Agent Systems
Autonomous Intersection

Contents

1 Introduction

Since concept of autonomous cars is becoming more and more prevalent, there emerges a need for systems that allow for safe and efficient traffic control. Case where there are no human-driven cars on roads allows for more advanced rules that would be impossible when dealing with different levels of driving skills and reaction times.

Efficiently managing multiple cars on road is a perfect fit for an agent-based approach. Vehicles could communicate between themselves to inform about their intentions and capabilities. While non-centralized approach would be sufficient to avoid collision in a single lane (e.g. on highways), intersections may benefit from systems that offer more advanced traffic control that could not be achieved with traffic lights or road signs.

This project is an attempt to design such intersection system that offers significant improvement in efficiency, while maintaining high level of safety for passengers.

2 Goals

The goal of this project is to design and simulate an autonomous intersection system utilizing agent-based approach. The agents are defined as vehicles that require no human interaction and can freely communicate with each other and the system that manages the intersection.

The desired end result is method of controlling flow of vehicles through a road crossing that does not utilize traffic lights or stop signs, while offering greater throughput of cars without compromising safety of passengers. For validation purposes there will be constructed a model that simulates regular, non-autonomous intersection (with traffic lights and taking into account human reaction speeds) that will allow to precisely compare efficiency of proposed intersection managers.

3 Related works

One of the first models for simulating car traffic using agents-based approach is Nagel-Schreckenberg model [1]. In this version the model is able to simulate vehicle flow on a single lane, including acceleration, deceleration and randomization of vehicles' velocity and resulting traffic congestion resulting when too many vehicles cluster in small area. The model was later extended in later works to e.g. include two-line traffic[2], but it is limited to freeway roads without any intersections.

To address intersection simulation a model was proposed by Vranken and Schreckenberg[3] based on cellular automata. It is able to model a crossing for four lanes, with or without traffic lights. The focus of this work is to provide a realistic and accident-free simulation with deadlock prevention of urban traffic with human drivers.

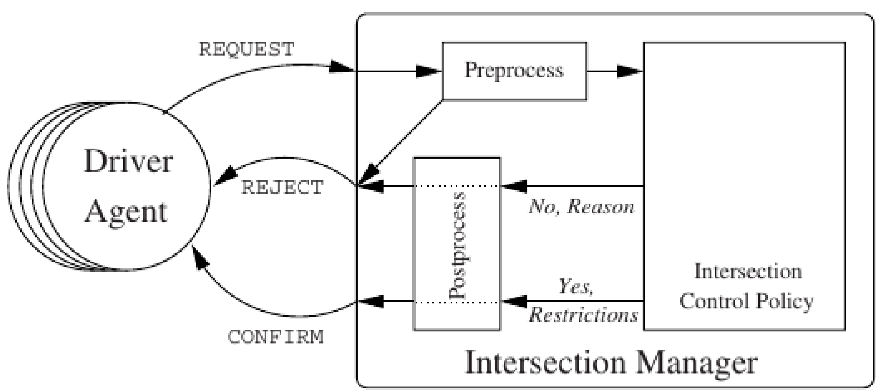

Figure 1: Reservation approach for autonomous intersection manager[4].

So far, the referenced works addressed only simulation of human drivers and did not account for capabilities introduces by autonomous systems. One of first and most influential papers on the subject is a work by Dresner and Stone[4] which is the main source of inspiration in this project. It aims to provide a realistic system that is efficient, safe and is designed to avoid deadlocks. It introduces the concept of reservation, where vehicles that are about to enter intersection send a request to intersection manager to reserve space-time required for save traversal of road crossing. The intersection manager system processes request from every car and through process of simulation determine whether the request should be accepted or rejected. The agent needs to send several parameters that allow to reliably simulate how the car will move on the intersection.

Later, the improvement of this model was proposed by Au and Stone[5] that focuses on improving efficiency by reducing the need for cars to stop before intersection and thus slow down the whole process.

Other similar approach was presented by Zhao et al.[6] which uses Internet communication to pass messages between agents. It simulates intersection flow using cellular automata and shows increase in efficiency of road traffic compared to regular, human-driven approach.

4 Implementation

4.1 Specification

Implementation of an autonomous intersection manager was done in an iterative approach, producing several prototypes with increasingly advanced rules to finalize the project with an efficient solution. The basis of the model is a four lane intersection, one for each direction. Cars come from every direction and can turn left or right or drive forward, depending on randomly assigned destination.

To control the simulation several parameters were created:

- Spawn rate – controls how probable is for a car to spawn at each entry to the simulation space. Higher values can simulate greater congestion of traffic.
- Max velocity – maximum velocity a car can reach.
- Acceleration - Vehicles' ability to gain velocity.

Contrary to most referenced works, this model is implemented as a continuous system, rather than a cellular automaton in order to achieve more smooth vehicle flow. The simulation operation on discreet time steps with singular one taking 50ms, and the smallest unit of space is equal to 10cm.

The simulation and intersection manager logic was build in Mesa – agent-based simulation framework for Python that allows for easy agent setup and

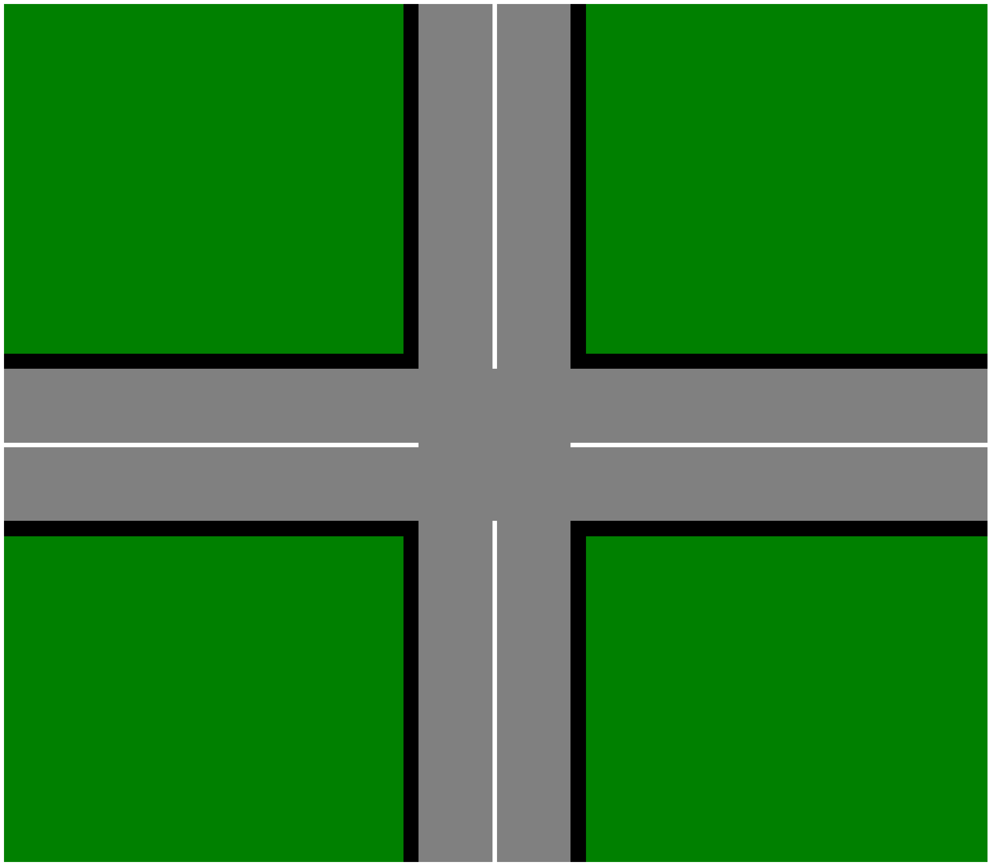

Figure 2: Intersection type used in model.

control, browser-based visualization, ability to create simulation parameters and various method of data visualization.

4.2 Validation model

To easily compare the efficiency of proposed autonomous intersection systems, a validation model was constructed that aims to imitate regular intersection with traffic lights and human drivers. It takes into account reaction time by introducing a delay between lights change and vehicles starting.

At a time, only single lane can traverse the intersection (only exception are cars that want to turn right on lane directly to the left) in order to achieve collision-free flow. The throughput achieved in this configuration serves as a basic for evaluation of implemented autonomous intersection managers.

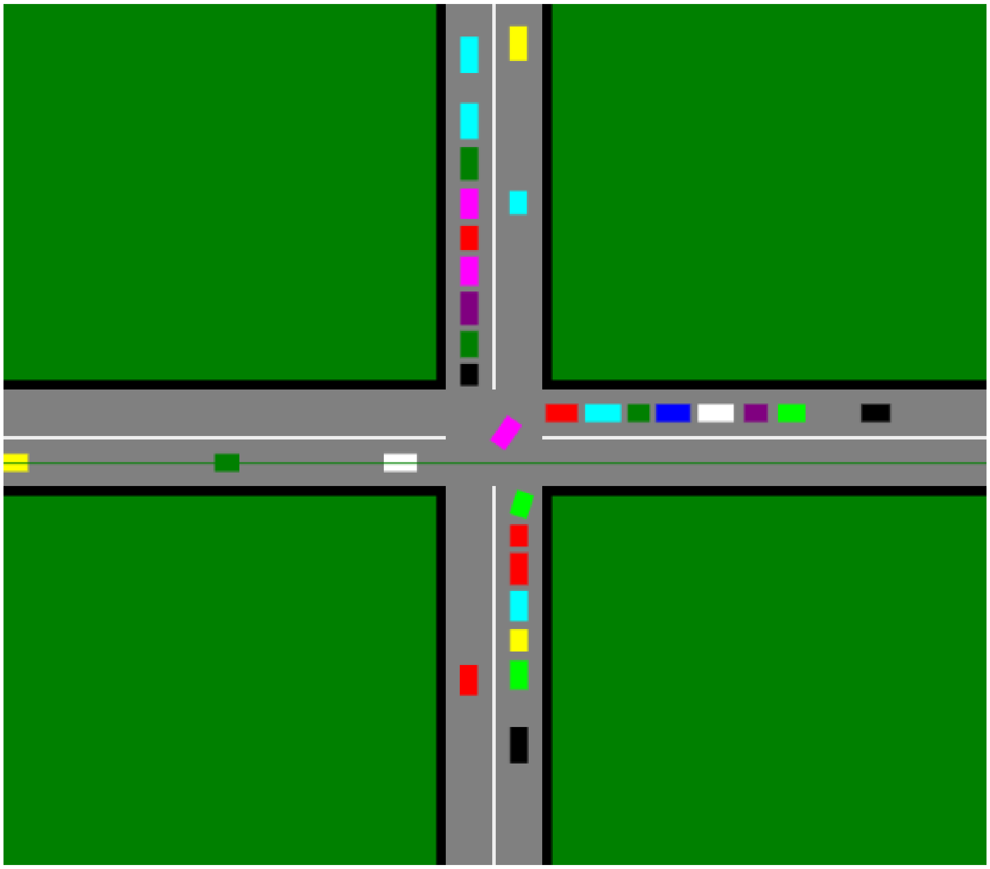

Figure 3: Traffic light based intersection. Green line indicates which lane has a green light and is able to traverse the intersection.

4.3 Basic reservation model

Basing on approach introduced in [4] a basic reservation model was created. In this and later configurations agents (vehicles) drive towards their desired direction by themselves. Intersection manager's role is to control flow of vehicles by ordering them to stop or start at certain points in time to achieve safety and efficiency.

The intersection space is divided into several sections, for this particular intersection type into quarters (but for more complicated types it would be

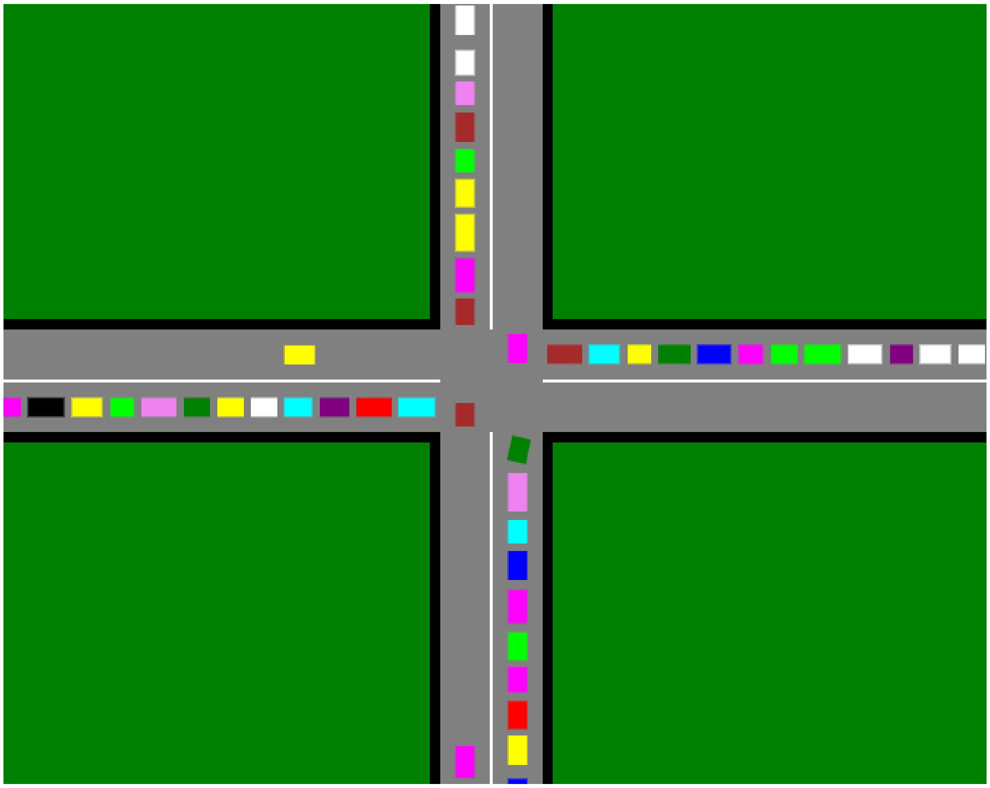

Figure 4: Basic reservation based intersection. Two cars from opposite lanes are traversing the intersection since they reserve different sectors at the same time.

more) where perpendicular lanes cross. Since car turning right needs only one quarter, left – three, and for driving forward – two, the vehicle may reserve the path needed for traversal instead of whole intersection. The car is given reservation when it is allowed to enter intersection, and after leaving it occupied sector can be reserved anew.

This allows for several concurrent scenarios:

- Cars from every direction can turn right at the same time.
- Cars from opposite direction can drive forward at the same time.
- A single car can turn left, leaving space for one car from other lane to turn right.

- A single car can drive forward, leaving space for one or two cars turning right.

This approach does not promote smooth flow of cars in single direction like traffic lights, but when traffic is small it may allow every car to pass the intersection without stopping.

4.4 Advanced reservation model

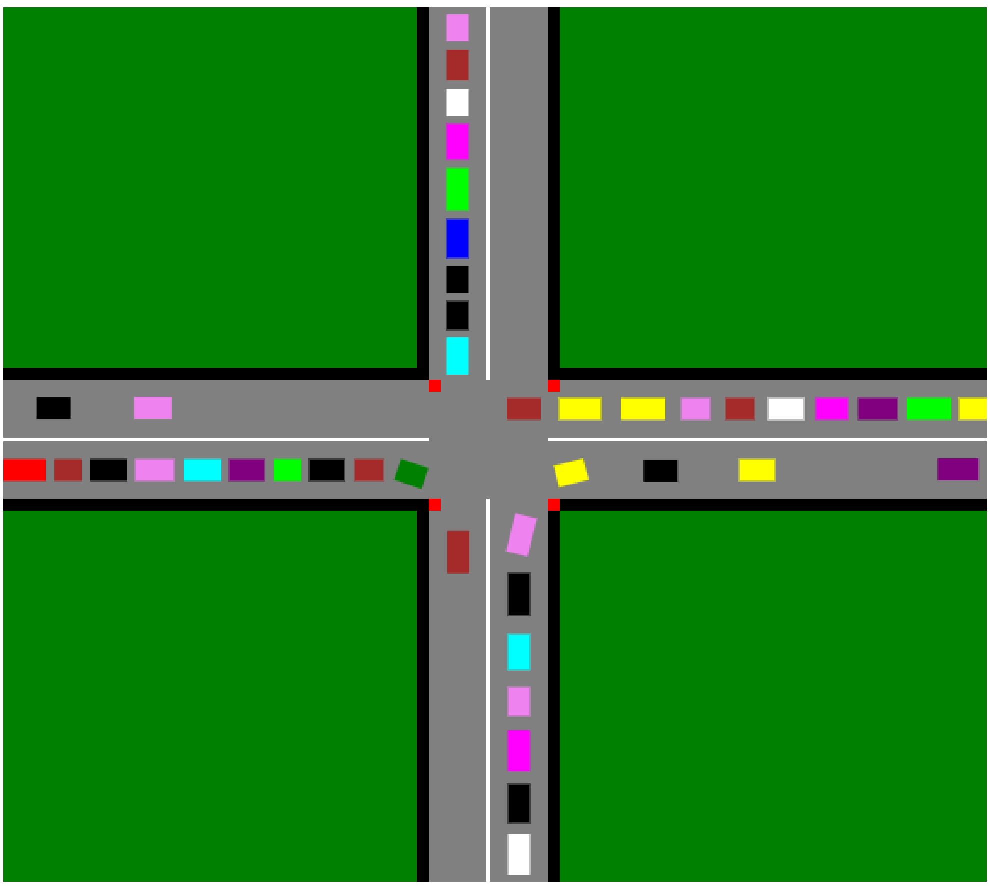

Figure 5: Advanced reservation based intersection. Allows for a slightly more efficient traversal while still retaining safety. The red points indicate that a quarter is currently reserved.

This model an improvement of one presented in previous subsection. Its behaviour is based on the fact, that a car does not need to keep reserved all sectors of its path throughout whole sequence of traversing the intersection. For example, car driving forward can free one quarter when it reaches the halfway point, allowing for a car from its left to safely drive forward too. This way it is possible to achieve slightly better throughput.

4.5 Reservation model with prediction

This model aims to utilize space-time way more efficient than two previous ones. While they could achieve semi-smooth flow, their approach does not account for capabilities that a fully autonomous system offers when reaction time becomes a non-issue.

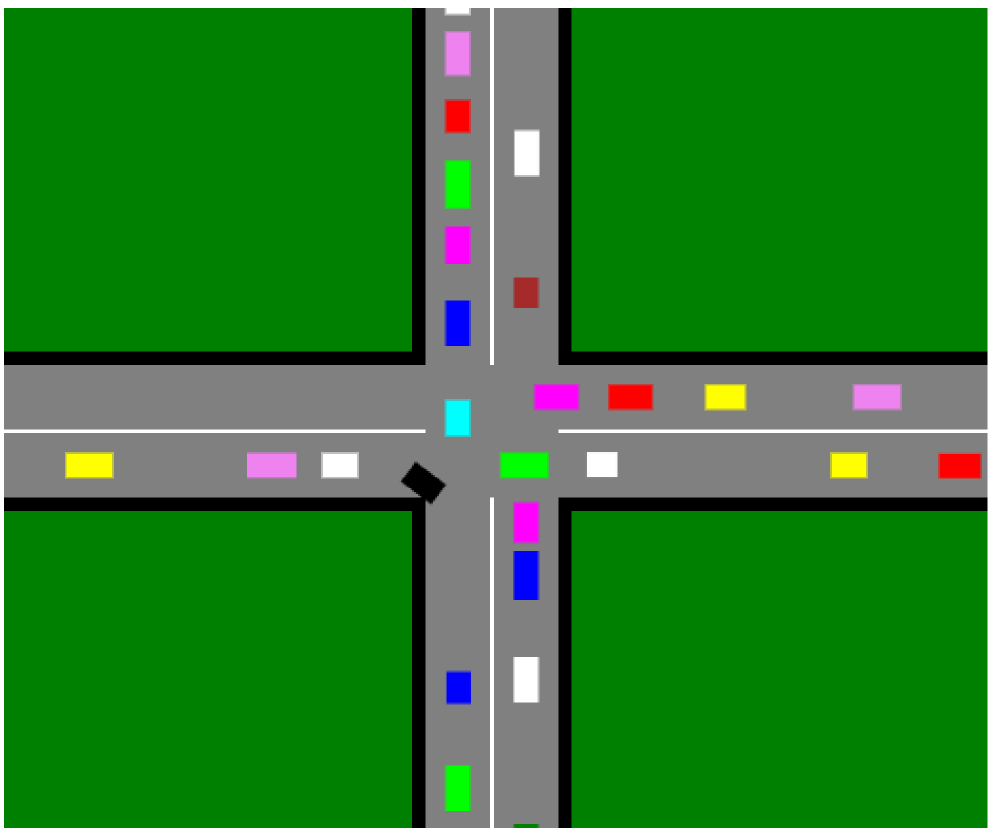

Figure 6: Reservation based intersection with prediction. System allows cars to traverse the intersection as long it deduces that they will not collide.

To achieve optimal throughput, the concept of sectors is ignored and a vehicle that is about to enter intersection needs to present the intersection manager its detailed traversal plan. The plan consists of position and rotation of vehicle for each time step (in this model – 50 ms interval), which is calculated based on car's allowed velocity, size and acceleration capabilities.

When presented with this information, the intersection manager can compare it with previous reservations, and if at no point in time there will be a collision with other car, the reservation is approved. This way vehicles can pass each other by tens of centimeters. This method of operation would be virtually impossible with a human driver, because the slightest hesitation would result in a car crash.

5 Comparison

After the implementation, all iterations of the autonomous intersection manager were benchmarked in regard of car throughput and were compared to the traffic light human-driven validation model. The result of benchmarks is show on figure 7.

The validation model with traffic lights and human reaction speeds achieved throughput between 60 and 80 cars per minute depending of maximum allowed velocity on intersection.

For basic reservation system, the efficiency is slightly better, although it is mostly due to not having to take human reaction speeds into consideration.

Advanced reservation model offers some improvements compered to the previous one and can reliably achieve throughput up to 140 cars per minute.

On the other hand, the final autonomous intersection manager model utilizing prediction offers substantially greater efficiency compared to both validation model and previous solutions.

It can also greatly benefit from higher allowed velocities, but even with relative small velocity of 30 km/h it results with over 300% bigger throughput than traffic lights solution and over 200% compared to advanced reservation model. At higher velocities the difference becomes even more apparent.

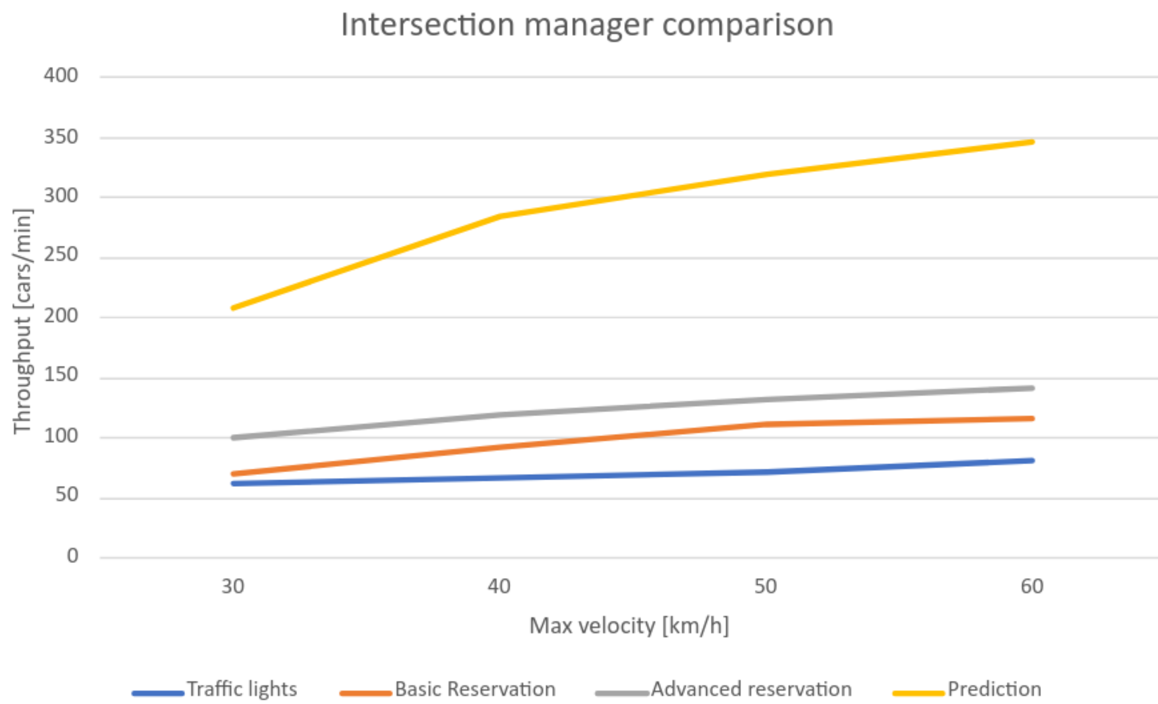

Figure 7: Comparison of different autonomous intersection managers compared to traffic light efficiency. The results were acquired from simulation with car acceleration of 30 $\frac{km}{h}$ per second.

6 Conclusions

As seen from the comparison above, autonomous intersections hold great potential to increase efficiency of road traffic. To achieve that however, there is need for autonomous cars to become more ubiquitous, so more advanced algorithms can be used. In the meantime there might be a possibility to introduce a hybrid approach to accommodate for both human reactions and potential for autonomous vehicles.

In the case of creating roads for automatic cars, the traffic flow can way faster than that what we experience today, as shown in experiments above. The model presented here was built for a simple intersection – one with one lane per direction, but it algorithm o reservation can be easily ported to more advanced road crossings.

In real life scenarios it is also needed to account for random deviations that are less probable compared to human-driven cars, but are still existent like a possibility of car breaking, problems with communications or intersection system malfunction. Therefore it may be a good idea to sacrifice some efficiency gain for additional safety e.g. mandating a greater required distance between cars on intersection or limiting the maximum velocity.

References

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