

# Accommodating driver preferences in reservation-based urban traffic management\*

## (Extended Abstract)

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### ABSTRACT

In this paper we combine two different economically inspired mechanisms, acting at intersection and at network level, respectively, to accommodate driver preferences in reservation-based urban traffic management. At intersection level, intersection manager agents assign space-time chunks through combinatorial auctions, while at network level a pricing scheme, based on general market equilibrium, accounts for an efficient use of network resources. Our experiments show that this combined approach on the one hand allows drivers to effectively improve their travel times if they are willing to pay more money for their trip, while on the other hand the negative impact on social welfare (average travel times) is unnoticeable.

### Categories and Subject Descriptors

I.2.11 [Artificial Intelligence]: Distributed Artificial Intelligence—*Coherence and coordination, intelligent agents, multiagent systems*

### General Terms

Algorithms, Design, Experimentation

### Keywords

Traffic and transportation, market-based mechanisms, combinatorial auctions

## 1. INTRODUCTION

Removing (at least partially) the human driver from the control loop by the use of autonomous vehicles and the integration of these with the intelligent infrastructure is a challenging long-term vision for the field of Intelligent Transportation Systems (ITS). In this paper we present a policy for managing future reservation-based [2] urban traffic management infrastructures that takes into account the drivers'

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different valuations of their travel times. An auction-based intersection control mechanism is in charge of assigning reservations of space-time slots to drivers. Combined with a distributed pricing scheme, which sets the publicly-known reserve prices of the auctions, the result is a combined policy that allows vehicles to travel the faster through the network the more their drivers are willing to pay for the trip, with no significant social cost in terms of average travel times.

## 2. AUCTION-BASED TRAFFIC CONTROL AND ASSIGNMENT

In this paper we present a control policy for reservation-based intersections that relies on an auction mechanism, so as to allocate their resources to the agents that value them the most. A reservation-based intersection is a control facility that allows each autonomous vehicle to reserve space-time slots at interactions, so as to safely pass through them [2]. In our scenario, the auctioned goods are bundles of space-time slots inside the intersection, implicitly defined by a reservation request, and allocated by a combinatorial auction. The auction proceeds as a continuous alternation of two phases: *bids collection* and *winner determination*. The auctioneer waits for bids for a certain amount of time, then it executes the winner determination algorithm. Since the auction must be performed in real-time, both the bid collection and the winner determination phases must be time bounded, that is, they must occur within a specific time window. This implies that optimal and complete algorithms for the winner determination problem are not suited for this kind of auction. An algorithm with *anytime* properties is needed, such as the stochastic local search proposed by Hoos et al. [3] that we have adapted to our scenario.

Since the auction-based policy is designed to grant a reservation to the driver agent that values it most, rather than maximising the number of granted requests, it is possible that the auction-based policy entails a significant social cost, in terms of a greater average delay for the entire population of driver agents. For this reason, if we focus on a urban road network with multiple intersections, an integrated strategy is needed that combines traffic *control* and *assignment* [5], i.e. which distributes traffic flows over the network elements in line with their capacities, thus reducing the demand of potentially congested intersections. An intersection manager, being the supplier of the reservations allocated through the combinatorial auction, controls the *reserve price* of the auctioned reservations, i.e. the minimum price at which it is

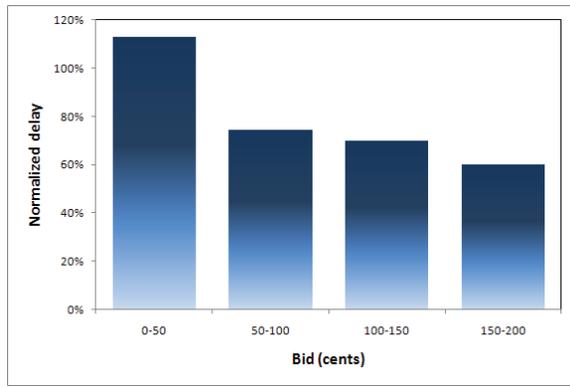


Figure 1: Relation between normalised delay and bid

willing to sell [6]. Thus the intersection managers compete with each other for driver agents, raising prices in case of increasing demand or lowering them in case of decreasing demand. The pricing strategy is based on the general market equilibrium theory [1]. At time  $t$ , each intersection manager  $j$  computes, independently from each other, the excess demand  $z_j^t$  and updates the price  $p_j^t$  using the formula:

$$p_j^{t+1} \leftarrow \max \left[ \epsilon, p_j^t + p_j^t \cdot \frac{z_j^t}{s_j} \right] \quad (1)$$

where  $s_j$  is the supply of intersection manager  $j$  (the number of driver agents that intersection manager  $j$  wants to participate in each auction),  $z_j$  is the excess demand (the difference between the number of driver agents that are bidding for a reservation at time  $t$  and the supply) and  $\epsilon$  is the minimum reserve price. Vehicles travelling on network links with low demand shall incur in costs as low as possible, so we chose  $\epsilon = 0$ . To define the supply  $s_j(l_h)$ , we rely on the fundamental diagram of traffic flow [4], considering that there is an excess demand when the density reaches the 50% of the optimal density.

The adaptive and concurrent pricing strategies applied by the intersection managers are in charge of computing in a distributed way the price vector  $\mathbf{p}^*$  that corresponds to the general market equilibrium, a situation where the amount of resources sought by the driver agents is equal to the amount of resources supplied by the network.

We compared the auction-based policy with the straightforward extension (i.e., without any traffic assignment) of the first-come-first-served control policy, proposed in the original paper by Dresner and Stone [2]. In the following we refer to the auction-based policy as CA and to the first-come-first-served policy as FCFS.

From figure 1 it is possible to appreciate an inverse relation between delay and bid value. The driver agents that submit bids between 150 and 200 cents reduce the delay of about 50% with respect to those which bid less than 50 cents. Figure 2 plots the *evolution* of the *overall* travel times in our experiment, in terms of the average travel times of vehicles that have completed their trips, and as a function of the percentage of completed trips. Since lower demand leads to a lower “social cost” of our auction-based policy with respect to FCFS at intersection level, a more homogeneous distribution of vehicles over the network leads to a better use of

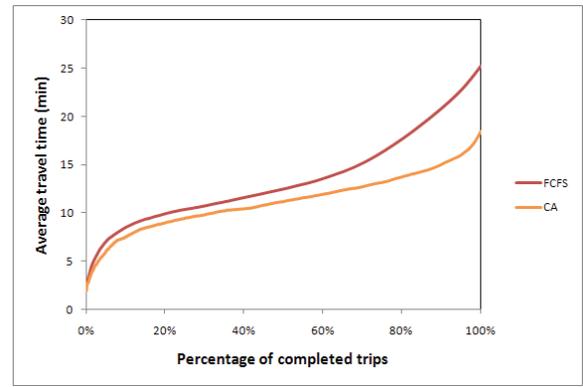


Figure 2: Overall average travel time

network resources, and thus to lower average travel times.

### 3. CONCLUSIONS

In this paper we have presented an economically inspired policy to accommodate the preferences of users of autonomous vehicles (“driver preferences”) in reservation-based urban traffic management. At intersection level, intersection manager agents assign space-time chunks through combinatorial auctions, so as to give priority to vehicles whose drivers are in a hurry. At network level, a decentralised pricing scheme, targeting the general market equilibrium, (implicitly) coordinates the reserve prices of the intersections’ auctions. As a result, we obtain a system in dynamic equilibrium where unused intersections become cheaper while more demanded ones become more expensive, leading to a more efficient use of the network resources. We have shown that vehicles whose drivers are willing to pay more for their reservations are effectively rewarded with lower travel times, while the social cost of our policy when compared to FCFS is reduced and often even compensated by the traffic assignment effects of our policy.

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