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# Airport capacity increase via the use of braking profiles

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ABSTRACT

Many airports are encountering the problem of insufficient capacity, which is particularly severe in periods of increased traffic. A large number of elements influence airport capacity, but one of the most important is runway occupancy time. This time depends on many factors, including how the landing roll procedure is performed. The procedure usually does not include the objective to minimize the runway occupancy time. This paper presents an analysis which shows that the way of braking during landing roll has an essential impact on runway throughput and thus on airport capacity. For this purpose, the landing roll simulator (named ACPENSIM) was created. It uses Petri nets and is a convenient tool for dynamic analysis of aircraft movement on the runway with given input parameters and a predetermined runway exit. Simulation experiments allowed to create a set of nominal braking profiles that have different objective functions: minimizing the runway occupancy time, minimizing noise, minimizing tire wear, maximizing passenger comfort and maximizing airport capacity as a whole. The experiments show that there is great potential to increase airport capacity by optimizing the braking procedure. It has been shown that by using the proposed braking profiles it is possible to reduce the runway occupancy time even by 50%.



## 1. Introduction

The aircraft crew typically carries out four tasks. These are:

- flight management, i.e. navigation and maintaining aircraft control,
- communication management related to all processes of information exchange, both internally within the crew members and also with the air traffic controller,
- system management, consisting of the necessary monitoring or operating of technical on-board flight support systems,
- task management, consisting of monitoring and prioritizing tasks and assigning necessary resources, such as crew time.

These tasks do not refer directly to air traffic management (ATM). However, the aircraft crew affects the realization of ATM services' tasks. For instance, air traffic safety and quality of the air traffic management process depend on the pilot's predictability, the calm and consequent execution of the controller's instructions, and, finally, on attention, vigilance and composure in case of an emergency. However, usually the pilot is passive in relation to ATM tasks.

In this paper we propose a model and a decision support system in which the pilot plays an active role in a task which is closely related to ATM. This task is runway capacity management. The pilot can select the braking force in such a way as to

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keep the runway occupancy time (ROT) as small as possible or so that occupancy time is compatible with the intentions of the air traffic controller. This problem is important in case of mixed operations because it allows for more departures between arrivals and also for reduction of departure queue length. It is also important when the volume of air traffic is close to the saturation value. However, the proposed method can be applied also to minimize noise, tire wear or to maximize passenger comfort. These issues are always important, even if (or perhaps especially if) the traffic is small and shortening of the ROT is not necessary. The method can be applied to any airport and for any type of aircraft.

### 1.1. Runway capacity

The airside capacity of an airport depends directly on the runway system capacity. This, in turn, depends on many factors, but the most important is the runway occupancy time (ROT). This time is the basis for determining the theoretical maximum runway throughput. A significant part of the runway occupancy time for landing operations falls on the landing roll, which is under consideration in this paper. The relations are (Sherry, 2009):

$$T_{max} = \frac{3600}{\overline{ROT}} \tag{1}$$

where

$T_{max}$ – maximum runway throughput with continuous takeoff and landing operations, expressed in the number of operations per hour.

$\overline{ROT}$ – the average runway occupancy time in seconds. This time depends on many factors, such as aircraft type, touchdown speed, touchdown point, selected runway exit, runway surface condition and many others. One of the key factors is the average aircraft speed between the touchdown point (which is random) and the runway exit point. This speed depends on the braking profile (BP), including the use of wheel brakes and the thrust reverser.

The maximum throughput $T_{max}$, determined according to formula (1), is a theoretical concept because it ignores separations between the following landings and take-offs that are required by international regulations. However, it can be used for comparisons for: different airports, different ways of air traffic organization, and, finally, different braking strategies. As shown in formula (1), reducing the ROT for each individual takeoff or landing helps to increase the maximum runway throughput. In practice, we usually use the concept of the so-called practical runway capacity, which takes into account many random factors affecting airport traffic operations and the delays resulting from this. Regardless of the selected definition of capacity, the general relationship between runway capacity and runway occupancy time is the same (Horonjeff et al., 2010).

From the airport capacity point of view, the ideal situation is when the aircraft leaves the runway through the rapid exit located at the point where the aircraft reaches a speed that is appropriate to turn into the taxiway after applying maximal braking. Unfortunately, such airport geometry rarely takes place. This is due to the fact that different types of aircraft use the airport, for which exit points as referred to above are located in different places. In addition, this location of the exit taxiway carries the risk that the landing aircraft will not have enough room to slow down if any distortion takes place, such as a different touchdown point and delay in brake deployment. Therefore, very often the available runway exit points are located at a distance much larger than the ideal one as referred to above. In this situation, the method of implementing the braking procedure has great importance for the runway capacity. The model and decision support system as discussed in this paper are about finding the braking profile (BP) that will allow for safe braking and at the same time for minimizing the ROT for a given airport layout.

### 1.2. Literature review

Airport capacity management is one of the most frequently found topics in the literature on air transport management. It is discussed, for example, in Irvine et al. (2015), Gelhausen et al. (2013), Kalakou et al. (2014), Farhadi et al. (2014), Sölveling and Clarke (2014), Stelmach et al. (2006) and Balakrishna et al. (2010). These papers focus on various factors affecting airport capacity, e.g. aircraft speeds, traffic mix, separation minima, passenger operations, taxi-out times, etc. Relatively little is devoted to issues regarding runway occupancy time (Trani et al., 1996), and particularly the influence of what technique is used when the aircraft braking process is being carried out. Our paper tries to fill in this gap.

Automatic control of the aircraft, also in the phase of ground movement, finds its place in the literature. For example, Chen et al. (2013) proposed to control the plane's movement in accordance with the trajectory determined on the ground by means of a adaptive dynamic backstepping algorithm. Similarly, Li et al. (2011) considered the stability of the braking aircraft track when the aircraft is equipped with an anti-skid braking system. The main emphasis in these papers, however, was put on correct mapping of the movement trajectory and not on operational issues, such as airport capacity, which are the main subject of our study.

In the literature, much attention is paid to avoiding skidding during braking, especially on wet surfaces or surfaces covered with snow. Yadav and Singh (1995) demonstrated that skid-free braking requires a variable braking force which has to be treated as a random variable. Cao et al. (2014) analyzed the impact of rainfall on various aspects of the movement of air-