Door-to-Gate Air Passenger Flow Model

Martin Matas
Air transport department
University of Zilina
Zilina, Slovakia
martin.matas@fpedas.uniza.sk

Milan Stefanik, PhD,
milan.stefanik@fpedas.uniza.sk
and Sandra Krollova, PhD
sandra.krollova@fpedas.uniza.sk
Air transport department
University of Zilina
Zilina, Slovakia

***Abstract*—Ever growing traffic in air transport with associated capacity constraints brings problems to air passenger flows at airports. In efforts for improvement new original future airport concepts are thought out. For the purpose of evaluation of future airport concepts the passenger flow model is developed. The model consists of two sub-models: Airport Ground Access Passenger Flow Model (AGAP) and Airport Terminal Passenger Flow Model (PaxMod). AGAP is based on random generation of passenger flows from the catchment area to Airport Bratislava using statistical data. PaxMod is based on linked cumulative diagrams representing airport queuing systems and simulates passenger flows through the airport terminal facilities. Both models are interconnected and are used to evaluate Airside-Landside Separation concept by simulating two scenarios. First scenario is baseline scenario where classic air passenger transport is simulated. Second scenario simulates passenger flows in Airside-Landside Separated airports and the result of simulation is compared to the baseline scenario. The analysis of the comparison leads to the evaluation of the new concept of airport operation.**

Keywords-Passenger Flow Model, Airport Terminal, Airport Access, Queuing, Cumulative Diagrams, Travel Time, Airport Catchment Area, Air Passenger

I. INTRODUCTION

The Door-to-Gate Air Passenger Flow Model is developed for the design and evaluation of different original future airport concepts. In particular it is designed for simulating the passenger flows in the concept of Airside-Landside Separation which idea was described in [1] and [2]. The passenger flows at airports consist of processes (check-in, security control, boarding) and movements among the processes.

The air passenger processes can be modeled by analytical queuing models (stochastic or deterministic) or by simulation models. In [3] an extensive survey on passenger behaviour at Manchester Airport was made for the purpose of developing an analytical model of passenger time spent at the airport. The model is based on a network of linked analytical queuing models where the nodes represent the processing centres, and the links represent the proportion of total passenger flow. Alternatively to stochastic approach [4] proposed deterministic queuing models which could be graphically analysed by cumulative diagrams as in [5]. This approach is used in [6] to model passenger arrivals to the departure lounge and their departure from the lounge to the aircraft. The proposed deterministic function describing cumulative passenger arrivals was a quadratic function. Simple landside aggregate model presented in [7] is an analytical aggregate model for estimating capacity and delays at airport terminals. The facilities in the terminal are divided into three classes: processing facilities, holding and flow facilities. In processing facilities passenger dwell time is calculated using deterministic equivalent queuing model. Analytical models can be used to study impacts of certain parameters on the system. On the other hand to keep their underlying equations tractable they are often based on strong assumptions which tend to be unrealistic. If the system becomes too complex for analytical modelling the simulation models might become preferable. The simulation model of the complete passenger flow from the check-in to boarding and from de-boarding to baggage claim was modelled in [8]. This model and other models of airport terminals presented in [9] and [10] were simulated using ARENA simulation software. Although many authors develop their own simulation tools [11], there exist specialized tools for passenger and baggage flows at airports such as PaxSim.

In the context of our research the air passenger movement at airport terminals is regarded as passenger walking. Walking behaviour can be analysed on a different level of detail (microscopic, mezoscopic, macroscopic) and using different modelling techniques or theories. In our literature survey models are classified according to modelling approach to the following classes: Microsimulation models, Cellular Automata models, Queuing theory based models, Gas-kinetics based models and Continuum physics based models. This classification has been adopted from [12].

For the purposes of our modelling we are interested in passenger flow as a whole rather than in individual passengers. However we still want to distinguish different types of passenger groups. In particular we are interested in the classification of passengers to business and leisure and their corresponding flights such as long-haul vs. short-haul, scheduled vs. charter, domestic vs. international and so one. Therefore we decided to use a simulation approach based on linked deterministic queuing models for modelling of passenger flows at airport terminals. The airport ground access flows are modelled by random numbers generation based on probabilistic distributions of passengers within the airport

This research is conducted thanks to the support from Eurocontrol Experimental Centre (Bretigny sur Orge, France) in cooperation with University of Zilina (Zilina, Slovakia).

catchment area and by assigning them the transport mode with the lowest perceived costs.

II. AIRPORT GROUND ACCESS AND EGRESS MODEL

The model represents the passenger transport to and from the airport. The access part of the model represents the transport from the point of origin, which could be at home or at office, to the airport departure hall entrance from where the Airport Terminal model (PaxMod) begins. The egress part of the model represents passenger transport from the airport arrival hall to the destination. The air passenger access and egress transport is connected with many activities. These mainly include the passenger's choice of transport mode, time planning (departure from the point of origin, the time reserve desired) and the actual transport to the airport. The modelling of passenger traffic from and to the airport depends on many factors from which the key ones are:

- Flight schedule
- Aircraft size and load factor
- Party size distribution
- Type of flight (scheduled/charter)
- Type of passenger (business/leisure)
- Passengers' spatial distribution within the airport catchment area
- Passenger's transport mode choice

These factors are integrated in the AGAP model. The process diagram of the model is shown on Fig. 3.

A. Flight Schedule

Flight schedule is the primary input to the AGAP model. It is the starting point for the model. Following algorithms within the AGAP model are using its data to generate passengers within the catchment area. The most important flight schedule data are the aircraft arrival and departure times, the aircraft capacity, the average load factor and whether the flight is scheduled or charter. Our flight schedule is based on CFMU data and the data from [13]. For the simulation purposes we used the data from the flight schedule valid on one representative day. The selected day was 8th July 2008, which was the busiest day in terms of passenger throughput at Bratislava airport in 2008. According to data that were provided by Operation Division of Bratislava airport, 49 arrivals and 45 departures of commercial passenger aircraft took place at Bratislava airport on 8th July 2008. These aircraft movements generated passenger flows of 5,497 departing and 5,900 arriving passengers, which passed through the terminal at Bratislava airport on that particular day.

B. Charter/scheduled party size profile

Party size profile is one of the parameters that describe the passenger behaviour. This parameter describes the groups of passengers travelling together. The most common groups in this sense are couples, families, friends or colleagues. There are significant differences in party size distribution considering the scheduled flights and charter flights. Data regarding party size shown in Tab 1 and Tab 2 were gathered from surveys that were conducted by Marketing and Commerce Division of Bratislava airport in summer months of the years 2003, 2004 and 2007.

TABLE I. PARTY SIZE PROFILES FOR LEISURE PASSENGERS AT BRATISLAVA AIRPORT

Party Size	**Count**	**Percentage**
1	2095	49.45%
2	1523	35.95%
3	313	7.39%
4 and more	306	7.22%
TOTAL	4237	

TABLE II. PARTY SIZE PROFILES FOR BUSINESS PASSENGERS AT BRATISLAVA AIRPORT

Party Size	**Count**	**Percentage**
1	2570	65.83%
2	971	24.87%
3 and more	363	9.30%
TOTAL	3904	

C. Allocation of passenger groups to the flight

In the process of allocation of passenger groups to the flight based on party size distributions the model randomly generates groups of passengers and fills the aircraft taking into account the seat capacity and the load factor. The random generation of the groups is designed as follows. From the party size profile the percentage of occurrence of each group is put into the chart in a cumulative way as it is depicted on the Fig. 1. Random percentage is generated according to the uniform distribution. This number is found on the vertical axis and from that point horizontal line is drawn against the group bars. Depending on which group bar the line crosses the group is selected. In the example on Fig. 1 there are two numbers generated 40% and 98%. According to the chart the number 40 transforms into the single passenger group and the number 98 transforms to the three or more passengers group. This generation of the groups goes in the cycle and the passengers are cumulated in the aircraft. Once the number of passengers reaches the aircraft capacity multiplied by load factor the group generating algorithm stops.

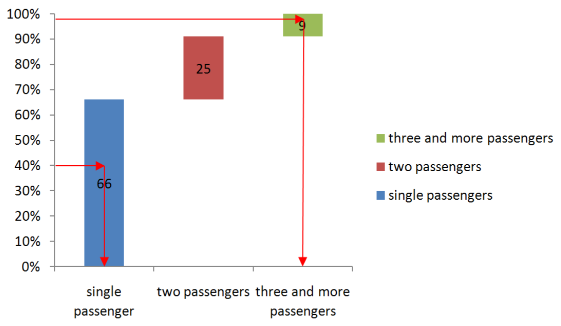

Figure 1. Random generator of passenger group size

D. Allocation of passenger groups to particular regions and cities

To be able to generate landside passenger trips to and from the airport it is necessary to know where the passengers start and end their trips. This can be derived from the passenger demand distribution within the airport catchment area. Air passenger demand distribution related data were gathered from the database of passenger questionnaire responses that was provided by Marketing & Commerce Division of Bratislava airport. It provides information about the demand distribution of various passenger groups within the country. However the distribution is based on eight autonomous regions of Slovakia and it is not subdivided further. To be able to generate passenger trips down to the cities we accepted following assumptions. All passengers within one group are assumed to be travelling together to/from the same city. The passenger demand within one single autonomous region in Slovakia is assumed to be uniformly distributed. Based on these assumptions and the data provided, we designed algorithm that allocates the city for each passenger group. The probability of allocation of the passenger group to the city is proportional to its population. Like this the algorithm firstly allocates the region to the passenger group based on the survey data and secondly allocates the city to the group based on the population distribution in the cities within the region.

E. Allocation of transport mode to charter/schedule groups

The process of allocation of the transport mode to the charter or scheduled group is based on passenger's choice among available transport modes. In our model we selected following representative transport modes:

- 'Kiss and drive' (Passenger is driven by car to the airport by someone else)
- 'Park and fly' (Passenger drives and parks the car at the airport)
- Taxi
- Public transport – combination of trains and busses

In the model the transport mode choice is based on the evaluation of transport costs while choosing the transport mode with the lower perceived costs. The perceived costs of transport consist of the financial costs, the costs of time and transfer costs. The financial costs represent the money value necessary to get from the place of origin to the airport and back including all related fees for example parking fees in case of car transport. The time costs represent the total travel time multiplied by the value of passenger travel time. The transfer costs represent a perceived value of additional physical and cognitive effort resulting from the transfer, and perceived value of risk of missing the connection.

III. AIRPORT TERMINAL PASSENGER FLOW MODEL - PAXMOD

The airport terminal passenger flow model (PaxMod) represents air passenger activities at the airport that start at entering the airport terminal and end after boarding an airplane. The flow input to the PaxMod is the flow generated by AGAP model. There are many activities that passenger does in airport terminal. These include visiting restaurants, the shopping, the renting a car etc. For the purposes of our research we are focusing only on activities related with the flight. These activities are divided into passenger processes and passenger movements. Passenger processes are mainly check-in, passport control, security check, customs, gate check-in and baggage claim. Passenger movements represent passenger walking from one service to another (e.g. from check-in to security).

A. Processes

In our literature review we identified three modelling approaches to model processes. These were stochastic queuing models, deterministic queuing models and simulation models. For the modelling of the processes we chose deterministic approach based on the work done by [14] and by [7]. The main reason for this is that we are interested in the flow from global view rather than from the view of individual passenger. Individual characteristics and microscopic level of modelling could be realised in microscopic simulation model. However the more complex the system is the more the simulation model tends to be difficult to develop. On the other hand application of queuing theory in stochastic queuing models removes some complexity as it is in the simulation models; however it is often based on strong assumptions which tend to be unrealistic. As an example queuing models hardly can capture varying rate of arrivals to the system which often occurs at the check-in counters at airports [11]. The deterministic approach allows modelling any kind of arrival profile and still the model could be relatively simple to develop so it might cause fewer difficulties in its development phase then in the case of the microscopic simulation model. Lastly the building blocks of our model should be transparent. Therefore we used relatively macroscopic level of modelling whereas only the behaviour of a group of passengers is modelled and not the individual behaviour.

The modelling approach is based on that the cumulative number of arriving passengers to the server (arrival profile) and the cumulative number of departing passengers from the server (departure profile) is known. It could be represented by $A(t)$ and $D(t)$ functions for arrival and departure profile respectively as it is depicted on Fig. 2

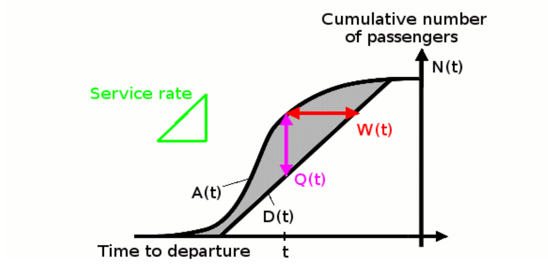

Figure 2. Cumulative diagram of passenger arrivals and departures from a server

From these functions average waiting time could be calculated as follows. Every passenger waits in the line certain time ranging from zero to some value. Sum of all waiting times could be calculated as an area bounded between *A(t)* and *D(t)* function:

$$T_{wait} = \int \left(A(t) - D(t)\right)dt$$

The cumulative number of passengers at the time *t* is represented by *N(t)*. Thus average waiting time per passenger until the time *t* is:

$$t_{wait\_avg} = \frac{T_{wait}}{N(t)} = \frac{\int \left(A(t) - D(t)\right)dt}{N(t)}$$

B. Movements

Movements in PaxMod represent passenger walking from one server to another e.g. walking from check-in to the security control. The movements are modelled by shifting the departure profile from the server by specific time delay. The time delay is a time needed for the passenger to get from one server to another. Due to simplicity it is assumed that all passengers get to subsequent server within same period of time. Each sub-function of the departure profile is shifted by the same time delay. If universal form of polynomial of 3rd degree is written as:

$$P(t) = a_3.t^3 + a_2.t^2 + a_1.t + a_0$$

then the shifted function by the time delay *d* has following form:

$$\begin{aligned} P(t-d) = {} & a_3t^3 + (-3a_3d + a_2)t^2 \\ & + (3a_3d^2 - 2a_2d + a_1)t \\ & - a_3 + a_2d^2 - a_1d + a_0 \end{aligned}$$

C. Initial arrival profile

The initial servers of the PaxMod airport terminal model are check-in desks. Arrival profile to the check-in desks are based on arrival earliness profile gained from AGAP model. PaxMod is based on polynomial functions representing cumulative passenger arrivals, service and departures. AGAP model provides cumulative arrivals in a microscopic form. It means that each passenger arrival is represented by a time stamp and that is stored in a table in a cumulative form.

To feed the AGAP arrival earliness profile to the PaxMod it is necessary to represent AGAP profile with a polynomial function. Our literature review showed that the polynomial functions of third or fourth degree are used. Within the PaxMod model the functions are further processed, combined and other data are from them calculated. Polynomial functions of fourth and higher degree are very complicated to process further. Therefore in PaxMod model the polynomials of third degree are used to represent passenger cumulative arrivals and departures. To fit the polynomial of third degree to the AGAP arrival earliness profile the linear regression is used.

D. Simulation and results

The Door-to-Gate Air Passenger Flow Model is used to simulate two scenarios of airport configuration - the baseline scenario and Airside-Landside separated scenario. The baseline scenario represents the classic concept of air passenger transport. The passenger leaves from home or work, travels by the public transport or by car to the airport and proceeds through the airport facilities to the aircraft. The Airside-Landside separated scenario (ASLS scenario) represents new concept of air passenger flows. This scenario is compared with the baseline scenario. The principal difference in the ASLS scenario is that passengers start the terminal processes in the hypothetical city-air-terminal collocated with City main railway station. In the ASLS scenario the passenger processes are different than those in Baseline scenario in following ways:

- The passengers are transported to the airport using hypothetical dedicated train.
- The check-in service, border control and the security are scheduled analogical way as in the Baseline scenario but are shifted by the transport time in advance.
- The check-in, border control and the security are operating in the train and may continue during the transport to the airport.

The preliminary results of the simulations showed that the ASLS concept performs worse for the passenger travel time in general. However the resulting time differences indicate that for the passengers that start their journey close to the city train station and for the passengers that transit via this train station it might be advantageous to travel in the context of ASLS concept.

IV. Conclusion

For the evaluation of future airport concept from passenger flow perspective the door-to-gate air passenger flow model was presented. The model is based on airport ground access and egress passenger flow generator that uses random number generation based on probabilistic distributions and on airport terminal passenger flow model that uses deterministic queuing models for flow representation. Preliminary simulation results of passenger flows through selected airport concept called Airside-Landside Separation Concept showed that the concept has negative impact on passenger travel time in general. However it showed that for specific group of passengers the concept might be advantageous which is the question of the ongoing research.

REFERENCES

[1] Marc Brochard. The airport of the future or breaking the constraints between the terminal and the runways. In Innovative Research Activity Report 2004, pages 37–45. Eurocontrol Experimental Centre, 2004.

[2] Martin Matas. Future airport concept. In Activity Report 2005, pages 83–92. Eurocontrol Experimental Centre, 2005.

[3] N. Ashford, N. Hawkins, and M. O'Leary. Passenger behavior and design of airport terminals. Transportation Research Board Record, 588:19–26, 1976.

[4] G. F. Newell. Application of queuing theory. Chapman and Hall, 1971.

[5] R. de Neufville and A Odoni. Airport systems planning design and management, pages 134–135. McGraw-Hill, 2003.

[6] Robert Horonjeff. Analyses of passenger and baggage flows in airport terminal building. Journal of Aircraft, 6(5):446–451, 1969.

[7] Lorenzo Brunetta, Luca Righi, and Giovanni Andreatta. An operations research model for the evaluation of an airport terminal: Slam(simple landside aggregate model). Journal of Air Transport Management, 5:161–175, 1999.

[8] M.R. Gatersleben and S.W. van der Weij. Analysis and simulation of passenger flows in an airport terminal. In Proceedings of the 1999 Winter Simulation Conference, pages 1226–1231, 1999.

[9] Kiran A. S., Cetinkaya T., and Og S. Simulation modeling and analysis of a new international terminal. In Proceedings of the 2000 Winter Simulation Conference, pages 1168–1172, 2000.

[10] Babeliowsky M. Designing interorganizational logistic networks: A simultion based interdisciplinary approach. PhD thesis, Technische Universiteit Delft, 1997.

[11] P.E. Joustra and N.M. van Dijk. Simulation of check-in at airports. In Proceeding of 2001 Winter simulation conference, pages 1023–1028, 2001.

[12] Winnie Daamen. Modelling Passenger Flows In Public Transport Facilities. PhD thesis, Technische Universiteit Delft, 2004.

[13] Flight timetable Bratislava Airport Summer 2007

[14] G. F. Newell. Application of queuing theory. Chapman and Hall, 1971.

[15] Milan Stefanik. Problems of Airport Capacity Assessment, Doctoral Thesis, Žilinská univerzita v Žiline, 2009.

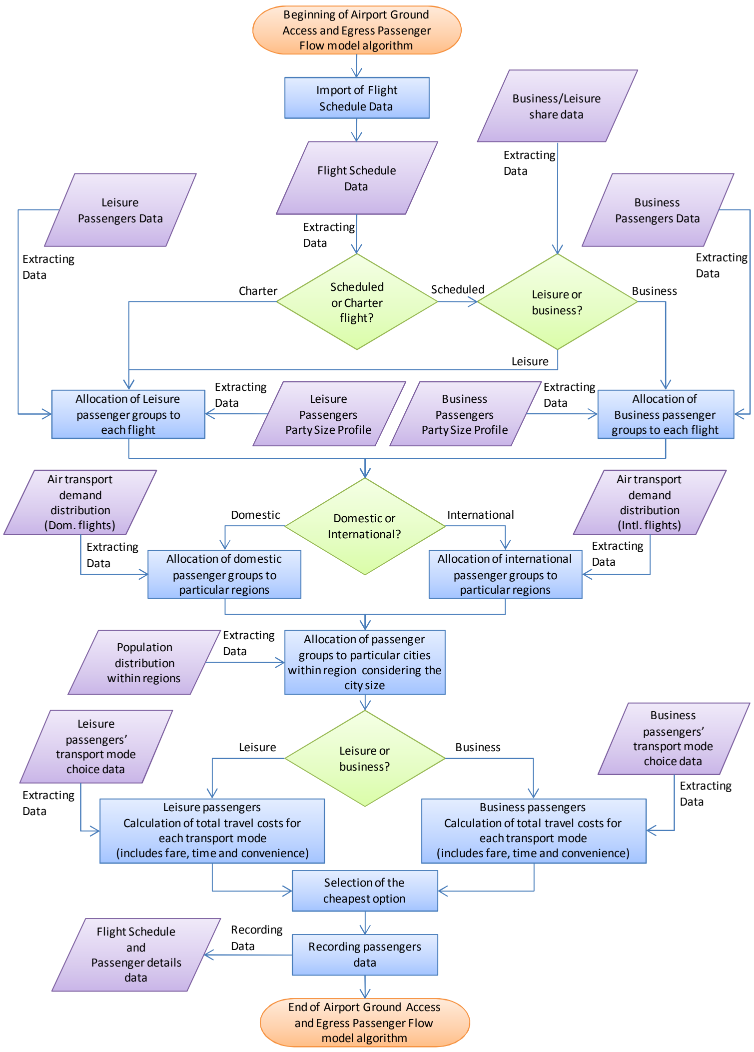

Figure 3. Airport ground access and egress passenger flow conceptual model [15]