AIRSIDE AND LANDSIDE MODELLING FOR DETERMINING AIRPORT CAPACITY

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Abstract. Air traffic is carried out in selected air zones that are controlled by Air Traffic Services. The basic problem they encounter during realization of their tasks is excessive congestion of aircrafts in the airspace. The biggest congestion is observed in the airport area. To provide safety of controlled aircrafts one must know so called airport capacity, i.e. number of planes that can stay in airport area in given meteorological conditions, traffic organization, etc. In this paper, the airport capacity is defined and then a method of calculating the capacity is proposed. In this method airport is modelled as a network, multiphase queuing system with several subsystems. In this model, output streams from one subsystem are the input ones to the next subsystem. Both airside and landside were modelled. Simulation experiments were conducted. They help us to make changes in airport organization that increase capacity.

1 Introduction

What we call an airport, is a separated area, together with all buildings and equipment included within its area. It is designed, in total or in part, to serve as a place for arrivals, departures and manoeuvring of aircrafts [2]. This definition puts a particular emphasis on the landing area (runways), manoeuvring area (taxiways) and aprons (parking and technical areas, ramps). In many cases however, it is necessary to broaden the idea of an “airport”, having also in mind the passenger, his comfort and needs, the terminal, parking lots and the net of access ways for rail and road vehicles, which assure ground communication with the nearest city centre.

In this paper it was assumed that the airport consists of two areas: airside - related to the aircraft service and limited to the airport area; and landside - related to the passengers’ service. Moreover, it was assumed that both within the first and the second area some disturbances among the traffic participants can occur. The passengers’ traffic affects the aircrafts’ traffic. An assumption was made that the passengers’ traffic is included in the aircrafts’ traffic model through specific characteristics of disturbance.

The key role in the proper functioning of an airport lays in adjusting the capacity of its individual elements to the real demand for the air transport service. From the passenger’s point of view, the most important issues are time and quality of service before and after the flight. The models described in this article may serve as tools for assisting decisions related to a planned construction or modernization of airports, in scope of balancing the development of both parts of the airport – the airside and the landside part.

2 Airport capacity

The problem of determining the air traffic sectors capacity is a part of a wider problem called: Air Traffic Flow Management (ATFM). This problem consists in planning and controlling the streams of aeroplanes in the area of more than regional size in a long and a medium - term horizon of control. The services dealing with planning of the flow of streams analyse the capacity of individual control sectors and accordingly to the results they suitably co-ordinate formation of these streams. The aim of these services is to minimise the waiting times of aircrafts being in the air, to avoid temporary overload in individual sectors, to increase the regularity of air traffic.

ATFM Services realise these tasks at many levels and with the use of varied technical and organisational means. Acting strategically they analyse and co-ordinate the flight plans so as to minimize the probability of occurrence of overload. Tactical operations consist in suitable delaying of take-offs of aircrafts, which would find themselves in overloaded sectors of control [10]. The basis for these operations is the fact that delays of aircrafts realised on the ground surface involve smaller costs than those resulting from waiting in the air for the possibility to land. In the latter case additional costs are costs of fuel and those connected with safety of passengers.

At present, worldwide, there are no accepted methods of determining the airport and TMA capacity. ICAO is conducting research in several world centres on settling norms for defining this capacity, as well as methods for their calculation. Establishing a widely accepted method for determining capacity would have a significant impact on the development of methods for controlling air traffic worldwide. It would also be beneficial for any airport modernisation. The realisation of the method for calculating airport area capacity requires full identification of the phenomena taking place in air traffic in these areas.

In literature on the subject so far, we can find several definitions of airport capacity, out of which two have been widely used [6]. One of them defines the so called practical capacity.

Airport capacity (practical) - is the number of starting and landing operations in a given time period corresponding to the allowable delay level. Another definition describes the so called maximum capacity.

Airport capacity (maximum)- is the maximum number of starting and landing operations which the airport can service in a time period, with a constant entry flow.

An important difference between the definitions is the fact that one takes account of delays and the other does not. Although both definitions describe airport capacity, it is usually runway capacity that is being tested. Many known analytical and probability calculus models are used to determine the hourly and annual capacity of runways. The factors included in the analysis were: number of runways and their configuration, number and configuration of departure ways (in a limited range), volume of aircrafts using the airport, weather conditions (IFR or VFR flights), time of runway occupancy.

The approach based on limiting the airport capacity to runway capacity is understandable since intuitively we know that runways are the most neuralgic area of the airport. It results from very small possibility of manoeuvring. In any other subsystem, it is possible to "stop" the aircraft. It is based on realising holding procedures in TMA area, which allows to wait for the air traffic congestion to cease. Similarly on taxi ways, waiting for runway clearance is possible. Naturally, the stopping can be realised more easily on parking posts, where the situation is inherently very static. The situation is quite different in the area in direct neighbourhood of the runways, especially during landing. There are, of course, appropriate procedures after a failed attempt to land, but they are rarely used because of the danger connected with them. That is why the reasons for examining only this part of airport space seem clear.

However, we should take a critical view of this approach because in the light of the quoted capacity definitions each of the subspaces of the airport area can be a "narrow path" which decides about decreasing the capacity. The capacity definition takes an average delay time as an evaluating criterion. Such delays can appear in any of the subsystems, what is more, we can suspect that they are biggest in the areas surrounding the runway subsystem. It may be the result of large separation minimums between the aircrafts settled according to the high risk during the starting and landing manoeuvres. Those separations ensure the safest flow through the most dangerous zone. We should note, however, that arranging aircrafts into suitable stream takes place in the areas preceding the neuralgic subsystem. It is, therefore, justified and even advisable to examine the remaining subsystems. The main issue of this paper is to propose a method for calculating capacity of all subsystems simultaneously – both airside and landside.

It has been proposed to carry out a study over a terminal area seen as a network, multi-phase queuing system, in which the output streams from one sub-system (phase) are the input streams for the next sub-system (the next phase of service). If in the case of an analytic model we have to deal with a kind of very complex queuing model, for which determining stationary characteristics is at present impossible, in the case of a simulating model the numerical experiments show its big simplicity and easiness of obtaining the results.

The proposed method of solution of the problem of airport capacity consists of the following stages:

1. Determination of model of studied space.
2. Recording the model with the use of special language of description.
3. Execution of series of simulating experiments
4. Analysis of received statistical sample and determining the capacity.

A detailed description of the method can be found in [13].

As the result of executing the series of simulating experiments a random sample of realisation of two-dimensional random variable (X,D) is obtained. Pairs X,D define: intensity of air traffic, size of average delay. On the basis of these data a table is created, which corresponds to the distribution of probability of relative average delay at the condition $X=x_0$ for all accessible values x_0 (intensity of air traffic). For this table the values of function G_x are calculated, which is the probability of that the average delay is larger or equal to a pre-set maximum value D_{max}. The probabilities are determined for all accessible values of x_0. For function G_x the value of inverse function is determined in point $\frac{1}{2}$. Because the inverse function can be not unique (and it usually is not) the smallest and the largest value fulfilling the pre-set condition is read, and from these values arithmetic average is then calculated.

3 Airport airside modelling

The goal of creating a model of airport is determining its capacity. Analysing the capacity definitions we can observe that they emphasize the dependence of the number of aircrafts, which can use the air space on the geometrical structure of the area and the time-space relationships called separations. The capacity depends on the distance between input and output points of the area and the periods between the subsequent reporting of aircrafts at the entries and the flight times through the examined air space. It seems that neither the aircraft's trajectory in the modelled air space, nor the workload of the air traffic controller, is important. This is comprehensible since in the first case any changes in the level, or the standard flight route (landing approach) could be statistically presented as flight time between the entrance and exit points. In the second case, however, the controlled space can be divided into several subspaces, controlled by different controllers which will decrease the workload for a single controller and will not be a limiting factor. In the light of the above it is easy to observe that the best model is the one with several input streams and several exits. At each entrance we can deal with a different probability distribution of reporting aircraft sequence. From each entrance the aircraft can proceed to each exit, while the time of flight can in each of these cases have any probability distribution.

In this approach to the problem, the phenomenon of queuing for the service proves to be a big interpretation difficulty. This waiting in traditional queuing systems takes place in a queue (with a given discipline) after checking occupancy of the service channel. This is done immediately after arriving in the system; the object is immediately serviced or takes a place in the queue. In the case of the controlled area of the airport the situation looks a little different. Both the examination of channel occupancy and waiting for the service must take place before reporting to the system. This feature makes a new approach to queuing systems modelling necessary.

The landing aircraft approaching the runway is being serviced by TMA controller. The next service channel for this object will be CTR area. However, the CTR controller will take the object for service only if it is possible, that is if adequate separations are fulfilled. Knowing this TMA controller can predict in advance whether CTR area will be able to receive it. If not, then it has to delay the flight of aircraft in such a way that it will report to CTR at a suitable moment (At the moment the service channel is empty). As can be seen, examining the occupancy of the channel, as well as possible queuing takes place before reporting to the system (in this case CTR). Evidently, queuing for entering CTR significantly influences the time of the aircraft's service in the former subsystem, that is TMA. There is a certain analogy to the loss system (the queue limited to 0). It is, however, a far-fetched simplification, since we cannot dismiss the landing of the aircraft in the air. That is why the following unified interpretation of the air traffic control is proposed.

We assume that airport area (S_{AA}) will be understood as an area, that is described in three dimensions, that is a sum of few components:

$$S_{AA} = S_{TMA} \cup S_{CTR} \cup S_{TX} \cup S_{TS} \tag{1}$$

where:

S_{TMA} - airspace that is used for landing approach procedures and for climbing after start procedures - it corresponds to Terminal Area (TMA);

S_{CTR} - runway area, includes both airspace and ground space in which aircraft carry out starting and landing manoeuvres - it corresponds to Airport Controlled Area (CTR);

S_{TX} - ground space, in which aircraft taxing before start and after landing takes place;

S_{TS} - ground space, in which all technical service procedures take place;

If we denote as S_{FIR} whole space that is used by civil aviation, and as S_{AWY} - airways area, then:

$$S_{FIR} = S_{AWY} \cup S_{AA} \tag{2}$$

The process of aircraft service consists of few consecutive phases; each of them is independent queuing system. There are *F* phases of service, related to airport area subsystems. Usually, in the case of typical airport, the number of phases is 7:

Phase 1 - process of flight through TMA sector and approaching to land,
Phase 2 - process of landing on one of the accessible runways,
Phase 3 - process of taxing to desired standing post,
Phase 4 - is identified as aircraft technical service,
Phase 5 - process of taxing to desired runway threshold,
Phase 6 - corresponds to the process of start,
Phase 7 - process of climbing after start and flight out of TMA area.

In special cases, in non-typical air traffic organisation, the number of phases may vary. Some of above mentioned may not appear or some other may be present.

Airport area may be described as a network queuing system, using a graph

$$G = \langle W,U,P \rangle \tag{3}$$

where:

W - set of nodes, corresponding to subsystems (phases of service): $W=\{Z_0, 1, 2, ..., F, Z_{F+1}\}$,

U - set of graph branches,

P - relation defining connections between elements of set W: $P \subset W \times U \times W$

Relation P fulfils the following conditions:

$$\underset{u\in U}{\forall}\ \underset{w,y\in W}{\exists}\ < w,u,y >\in P \tag{4}$$

and

$$\underset{<w,u,y>\in P}{\exists} \wedge \underset{<v,u,z>\in P}{\exists} \Rightarrow \left((w=v)\wedge(y=z)\right)\vee\left((w=z)\wedge(y=v)\right) \tag{5}$$

Two additional elements were defined in set of nodes W. Z_0 is the source (generator) of entries, and Z_{F+1} is destination (absorber) for entries served. If a graph G describes airport area, then relation P consists of the following elements.

$$P=\{<Z_0,u_1,1>,<1,u_2,2>, \dots ,<f,u_{f+1},f+1>, \dots,<F,u_{F+1},Z_{F+1}>\} \tag{6}$$

For each phase f: $(f=1,2,\dots,F)$ one can define:

$A^f(x)$ - distribution function of entries to the system, $B^f(x)$ - distribution function of service time, λ^f - input process intensity, μ^f - service process intensity.

Each of subsystems of the examined space (each of phases) consists of service lines i^f: $(i^f=1,2,..,m^f)$. A service line corresponds to the route from the entry point to the exit point of the air space. For $f=1$ it is a part of the airway in TMA, for $f=2$ - the runway, etc.

Aircraft report to the entrance of the service line i^f: $(i^f = 1,2,\dots,m^f)$, in phase f: $(f=1,2,\dots,F)$, with λ_i^f intensity. It is assumed that the distance between successive reports cannot be smaller than time t^f_{min}, which corresponds to the minimal separation obligatory in the given air space. The service time depends on the line number i^f and on the k category of the reporting object, thus the intensity of service equals $\mu^f_{i,k}$. The object category corresponds to the weight category of the aircraft (volume of the aircraft). Depending on that category there are different times of flight through corresponding areas. Naturally the weight categories of the aircraft should also be included in the input stream. Thus the input stream with λ_i^f intensity is the sum of component streams,

$$\lambda_i^f = \sum_{k=1}^{K} \lambda_{i,k}^f \tag{7}$$

where K - number of weight categories.

On every line in phase f there are S^f_i service posts, where S^f_i is the maximum number of aircraft which can at the same time be under control in line i in subsystem f. Output streams from each of the m^f lines of the subsystem f, comprise the input stream to one or more lines i^{f+1} of the next subsystem. Queuing for the next subsystem takes place in the proceeding one, that is in the time of service $\tau_{i,k}^f$ the queuing time to the next subsystem is included. If all service channels in subsystem f are occupied, then the object blocks the post so far occupied in the subsystem $f-1$ and does not release it until one of the posts in the next subsystem is empty. Thus we deal with system with limited capacity. Entries may be lost only during input to the system (to Phase 1), due to first phase overfilling.

Queuing system, that comprises f-th service phase, can be described using the following symbolism:

$$m/\mathbf{S}/\mathbf{A}/\mathbf{B}/\mathbf{N}/\mathbf{P}/\mathbf{RO}/\mathbf{RK} \tag{8}$$

m - number of service lines.

S - vector $[S_1, S_2, \dots, S_i, \dots, S_m]$ determining the number of service posts in each of service lines.

A - vector $[A_1, A_2, \dots, A_i, \dots, A_m]$ of distribution functions of random variable describing the time between $(n-1)$-th and n-th entry (ξ_n), to i-th service line. This vector has a corresponding one $\Lambda=[\lambda_1, \lambda_2, \dots, \lambda_i, \dots, \lambda_m]$ - vector of intensity of input to every line and vector $TW=[tw_1, tw_2, \dots, tw_i, \dots, tw_m]$ describing minimal time that must pass between two successive inputs for service in a given phase.

B - vector $[B_1, B_2, \dots, B_i, \dots, B_m]$ of distribution functions of n-th object service time (η_n). This vector has a corresponding one $M=[\mu_1, \mu_2, \dots, \mu_i, \dots, \mu_m]$ vector of service intensity in each of service lines. It is assumed, that random variables η_n has identical distribution function on each of S_i service posts of i-th service line. It is also necessary to define a vector $TU=[tu_1, tu_2, \dots, tu_i, \dots, tu_m]$ that describes minimal time that must pass between two successive service ends in a given phase.

N - vector $[N_1, N_2, \dots, N_i, \dots, N_m]$ defining the number of places in the queue in every service line.

RO - vector $[RO_1, RO_2, \dots, RO_i, \dots, RO_m]$, describing queue discipline in i-th service line.

RK - vector $[RK_1, RK_2, \dots, RK_i, \dots, RK_m]$ describing queue discipline in input queue.

$$\mathbf{P}\text{ - Matrix}\begin{bmatrix} p_{1,1} & p_{1,2} & \cdots & p_{1,j} & \cdots & p_{1,m^{f+1}} \\ p_{2,1} & p_{2,2} & \cdots & p_{2,j} & \cdots & p_{2,m^{f+1}} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ p_{i,1} & p_{i,2} & \cdots & p_{i,j} & \cdots & p_{i,m^{f+1}} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ p_{m^f,1} & p_{m^f,2} & \cdots & p_{m^f,j} & \cdots & p_{m^f,m^{f+1}} \end{bmatrix},$$

in which $p_{i,j}$ describes probability of transition from *i*-th service line in phase *f*, to *j*-th service line in phase *f+1*. Of course

$$\sum_{j=1}^{m^{f+1}} p_{i,j} = 1 \qquad \forall_i \left(i = 1,2,\ldots,m^f\right) \tag{9}$$

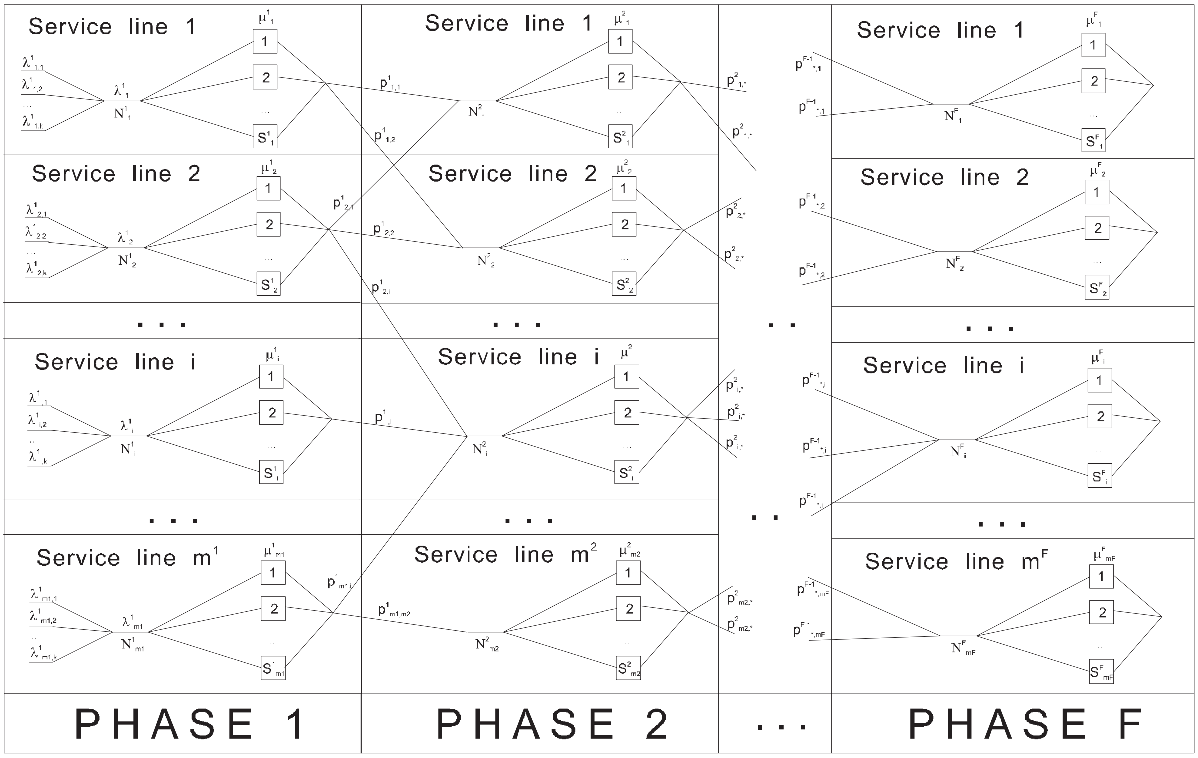

Figure 1. Air traffic control system as a network queuing system

Using such defined symbolism one can denote model of airport area in the following way:

$\mathbf{m^1/S^1/A^1/B^1/N^1/P^1/RO^1/RK^1} \rightarrow \mathbf{m^2/S^2/B^2/N^2/P^2/RO^2/RK^2} \rightarrow \ldots \rightarrow \mathbf{m^i/S^i/B^i/N^i/P^i/RO^i/RK^i} \rightarrow \ldots \rightarrow \mathbf{m^F/S^F/B^F/N^F/P^F/RO^F/RK^F}$

In some subsystems (phases) priority rules must also be considered. For instance in runway subsystem one can demand that landing aircraft had priority over starting one.

For modelling the airport area, algorithm relations between service processes in various phases were also considered. Such a relation may, for example, consist in existence of possibilities to ‘block’ one subsystems by others. In such a case, even though there are available check-in points, the service in one phase will not be possible until the complete termination of the service realized in another phase takes place, or termination of a given part of the phase. These relations may be defined in the following way. We determine a binary matrix of the algorithm relation **MZA**, with FxF dimensions.

$mza_{i,,j} = 1$, if there exists a dependence of „blocking” between two arbitrary lines in phases *i: (i=1,2, ...,F)* and *j: (j=1,2,...,F)*,

$mza_{i,,j} = 0$, otherwise.

If $\forall_{i=f_1, j=f_2} mza_{f_1,f_2} \neq 0$, then we define a matrix of blocking:

$$MB^{f_1 f_2} = \left[mb_{k,l}\right]_{m^{f_1} \times m^{f_2}} \tag{10}$$

which values $mb_{k,l}$ are equal:

$mb_{k,l} = p_b$ if there exists algorithmic dependence between line k in phase $f=f_1$ and line l in phase $f=f_2$; in this case p_b defines percentage of object service time in phase f_1 that must past, so as the service of another object in phase f_2 may begin.

$mb_{k,l} = 0$ if „blocking" dependence does not exist.

The sequence of passages between various subsystems, represented by **m/S/A/B/N/P/RO/RK,** together with additional information included in the **MZA** and **MB** matrixes, constitutes a complete model of air traffic in the area of an airport.

There are several ways of verification of results received with the use of the described method. The following have been applied:

1. Creation of a precise detailed simulating model of fragments of area of the airport and assessment of results obtained with the use of the simplified model (designed for utilisation in target system) when compared to the results from the detailed model.
2. Calculation of stationary characteristics of fragments of network queuing system, treating the system described here as an open net of Jackson type [7]. Such treatment is, of course, sensible only in the case of Poisson's processes, taking place at the inlet and inside the system. In a real case of modelling of the movement of aeroplanes in the region of airport, such assumption is not fulfilled, however, for the purpose of verification of the model it is possible to have the results of such theoretical analysis compared with those obtained from the simulating models, in which all the stochastic processes taking place are Poisson's processes.
3. Determining the capacity of runways, with the use of presented method, for a chosen configuration of runways, weather conditions, constitution of the stream of aircrafts etc., and comparison thereof with the capacities of runways given in literature, for the same input parameters.
4. Comparison of the value of average delay of an aircraft obtained from the model, with statistical data collected for actual airport (in this case Warsaw Okęcie airport).

An example of use of the second way of verification has been described below.

It is possible to select a small fragment of airport and to simplify the phenomena taking place there to such extent, that analysing of this fragment as a simple queing system is possible. For verification of the realised simulating modelling program, such theoretical analyses were executed and compared with the results of simulating modelling, for chosen fragments of the region of airport.

Simplifying assumptions:

1. Intervals of time between individual reporting are exponential.
2. Times of flying over the TMA area are exponential.
3. Separation at the outlet from TMA (at the entry to CTR) is equal 0.
4. Time of service in the CTR region is equal 0, or equivalently - the number of aircrafts which can be in the CTR region is unlimited.
5. Aeroplanes reporting to TMA are of the same type (homogeneous stream of reporting).
6. Lack of separation at the entry to TMA.
7. In TMA there exists only one airway.
8. The queue of aircrafts at the entry to TMA is limited to 0.

For such simplification the TMA region becomes isolated from the surrounding areas, which makes possible to investigate it as a system M/M/n/0, where n is equal to the number of aircrafts which can find themselves on the airway in TMA.

Because in this system the average time of waiting equals zero (a reporting is either immediately served, or lost), therefore the quantity which can be compared is e.g. the probability of loss of reporting. It is expressed by equation [8]:

$$P_{n+N} = \frac{\rho^{n+N}}{n!n^N}\left[\sum_{k=0}^{n}\frac{\rho^k}{k!} + \frac{\rho^n}{n!}\sum_{k=1}^{N}\left(\frac{\rho}{n}\right)^k\right]^{-1} \tag{11}$$

wherein: N - limitation of queue (in this case 0), P_i - probability that in system there are i objects,

$\rho = \frac{\lambda}{\mu}$ - coefficient of the system being occupied, λ - intensity of reporting, μ - intensity of service of one channel of service.

Using the formula shown above the calculations of probability of refusal have been duly calculated. The same probability was determined with the simulating model, having used the simplifying assumptions as described above. The results of calculation have been presented in the Table 1. We can see that the results are very close, so the verification is positive.

Flight time in TMA (min)	Average time between reportings (min)	Number of servicing stands n	Probability of loss of reporting (analytically)	Probability of loss of reporting (model)
15 minutes, or μ=0,067	3 minutes, or λ=0,333	5	0.28	$\frac{202}{645}$=0.31
10 minutes, or λ=0.1	3 minutes, or λ=0,333	3	0.38	$\frac{297}{754}$=0.39
15 minutes, or μ=0,067	3 minutes, or λ=0,333	8	0.07	$\frac{35}{562}$=0.07

Table 1. Verification of the model with the method of comparison of probability of loss of reporting.

4 Airport landside modelling

A passenger using air transport is mostly attended by an air transport company (airline). Such a service is composed of three main phases:

- Flight preparation phase: reservation and buying the ticket; luggage check-in, ticket and passport control, customs clearance; entering the aircraft.
- Flight from the starting to the final destination airport phase.
- Ending phase of the air service: leaving the aircraft; luggage collection; passport control and customs clearance.

From the passenger's point of view, the most important element of the airport is the terminal. It is the place, where the passenger handles the majority of formalities related to his journey and the time needed to deal with this is frequently comparable to the time of the flight itself. The quality of service during the check-in procedures and the comfort provided to the client is one of the criteria used by passengers for evaluating the air companies.

The size and shape of the terminal depend on the maximum number of passengers foreseen for attendance in a unit of time. The capacity of the terminal is limited by two fundamental factors:

- the size of the terminal and practical arrangement of rooms,
- the capacity of check-in systems.

The service provided to the departing passengers may be performed in the following three ways:

- scheduled – for every flight, separate points for ticket and luggage check-in are assigned,
- free – the passenger's ticket and luggage check-in may be performed by any check-in point,
- mixed – free for a certain period of time before closing the registration for a given flight, additional check-in points are assigned to serve as a scheduled flights model.

Below there is a description of a computer presentation of the model, which serves as a convenient tool for testing and evaluating the impact of organizational changes within the terminal on its capacity level.

A fundamental element of the drafted simulation method for analyzing the check-in system's capacity is a model of passenger's service. This specific model assumes that a passenger may be situated in one of the following eight elements: *Entrance*, *Departure Hall*, *Profiling*, *Security Check*, *Check-in*, *Customs Clearance*, *Passport Control*, *Abroad*. Each of these elements is related to a certain state variables, describing the state of the model.

The *Entrance* element is described by a variable of arrival, which determines the number of persons arriving in a given moment to the Departure Hall. The *Departure Hall* element is described by a variable of presence, which determine the number of persons present in the Departure Hall in a given moment. The *Profiling* element is described by a set of state variables, which are:

- flight number vector – determines the flight numbers, which passengers are attended in a given moment by a *i*-th profiling point;
- queue for profiling – determines length of the queue to the *i*-th profiling point;
- time of profiling – determines the time needed for attending the first passenger in the queue for the profiling point.

The state variables of the remaining model elements were determined in a similar way (Figure 2).

It is assumed that five attributes describe every passenger in a model:

- what to do – determines the probability whether the passenger after finishing the check-in operations proceeds to *i*-th element;
- whether to declare – determines the probability whether the passenger decides to declare his luggage for customs clearance;
- which flight – determines the number of the passenger's flight;
- which class – determines, which class offered by the carrier shall the passenger choose to fly;
- visiting – determines the time spent by the passenger in the Departure Hall.

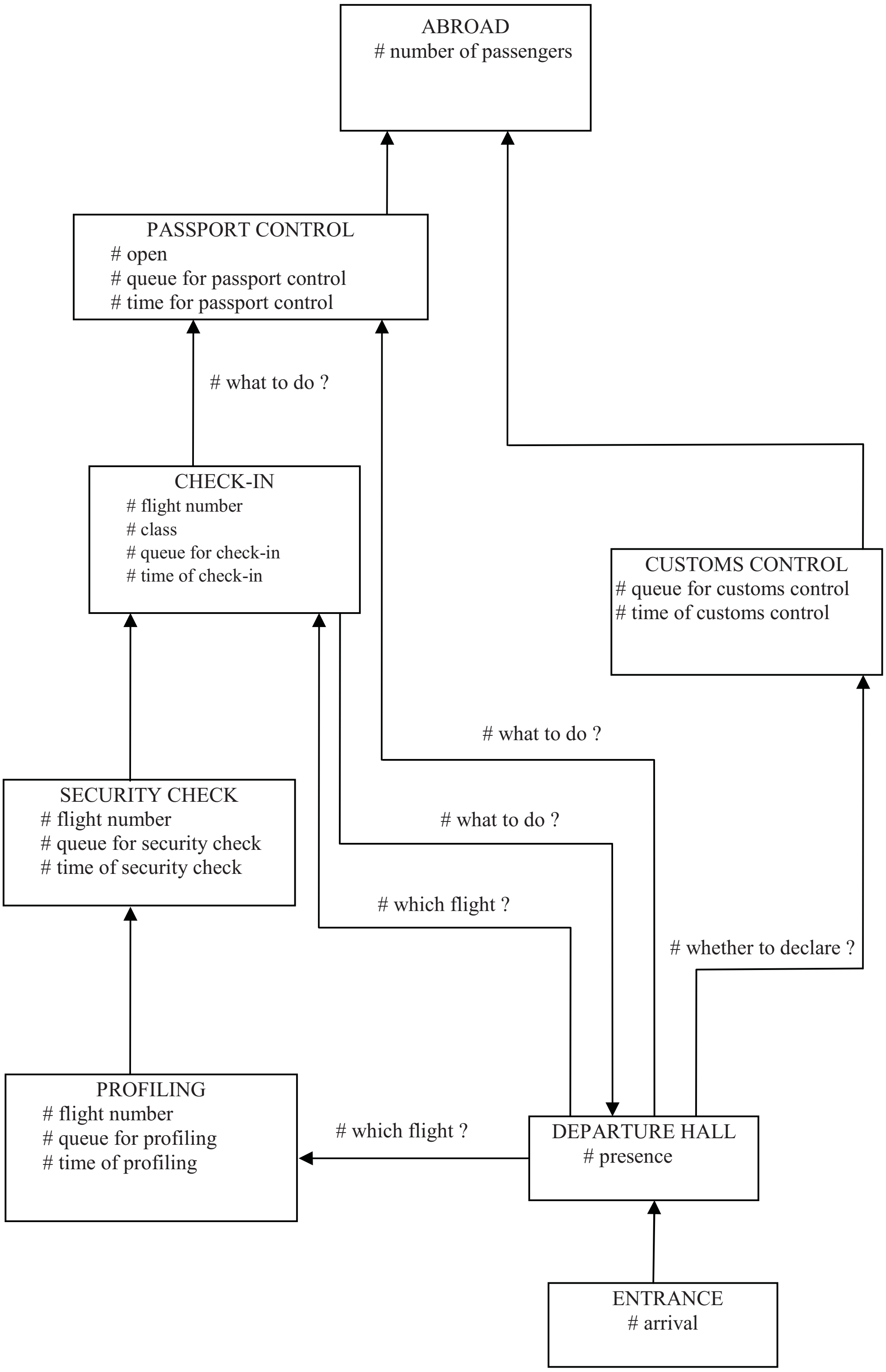

Figure 2. Scheme of interactions between the elements of model

The scheme of influences demonstrates visually the elements of the described model, together with the variables characterizing the state of these elements. This scheme is shown on Figure 2. It does not include, however, the internal structures of individual elements, such as the number of servicing points or the division of servicing points among different groups of passengers. The elements of the model are connected with lines, representing the influence of one element towards the other. Some of the lines are marked with names of parameters or variables characterizing the passenger, which state determines the path chosen for the passenger. In case there are no markings near the lines, it means there is no alternative flow path.

5 Simulation experiments and results

Model investigations were carried out with the use of computer program, using the method of discrete simulation. This program has been worked out in order to determine the capacity of airport basing upon modified definition of practical capacity. The algorithm of the program is following:

1. Setting the values of parameters having influence on the capacity of airport area. A file system.dat is created, which contains the description of airport area with use of special language of description of data.
2. A series of simulating experiments is done. In dependence on intensity of reports at the input to the system, the number of experiments carried out for determining the capacity of airport area may oscillate from about 100 to about 300. A file system.out is created, which includes pairs of random variables (X,D), being the realisation of a two-dimensional random variable defined in paragraph 2.
3. The capacity of region of airport is defined. In order to do that a graph of function G_x is created, and then on its basis the value C_T is determined.

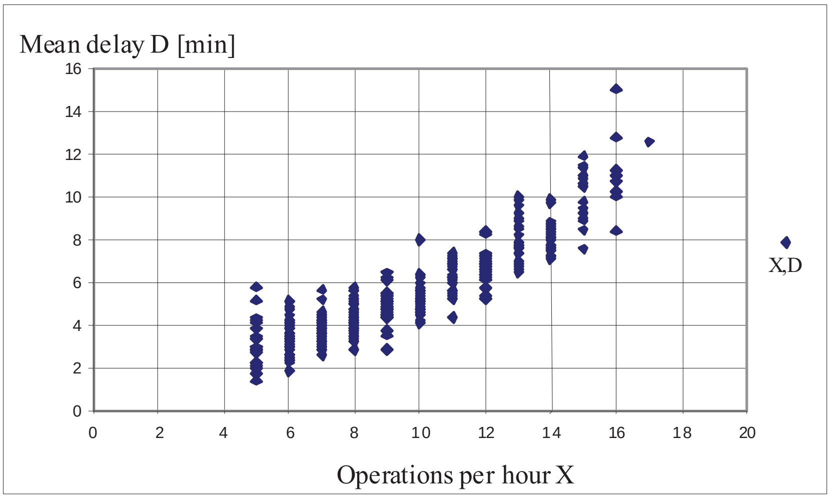

Figure 3. Simulation results for Warszawa-Okęcie airport - random variable (X,D)

The program has been realised in such a way, that a wide range of parameters could be modelled. An individual simulation experiment is carried out for a definite set of parameters influencing on the capacity. Its outcome is a single realisation of two-dimensional random variable (X,D). The next experiments are carried out for the same input data with altered intensity of reporting to the system. The character of input stream to the airport area remains unchanged. The step of change of intensity of reporting is so small, that there are about 200 realisations of two-dimensional random variable (X,D) obtained altogether. The time of simulation is 24 hours at constant intensity of reporting. For such a period all the occurring delays are then added up. An example of a sample of two-dimensional random variable (X,D) that was obtained is represented graphically on Figure 3.

Then a capacity of considered airport is calculated. For each of obtained values of traffic intensity X, the probability that mean delay D is equal or greater than 8 minutes (D_{max}) is calculated. It means the values of function G_X are calculated. They are shown on Figure 4.

Basing on above G_X function, and according to proposed in paragraph 2 definition, one may obtain the value of airport capacity (in this case the capacity equal 14).

Building a model and a computer simulation tool is the starting point for many simulation experiments, that result in much deeper understanding of system that was examined. Also possibilities of improvements may be checked. As an example a research of relation between airport capacity and starting or landing separations is described below. The following plan of experiment was assumed:

- Separation between aircrafts changes from 0 to 10 minutes in 0,5-minutes interval.
- For each value of separation, capacity calculation is performed 10 times. Then maximum and minimum values of capacity are rejected, and from the remaining 8 the mean value is calculated.

- For each experiment traffic intensity is increased by 0,5%.
- Every simulation resulting in obtaining one pair of (X,D) random variable relates to 50 hours of simulated traffic.

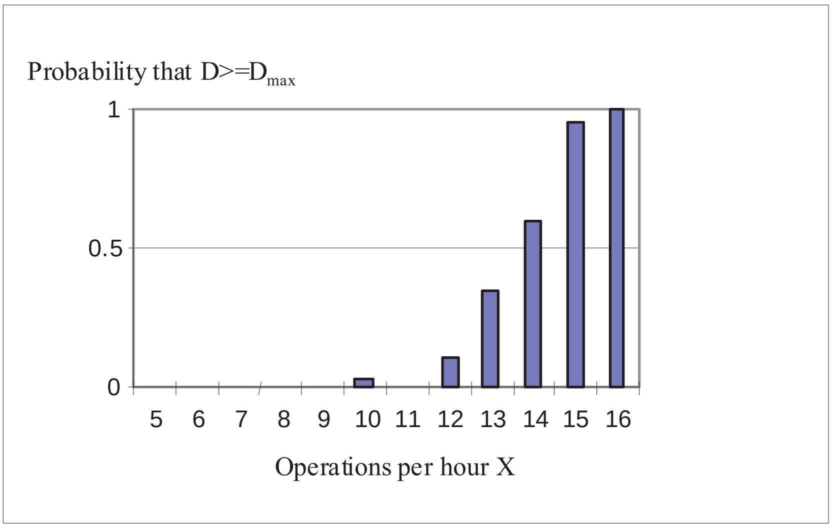

Figure 4. Probability that mean delay is equal or greater then maximum allowed

Relation between separation used in runway subsystem and airport capacity is shown on Figure 5.

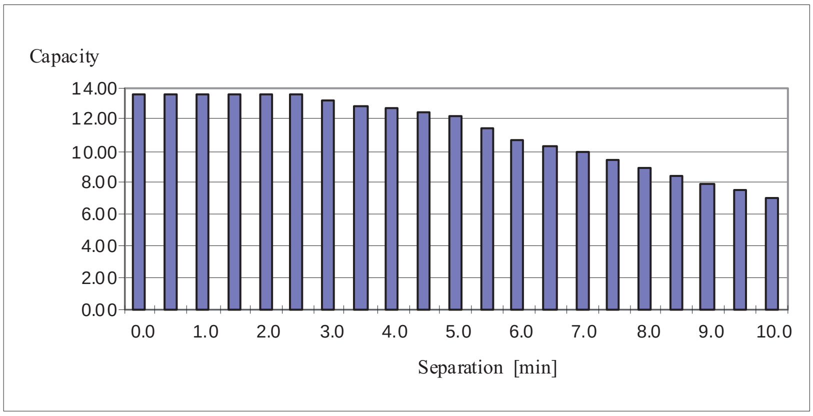

Figure 5. Relation between separation used in runway subsystem and airport capacity

In order to carry out simulation experiments for landside area, statistical data was collected, which describe: intensity of passengers' requests, distance and time of transfer between successive servicing points, passenger's traffic within terminals, where no check-in operations are realized (for example, in the terminals' service area), duration of service in given points.

Simulation experiments were conducted, which consisted in testing of a real check-in systems' configuration, so as to point out the system's bottlenecks. Later on, some other experiments were realized, which were to evaluate the impact of the flight schedule, the number of points on different stages of the passenger's check-in procedure as well as of the distribution of check-in points among airlines, on the system's capacity. Below there are examples of results for a real situation's simulation and a planned reconfiguration of the check-in system. The figures show the length of the queue and the waiting time.

Simulation of actual configuration

security check - 6 points (3 LOT + 3 PPL),
passenger check-in LOT - 19 points,
passenger check-in PPL - 12 points,
passport control - 8 points.

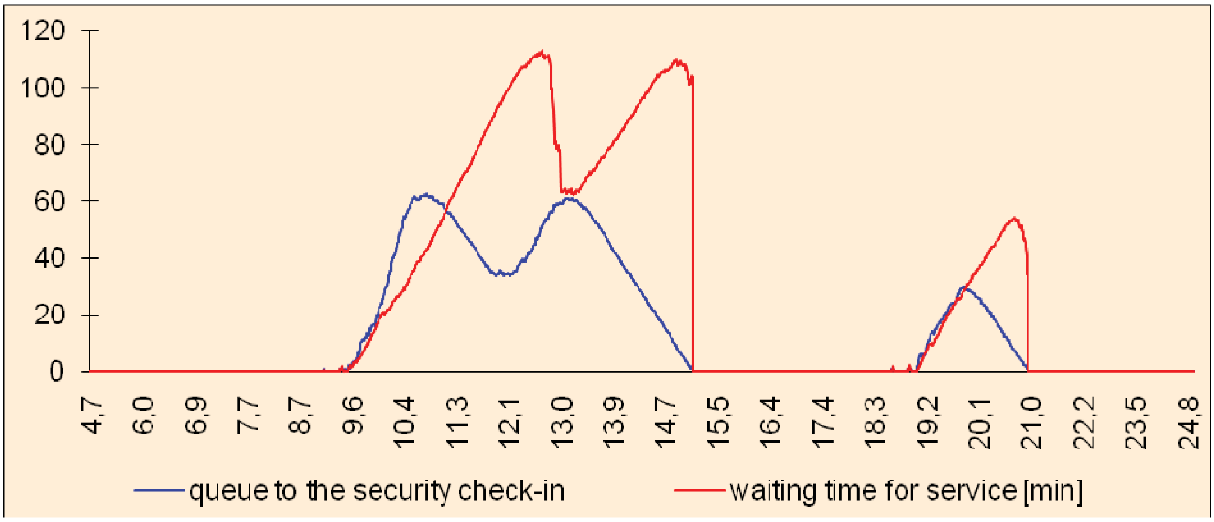

Figure 6. Results of simulation of actual configuration in landside area

Simulation of situation after reconfiguration I

security check	in LOT	- 3 points,
security check	in PPL	- 3 points,
passenger check-in LOT		- 19 points,
passenger check-in PPL		- 12 points,
passport control		- 12 points.

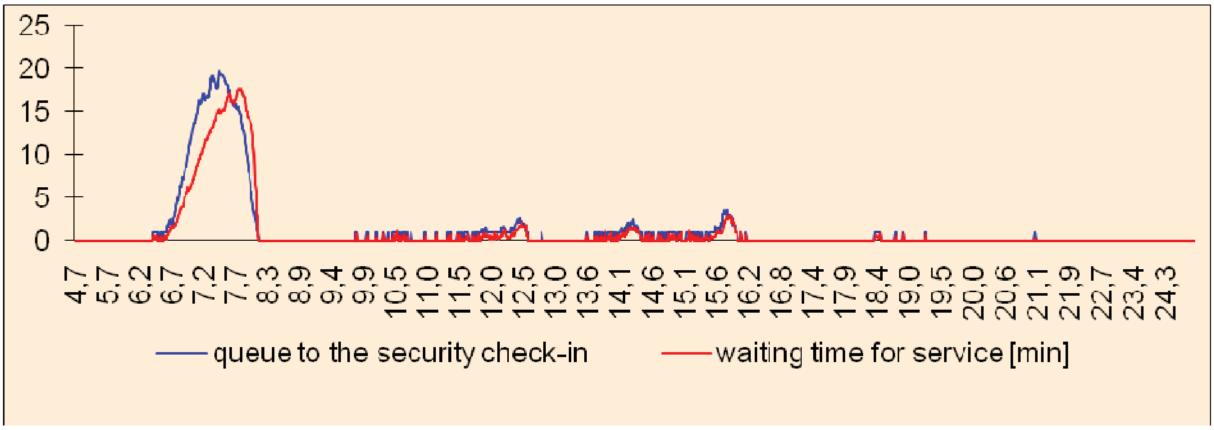

Figure 7. Results of simulation for a check-in system after reconfiguration I

On the presented figures it is clearly visible that reconfiguration results in lowering the maximum values of waiting time and queue length. Analysis allowed for choosing such organizational solutions for a terminal, which may maximize the capacity and minimize the costs as well as the number of changes in the flight schedule.

6 Conclusions

This paper presents methods for model examination of the airport area. Their task is to establish and implement a method for determining airport capacity. Building a computer system for determining capacity in real time is proposed. To this end, it was necessary to establish a method for modelling airport space, so as to allow an effective calculation of capacity, at the same time keeping track of the important dependencies between the examined objects and systems. Considering the experience gained from the works on the topic, it is proposed to examine the whole air traffic system in the airport area, including the relationships between the subsystems. A simultaneous determination of capacity of all systems should be used, as well as the whole area of controlled airport, since any of the subsystems can be a limiting area.

It is proposed to treat the examined area as a network, multiphase queuing system, where output streams of one subsystem are input streams for the next. An attempt at analytical determining of stationary characteristics of the system should be made. More detailed information could be obtained through simulation modelling. Whereas in the case of analytical model we are dealing with a complex type of queuing system, in the case of simulation model the initial numeric experiments indicate a simplicity of the model and an easy access to results.

Examinations, which were realized, concerned movements and service of aircraft in controlled airport area and also service of passengers in terminal. Phases and stages of airport traffic were analyzed and modelled, taking into account on-ground service of aircraft and passengers. Air traffic models in airport area consists of simulations of movements and service of aircraft processes in conditions of periodically occurring disturbances.

Developed methods of estimating of air traffic service process in airport area can be used for: verification of schemes concerning constructing and enlargement of airport, establishing existing capacity reserves, designating effective investments and organisational ventures in specific area, establishing rim conditions of slot policy, studies concerning meeting of international aviation organisations requirements.

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