boarding”

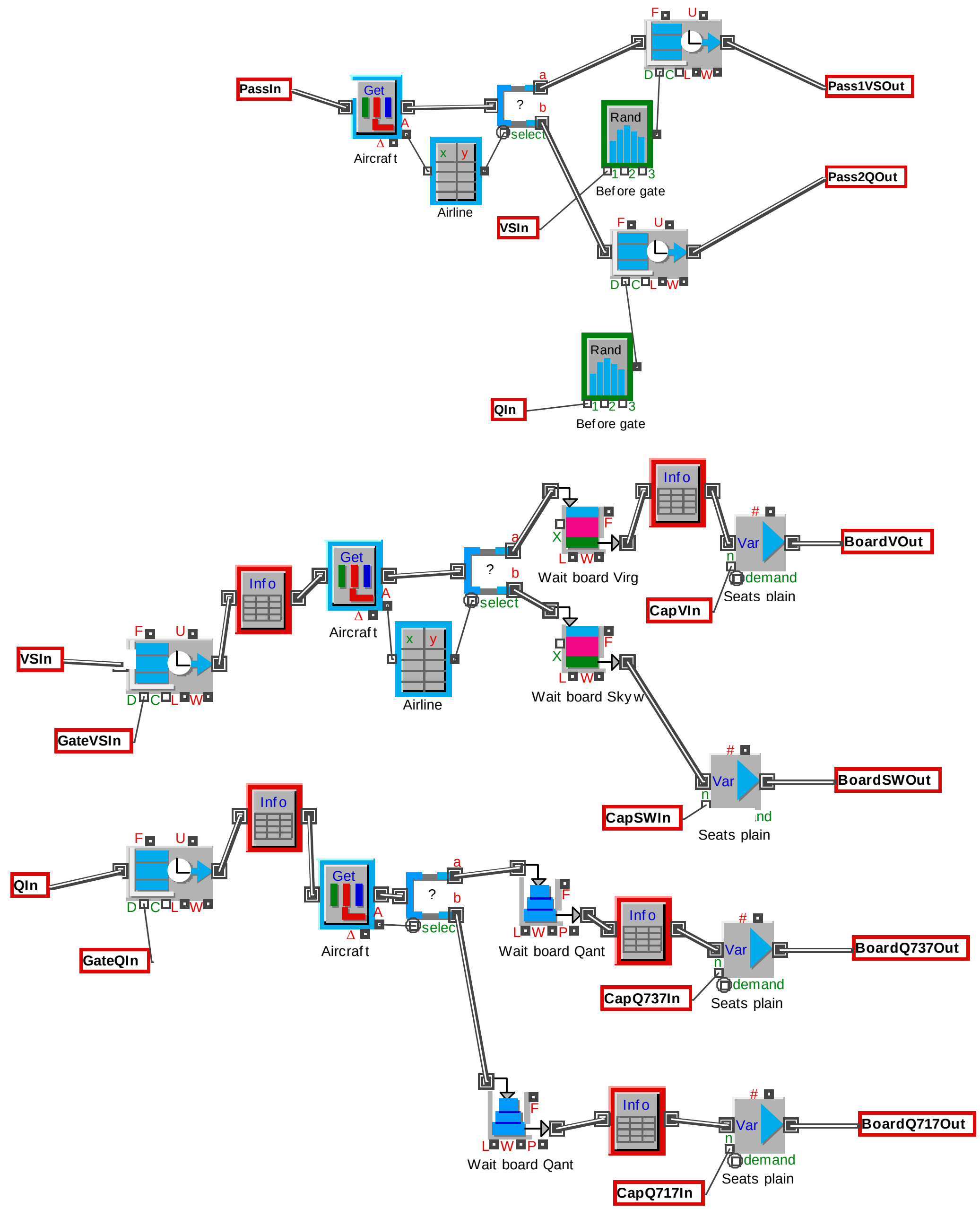

Figure 8 Structure of the hierarchical blocks “Activities before boarding”

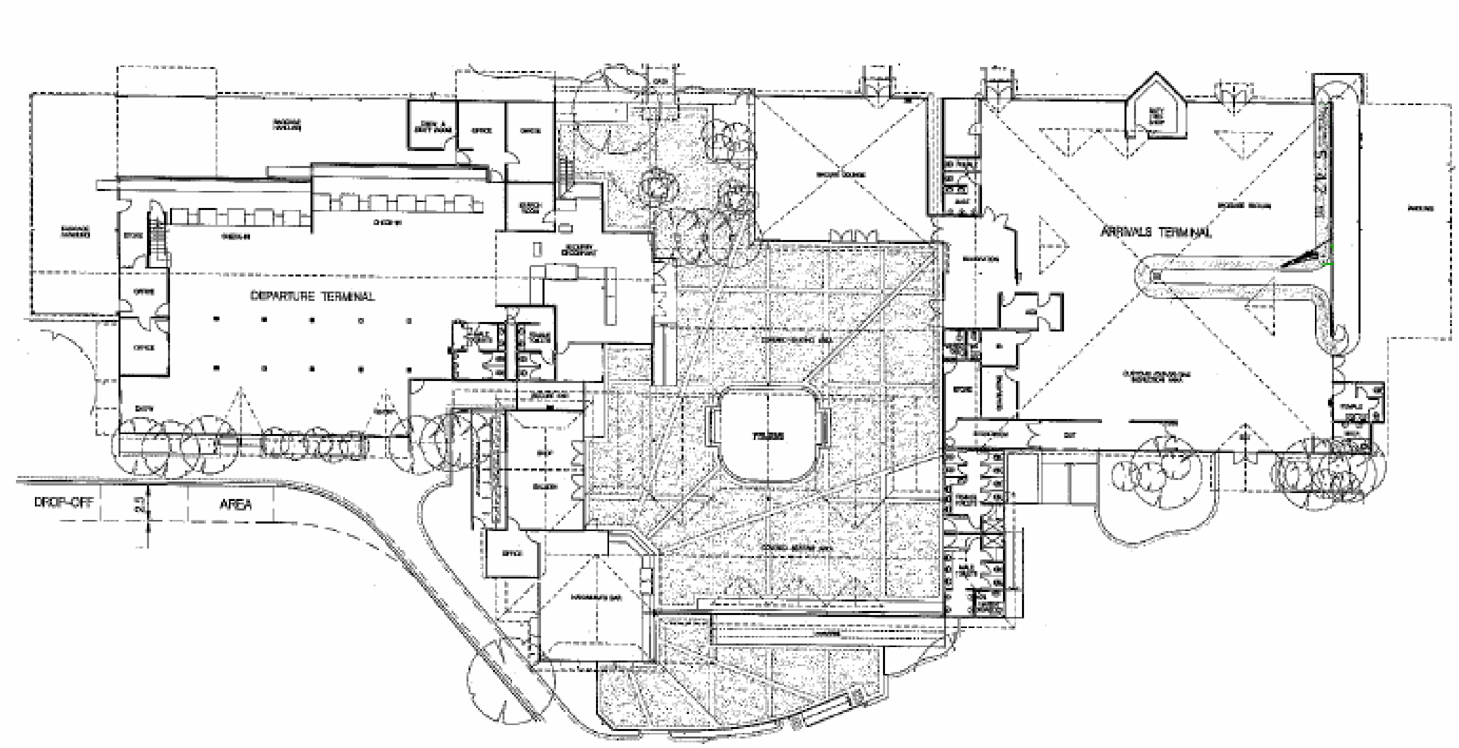

Figure 9 Plan of the terminal building, with check-ins on the left, waiting in the centre, and arrivals on the right

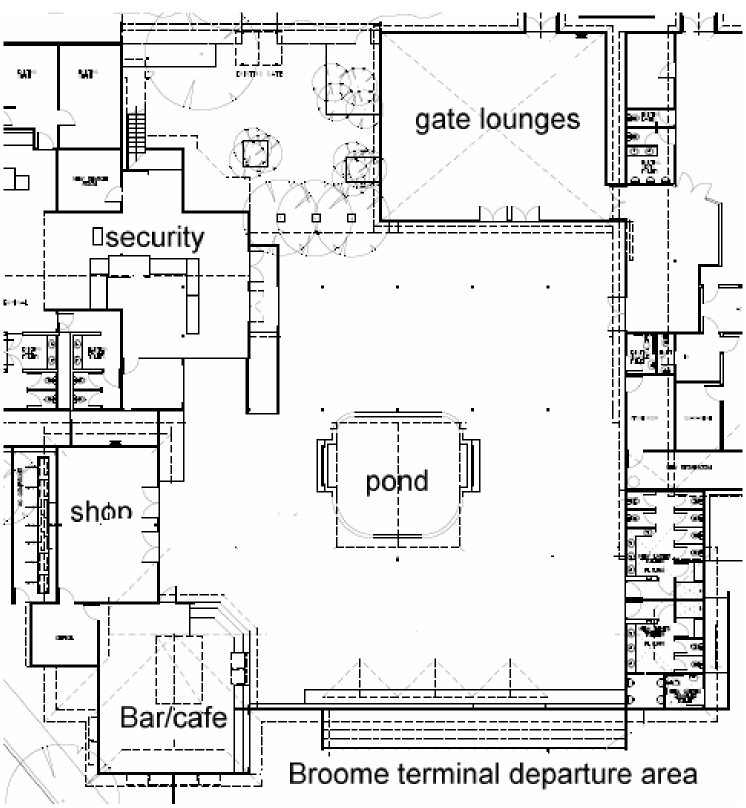

Figure 10 Layout departure lounge area

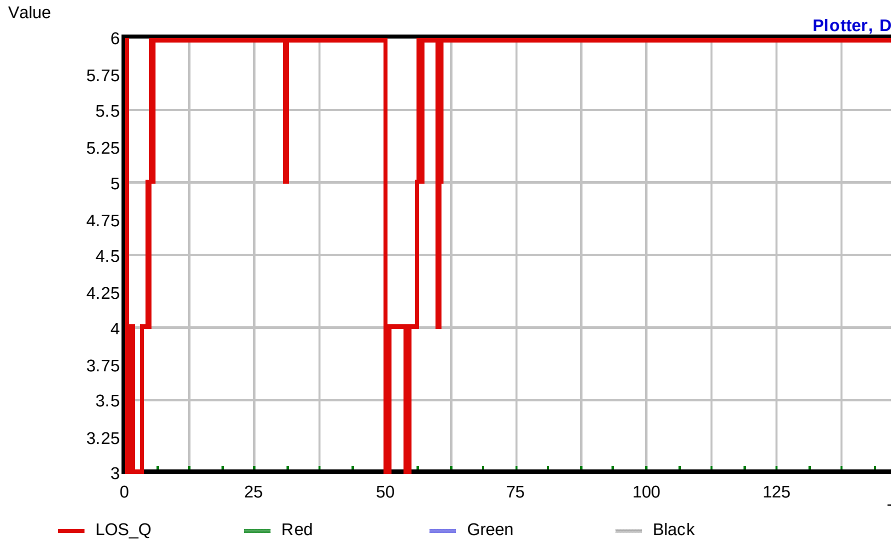

Figure 10 Example chart LOS for check-in areas (Scenario 1)

Figure 11 Example chart length of the queue and waiting time for check-in areas (Scenario 1)