Discrete Event Passenger Flow Simulation Model for an Airport Terminal Capacity Analysis

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This paper describes analysis of departure passenger flow in an airport terminal, from the passenger entrance to boarding; involving the development of simulation model. The basis for the simulation model was a snapshot of the passenger flow data taken during the summer periods from 2003 to 2004. Various data were collected and used to define the inputs to a simulation model. The next step was a statistical analysis of the collected data. A discrete-event simulation model using simulation programming language General Purpose Simulation System (GPSS) was constructed. The performance of the system in the present and expected future was studied. The simulation model helped us to evaluate the passenger flow, identify the system bottlenecks as well as the system capacities. Critical aspects in the passenger

Key words: modeling, discrete event simulation, airport, passenger flow, GPSS

Dogodkovni model dinamičnih potniških tokov za potrebe analize kapacitet v letališkem terminalu

V prispevku smo analizirali karakteristike dinamičnih potniških tokov na letališču Ljubljana. Z ozirom na kompleksnost problema smo se osredotočili na študij funkcionalnosti strežbe odhodnega potniškega toka in sicer od prihoda potnikov na letališče do vkrcanja potnikov v letalo. Osnova za izgradnjo prototipnega simulacijskega modela so bili zbrani podatki v času posameznih dnevnih prometnih konic v poletnih mesecih v letih 2003 in 2004. Na osnovi statističnih analiz zbranih podatkov smo dobili statistične porazdelitve medprihodnih časov prihodov in časov strežbe potnikov, ki so vstopili v letališki sistem. Dogodkovni simulacijski model smo razvili z uporabo simulacijskega jezika General Purpose Simulation System (GPSS). Z eksperimentiranjem na simulacijskem modelu smo proučevali dinamiko obstoječih in bodočih potniških tokov na letališču, identificirali ozka grla ter pomanjkanje tako obstoječih kot tudi bodočih kapacitet. Na podlagi dobljenih simulacijskih rezultatov so podani konkretni predlogi za izboljšave.

Ključne besede: modeliranje, dogodkovna simulacija, letališče, potniški tokovi, GPSS

1 Introduction

An airport is an operational system comprising of a framework of infrastructure, facilities, equipment, systems and personnel which collectively provide a service to a customer. Fast growth in airline passenger traffic and, on the other hand, slow expansion of airport capacity, is straining the ability of airports to maintain satisfactory customer service. The complexity of the logistical process of an airport is huge and many airports are faced with operational efficiency problems. Airports are nowadays struggling with increasing numbers of passengers with strong variations in processing time, shorter transfer connection times, environmental and noise limitation, increased security (baggage screening, biometrics, etc.), pressuring them to become more efficient. Widespread increases in queuing and processing times are well-documented frustration for airports, airlines and passengers.

Although passengers acknowledge the need for increased security (especially post 9-11 event), delayed boarding, cancelled flights, long waits have created an environment of passenger dissatisfaction. The urgent need to better use assets, handle more flights, coordinate schedule and quickly respond to delays confronts many airports which are trying to meet passenger needs by improving overall operational flexibility and increasing customer services. Interested study of Airport Operational Efficiency principles, characteristics, regulating and measuring it, was done by International Civil Aviation Organization (Vreedenburgh, 1996). Operational efficiency at an airport can have a direct impact on safety, user and customer satisfaction and also at the financial performance of the airport (Durante, 2003). The level of communication between airports, airlines and handlers can also be a problem to solve (Verougstraete, 2001). Airports do all possible to get the passengers from the entrance point near check-in to the gate and the aircraft as smoothly as can be. Several studies have focused on the most important customers of the airport, the passengers. Aviation industry is focused on simple processes that bring value to the passenger; the same passenger will feel as a welcome guest.

Deciding what mix of resources, processes and technologies will deliver the best combination in improved customer service is very difficult. There are studies, which are dealing with the airport capacity problem from the mathematical point of view (Usenik and Radačič, 1997). Using analytical methods, queuing time can be hardly accurately predicted. The most important reason is the peaks in arrival patterns. Better approach is simulation, which offers additional advantages like flexible modeling and animation. Simulation is a process of building a model of a system and conducting experiments on that system to determine the performance of the system under varying conditions. Some international (big) airports (e.g. Amsterdam Schiphol, Vienna Schwechat, Istanbul Ataturk, Washington Dulles, etc.) have done some extensive simulation studies in this area. Regardless of all contemporary (and not so cheap) software tools in the market (Arena, Incontrol ED, Simul8, ProModel, Simmod, etc.) and some very high specialized companies such as Incontrol Enterprise Dynamics, Kiran Consulting Group and others, there is still place for improvements, especially from the »small« airports perspective (such as Airport Ljubljana), considering the »cost«.

In 2004, Ljubljana Airport has, for the first time in the airport's history, served its millionth passenger in a single year. This is a round number that has great symbolic value for the airport and obligates it to undertake new development projects in the future. In 2005, more than 1.2 million passengers used the airport. Annual growth in the past few years is above 10 percent (Aerodrom Ljubljana, 2006).

With the Slovenia's accession to the EU in 2004 and consecutive application of the Schengen standards, five new categories of passenger traffic will be introduced:

- International departures (existing passenger flow),
- International arrivals (existing passenger flow),
- Transfer: International arrivals - International departures (existing passenger flow),
- Departures: Schengen traffic (new passenger flow),
- Arrivals: Schengen traffic (new passenger flow),
- Transfer: Schengen arrivals - Non Schengen departures (new passenger flow),
- Transfer: Non Schengen arrivals - Schengen departures (new passenger flow),
- Transfer: Schengen arrivals - Schengen departures (new passenger flow).

A Schengen standard means providing an appropriate airport infrastructure for inspecting passengers from the »Schengen« area to the »Non Schengen« area. In order to provide an analysis of existing and future airport facilities, concerning that real life testing are expensive or not (yet) possible, we decided to investigate computer simulation modeling techniques as a possible solution to the problem. Main reason, comparing the mathematical models, is flexibility and versatility. Simulation has been proven very valuable in airport passenger logistic to study bottlenecks and test potential solutions (Kukulich & Leone, 2002; de Ruiter, 2002; Park & Ahn, 2003).

2 Simulation objectives

The primarily objectives of the simulation modeling were to identify the bottlenecks and evaluate the airport system alternatives during peak day operations. Other objectives were: a dynamic analysis of the existing system under current and projected levels of activity, find solutions from which can we benefit most from, support for making decisions about future airport developments and hopefully, continuous use of the model for »what-if« scenarios.

3 Simulation model

3.1 Data collection

Correct data is essential to get valid and valuable results about bottlenecks and to define relevant scenarios. Simulation studies require an exact description of processes and representative data. Airport processes involved with passenger handling have been analyzed and the numbers of resources estimated. A large amount of information had to be collected and laid down. Process times, waiting times, and queue lengths have been measured and collected statistics has been analyzed. Annual growth in the airport Ljubljana in the past few years is above 10 percent (Fig. 1). The basis for the simulation model was a snapshot of the passenger flow data, taken during the summer periods between 2003 and 2004 (Fig. 2).

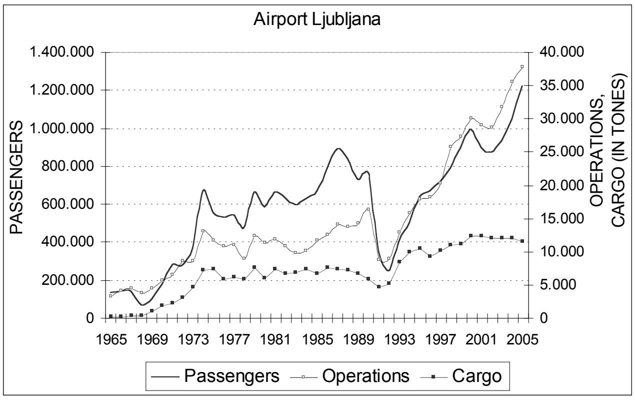

Figure 1: Annual traffic figures (1964-2005)

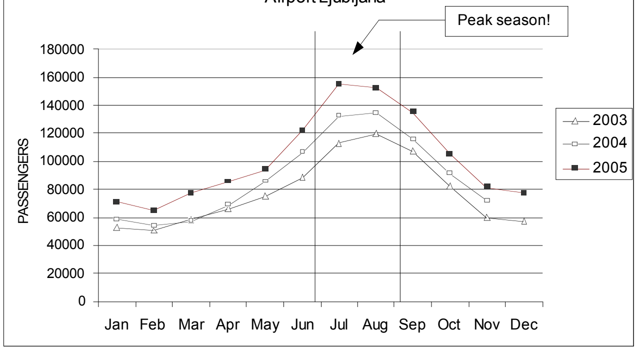

Figure 2: Passengers departures monthly traffic figures (comparision 2003-2005)

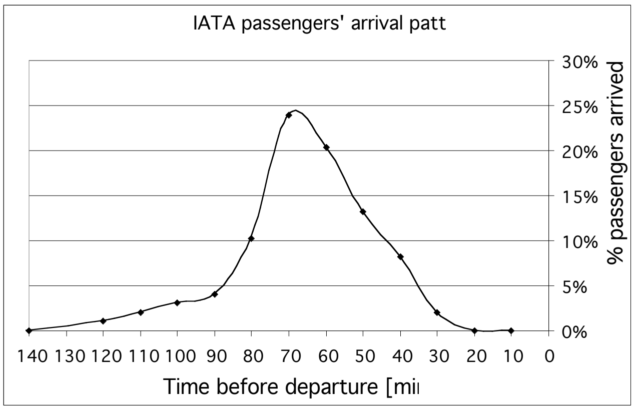

Figure 3: IATA passengers' arrival pattern (IATA, 1995)

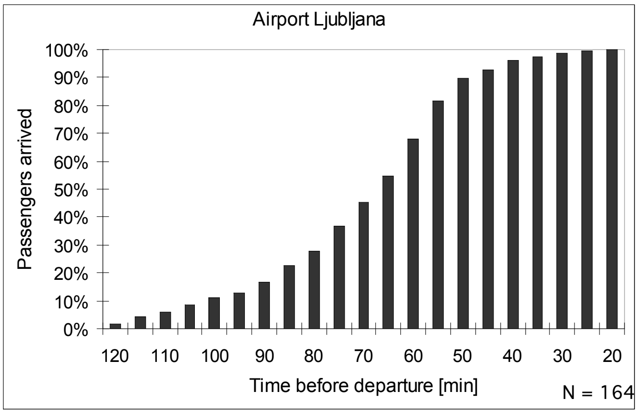

Figure 4: Passengers' arrival pattern

The typical peaked ness of the IATA arrival pattern (IATA, 1995) is shown on Figure 3. United States Federal Aviation Authority for example, uses typical peak hour passenger (TPHP) concept (FAA, 2004). The TPHP measure depends on total annual count of passengers (Ahyudanari, 2001). In some previous relevant work in other airports was shown that more than 60% of the passengers arrive approximately two hours before scheduled time of departure (de Ruiter, 2002). But patterns and peaks of passengers varies for each airport. The arrival pattern in the simulation model we used is an actual observed data in Airport Ljubljana (Fig. 4). Data samples were collected for two-hour periods before the flights departure time. The passenger arrival distributions per flight were averaged to get an aggregated arrival pattern.

Distribution of arriving passengers might be different. The average of different daily patterns is applied to represent the »Airport Ljubljana pattern« (Fig. 5). In the existing simulation model the different distribution type can be also quite easily applied.

We analyzed the statistical data and compared it to the most useful analytical distributions. We used several statistical software for curve fitting (Stat:Fit, Curve Expert and Expert Fit) and Chi-Square goodness-of-fit tests. After thorough analysis, comparing collected statistical data to the useful »standard« distributions (and not so perfect fitting results), we decided to use empirical data in the simulation

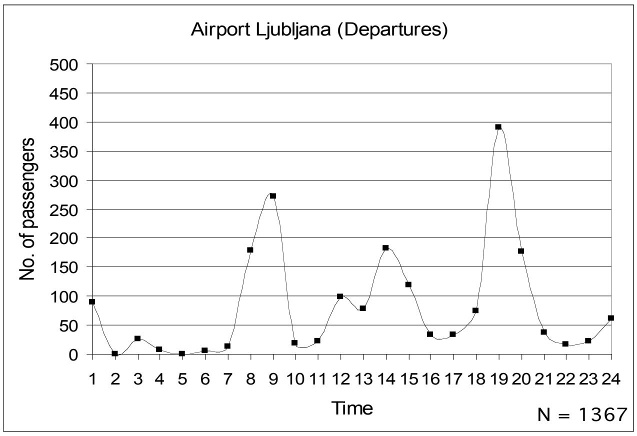

Figure 5: Daily average departures' pattern

model. That was, considering the amount of the gathered data, quite reasonable.

3.2 Discrete event simulation model

A discrete-event simulation model can be described as one in which the state variables change only at those discrete points in time at which events occur (Kljajić, Škraba & Bernik, 1999). Airport traffic (passenger) flow is discrete stochastic process. Discrete event simulation is often used to model system where complex processes are combined with a limited infrastructure of capacity (Verbraeek & Valentin, 2002). Airports are quite an ideal application area for discrete event simulation.

A simulation model was constructed using simulation programming language GPSS (General Purpose Simulation System). There are multiple versions of GPSS available (Chisman, 1992) and the one used in the model was GPSS/H, specifically designed for the personal computer. GPSS was felt to possess the versatility, reliability and ease of programming necessary to produce a model of sufficient detail and sensitivity.

3.3 Simulation model development

The first step in the simulation model development was to understand and describe the current situation completely. Simulation model, which is a representation of an actual system, does not solve a problem but tells us how a system will operate under a given set of parameters. The key entities are passengers that move through a set of processes and activities that consume resources (Fig. 6).

We detaily analyzed departure passenger flow, as more complex than the arrival one, from the passenger entrance to boarding. Simulation starts with passengers entering the airport terminal (departure hall) at a certain time before departure and walking to the check in desks. Hereafter passengers have to pass the immigration to get into the international hall area. Finally, the passengers go to boarding and leave the airport.

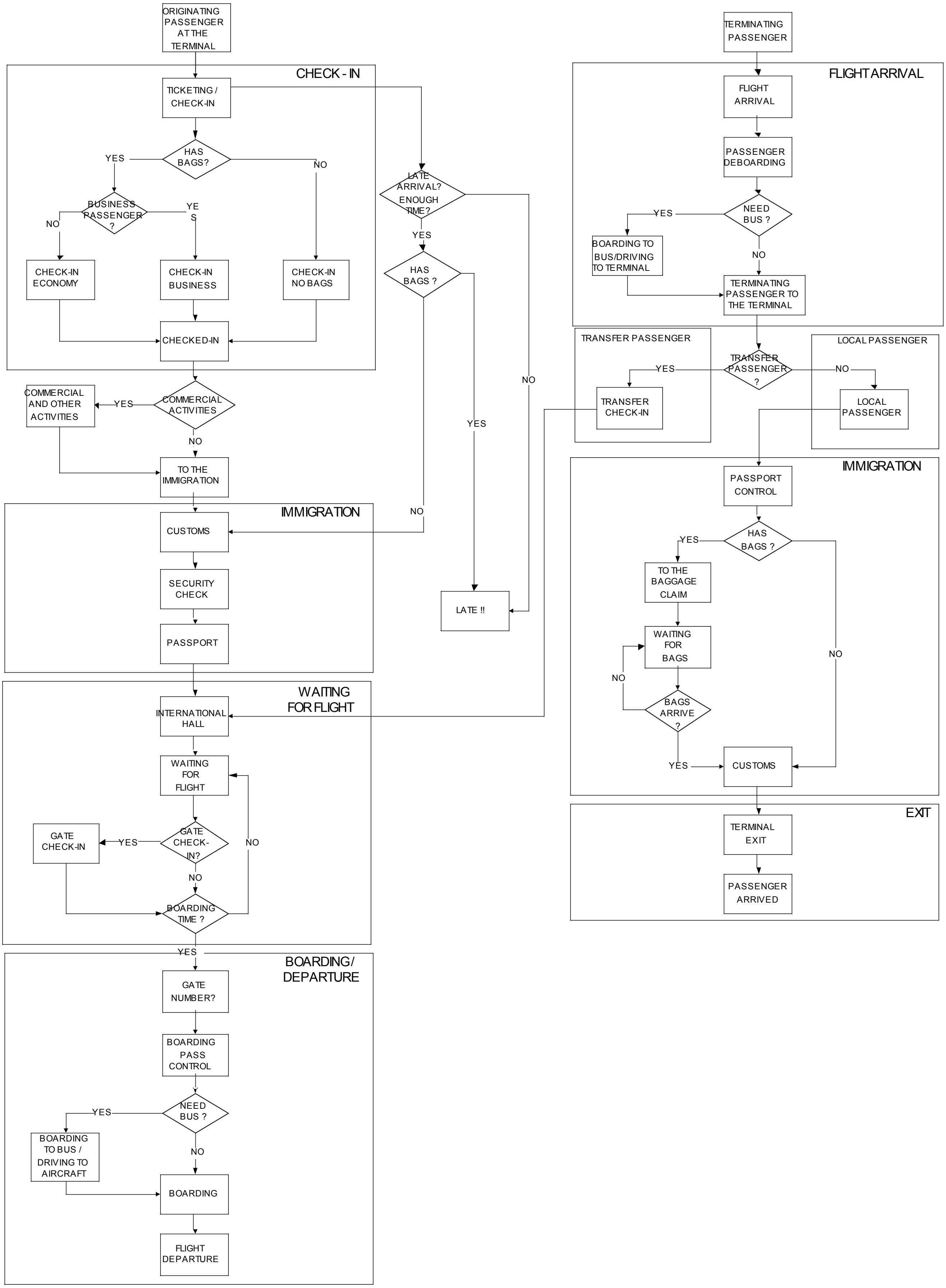

Figure 6: Passenger processing flowcharts (Rauch, 2005)

Ljubljana Airport has a special feature. Even though it is not a large airport, airport has substantial transfer traffic. This distinguishes it from many regional European airports. The airport is an especially important connection point between the southern Balkans and Central Europe. These traffic flows are subsiding somewhat, but transfer traffic still represent more than 20 percent of all traffic at Ljubljana Airport (Aerodrom Ljubljana, 2006). For the simulation purpose it is very important to accurately represent the passengers structure. Considering the gathered statistical data, we have 74 percent Economy passengers, 16 percent Business passengers and 10 percent passengers with no bags.

Check-in area is the main component of passenger service areas in airports. The queuing time passengers spend at check-in in one of the most important criteria of passengers satisfaction and service performance. Check-in queues are generally dependent of: flight departures, dynamic arrival pattern, available capacity and also of the alternative such as self service and internet/WAP check-in. The process of check-in is stochastic and the number of required check-in counters varies with time since the total number of passengers per flight is different (Chun, 1999). The queue discipline at check-in counters is FIFO, which means passengers are served in a »first-in, first-out« fashion.

Check-in capacity in Airport Ljubljana is generally sufficient to meet the total daily demands but because of strong fluctuations and peaks over the day in the number of arriving passengers, queuing takes place much stronger than it should on average. Check-in process is modeled using statistics collected on check-in servicing time. For the service rate, sample data were randomly collected at different times using stopwatch methodology. The statistics include check-in servicing time for different destinations and times of the day. The graph of the passenger check-in data is known in the industry as a »check-in curve« (Fig. 7).

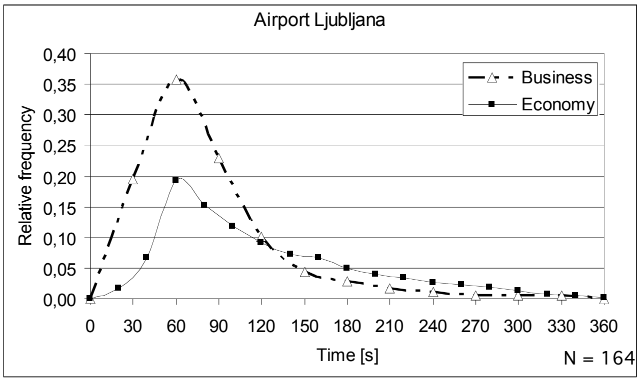

Figure 7: Check-in service distribution

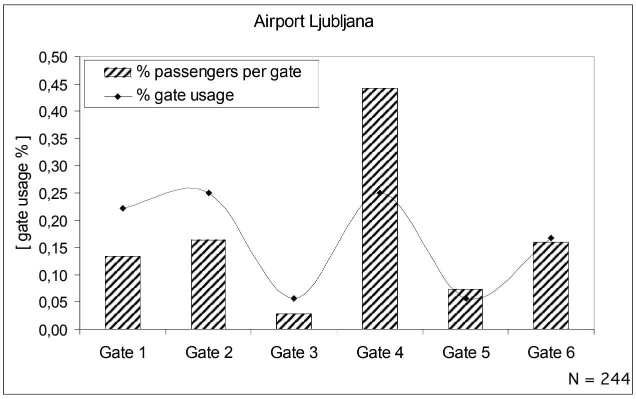

Figure 8: Existing gate usage

The immigration processing time (customs, security check, passport control) are dependent on factors such as passenger immigration arrival pattern, available capacity (number of security check points) and factors related to the flight. For example, flights to certain destinations may require more processing time because certain countries may require a more stringent passport and visa check etc. Airport, in the present situation has 6 gates (in the time of the study the seventh one was still constructed). The most used one is Gate 4, with almost half of the daily boarded passengers, in average (Fig. 8).

Constructing a suitable model of an airport passenger service process presents a number of challenges (Kyle, 1998). The passenger arrival rates are dependent on many factors such as the time of departure, destination of the flight, etc. For example, if the flight is scheduled to depart early in the morning, passengers will usually arrive a bit later than the statistical average. The arrival process is modeled using passenger arrival statistics which showed that the arrival rate of passengers is a function of time. The passenger arrival rate is non-stationary distribution with more passengers arriving during the middle part of the check-in counter opening period (de Ruiter, 2002).

The normal congestion condition is based on the flight operations for a busy operating day, that is, the number of departing flights is 60 (in the summer period) and the boarding ratio is 70 percent. On busy days more than six thousand people arrive and depart from the airport. Approximately half of them are departures and 20 percent of all are transfer passengers. For the simulation model purpose a »company« is selected to be analyzed (more than 70 percent of all flights are on this company). Passengers are generated in the simulation model (Fig. 9) using the arrival pattern and the passenger service time considering pas-

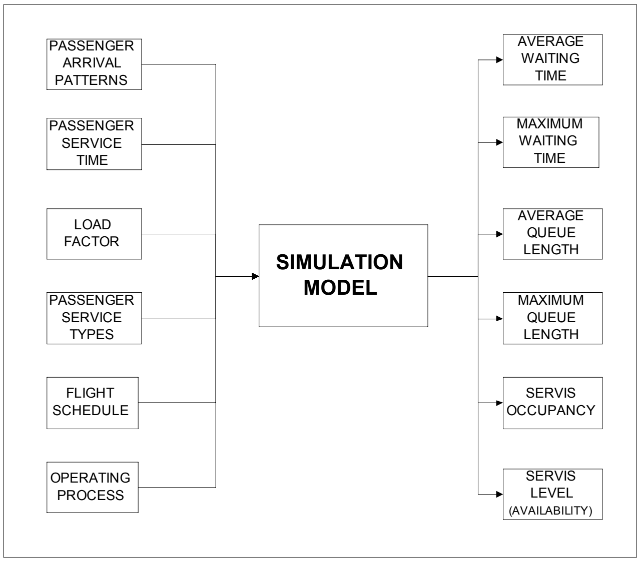

Figure 9: Simulation model (inputs and outputs summary)

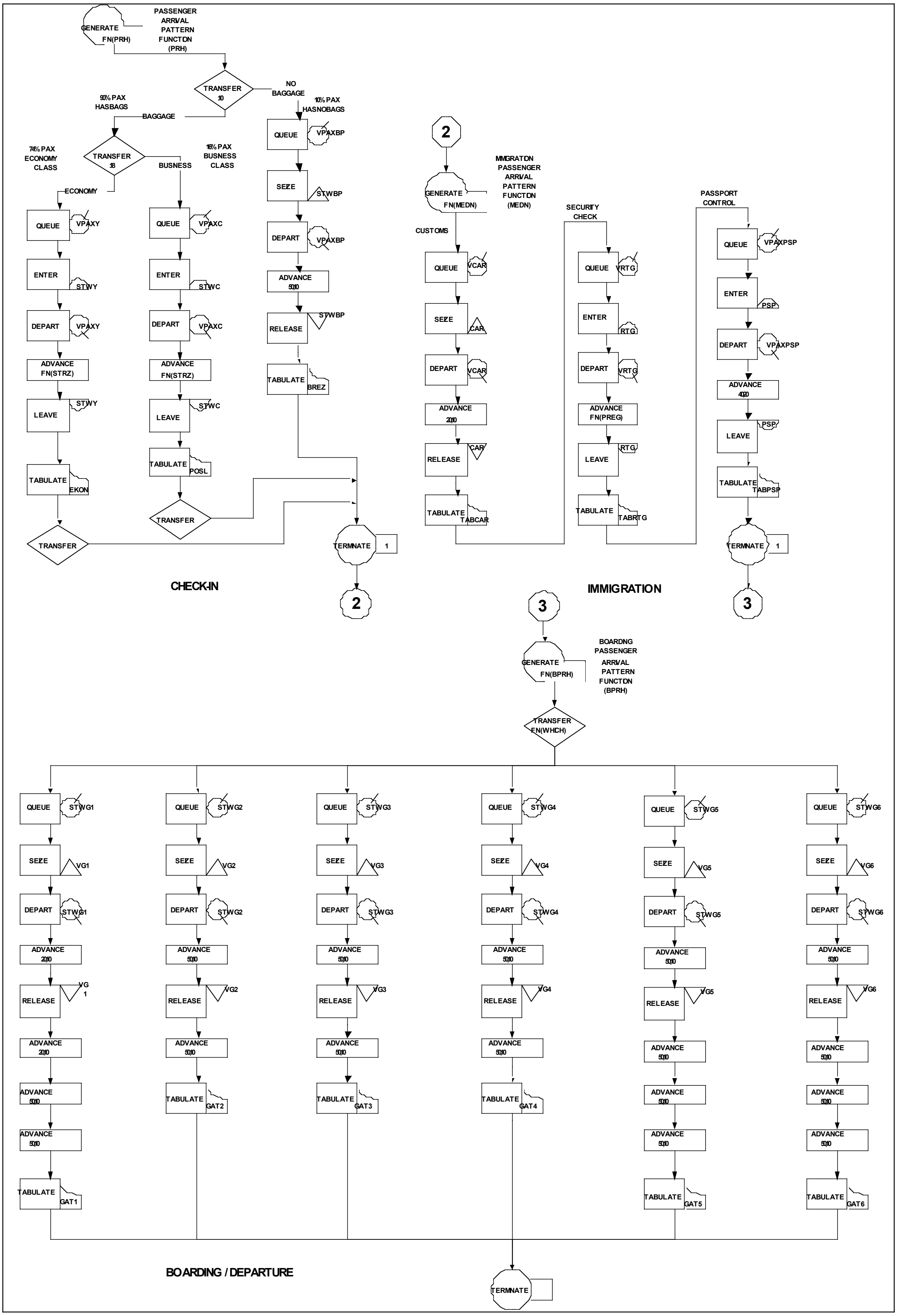

Figure 10: Simulation model block scheme

senger service type, load factor and the scheduled time of departure of a flight (passenger load factors are the number of passengers who flew on the aircraft divided by the total available seats). Simulation model block scheme is shown in Figure 10.

3.4 Model validation

Model validation is critical in the development of a simulation model. Validation is the process of ensuring that the model is an accurate representation of the real system. Input data for the model was the first to be validated. The second step of the model validation involved verification of the model to make sure that reflected the provided data accurately. The next step involved validation of the simulation model. Simplified version of the model development process and validation is shown in Figure 11 (Sargent, 2003).

Data that we collected on a system for building the test model were partly used to build the model and partly to determine weather the model behaves as the system does. Several replications (runs) were made to determine the stochastic variability of the model. The results were then compared with real conditions. Luckily, because we already have an existing »system«, we can easily compare simulated results with »real word data«. We also asked knowledgeable (independent) colleague about the system, whether the logic (input-output) of the model is reasonable to them. Further validation included a structured »walk through« to verify the model logic and compared the model output with the actual system key performances (by observing actual passenger arrivals at the check-in and immigration lines).

Comparison of the model results with the actual system showed that the model quite accurately represents the actual system. Once the model is calibrated, input require-

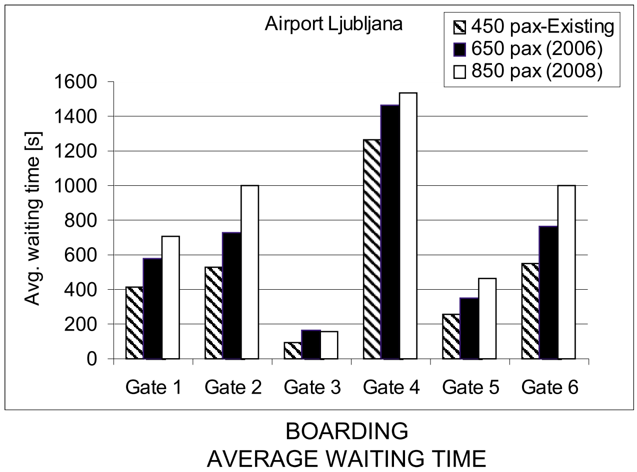

Figure 12: Extracts of some simulation results

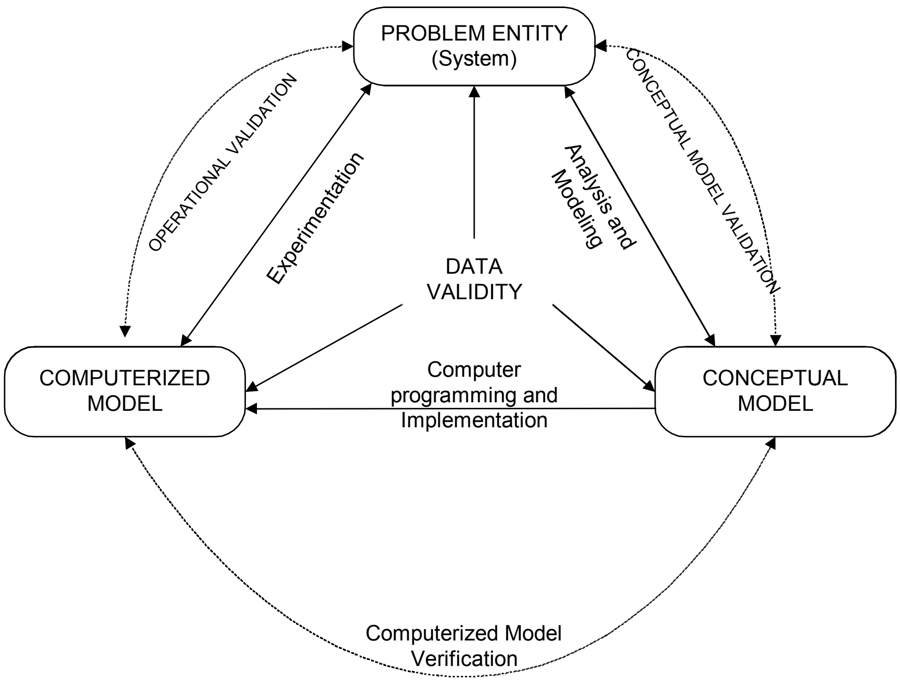

Figure 11: Modeling process and validation (Sargent, 2003)

ments can be changed for evaluating the »What-if« scenarios. We are aware of the fact determining that a model has sufficient accuracy does not guarantee that a model is valid everywhere in its applicable domain (Sargent, 2003). There is no set of specific tests that can be easily applied to determine the »correctness« of a model. Since the airport is exposed to air traffic developments and external influences, it is desirable to validate and repeat the study results frequently.

4 Simulation results

After analyzing all collected simulation statistics, we focused on investigating conditions where passenger waiting time exceeded. Bottleneck resources for the peak hours were found to be in the check-in process and in the immigration control process (especially in the security control). Several simulations were performed; simulated statistics were then compared with the tolerable waiting time and queue length (IATA, 1995). The overview of bottlenecks and the comparison of measurements formed the required results of the simulation study. Recommendations based on the results of models runs were made (Fig.12).

Some proposed solutions turned out to be quite very effective, whereas others showed no effect. However, some other effects of the study turned out to be just as useful such as exact analyzing of processes and representative data.

5 Conclusion

A model was developed as much as flexible, allowing modifying the different parameters of the system easily. Critical aspects in the passenger flow through the airport terminal have been explored and studied. The advantage of using simulation models (software) is that you can explore »what-if« scenarios or new methods without the expense of experimenting with the real system.

One result of growing air traffic at Ljubljana Airport and Slovenia's entry into the European Union, which requires the separation of traffic into Schengen and non-Schengen, is the planned construction of a new airport terminal with planned capacity of 850 departing passenger and 850 arriving passengers per hour. The current terminal will be renovated and in the next years expanded to 32,000 square meters, where 40 check-in counters will be set up, including some automatic ones (Aerodrom Ljubljana, 2006). The complete separation of Schengen and non-Schengen traffic will be ensured, as well as the separation of arriving and departing passengers. An IATA level C standard of services (IATA, 1995) is envisaged to ensure the necessary quality for passenger arrivals and departures. Passenger volumes will double in the next decade, airport space will remain relatively unchanged. New technologies such as e-ticketing and check-in from remote locations are major opportunities (passengers can bypass counters and proceed directly to boarding area), clearly, considering the increased security in the recent years. Wireless communications are rapidly infiltrating in all sectors of airport operations and instituting new services to improve service on a real time basis with their customers.

One of the greatest advantages of using simulation software in airports is that once you have developed a valid simulation model, you can explore new policies, operating procedures or methods without the expense and disruption of experimenting with the real system. Modifications are incorporated in the model, and you observe the effects of those changes on the computer rather than the real system. Simulation lets you »Test Drive« your Airport before you build or change it. Nevertheless, frequent maintenance of the simulation model is necessary, because airports are in a continuous state of change. Future works that may improve this study include the development of a friendly user interface to the model to allow users to change variables. Using simulation it is also possible to test alternative check-in methods, e.g. dynamic opening and closing of check-in counters depending on the number of queuing passengers.

Hopefully, this paper can provide some insights on how computer simulation can help to find bottlenecks and solutions insight in peak flows, optimize quality of service to our customers and at the same time reduce costs.

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