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Increase of runway capacity using the Departure Manager

The study proposes the operating principle of the electronic *Departure Manager (DMAN)*.The principle forms recommendations to the dispatcher on streamlining the queue of delayed aircraft, which minimizes the runway occupancy time. The requirements for the manager and the possibility of its integration into the air traffic control system are determined. The simulation results showed the feasibility of introducing an electronic manager in the busiest airports and the possibility of increasing the capacity of the runway by more than 6 % at its usage.

Keywords: capacity, runway, efficiency, aircraft, optimization, departures

Introduction

The most important performance indicators of a runway (RWY) include its capacity and average delay time of flights waiting their turn for take-off and landing approach. Reduction of flight delay time also means reduction of fuel consumption and, as a consequence, growth of economic profit from transportation, and abatement of carbon dioxide emissions into the atmosphere. In order to increase RWY capacity and reduce dispatcher workload, it is suggested to develop a *Departure Manager* (*DMAN*) to optimize the queue of departing aircraft (A/C) by the criterion of RWY minimum occupancy time and minimum average flights delay time (minimum fuel consumption and hazardous emissions into the atmosphere). The relevance of solving this task has been confirmed by the recommendations of the Global Air Navigation Plan [1], as well as certain studies [2, 3].

The input data for *DMAN* are: current parameters of A/C movements; A/C characteristics; flight plan; information on RWY occupancy and operation mode. *DMAN* outputs recommendations regarding management of the departing A/C to the dispatcher. The dispatcher makes a final decision on the A/C queue management. Thus, *DMAN* takes up some of the dispatcher's workload to perform standard operations considering more decision-influencing factors than human is able to memorize.

Due to wake turbulence, the departing A/C shall maintain an appropriate interval between take-offs, as defined by the Federal Aviation Regulations. The larger is the mass value of the fist A/C and the smaller is the mass value of the second A/C, the longer is the interval between their take-offs. Depending on the mass of both A/C, these intervals constitute 1–3 min. The queue is optimized through selecting an A/C sequence having the largest/smallest optimization criterion value. For example, a sequence, at which total RWY occupancy employs less time.

Objective

The objective is to determine a dependency between the time of reduction of the average A/C departure delay and the density of departing A/C through prioritization of the queue of A/C delayed at take-off. The A/C are prioritized based on the criterion of the minimum duration of RWY occupancy by the queue. Besides, a calculation will be performed to determine potential increase of RWY capacity by such queue prioritization. Requirements to *DMAN*, its sources and information users will be determined.

Requirements to *DMAN*

DMAN project shall be implemented as a separate universal software module, which can be easily integrated in the automated system for air traffic control (ATC AS) without changing network interfaces of other modules and disturbing its integrity. Based on the above, the requirements to the same shall be defined as follows:

• adaptability to any airport architecture;

• modular architecture allowing to change configuration depending on the types and number of sources and information users;

• sufficiently high operational reliability and information integrity;

• output of complete information used by ready-developed HMI, processing of commands received from them by *DMAN* computing core;

• possibility of operation in the "first in – first out" (FIFO) departures processing mode (first registered – first departed) and in the mode of queue optimization by the criteria of minimum RWY occupancy or minimum fuel consumption, taking into account the limits of maximum departure delay time and A/C priorities;

• possibility of communication with the system of arriving A/C management, i. e., *Arrival Manager* (*AMAN*), and airfield traffic control system.

The pattern of *DMAN* communication with other modules of ATC AS is shown in Fig. 1. The sources of information for the routing module are radars, optical cameras of airfield observation and A/C systems of automatic dependent surveillance broadcast (ADS-B), for *AMAN* – regional radars and A/C ADS-B.

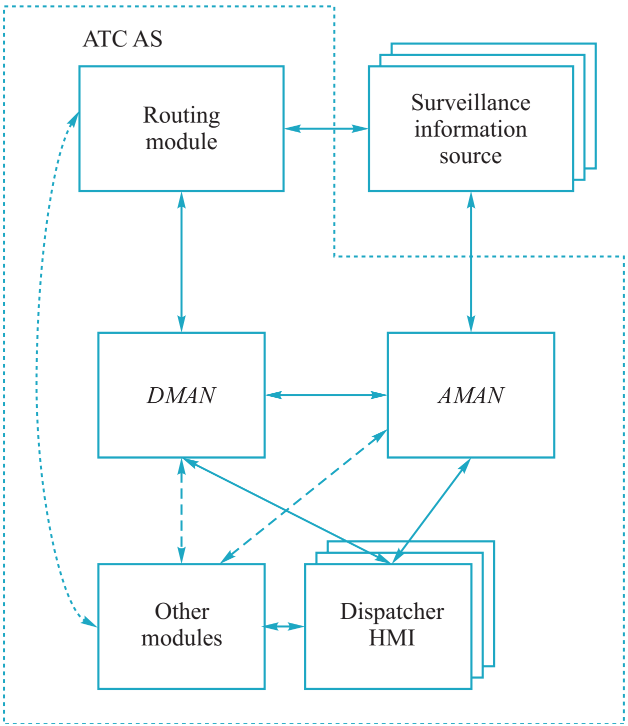

Fig. 1. *DMAN* communication with other system modules

DMAN receives departure slots from *AMAN*. Time intervals of RWY occupancy by departing A/C are sent from *DMAN* to *AMAN*. *DMAN* sends A/C departure and destination points and estimated position holding time to the routing module. *DMAN* receives a taxi route from the routing module in the form of 4D-points sequence. Besides, *DMAN* receives estimated information from the airspace management and planning module, and can receive meteorological information from the meteomodule.

In the course of queue streamlining, the following parameters shall be taken into account:

• density of take-off and landing on RWY;

• RWY capacity;

• departure slots on RWY;

• routes of A/C and machinery in airfield traffic;

• A/C wake turbulence, depending on their mass and type;

• standard instrument departure routes (*SID*) and A/C speed performance;

• A/C priority and delay time.

Queue optimization

Optimization consists in minimization of the average delay of A/C departure

$$\Delta W = \sum_{i=1}^{N} \left(t_i^{\text{факт}} - t_i^{\text{план}} \right),$$

where N is the number of departed A/C;

$t_i^{\text{факт}}$ is actual time of A/C departure;

$t_i^{\text{план}}$ is estimated time of A/C departure.

The actual time of departure depends on the sequence of preceding A/C classified by the maximum take-off mass.

The main parameters causing delay are time intervals between A/C take-offs, defined by the Federal Aviation Regulations depending on the waiting time of A/C wake turbulence scattering $t_i^{\text{ож}}$. $t_i^{\text{ож}}(m_i, m_{i-1})$ depends on mass m_i of the current i-th and the preceding m_{i-1} (i–1-th) departing A/C [4]. The larger is the maximum take-off mass of the preceding A/C and the smaller is the mass of the following one, the longer is the waiting time.

According to the classification of *ICAO Doc 8643*, A/C can be subdivided into 3 types by their take-off mass: light, medium and heavy. In this case, there will be 9 delay time values in total, corresponding to all combinations of pairs of 3 types. It is convenient to store the delay time values in the form of matrix $T_{ож}^{3\times3}$, with the equal diagonal elements. For civil aircraft in the territory of Russia, matrix elements $T_{ож}^{3\times3}$ are defined by the Federal Aviation Regulations of the Russian Federation.

Time interval $t_i^{ож}$ is minimized through changing the sequence of A/C in the queue. When forming the sequence, A/C speeds shall be taken into account in order to exclude crossing of A/C 4D-trajectories.

The average A/C delay time on l-th RWY $\bar{\tau}_l$ is determined by formula

$$\bar{\tau}_l = \frac{1}{N}\sum_{i=1}^{N} t_i^{ож},$$

where N is the number of A/C departed from RWY.

When binding A/C parking aprons to several runways, total average delay time for all runways shall be minimized:

$$\bar{\tau}_\Sigma = \sum_{l=1}^{N_{ВПП}} \bar{\tau}_l \to \min .$$

Here, $N_{ВПП}$ is the number of runways.

The efficiency of departures prioritization is determined by formula

$$\chi_\Sigma = \frac{\bar{\tau}_\Sigma}{\bar{\tau}_\Sigma^*},$$

where $\bar{\tau}_\Sigma$ is the average time of delay of departures from an aerodrome without queue optimization;

$\bar{\tau}_\Sigma^*$ is the average time of delay of departures from an aerodrome with queue optimization.

Capabilities of increasing RWY capacity

According to the Federal Aviation Regulations of the Russian Federation, the minimum time intervals will be defined (see Table) between two nearest departing A/C [5]. By their mass, A/C are subdivided to light (L) – less than 7,000 kg, medium (M) – more than 7,000 kg and less than 136,000 kg, heavy (H) – more than 136,000 kg.

Minimum time intervals between A/C

First	Second		
	Light	Medium	Heavy
Light	1	1	1
Medium	3	1	1
Heavy	3	2	2

Based on the example of a departure queue consisting of 2 light, 2 medium and 2 heavy A/C, the optimum and the worst departure sequences will be defined below. The worst sequence, with the maximum RWY occupancy time, is as follows: H M L H M L. This sequence ensures 2 + 3 + 1 + 2 + 3 + 1 = 12 minutes of RWY occupancy. The optimum sequence, with the minimum RWY occupancy time, is as follows: L L H M M H. This sequence ensures 1 + 1 + 2 + 1 + 1 + 1 = 7 minutes of RWY occupancy. Optimization of A/C departure sequence specified in this example reduces RWY occupancy by more than 41 %.

Modelling

DMAN is a queueing system $M/G/1$, having a Poisson arrival of A/C scheduled by the estimated line-up time received at the input. Systems $M/G/1$ are considered in detail in [6]. The queue considered 3 mass categories of aircraft (light, medium and heavy) at a ratio of 0.3, 0.4, 0.3, accordingly.

Fig. 2 shows the dependencies between the average departure delay and the rate of departing A/C, obtained by modelling. Value $\Delta\lambda$ demonstrates an increase of RWY capacity through minimization of RWY occupancy by a queue of delayed A/C; ΔW demonstrates the amount of average A/C departure delay reduction relative to the maximum permissible delay. At a rate of departures causing maximum permissible average departure delay of 15 min $\chi_\Sigma = 1{,}4$.

Conclusion

Modelling results demonstrated the possibility of RWY capacity increase by 6.3 % through prioritization of the queue of departing A/C by departure intervals. *DMAN* functional analysis has been performed. *DMAN* applicability in the busiest Russian airports has been demonstrated.

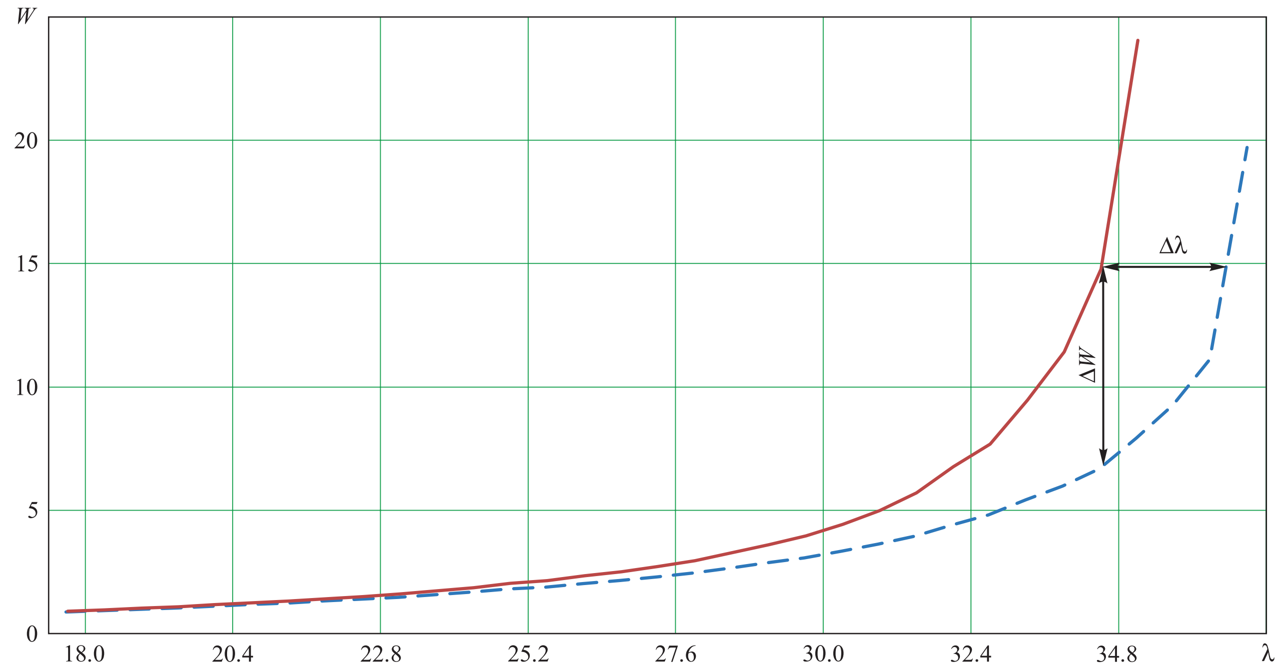

Fig. 2. Dependency between the average departure delay time and the density of departures for prioritized (— — -) and non-optimized (———) queues

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Повышение пропускной способности взлетно-посадочной полосы с использованием менеджера вылетов воздушных судов

Предложен принцип работы электронного менеджера вылетов воздушных судов *Departure Manager* (*DMAN*), формирующий рекомендации диспетчеру по упорядочиванию очереди задержанных воздушных судов, что позволяет минимизировать время занятости взлетно-посадочной полосы. Определены требования к менеджеру и возможность его интеграции в систему управления воздушным движением. Результаты моделирования показали целесообразность внедрения электронного менеджера в наиболее загруженные аэропорты и возможность возрастания пропускной способности взлетно-посадочной полосы более чем на 6 % при его использовании.

Ключевые слова: пропускная способность, взлетно-посадочная полоса, эффективность, воздушные суда, оптимизация, вылеты.

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