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ScienceDirect
European Journal of Operational Research 177 (2007) 1180–1196
EUROPEAN JOURNAL OF OPERATIONAL RESEARCH
www.elsevier.com/locate/ejor

O.R. Applications

On the waiting time of arriving aircrafts and the capacity of airports with one or two runways

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Received 7 March 2005; accepted 4 January 2006
Available online 17 February 2006

Abstract

In this paper we examine a model for the landing procedure of aircrafts at an airport. The characteristic feature here is that due to air turbulence the safety distance between two landing aircrafts depends on the types of these two machines. Hence, an efficient routing of the aircraft to two runways may reduce their waiting time.

First, we use M/SM/1 queues (with dependent service times) to model a single runway. We give the stability condition and a formula for the average waiting time of the aircrafts. Moreover, we derive easy to compute bounds on the waiting times by comparison to simpler queuing systems. In particular we study the effect of neglecting the dependency of the service times when using M/G/1-models.

We then consider the case of two runways with a number of heuristic routing strategies such as coin flipping, type splitting, Round Robin and variants of the join-the-least-load rule. These strategies are analyzed and compared numerically with respect to the average delay they cause. It turns out that a certain modification of join-the-least-load gives the best results.

Keywords: Queuing; Applied probability; Air traffic control; Heuristic routing; Airport planning

1. Introduction

In this paper we examine the queuing process of aircrafts arriving at an airport and its implications for the capacity of the airport.

The particular feature of this process is the character of the safety distances between consecutive landing operations. An aircraft causes an air turbulence that endangers the stability of trailing aircrafts. The strength of the turbulence depends on the type (size, weight) of the leading aircraft. On the other hand, the type of the trailing aircraft determines its susceptibility to turbulences. Hence the required separation times between

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0377-2217/$ - see front matter
doi:10.1016/j.ejor.2006.01.002

consecutive landings depend on the types of the two aircrafts involved. The order in which the aircrafts land may therefore play an important role for the capacity of the runway.

This problem can be modelled as a special queuing system with the incoming planes as customers of different types. The service time of the nth aircraft is the separation time between the nth and the $n+1$st aircraft, see Fig. 1. The service starts at the time of touch-down of the nth aircraft and ends at the earliest time-point at which a trailing aircraft could land as indicated in Fig. 3. This separation time depends on the types of the nth and the $n+1$st aircrafts (i and j in Fig. 1), the next separation or service time depends on the type of the $n+1$st and the $n+2$nd aircraft (j and k in Fig. 1). Hence the service times are no longer independent as it is assumed in standard queuing systems, see Section 2 below for a formal definition.

The arrival time here is the point of time at which the incoming aircraft passes a certain threshold and is within the reach of airport traffic controllers. If there are two runways, the aircraft is assigned to one of them at the time of its arrival. To simplify the model, we neglect the time the aircraft needs from this arrival threshold to the runway and assume that an arriving aircraft could start service at once provided the server is idle, i.e. it could have touch-down without delay, given that the necessary separation time to its predecessor has elapsed. If the server is not idle, the aircraft has to wait, circling in a holding position. The waiting time (in the queue) of an aircraft is therefore the time from its arrival at the threshold until the actual time of touch-down.

We are interested in stability results and bounds for the average waiting times of the aircrafts on a single runway. If there are two runways available, we investigate the assignment of aircrafts to runways and the resulting waiting times.

We use the general assumption that the arrival times can be modelled by a Poisson process. This is in accordance with standard models in aircraft literature (see e.g. [5] and [8, Chapter 8]) and reflects the experience that in practice the flight schedule is disturbed by many independent external sources like weather or technical delays such that a Poisson model is sufficient for the type of average analysis intended here. The single runway problem can therefore be modelled as an M/SM/1 queuing model, where 'SM' stands for 'Semi-Markov', see e.g. [6,10–12].

For a single runway, we can use these results to derive the stability condition and to give an analytic formula for the expected stationary waiting time of the aircrafts which can be evaluated numerically. Moreover, simple bounds are derived by comparison to M/G/1 and M/D/1 models. We examine the bias introduced when the dependencies of the service times are neglected and simple M/G/1-models are used for the estimation of the average waiting time (which has been done for example in [5]). It is shown, that under heavy traffic this leads to a constant over- or underestimation of the average waiting time depending on the correlation of consecutive service times.

In the case of two runways we are interested in good heuristic routing strategies which make the average waiting time of the aircrafts small. Note that we do not address the problem of optimal assignment of aircrafts to runways here (see [1] for a qualitative result in that direction). Instead we only consider easy to implement heuristics like coin flipping, type splitting, Round Robin and variants of join-the-least-load. Type splitting is a randomized allocation of types to runways and allows to use the analytic results from the single runway case. It turns out that a certain modification of join-the-least-load performs quite well in our numerical example.

A possible extension of the model to include departing flights is sketched in the conclusion.

The scheduling of aircrafts has been treated before by different approaches, see e.g. [3] for an overview. The authors of [3] use a non-stochastic model in which they minimize waiting time related costs for a fixed set of planes by a mixed-integer approach. Beasley et al. [4] presents an approach that tries to take the dynamics of

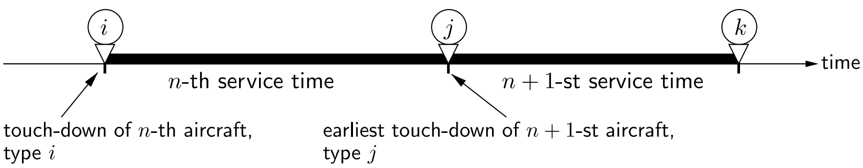

Fig. 1. The service time of an aircraft is its separation time to the next machine.