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# Capacity, information and minority games in public transport

P.C. Bouman [a,*], Leo Kroon [b], Peter Vervest [b], Gábor Maróti [c,d]

[a] Erasmus School of Economics, Erasmus University, The Netherlands
[b] Rotterdam School of Management, Erasmus University, The Netherlands
[c] Netherlands Railways, Utrecht, The Netherlands
[d] VU University, Amsterdam, The Netherlands

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ABSTRACT

Many public transport operators are faced with high peak demands. This leads to crowded vehicles and discomfort for the passengers. The increasing availability of information technologies creates new opportunities for passengers to avoid crowding and for operators to inform passengers and reallocate capacities quicker than before. We define and implement a simple model based on minority games, a class of games that deals with crowding dynamics, adapted to a public transport setting.

We propose a model which includes multiple resources and heterogeneous passenger preferences. We have conducted two simulation studies, investigating the dynamics of crowding within a simplified public transport setting. In our first experiment we investigate the effect of the availability of information on crowding. In our second experiment we study dynamic optimization of rolling stock capacities. We find that both the information disclosed and the capacity optimization mechanism have an impact on the number of passengers utilizing resources and their satisfaction. As such, these models enable the development and analysis of new operator policies to deal with crowded situations.



## 1. Introduction

Operators in public transport are often faced with peak demands, typically during the morning and afternoon rush hours. As a result, vehicles can become very crowded, greatly reducing the comfort experienced by the passengers. The increasing emergence of information technologies creates many new opportunities for public transport operators. They can now use smart phone apps to communicate with passengers, providing advice and information on their journey. Decision support systems are influencing the way operational decisions are made. The increasing adoption of smart card technologies provides operators with a lot of new data that can be used by these decision support systems. Complex schedules that used to require a lot of labor to create can now be adapted to new circumstances with the push of a button, due to improved algorithms and faster computers. Passengers get more and more opportunities to work remotely via the Internet, creating greater flexibility in when they have to be at the office. They can also use apps to make travel choices in a more strategic manner, for example if they want to avoid vehicles which are too crowded.

However, the impact of crowding on passenger behavior and the interaction between railway operations and passengers is not well understood. In this paper we develop a model, based on the concept of minority games, that allows us to study the dynamics of crowding in public transport through computational experiments and evaluate the impact of operational and

* Corresponding author.
*E-mail address:* research@pcbouman.nl (P.C. Bouman).

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behavioral models on a number of performance measures, most importantly the utilization of available capacities. We show that we can experiment and study interactions between passengers as well as the interactions between the public transport operator and the passengers. In particular, we investigate how information impacts passengers under different assumptions about the way they process information. Different strategies for the optimization of capacities based on data collected about passengers travel choices that an operator can adopt can impact these travel choices, causing a feedback loop.

Since the "El-Farol Bar Game" (Arthur, 1994) was first introduced in 1994, the concept of the *minority game* has received a lot of attention from researchers. One of the great strengths of this model lies in the simplicity of its description: there is a population of decision makers who have to decide every Thursday night whether to go to the bar. Once they go the bar, they have a positive payoff if less than 60% of the population goes to the bar, while they have a negative payoff if it is too crowded. As everyone makes this choice every Thursday, the El-Farol Bar Game has an iterative nature. While historic information is provided, the interesting aspect comes from the fact that there is no direct coordination between the decision makers.

Issues related to limited availability of resources and a lack of explicit coordination occur in many real world systems. The applications of these models include car traffic (Bazzan et al., 2000), congestion in computer networks (Huberman and Lukose, 1997) and financial markets (Challet et al., 2004). While these types of applications were considered earlier from a game theory perspective, most notably under the name of *congestion games* (Rosenthal, 1973), the novelty from the "El-Farol Bar" study was the application of a complex systems approach enabled by simulation of a repeated game, while game theory is mostly concerned with the properties of equilibria.

In this paper, we focus on minority games where the operator cannot control agent behavior, but has control over the disclosure of information and the system capacities. The main application domain is public transport systems, where passengers share vehicles depending on their chosen route and time of travel. If a connection is operated frequently, passengers with some flexibility in their schedule can try to avoid crowded situations by shifting their time of travel. Since it is reasonable that a passenger does not want to travel at any time, we introduce the concept of individual choice sets representing the acceptable choices. To our best knowledge, this type of heterogeneity of the choice sets has not been studied in the context of minority games before.

Within public transport systems new technologies have introduced many opportunities to provide passengers with additional information: many stations and vehicles have screens with travel information, and many passengers use smart phones to receive information during their journeys. The increasing adoption of smart card ticketing systems allows operators to have accurate data on the utilization of each vehicle. As operators in railway and metro systems can extend or shorten the trains (Fioole et al., 2006) and bus operators can employ different vehicle sizes, adaptive capacity allocation based on (almost) real-time information is becoming a possibility.

The main observation in the original "El-Farol Bar Game" simulations (Arthur, 1994) is that even though individual decision makers keep switching their preferred predictive model from an individual fixed set of random models, the average utilization of the bar converges to the efficient level. In order to explain this phenomenon the minority game was introduced, where the utilization history was replaced with a history of binary values indicating whether the bar was overcrowded or not. The main idea of this approach is that the set of all possible deterministic strategies can be finitely characterized so that methods from statistical mechanics can be applied (Challet et al., 2000).

In the scientific literature of different fields different names are used for entities which make decisions. In the game theory literature, these entities are often called *players*. In the operations research literature these entities are often referred to by the name of their role in the operational process, for example 'dispatcher', 'manager' or 'operator'. In settings where simulation is used and many autonomous decision makers interact, the term *agent* is popular for these decision making entities. In this paper we will use the term *agent* to refer to modeling entities that represent passengers, and use *operator* to refer to the public transport operator (which can be regarded as a very special type of agent).

The remainder of this paper is organized as follows: in Section 2 we introduce our class of minority games. In Section 3 we discuss the architecture of the components of our simulation. This simulation framework is then applied in order to investigate the effect of different information policies in Section 4. In a second simulation study we evaluated the effect of rolling stock optimization in the context of public transport (Section 5). In Section 6 we show that the inclusion of individual choice sets and scoring functions leads to NP-hardness of maximizing the efficiency of a given system. We discuss our findings and plans for future research in Section 7.

### 1.1. Related work

A variation of the minority games are the *resource allocation games*, introduced by Galstyan et al. (2003). This extension of minority games introduces multiple resources and capacities that vary over time. Conditions are given under which the agents can use a social network structure in order to adapt efficiently to variations of the capacities. The fluctuations of the capacities considered in the studies associated with the *resource allocation games* only depend on time and do not depend on the distribution of agents over the resources during the game.

While the body of knowledge on learning techniques for agents in minority games (Kets, 2012) is very useful for the engineering and design of artificial agents, it is a question whether it is applicable within systems where real humans are involved. Selten et al. (2007) conducted a laboratory experiment involving route-choice. The participants could be divided into three groups: participants who had the tendency to switch away from a road if it was congested during the previous round, participants who had the tendency to stay on their current road regardless of it being congested during the previous