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Decision Support

On the impact of information disclosure on advance reservations: A game-theoretic view

Eran Simhon*, David Starobinski

Division of Systems Engineering, Boston University 8 Saint Mary Street, Boston, MA 02215, USA

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ABSTRACT

In many branches of the economy, customers can reserve resources in advance. Yet, service providers often differ in the information they disclose to customers. In this paper, we evaluate how information about server availability impacts the strategic behavior of customers in a loss system with N servers, where each customer can either reserve a server at a certain cost, or take the risk of finding no server available. We formulate the problem as a non-cooperative game with a random number of players. Our main contributions are to establish the existence, structure, and uniqueness (or lack thereof) of pure Nash equilibria, depending on the information disclosed to customers. Specifically, we first prove that if the number of available servers is always disclosed, then there exists exactly one pure Nash equilibrium. High reservation costs lead to an equilibrium in which all servers remain unreserved, while low reservation costs lead to an equilibrium that consists of N "time-thresholds." A customer that observes n available servers, makes a reservation only if she makes her inquiry before the nth time-threshold. Next, we consider the case where the number of available servers is disclosed only when that number falls below a certain threshold. We show that, in this game, the same types of equilibria prevail. However, multiple Nash equilibria may exist. Finally, we numerically compare the performance of the different policies and we formulate the conjecture that it is preferable for a provider to hide information about the number of available servers.

1. Introduction

Consider a service provider that lets its customers reserve resources in advance. The provider may weigh different options for disclosing information to its customers. For example, it may disclose full information about the number of available servers. This practice is common in entertainment services, where customers are allowed to choose their seats and observe the precise number of available seats before making their reservations (e.g., using Ticketmaster[1] reservation services). At the other extreme, the provider may opt to hide any information about the number of available servers. This policy is adopted by some airlines, such as Delta Air Lines,[2] where customers can only choose their seats after buying their tickets. Finally, the provider may choose a middle ground solution where information about server availability is disclosed only when the number of available servers falls below some threshold. This policy has been adopted by lodging web sites, such as Booking.com[3], that alert potential customers when a few rooms are left available.

In this work, we study the impact of different information disclosure policies on the equilibrium outcomes of systems supporting advance reservation (AR). Specifically, we consider a loss system consisting of N servers. Thus, a customer leaves the system if no server is available (e.g., if all the servers have already been booked by other customers), rather than waiting in a line. This assumption is made for the sake tractability, and is reasonable for several of the aforementioned applications. The number of customers is a random variable that follows a *general* distribution. The arrival time of each customer, which represents the time at which she makes a reservation inquiry, is also a generally distributed random variable. We assume that customers behave strategically. Each customer needs to decide whether or not to make a reservation, based on information disclosed by the provider. Making AR guarantees service but is associated with an additional fixed *cost*. This cost can be interpreted as a reservation fee (Wang, Niu, Li, & Liang, 2013) or as the time or resources required for making the

* Corresponding author.
E-mail address: simhon@bu.edu (E. Simhon).

[1] See www.ticketmaster.com, accessed on 12/01/2016.
[2] See www.delta.com, accessed on 12/01/2016.
[3] See www.booking.com, accessed on 12/01/2016.

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reservation (Shugan & Xie, 2005). When avoiding AR, this cost is spared but may cause denial of service.

Our main contributions are as follows. We first analyze a *full-information game*. In this game, customers observe the exact number of available servers. We determine the equilibrium structure and prove the existence of exactly one pure Nash equilibrium (for simplicity, we only focus on the existence, structure, and uniqueness of pure equilibria in this paper). High AR costs lead to an equilibrium in which all servers remain unreserved, while low AR costs lead to an equilibrium that consists of N time-thresholds. A customer that observes $1 \leq n \leq N$ available servers, makes a reservation only if she makes her inquiry before the nth time-threshold.

We next analyze a *partial-information game*. In this game, the provider informs customers about the number of available servers only if this number falls below a certain threshold. We assume that unnotified customers realize that the number of available servers is larger than the threshold and take this fact under consideration upon making their decisions. We show that, in this game, Nash equilibria have the same structure. However, multiple equilibria may exist.

Informing customers about the number of available servers leads to a trade-off. On the one hand, customers that observe that all or almost all servers are available may be less prone to make a reservation (compared to a system where no information about server availability is disclosed). On the other hand, customers that observe that only a few servers are available may be more likely to make a reservation. To evaluate this trade-off, we resort to simulations. The simulation results indicate that, on average, the number of reservations decreases as more information is provided to customers. More specifically, the *full-information* policy yields the lowest number of reservations. In the *partial-information* policies, the number of customers making advance reservation increases as the threshold is lowered, and the largest number of reservations is achieved when no information is provided.

The rest of the paper has the following structure. In Section 2, we review related work. In Section 3, we define and analyze the *full-information* game. In Section 4, we define and analyze the *partial-information* game. In Section 5, we present simulation results that compare the performance of the different policies. The proof of Theorem 1, which establishes the structure of the equilibria, is deferred to Section A.1 due to its length. Section 6 concludes the paper and points out directions for future research.

2. Related work

In this section, we discuss how prior work in the literature relates to our paper and point out salient differences. First, we review prior work on game-theoretic analysis of customer behavior in queueing systems with and without information disclosure. Most of that prior work focuses on queueing systems with waiting lines rather than loss systems with advance reservations. Next, we review related work on algorithmic, queueing-theoretic and revenue management aspects of systems supporting advance reservation. In contrast to our paper, most of that earlier work ignores strategic customer behavior.

The application of game theory to analyze the behavior of customers in queues (also known as *queueing games*) is pioneered in Naor (1969). In that paper, the author considers an $M/M/1$ queue where customers observe the queue length and then decide whether to join or balk (i.e., refuse to join the queue). In contrast, in Edelson and Hilderbrand (1975) the authors analyze an unobservable $M/M/1$ queue, where customers decide whether to join a queue or balk, based only on knowledge of statistical parameters of the queue. Research on queueing games has been subsequently extended to address other aspects of queueing systems. For a review of results on queueing games, see (Hassin & Haviv, 2003) and (Hassin, 2016).

In recent years, research on the impact of information on customer's behavior in queueing systems has emerged. Several studies use game theory to compare the outcomes of different information disclosure policies in $M/M/1$ queues. In Guo and Zipkin (2007), the authors study the effects of disclosing information about delay based on three approaches: no information is disclosed, information about the queue length is disclosed, and precise information about delay is disclosed. They find that disclosing precise delay information sometimes improves social welfare and sometimes reduces it. In Hassin (2007), the author studies the impact of disclosing other types of information, such as the service rate or the quality of service (it is assumed that both parameters may change over time). The author shows that in some cases the provider is better off revealing the realizations of those parameters, while in other cases it is better off concealing them. In Simhon, Hayel, Starobinski, and Zhu (2016), the authors evaluate a *partial-information* disclosure policy, where customers are notified about the queue length when it falls below a certain threshold. The authors show that such a policy is never optimal. Thus, to maximize the effective arrival rate of customers, a provider should either always disclose information about queue length or always hide it (depending on the system parameters). The problem formulations and insights of our paper differ considerably from previous contributions on game-theoretic analysis of $M/M/1$ queues, which focus on delay metrics (rather than loss metrics) and do not incorporate advance reservations.

In Yin, Aviv, Pazgal, and Tang (2009), the authors evaluate the impact of disclosing inventory information on the strategic behavior of customers, assuming that the demand follows a Poisson distribution. In contrast, our analysis applies to demand that follows a general distribution and also establishes results for the case where partial information is disclosed. A comprehensive review on the impact of information in queuing games can be found in Hassin (2016, Chapter 3).

AR games are introduced in Simhon and Starobinski (2017) (see also Simhon & Starobinski, 2014; 2016). In that work, the authors consider a loss system operating under a *no-information* policy. Under this policy, decisions of customers are only based on statistical information. The authors show that, at equilibrium, either none of the customers make advance reservations or only those with arrival times smaller than some time-threshold. While based on a similar game-theoretic formulation, our paper differs from Simhon and Starobinski (2017) by assuming that customers can observe or partially observe the number of available servers prior to making their decisions. In contrast, in Simhon and Starobinski (2017), customers are *not* notified about the number of available servers and their decisions are only based on statistical information. This change in the model greatly affects the analysis and nature of equilibria, since the decision of one customer affects information provided to other customers.

Research on advance reservations of reusable resources can also be found in the literature of communication networks and revenue management. In the field of communication networks, most research focuses on performance evaluation and algorithmic aspects of AR systems. For example, the authors in Kaushik, Figueira, and Chiappari (2006) analyze an AR scheme for a loss system where customers have flexible starting time and show that this scheme leads to lower blocking probability and a higher utilization than those attainable in an inflexible scheme. In Guérin and Orda (2000), the authors analyze the effect of AR on the complexity of path selection. In Virtamo (1992), the author evaluates the impact of advance reservation on server utilization. In Cohen, Fazlollahi, and Starobinski (2009), the authors propose algorithms