# An Auction Game for Railway Capacity Allocation

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**Abstract.** The deregulation of railway systems across western countries have brought the subject of pricing railway slots to the surface. The majority of the infrastructure remains under the ownership and supervision of governments, which in turn further complicates the pricing of slots, since profit does not become the sole aim. This paper proposes an auction model for pricing railway slots aimed at been applied in the Swedish railways. Moreover, in this paper, a game built on top of the auction model is presented as an interface that would enable testing the auction model with railway operators.

**Keywords:** auctions · railways · web technologies.

## 1 Introduction

In the last couple of decades, the railway systems across many western countries have been deregulated. Not all countries have deregulated the market in the same way; though the two main variations depend on who owns and operates the infrastructure, a public or a private company. This is a significant distinction because unlike a private company, a public railway company is not only concerned with profit but also with increasing the societal benefits and welfare [1].

While the deregulation has benefited passengers and the market as a whole in many ways, it has introduced several challenges that did not previously exist. One of these challenges is the conflicts that arise between different operators' capacity requests [1], especially in key corridors and peak hours, and subsequently the methods used to price these slots. In this context, pricing should be fair in the sense that it should create profit for the railway company but also be affordable by operators and prevent the formation of monopolies.

This paper aims to propose an auction model for the pricing of slots in the Swedish railways that would hinder monopolistic practices, foster competition and promote societal welfare. In order to accomplish these goals, a game is

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | | **Large Company** | | **Variables** | |
| 2 | **Slots Asked** | 4 | | **# of Passengers** | 1500 |
| 3 | **Slot Cost** | 88,648 kr | | **Ticket Cost** | 350 kr |
| 4 | **Train Cost** | 40,000 kr | | **Total Slots Asked** | 9 |
| 5 | **Operation Cost** | 46,667 kr | | | |
| 6 | **Total Cost** | 175,315 kr | | **1st Slot Cost** | 15,000 kr |
| 7 | **Revenues** | 233,333 kr | | **Slot Increase** | 1.05 |
| 8 | **Profit** | 58,018 kr | | | |
| 9 | **1 Additional Slot** | 23,270 kr | | | |
| 10 | **1 Less Slot** | 22,162 kr | | | |
| 11 | **Competitors Slots** | 5 | | | |

**Fig. 1.** The prototype.

developed that enables railway operators to choose the amount of slots they want and then, based on the total number of slots chosen by all operators, the price of slots is determined. The underline model has two variations: i. the price per slots is applied to all operators regardless the amount of slots chosen by each operator individually, hence "punishing" all operators for overwhelming the network, and ii. operators that choose many slots are "punished" by paying additional fees, whereas operators that choose fewer slots are "rewarded" through reduced fees. The idea of having two variations of the model is to determine which method would be more effective in dissuading large operators to outbid small ones and thus creating a monopolistic market.

In Section 2, related work that set the basis of the proposed methodology is analysed. In Section 3, the auction model and the subsequent game are presented. Finally, in Section 4, future work is illustrated and final remarks are made.

## 2 Background Work

A conflict-free timetable is at the heart of railway scheduling. Consequently, auctions for railway capacity are modeled as auctions of discrete goods, the train slots [10]. Being discrete and in many occasions, like during peak hours, scarce, most auction models have been focused on identifying the most efficient and lucrative pricing mechanism. In [3], the authors proposed an auctioning algorithm for bidding in a bundle of slots as opposed to one slot at a time. This approach is to an extent adopted in the proposed game, in the sense that operators bid once for acquiring a set of slots. While from a purely financial point of view, in [4], the author examined auctions as a mechanism for allocating railway capacity in North America. One of the main conclusions and pertinent to this study was the high level of transparency that auctions offer, which in turn increase accountability and social welfare. Transparency is at the forefront of the proposed game as it is described in detail in Section 3.

## 3 Design Methodology & Implementation

The game has two main components, the underline auction model and the gaming/user interface (UI). An important characteristic of the game is that it is multiplayer in real-time, since the decision of each player (i.e. railway operator) instantly affects the outcome of all others. The auction model, the prototype of the game and the final implementation of the game are analysed in more detail in Section 3.1, Section 3.2 and Section 3.3.

### 3.1 Auction Model

The auction model is to a large extent an oversimplification of reality, using aspects from game theory [6], since the goal of the game as a whole is not to realistically depict the actual system but to determine whether and how the rewards and punishments implemented in the model could improve competitiveness and social welfare. The game is round-based with theoretically an endless number of rounds; what game theory refers to as a repeated game with incomplete information [2]. Each game session can have a different scenario, which consists of the departure station, the arrival station, timeframe (e.g. 7:00 - 10:00 am.), type of trains (intercity, regional etc.) as well as the characteristics of the participating operators, like the trains they have available to use. The only input of players in the game is the number of slots in each round. In turn, given the number of slots, the revenues and cost and consequently the profit for each operator are calculated. The calculation of revenues is fairly straightforward, based on assumptions like the total number and distribution of passengers within the given timeframe, the market share of each operator and the ticket price. The cost on the other hand is the sum of three different components: i. the cost of borrowing trains, in case the operator does not actually own enough trains, ii. the operational (variable) cost of running a train, which is a percentage of the revenues, and iii. the cost of acquiring the slots. The latter is where the novelty of the model and the game lies.

There are two variations on how slot cost is determined. In both variations, the price of slots increases for every additional slot asked and this price increase applies to all slots. It is natural to expect that the largest company, which is also usually the market leader, will ask the highest number of slots and this is the point where the two variations kick in. The first variation is about "punishing" all participating operators equally for any additional slots demanded by any operator. This means that all operators will pay per slot the same amount regardless the number of slots they asked. The idea behind this pricing policy is that all operators bear equally, though proportionally, the cost of occupying the railway network. Nevertheless, this pricing method has the negative potential to be used by the market leader to render the cost of slots unbearable for the smaller operators, thus slowly pushing the market towards a monopoly. In the event that the market leader could afford for a period of time to operate with losses by asking too many slots, the smaller companies could not afford to pay for the increasingly expensive slots, which in turn could take them out of business.

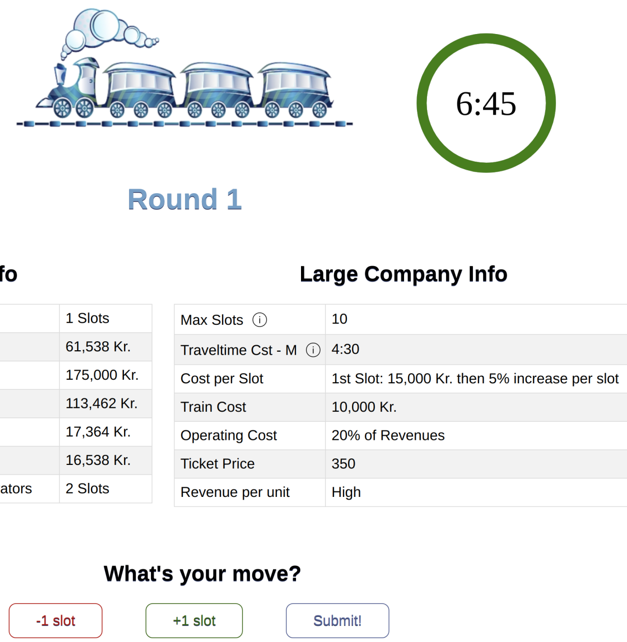


**Fig. 2.** The game interface.

Due to this potential negative effect of this pricing method, a second variation is also considered. The second variation is about "rewarding" the operators that asked for fewer slots. Initially, the slot price is calculated in the same way as in the first variation, meaning that there is a base price that increases the more slots are asked; but after the bidding, the operator that asked the highest number of slots pays a penalty over the final price of the slots whereas the operator that asked the fewer number of slots receives a deduction on the final price they have to pay. The idea behind the variation of the auction model is to give incentives to smaller operators to participate even for as little as one slot thus reducing the market share of large operators.

As stated previously, in theory the game can continue indefinitely, so the game ending criteria is up to the designer. Currently two options for finishing the game have been considered. The first option is to have a fixed amount of rounds (e.g. 6 or 7 rounds) after which the game ends and participants are presented with the final results. This option has the advantage of knowing when the game will end but also enables operators to strategically "game the game", since they know when the game ends. The second option is to end the game when there is no change in the number of slots operators ask for two consecutive rounds. This option prevents operators from strategies like *wait and see* and forces them to act because the game can end at any given point. The disadvantage though is that the game duration is completely unpredictable, which in turn makes game sessions logistically difficult to coordinate.

### 3.2 Prototype

The prototype of the game, which is 100% playable though lacking certain interactive features, is designed in Excel and is shown in Figure 1. Players can only change the number of slots they want (Cell B2), as it is explained in more detail in Section 3.3, whereas cells B3-B10 are calculated based on the number of slots players chose and that of their competitors, which is in cell B11. Cell B11 is pulled from the Excel files of the other operators. Column E are the variables, which with the exception of E4 are all constant. Cell E4 is the sum of all slots asked, i.e. B2 + B11. The prototype enabled us in identifying issues that would be difficult or counter-intuitive to have in Excel, like a timer, and led in implementing the game in a more feature-rich environment, which is described in more detail in the next section.

### 3.3 Implementation

The final game is implemented with web technologies (HTML5, CSS, Javascript including AJAX, PHP and MySQL). After logging in, participants go through 4 pages of instructions, in the end of which they make their initial bidding by choosing the number of slots they want. After all participants have placed their bids, the game begins. The UI of the game, which is shown in Figure 2, has four distinct elements:

1. *Timer:* On the right up corner of the UI, there is a timer showing the remaining time for the round. Players have to submit their answer during that time; failing to do so would trigger the game to submit automatically the number of slots currently selected.
2. *Auction Information:* On the left side of the UI, there is a table displaying information about the auction pertinent to the operator. The first row of the table shows the number of slots the operator has currently asked for and it is the only field that can be changed by players. The remaining rows show the cost, revenues and profits, as well as the cost increase and decrease if players choose one additional or one less slot respectively; all these fields cannot change directly by the player but they change based on the number of slots selected by the player. The final row shows the sum of the slots chosen by all the other operators, i.e. the competitors.
3. *Company Information:* On the right side of the UI, there is a table displaying static information related to the company, like the maximum number of slots they can choose based on its size as well as information about how the financial figures on the left table are calculated.
4. *Controls:* On the bottom of the UI, there are the controls with which players interact with the game. With the first two buttons, players can decrease or increase the number of slots, i.e. changing the first row on the left table,

which also gives them a preview on how the financial figures change if the other operators do not change their bid. The right button submits their final demand.

## 4 Conclusion & Future Work

In this paper, a game for introducing auctions for acquiring slots in the railways is presented. A prototype was first designed in Excel, whereas the final implementation of the game is web-based. The underline auction model for calculating the cost of slots has two variations, based on a "reward" and "punishment" system, with the aim to eliminate, or at least minimise, the effect of monopolistic practices by large operators.

With regards to future work, the next step is to validate the game in two ways. First validate the auction model using analytical methods [8, 9] and then test the game with experts in the field of railways, thus capturing their tacit knowledge [7], in order to fine-tune both the auction model and the interaction of players with the gaming interface [5]. Finally, the game will be played by representatives of railway companies, so they can get acquainted with the new auction mechanism the Swedish railways are planning to implement and begin adjusting, and potentially improving, their decision-making processes.

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