Auction-Based System for Intersection Traffic Management of Autonomous Vehicles

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Introduction:

With the recent advancements in the development of driverless vehicles, it is commonly believed that the traditional human-driven automobile is one day going to be replaced by cars that will be completely autonomous. When this becomes a reality, some issues that exist in today's traffic systems could be addressed by using software systems to control traffic flow more efficiently than is possible with human drivers. One common cause of congestion on surface streets is at intersections where busy roadways meet and drivers must wait at stoplights for up to several minutes while traffic moves in only two directions at one time. If the limitations of human drivers were eliminated from the equation, it would be possible to manage cars crossing at intersections without any vehicle ever having to come to a complete stop.

Previous Work:

While roads full of autonomous vehicles may be years away, research is already being conducted into traffic management systems using wireless communication between autonomous vehicle agents. Basic schemes involve a centralized management server that would process requests from vehicles as they approach an intersection and allow cars to proceed through the intersection on a first-come-first-served basis. A simulated implementation of this reservation system yielded favorable results when compared to a traditional traffic light system. Researchers at the University of Texas at Austin simulated a four-way intersection with six lanes traveling in each direction and found that, on average, the reservation based system caused less than one half of one percent the delay of the traffic light system [1]. The system is able to maximize traffic flow by allowing for cars to travel through the intersection in all four directions simultaneously without colliding. Coordination on this scale would obviously be impossible in a system with human drivers.

Original Work:

In my project, I built on this basic reservation scheme with a more complex auction system that takes into account priorities among drivers who are willing to pay to proceed through an intersection quicker than they otherwise would on a first-come-first-serve basis. To do this, autonomous vehicles communicate with a central server at an intersection and bid some dollar amount representing how urgently they need to pass through the intersection. This bid amount would have been preconfigured before the intersection was reached. The central server takes into account all incoming bids and then prioritizes which vehicles are to be permitted to pass through the intersection first. Vehicles with higher priority are permitted to accelerate towards the intersection and pass those with lower priority who would decelerate and wait for the higher priority traffic to clear before proceeding.

This scheme is a variation on other auction-based intersection traffic management systems that require vehicles to stop at the intersection before bids are made and the highest-bidding vehicles are allowed to proceed [2]. My system still allows for traffic to flow – without stopping – through intersections in multiple directions simultaneously as was possible in the reservation system, but also allows for people with a high need to arrive at their destination quickly to be given priority over those who do not.

Experimental Design:

This auction based system assumes that the roadway has two lanes in each direction to facilitate the need for higher priority vehicles to accelerate ahead of lower priority vehicles to reach the intersection sooner. Thus vehicles that bid a higher amount are able to use a “fast lane” to pass vehicles that bid smaller amounts.

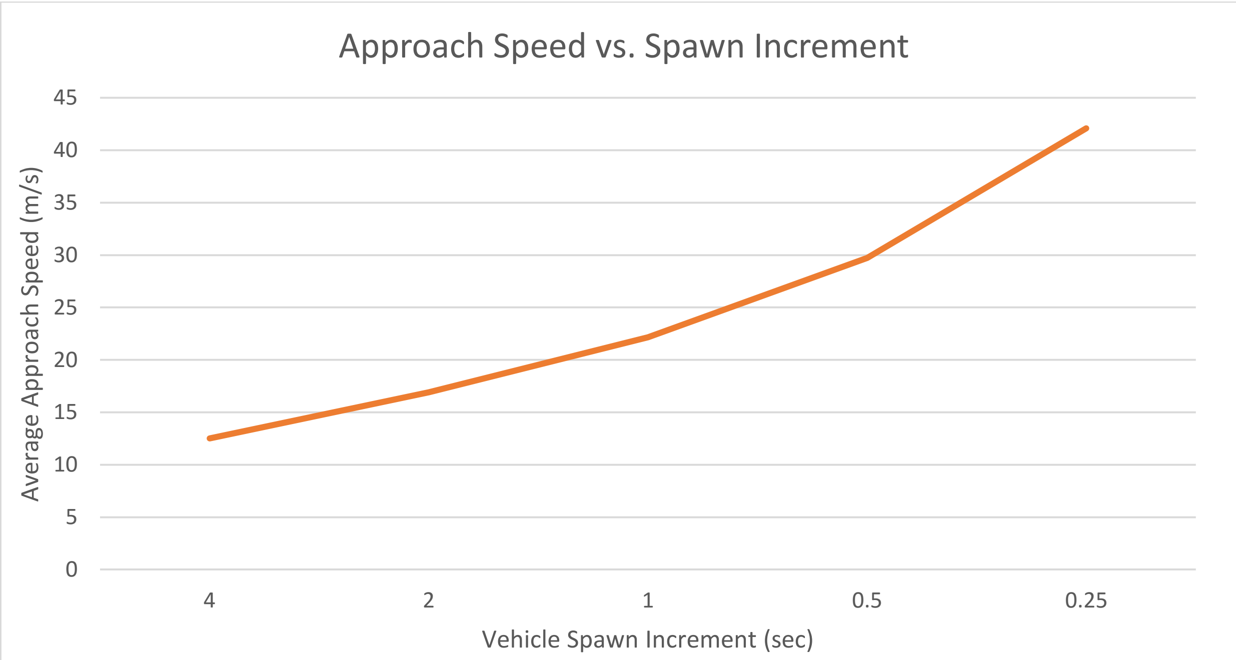
In the simulation code, the auctioneer considers a perimeter of 100 meters around the intersection in each direction. For every one second increment, a new vehicle is spawned 100 meters from the intersection traveling in a random direction either north, south, east or west towards the center of the intersection at 20 meters/second. After a new vehicle spawns, a new auction is held. In the auction, each vehicle transmits its bid to the auctioneer which could be thought of as a central server located near the intersection. The auctioneer handles the bid from every vehicle that is within 100 meters of the intersection but has not yet passed through the intersection. The auctioneer then orders these bids from highest to lowest. Vehicles are then permitted to accelerate at some speed based on their standing in the bid order. Vehicles who bid the highest are therefore able to accelerate to a higher speed than the vehicles that bid less. The auctioneer instructs each vehicle to accelerate based on their standing in the auction order.

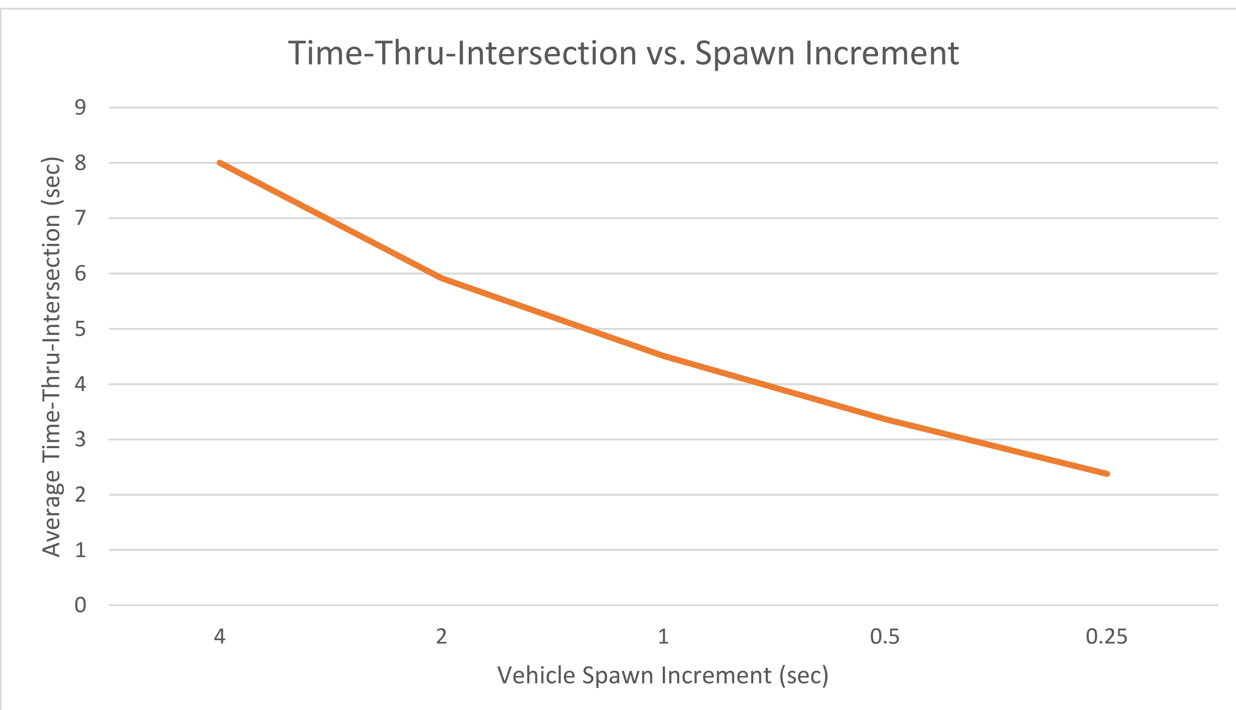
In the event that a fast-moving vehicle closes in on a slower moving vehicle in the “slow lane”, that faster vehicle is able to move into the “fast lane” to safely pass the slower vehicle and avoid a collision. However, once a vehicle has moved into the “fast lane”, if it happens to close in on another vehicle in front of it, it must slow its speed to match that slower vehicle to avoid collision. Obviously with only two lanes, there is the potential that a fast moving vehicle with a high bid could end up stuck behind another vehicle with a lower bid after moving into the “fast lane”. With more lanes of traffic traveling in each direction, the likelihood of this gridlock occurring decreases. Although this gridlock is possible with only two lanes of traffic moving in each direction, we will see that, on average, vehicles are able to pass through the intersection very efficiently.

Finally, the system also makes safety a primary priority by assuring that, given each vehicle travels at the speed it is commanded to by the central server at all times, there will be no collisions between vehicles in the intersection. The central server checks that if two vehicles are approaching the intersection at the same distance and speed from different directions, one will accelerate slightly to avoid collision with the other in the intersection.

Results:

To get an idea for the efficiency of the auction system, I ran several simulations, each with varying parameters. Each simulation was run for 100 seconds, however the time between spawning new vehicles was varied to see how it affected the average amount of time that it took to travel through the intersection. This “spawn increment” was set to 4.0s, 2.0s, 1.0s, 0.5s and 0.25s, and data was then accumulated to compute the average amount of time it took for a vehicle to travel the 100 meters from the perimeter of the intersection to pass through the intersection. The results of these tests are shown in the following graphs:





As the data shows, when the spawn increment decreases – therefore causing there to be more vehicles involved in each auction – the average time to pass through the intersection decreases. Likewise, as the spawn increment decreases, the average approach speed into the intersection increases. The reason for this has to do with the scheme used to direct traffic. The auctioneer directs vehicles to accelerate at a rate proportional to their auction standing. More specifically, the highest-bidding vehicle is allowed to accelerate at a rate equivalent to 0.1*n m/s, where n is the number of vehicles that bid in the auction. The next highest-bidding vehicle is allowed to accelerate at a rate equivalent to 0.1*(n-1) m/s, and so forth. Therefore, as the number of vehicles increases, vehicles are actually able to accelerate faster and faster according to their auction standing. Given these results, until some upper speed bound is reached where the vehicles are simply not capable of accelerating any more, it is actually beneficial for cars to enter the intersection more frequently based on the scheme implemented.

Future Work:

Due to the limited amount of time that I had to implement my own auction simulation, I was unable to develop other types of simulations with which to compare results. The next step in my research would be to develop a simulation of a traditional intersection with stoplights where each direction of travel would be stopped for some amount of time to allow other traffic to flow through the intersection. It would be interesting to compare the average amount of time for vehicles to pass through a traffic light system with that of the auction system. Although there would be some cases where vehicles would be able to pass through the intersection without being stopped at a stoplight (when they hit a green light), I would assume that the average time-through-intersection would be significantly higher than in the auction-based system. Comparing these results would validate whether or not the auction-based traffic management system would be viable in a real world situation and more efficient that the traditional stoplight system that exists at most intersections today.

References

[1] K. Dresner and P. Stone, “Multiagent Traffic Management: A Reservation-Based Intersection Control Mechanism,” New York: AAMAS, 2004.

[2] D. Carlino, S. D. Boyles, and P. Stone, “Auction-based Autonomous Intersection Management,” Proceedings of the 16th International IEEE Annual Conference on Intelligent Transportation Systems, pages 529-534, The Hague, The Netherlands, October 6-9, 2013.