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# ANALYSIS OF AIRCRAFT DELAYS AT THE STAGE OF ARRIVAL AT AIRPORT

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**Abstract.** *Delays in arrival phase of flight depend on the manner in which airspace is organized, the application of technology and runway availability. Service process at the stage of arrival at airport is modeled. Service rate at airport that has influence on waiting time for landing is analyzed.*

**Keywords:** airport; arrival; delay; queue; service process; waiting time.

## 1. Introduction

All Air Traffic Flow Management (ATFM) delays occur for a variety of reasons and have been grouped into one of the following four categories [7]:

– delays due to ATC reasons (en route or aerodrome);

– delays due to airport infrastructure;

– delays due to weather conditions;

– delays due to other events not covered in the above categories (military activity, special events) or network management (ATC routing).

ATFM delays due to airports accounted for 43.4 % of total ATFM delays.

One of the prime reasons for airport delay, on a daily basis, is due to traffic demand that exceeds the agreed capacity of an airport as well as poor ATFM slot adherence.

According to [3] the average delay per flight on arrival from all causes decreased from 10 min to 9 min per flight in 2013 (Fig. 1).

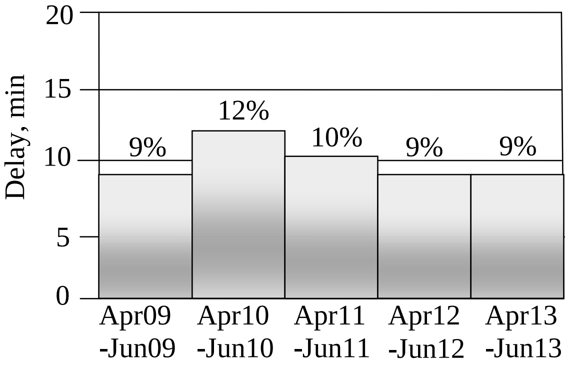

**Fig. 1.** Average delay per flight (all-causes) for arrivals

The percentage of delayed flights decreased to by 1.3 percentage points to 33.3 % in comparison to 2012 (Fig. 2).

In Europe, arrival delays are mainly influenced by the departure punctuality.

The easiest way to improve arrival punctuality is by improving the departure punctuality.

Arrival punctuality on the other hand is a very important indicator for the stability of the airline’s network. On-time arrivals are of greater importance for the stability of the airline’s flight operations than an on-time departure.

On-time arrivals mean that passengers can make their connections, that aircraft can be prepared in time for the next flight, that crew have sufficient time to change aircraft in case they are operating multiple-sectors, and it avoids late minute gate changes with possible lost passengers etc.

Airlines will still focus on the departure phase because an on-time departure is the best guarantee for an on-time arrival.

Strong headwinds, very long taxi-times, unrealistic block times, and holdings can still cause arrival delays in case of an on-time departure.

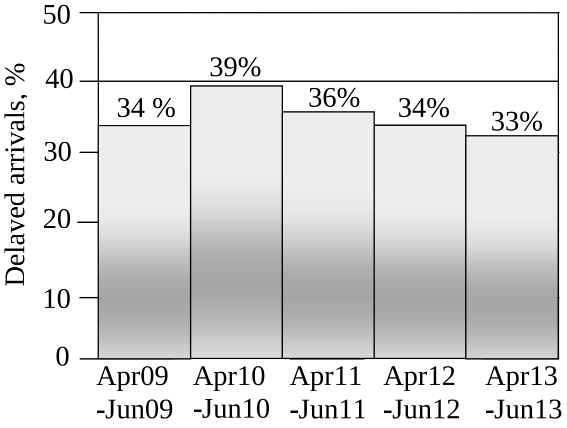

**Fig. 2.** Percentage of delayed flights (all-causes) for arrivals

Future aviation demand will rely on the ability of airports to accommodate increased aircraft operations, larger aircraft, and more efficient passenger throughput.

## 2. Literature overview

The capacity of the airport system is affected by many factors, including the layout of individual airports, the manner in which airspace is organized and used, airport operating procedures, weather conditions, the aircraft type using the system, and the application of technology [8].

The concentration of aircraft arrivals at an airport can result in congestion and delay.

Delay is an indicator that activity levels are approaching or exceeding throughput capacity levels.

In literature service process of arrival flows in airport is determined by Queuing Theory.

In work [6] employs results from Queuing Theory to quantify the relationship between trajectory uncertainties and traffic flow efficiency in the airspace. It proposes to employ approximate queuing network analysis methods that model the arrival and service processes with the first and the second moments.

In work [11] performs a comparative environmental analysis of ground and en-route delays, along with assessing the corresponding costs.

In paper [5] gives a characterization of the traffic flow, a queuing analysis of delays.

It is analyzed metering delays in an arrival flow and discussed a strategy to absorb metering delays during the cruise phase instead of the descent phase.

In [1] describes an approach for modeling flight delay appropriate to such an application, specifically due to airport capacity constraints.

In [9] develops a queuing model for aircraft landings at a single runway under trajectory-based flight operations.

A recursive queuing model is formulated, and Clark's approximation for the maximum of a finite set of random variables is employed to analytically approximate the mean and variance of flight delays.

In [4] reviewed models for the analysis of air traffic flow.

Flow models can provide insight into the mechanisms of congestion.

In [7] paper presented a methodology to analyze the impact of trajectory uncertainty and precision on air traffic flow efficiency using queuing theory.

The central idea is to model every quantifiable uncertainty in aviation operations and cast it into queuing model parameters such as arrival rate distributions, queuing time distributions, transition probabilities and number of servers per node.

The **purpose** of this paper is to model arrival service process in an airport, analyze waiting time for landing and time of service.

## 3. Arrival service process in airport

Congestion management is a broad term that includes a number of federally imposed administrative measures, for example, slots, which limit the number of flights that may be scheduled, to reduce congestion and delay and allocate constrained capacity [8].

Congestion usually appears by the combination of

– a flow of customers needing service;

– some restrictions on the availability of service;

– irregularity in the flow of customers, the servicing operation or both.

In air traffic management, the flow of customers corresponds to aircraft requiring entering a runway, (Fig. 3).

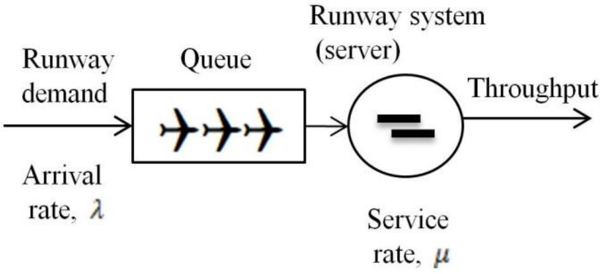

**Fig. 3.** A sample queuing network representing arrival process

Currently, runway capacity is limited by five factors that have influence on service rate in airport [2]:

– separation of aircraft – how closely aircraft can be spaced one after another when approaching the runway;

– lateral separation, especially in bad weather, between aircraft approaching the same airport on parallel runways;

– the sequencing and separation of departing and landing aircraft on runways that intersect;

– the sequencing of departing and arriving aircraft on a single runway;

– the sequencing of aircraft approaching airports located in close proximity to one another, where one aircraft must cross the path of another aircraft landing at a nearby airport.

In this queuing system the aircraft arrive according to a Poisson process with rate, where $\lambda > 0$, and where the service times of the aircraft are independent with the same, arbitrary, $G(x)$.

More precisely, if $\sigma_i$ and $\sigma_j$ are the service times of two aircraft, say *i* and *j*, $i \neq j$, respectively, then $\sigma_i$ and $\sigma_j$ are independent

$$G(x) = P(\sigma_i \le x) = P(\sigma_j \le x)$$

for all $x \ge 0$.

Let set

$$p = \frac{\lambda}{\mu},$$

also assume that aircraft are served according to the service discipline First-In-First-Out (FIFO).

Define $W_n$ to be the waiting time in queue of the $n$-th aircraft under the FIFO service discipline.

Let

– $\overline{W}$ be the mean waiting time;

– $X(t)$ be the number of aircraft in the holding pattern waiting for landing at time $t$;

– $R(t)$ be the residual service time of the aircraft in the server at time $t$, if any

– $t_n$ denote the arrival time of the $n$-th aircraft for all $n \ge 1$;

– $\sigma_n$ the service time of aircraft $n$.

Let $\frac{1}{\mu}$ be the mean service time, namely,

$$E(\sigma_n) = \frac{1}{\mu}.$$

We will assume by convention that $X(t_i)$ is the number of aircraft in the holding pattern just before the arrival of the $i$-th aircraft.

We have

$$E(W_i) = E[R(t_i)] + E\left[\sum_{j=i-X(t_i)}^{i-1} \sigma_j\right] =$$

$$= E[R(t_i)] + \sum_{k=0}^{\infty}\sum_{j=i-k}^{i-1} E[\sigma_j | X(t_i) = k] P(X(t_i) = k) =$$

$$= E[R(t_i)] + \frac{1}{\mu} E[X(t_i)].$$

To derive $E(W_i)$ used the fact that $\sigma_j$ is ndependent of $X(t_i)$ for

$$j = i - X(t_i), \dots, i-1,$$

which implies that

$$E[\sigma_j | X(t_i) = k] = \frac{1}{\mu}.$$

Indeed, $X(t_i)$ only depends on the service times $\sigma_j$ for

$$j = 1, \dots, i - X(t_i) - 1$$

and not on $\sigma_j$ for

$$j \ge i - X(t_i)$$

since the service discipline is FIFO.

Letting now $i \to \infty$ in yields

$$\overline{W} = \overline{R} + \frac{\overline{X}}{\mu},$$

with

$\overline{R} := \lim_{i\to\infty} E[R(t_i)]$ is the mean service time at arrival epochs in steady-state;

$\overline{X} := \lim_{i\to\infty} E[X(t_i)]$ is the mean number of aircraft in the holding pattern at arrival epochs in steady-state.

Applying Little's formula to the waiting in holding pattern yields

$$\overline{X} = \lambda \overline{W}$$

so that,

$$\overline{W}(1-p) = \overline{R}.$$

From now on we will assume that $p < 1$,

$$\overline{W} = \frac{\overline{R}}{1-p}.$$

The condition $p < 1$ is the stability condition of the M/G/1 queue [10].

We will compute $\overline{R}$ under the assumption that the queue empties infinitely often (it can be shown that this occurs with probability 1 if $p < 1$.

Let $C$ be a time when the queue is empty and define $Y(C)$ to be the number of aircraft served in.

We have

$$\overline{R} = \lim_{C\to\infty} \frac{1}{C} \sum_{n=1}^{Y(C)} \frac{\sigma_i}{2} =$$

$$= \lim_{C\to\infty} \frac{Y(C)}{C} \lim_{C\to\infty} \left( \frac{1}{Y(C)} \sum_{n=1}^{Y(c)} \frac{\sigma_i}{2} \right) =$$

$$= \lambda \frac{E[\sigma^2]}{2}.$$

Where $E[\sigma^2]$ is the second-order moment of the service times, for all $i \ge 1$.

Hence, for $p<1$, waiting in an queue (Fig.4):

$$\overline{W}=\frac{\lambda E\left[\sigma^2\right]}{2\ 1-p}.$$

Thus, the mean system response time (Fig. 5), $\overline{T}$ is given by

$$\overline{T}=\frac{1}{\mu}+\frac{\lambda E\left[\sigma^2\right]}{2\ 1-p},$$

and, by Little's formula, the mean number of aircraft $E\left[\overline{N}\right]$ in the entire system (holding pattern + server, Fig. 6) is given by

$$\overline{N}=p+\frac{\lambda^2 E\left[\sigma^2\right]}{2\ 1-p}.$$

It should be emphasized that $\overline{W},\overline{T},\overline{N}$, depend upon two moments $\frac{1}{\mu}$ and $E\left[\sigma^2\right]$ of the service time and of course upon the arrival rate.

Delays will occur when the demand rate exceeds the service rate but it may also occur when the demand rate is *less* than the service rate – this is due to probabilistic fluctuations in inter-arrival and/or service times (i.e., to short-term surges in demand or to slowdowns in service).

The closer the demand rate is to capacity, the more sensitive expected delay becomes to changes in the demand rate or the capacity.

The expected delay at any given time depends on the “history” of the queue prior to that time.

Thus, as the demand rate approaches the service rate (or as ρ → 1, or as “demand approaches capacity”) the average queue length and average delay increase rapidly.

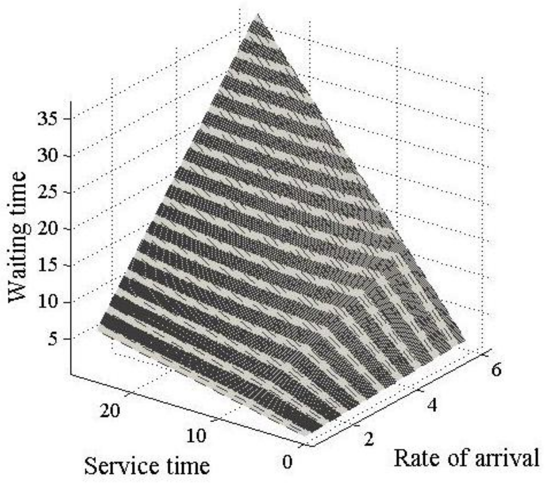

**Fig. 4.** Waiting time in min. for landing in an queue

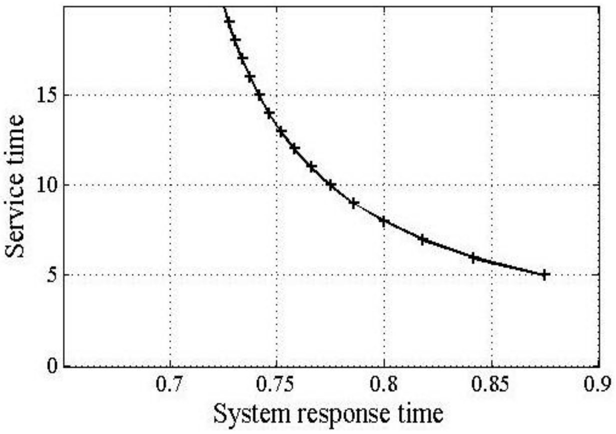

**Fig. 5.** System response time with fixed rate of arrival

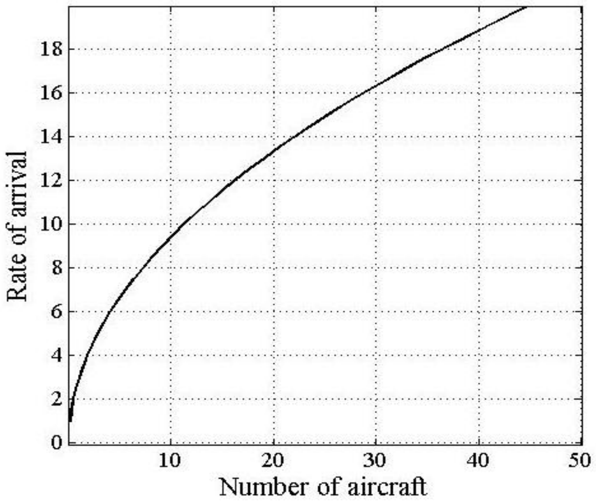

**Fig. 6.** Number of aircraft in holding pattern and runway system with fixed rate of service

## 4. Conclusions

The concentration of aircraft arrivals at an airport can result in congestion and delay.

Arrival delays can be reduced by modifying air traffic control procedures or introducing new technologies to improve the flow of aircraft in the terminal area.

Airspace design changes can establish more effective airspace structures and provide better access and improved use of available runways.

Terminal RNAV and RNP procedures are currently in use at numerous airports in the USA and Europe.

PBN procedures in the terminal area has the potential to provide benefits to both ATC and operators in form of reduced communications, reduced flight time and distance due to a more efficient flight profile.

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### В.П. Харченко[1], К.М. Тапіа[2]. Аналіз затримок повітряних кораблів на етапі прибуття до аеропорту

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Змодельовано процес обслуговування повітряних кораблів на етапі прибуття до аеропорту. Проаналізовано швидкість обслуговування повітряних кораблів в аеропорту, яка впливає на час очікування посадки. Розглянуто причини затримки обслуговування повітряних кораблів на етапі прибуття до аеропорту: неефективна організація повітряного простору, застосування застарілих технологій, доступність злітно-посадкової смуги. Показано, що чим більша частота запитів на обслуговування до пропускної здатності, тим більш чутлива очікувана затримка на зміни в системі.

**Ключові слова:** аеропорт; затримка; прибуття; процес обслуговування; час очікування; черга.

### В.П. Харченко[1], Е.Н. Тапиа[2]. Анализ задержек воздушных судов на этапе прибытия в аэропорт

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Смоделирован процесс обслуживания воздушных судов на этапе прибытия в аэропорт. Проанализирована скорость обслуживания воздушных судов в аэропорту, влияющая на время ожидания посадки. Рассмотрены причины задержки обслуживания воздушных судов на этапе прибытия в аэропорт: неэффективная организация воздушного пространства, применение устаревших технологий, доступность взлетно-посадочной полосы. Показано, что чем больше частота запросов на обслуживание к пропускной способности, тем более чувствительна ожидаемая задержка на изменения в системе.

**Ключевые слова:** аэропорт; время ожидания; задержка; очередь; прибытие; процесс обслуживания.

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