

## AEROSPACE SYSTEMS FOR MONITORING AND CONTROL

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### ANALYSING SURFACE MOVEMENT DELAYS IN AN AIRPORT

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**Abstract.** *Queuing effect can be in the different components of ground operations. Causes of surface – movement delays are long taxi – in and taxi – out operations during departure and arrival of aircraft. Surface movement delays in an airport are analyzed.*

**Keywords:** aircraft; capacity; delay; queue; service.

#### 1. Introduction

Congestion is becoming increasingly acute problem in many airports.

A planning activity called Air Traffic Flow Management (ATFM) tries to anticipate and prevent overload of Air Traffic Control (ATC) and takes into consideration its limitations that resulting delays.

When the traffic exceeds the airport arrival and departure capacities a delay occurs [1].

Delays are a result of any overloaded or poorly performing service component of the system.

As for an airport the main bottleneck is the runway, which manifests itself as a result of following rules:

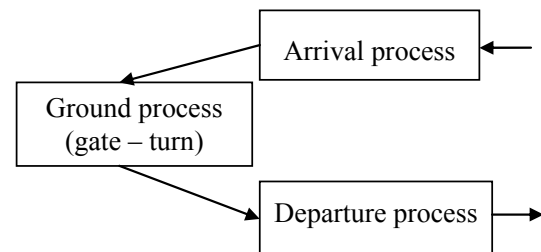
- separation requirements between successive departures;
- capacity limitations based on runway configurations;
- allocation of runway occupancy to landing aircraft;
- limitations of runway crossings.

The variable and often relatively high demand due to weather conditions, made it obvious that runway overloaded can explain a majority of the surface – movement delays encountered at airports [5, 7].

Modeling the airport as a ground operation server can show the best course of action to take in reducing delays, determining the value in terms of delays, adding runway or adding equipment so that more aircraft can use the runway in inclement weather.

#### 2. Literature overview

In [6] mentioned that long queues for departure runway impeded both taxi – in and taxi – out operations, and that taxi operations were impeded by poor visibility (Fig. 1).



**Fig. 1.** Ground – operations pattern

In [2] presents three models designed to capture the dynamics of ground operations at busy hub airports. Finally, the paper presents possible applications for managing airport congestion by queue delay management.

In [3] presented a new artificial intelligence based taxi – out time prediction technique that adapts to changing airport dynamics. The method is based on the theory of stochastic dynamic programming.

In [4] work is based on extensive analysis of departing aircraft from two airports, it was found that the number of arriving aircraft does, in fact, affect taxi – out times.

This impact increases as interaction between departures and arrivals increases, as one might expect.

According to the queuing theory large delays are anticipated as the demand for departures and approaches of the airport.

Even larger delays are expected when the demand exceeds capacity.

This mismatch often occurs during bad weather conditions: in such scenarios, delays of an airport can rise significantly [8].

Thus queuing effect can be in the different components of ground operations.

Causes of surface – movement delays mentioned were [6]:

- taxiways crossing active runways;
- aircraft backing out of gates into taxiways;
- segments of taxiways too narrow for two-way traffic;
- taxiways intersecting.

The goal of this paper is to analyze surface movement delays that occur during departure and arrival operations.

### 3. Assessment the impact of aircraft departure and arrival queues on delay

At Fig. 2 traffic enters the arrival queue  $q_a$ , according to a Poisson arrival process with parameter  $\lambda_a(t)$ .

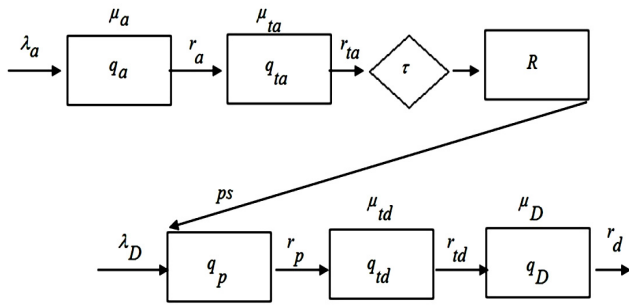


Fig. 2. Airport queuing network

An arriving aircraft enters the taxi-in queue  $q_{ta}$ .

After the turnaround delay  $\tau$ , the output of the taxi-in queue  $r_{ta}$ , enters the ready-to-depart reservoir  $R$ .

Departures enter the queue for aircraft  $q_p$ , according to a Poisson process with rate  $\lambda_D$ . Service rate of departure aircraft –  $\mu_{td}(t)$ .

When a departure aircraft is assigned  $R$  is reduced by 1.

The departure aircraft leaves  $q_p$  and enters the queue for taxi-out service  $q_{td}$ .

The queue for service at a departure runway  $q_D$ , where it is served according to the departure service process with rate  $\mu_D$ .

Output from the departure queue  $q_D$ , is output from the airport.

The first moment of the distribution of the number of clients in the queue:

$$\dot{q}_a = f_1(\lambda_a, \mu_a, k, q_a),$$

where

$$f_1(\lambda_a, \mu_a, k, q_a) \equiv k(\lambda - \mu) + k\mu \frac{k(k+1)}{k(k+1) + 2kq_a}.$$

### 4. Arrival operations process

Conservation of aircraft in the arrival process requires the condition on the process output rate  $r_a$ :

$$r_a = \lambda_a - \dot{q}_a.$$

It shows that the rate at which aircraft arrive is equal to the sum of the rate at which aircraft leave the arrival process and the rate-of-change of the arrival queue. That is, arriving aircraft either exit the arrival process or enter the arrival queue.

The output rate  $r_a$ , is the input to the taxi in queue  $\dot{q}_{ta}$ :

$$\dot{q}_{ta} = r_a - \mu_{ta} [1 - P_0(q_{ta}, v_{ta})],$$

and

$$\dot{v}_{ta} = r_a + \mu_{ta} (2q_{ta} + 1) P_0(q_{ta}, v_{ta}),$$

where

$$P_0(q, v) \equiv \left(\frac{q}{v}\right)^{\frac{q^2}{v-q}}.$$

To conserve aircraft, we impose:

$$r_{ta} = r_a - \dot{q}_{ta}.$$

It implies that the rate of output,  $r_a$ , of the arrival process is equal to the rate at which aircraft leave the taxi – in process plus the rate of change of the taxi – in queue (Fig. 3).

Present airport delay, arrivals either exit the entire arrival – taxi – in process or accumulate in either the arrival queue or the taxi –in queue can be shown:

$$\lambda_a = r_{ta} + \dot{q}_a + \dot{q}_{ta}.$$

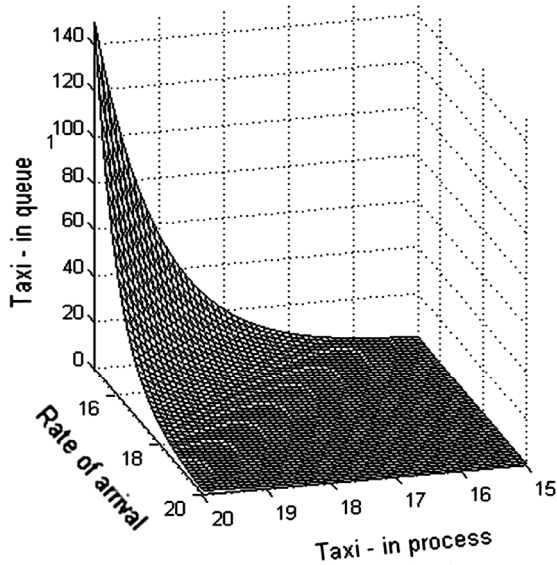


Fig. 3. Rate of output of the arrival process

The output rate of the taxi – in process  $r_{ia}$ , after the turnaround delay  $\tau$ , is the input rate to the reservoir,  $R$ , of “ready to depart” aircraft. Conservation of aircraft for the reservoir is expressed by

$$\dot{R} = r_{ia}(t - \tau) - ps,$$

where  $ps$  – plane service rate.

### 5. Departure operations process

A departing flight first queues for service with a “ready to depart” airplane.

Our equations for this queue for airplanes are

$$\dot{q}_p = f_{fluid}(\lambda_D, ps, q_p),$$

$$f_{fluid}(\lambda, \mu, q) \equiv \begin{cases} \lambda - \mu, q > 0 \\ (\lambda - \mu)^+, q = 0, \end{cases}$$

where  $x^+$  – equal to  $x$  when  $x > 0$ , and is zero for nonpositive  $x$ .

It follows that  $q_p$  will remain zero, if

$$ps = \lambda_D.$$

The departure processes begin with service at the queue for “ready to depart” aircraft.

This service depends reservoir,  $R$ .

If  $R = 0$  then  $ps$  cannot be greater than the input rate to the reservoir.

If  $R$  is not empty, then the service rate,  $\mu_p(t)$  is large compared to 1.

If  $R$  is empty, then departing aircraft are supplied by output of the arrival queue, delayed by the turnaround time,  $\tau$ :

$$ps = \begin{cases} \lambda_D, R > 0 \\ \left. \begin{cases} r_{ia}(t - \tau), q_p > 0 \\ \min(\lambda_D, r_{ia}(t - \tau)), q_p = 0 \end{cases} \right\}, R = 0 \end{cases}.$$

To conserve aircraft, we determine the output rate,  $r_p$ , of the queue for “ready to depart”: airplanes by

$$r_p = \lambda_D - \dot{q}_p.$$

The output rate,  $r_p$ , is the input to the taxi-out queue,  $q_{td}$ :

$$\dot{q}_{td} = r_p - \mu_{td} \left[ 1 - P_0(q_{td}, v_{td}) \right],$$

and

$$\dot{v}_{td} = r_p + \mu_{td} (2q_{td} + 1) P_0(q_{td}, v_{td}).$$

By conservation, we determine the output rate,  $r_{td}$ , of the taxi-out queue by

$$r_{td} = r_p - \dot{q}_{td}.$$

The output,  $r_{td}$ , of the taxi-out queue is then input for the departure queue,  $q_D$ :

$$\dot{q}_D = f_1(r_{td}, \mu_D, q_D).$$

Finally, for conservation, the output rate of the departure process (Fig. 4):

$$r_d = r_{td} - \dot{q}_D.$$

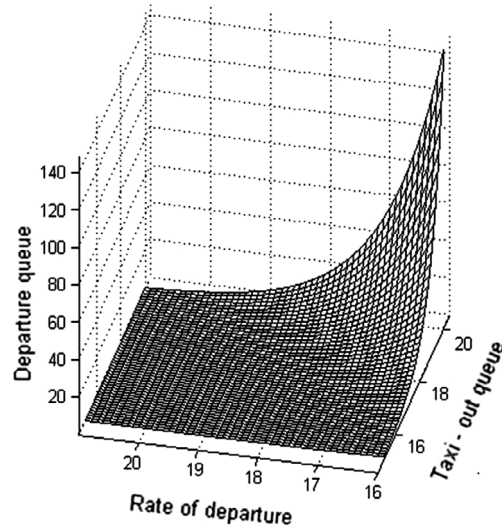


Fig. 4. Rate of the departure process

Analyzing of airport ground operations (Fig. 3, 4) give us a value of the traffic that should be expected according to arrival and departure ground operations processes.

Before departure and after arrival aircraft pass stages of taxi – out and taxi – in processes that can influence on rate of traffic in airport and, of course, can be the reason of delays.

Delays can be introduced into the system from any overloaded or poorly performing service component.

If the same runway is being used for both arrivals and departures, the tower controller only allows takeoffs to occur during gaps in the arrival sequence.

Thus departing aircraft are often delayed while waiting on the taxiways or at terminals for takeoff clearance. And these aircraft can be delayed for a much time.

## 6. Conclusions

Traffic demand is input by a schedule of hour-by-hour departures from the network airports and a schedule of arrivals to network airports from terminals outside the network.

Large delays are anticipated as the demand for ground operations before departures and after landings of the airport. Service of an airport is the most sensitive in bad weather conditions and it means that the rate of service can drop significantly.

The result of this can be queuing effects in the different components that lead to longer taxi times so even modest increases in traffic will result in substantially increased delays.

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Розглянуто етапи обслуговування, які надає аеропорт як єдиний макроскопічний сервер. Проаналізовано причини затримок наземного руху в аеропорту, процесу рулювання повітряних кораблів перед вильотом і після прибуття, який впливає на швидкість руху в аеропорту, чергу на обслуговування. Показано, що під час використання злітно-посадкової смуги для прильоту і вильоту диспетчер управління повітряним рухом дозволяє тільки зльоти в перебігу проміжків послідовних прибуттів. Досліджено затримки повітряних кораблів під час процесу руління після прибуття та перед зльотом.

**Ключові слова:** затримка; обслуговування; повітряний корабель; пропускна здатність; рулювання; черга.

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Рассмотрены этапы обслуживания, которые предоставляет аэропорт как единый макроскопический сервер. Сделан анализ причин задержек наземного движения в аэропорту, процесса руления воздушных судов до вылета и после прибытия, оказывающего влияние на скорость трафика в аэропорту, очередей на обслуживание. Показано, что при использовании взлетно-посадочной полосы для прилета и вылета диспетчер управления воздушным движением разрешает только взлеты в течение промежутков последовательных прибытий. Исследованы задержки воздушных судов в процессе руления по прибытию и перед взлетом.

**Ключевые слова:** воздушное судно; задержка; обслуживание; очередь; пропускная способность; руление.

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