Improving Traffic by Exploiting Autonomous Vehicles

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ABSTRACT

Congestion can easily be induced by any bottlenecks on road, including lane closures and on-ramp merging sections. When enough aggressive drivers do not give way to merging vehicles, the length of traffic further increases and throughput decreases leading to a longer travel time. For this reason, we propose exploiting the advanced radar technology of autonomous vehicles in order to record and punish aggressive drivers who are not giving way in order to push them to give way.

KEYWORDS

autonomous vehicles, bottlenecks, road management, traffic simulation tool

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1 INTRODUCTION

Reduction in roadway width is a common traffic bottleneck. A traffic bottleneck can simply be defined as any localized constriction of traffic flow and is often seen as the root cause of congestion[1]. Reduction in roadway happens when there is a lane drop, where the number of lanes provided for through traffic decreases, or when lane closures occur causing one or more lanes to become unavailable due to temporary situations such as accidents on-road or constructions that temporarily close lanes.

Severe congestion can be caused at locations where a physical reduction in roadway width occurs. If enough drivers are not giving way to merging vehicles, it can lead to what is known as a free-rider problem. The free-rider problem is an economic concept of a market failure that occurs when people are benefiting from resources, goods, or services that they do not pay for. If there are too many free riders, the resources, goods, or services may be under-provided and thus create a free-rider problem.

All drivers can benefit from the road even if they are not giving way to the merging lane drivers. If too many drivers are free-riding, the traffic on the merging lane will overflow, causing traffic in the entire area. There may be even less incentive for anyone to give way then because the traffic has become locked, but that would worsen the problem. Yet, if the vehicle drivers can cooperate properly at lane drop and lane closure points, the overall traffic length can be reduced by up to 40% and the throughput can be improved, even with heavy congestion[2].

The solution we propose to this solving problem is through exploiting the advanced technology of autonomous vehicles which are already making their way into our roads. Vehicles with self-driving capabilities could potentially solve our free-rider problem by tracking drivers who do not give way and storing their data. Those drivers may then be punished by not being giving way. This will give them an incentive to give way in the future in order not to be punished. This leads us to our main research question, what is the minimum penetration rate of autonomous vehicles on road need?

2 APPROACH

2.1 Road Layout

In our layout, we create a simple version of our problem. We build a 950 meters long freeway. The freeway starts with three lanes, two lanes, and a merging lane. About halfway through the freeway, the road width reduces two due lanes as the merging lane drops.

2.2 Simulation Tool

We use PTV Vissim traffic simulation tool to run our simulation scenarios. PTV Vissim is a microscopic multi-modal

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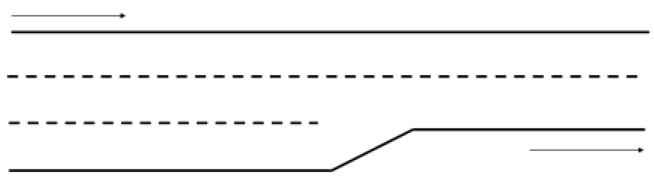


Figure 1: Road Layout

traffic flow simulation tool with various vehicle types including Cars, trucks, busses, bikes. PTV Vissim allows us to simulate different driver behaviors needed for our research study, including autonomous driving and aggressive driving, with plenty of adjustable variables. Penetration rates of different vehicle types and traffic volume can easily be adjusted. Many large-scale projects worldwide featuring autonomous vehicles have also used PTV Vissim, including:

CoExist

CoEXist is an EU-funded project which aims to bridge the gap between connected and automated vehicles technology (CAVs) and transportation and infrastructure planning by strengthening the capacities of urban road authorities and cities to plan for the integration of CAVs in the same network [4]. The CoEXist Automation-ready modelling and impact assessment tools will enable road authorities to understand in detail the impact of increasing numbers of CAVs and of increasing automation levels on a shared road network.

PRE-DRIVE C2X

The European project PRE-DRIVE C2X prepared a large-scale field trial for connected and automated vehicular transport [5]. It developed an integrated simulation model for cooperative systems to that enables a holistic approach for estimating the expected benefits in terms safety, efficiency, and environment. This includes all tools and methods necessary for functional verification and testing of cooperative systems in laboratory environment and on real roads in the framework of a field operational test.

2.3 Vehicle Types

We include three different vehicle types in our simulation:

a. Human-Driven Vehicles

Human-driven vehicles are regular human-driven vehicles with no communication capability or advanced radar technology.

b. Aggressive Human-Driven Vehicles

Aggressive human-driven vehicles are human-driven vehicles with aggressive behavior. In our research study we define aggressive vehicles as those which do not feature cooperative lane changing, for example, if they see a vehicle trying to merge from the merging lane to the left lane, they will merge from the left lane into the right lane to facilitate lane changing for the merging vehicle. Moreover, with regular human-driven vehicles, the vehicle falls back in distance from the vehicle ahead of it when the vehicle ahead accelerates, leaving some space in which merging vehicles can take advantage of and merge. Aggressive human drivers do not leave that gap and accelerate as soon as the preceding vehicle accelerates.

c. Autonomous Vehicles

Autonomous vehicles are vehicles with some level of self-driving capability. Automation in vehicles is broken down into 6 levels. Level 0 vehicles are fully manually controlled. Level 1 features some driver assistance such as cruise control and adaptive cruise control. Level 2 offers an advanced driver assistance where the vehicle can control both the steering and the accelerating and decelerating. Level 3 vehicles have limited self-driving capability the vehicle can control both steering and braking/accelerating simultaneously under some circumstances, but still requires human override at any moment. With level 4 automation, vehicles can operate in self-driving mode in most situations and the driver can optionally override if necessary, and if not, the vehicle is capable to safely abort the trip. Level 5 is fully autonomous and eliminates the driver completely. Level 3 automation and high are considered to be autonomous vehicles.

2.4 Scenarios

We run the simulation with different penetration rates of autonomous, human driven, and aggressive human driven vehicles. Aggressive human driven vehicles are only inputted into the first two lanes, excluding the merging lane. We run the simulation for three different aggressive human drivers penetration rates: 10%, 30%, and 50%. For each of those penetration rates, we test for 5 different autonomous vehicles penetration rates: 10%, 20%, 30%, 40%, and 50%.

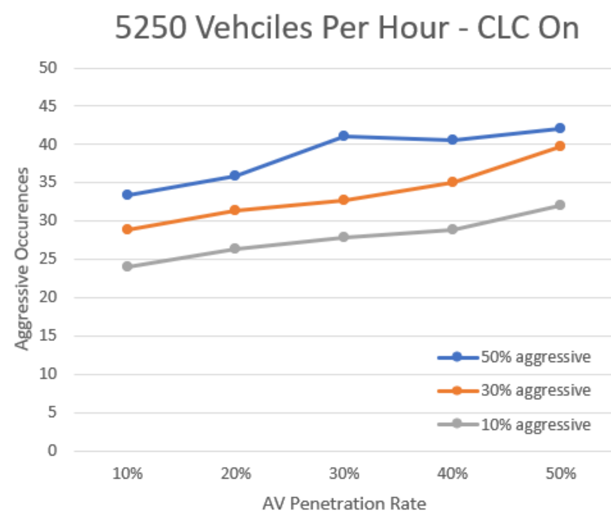
As we do not input any aggressive drivers into the merging lane, the penetration rate of human driven vehicles in that lane is equal to 100 minus autonomous vehicles penetration rate. In the other two lanes, it is equal to 100 minus autonomous vehicles penetration rate minus aggressive vehicles penetration rate. So, if we have 10% aggressive human driven vehicles distributed across the two main lanes, and 10% autonomous vehicles across the entire simulation, we will have 90% regular human driven vehicles on the merging lane and 80% human driven vehicles along the two main lanes.

We run all of the scenarios at a traffic volume of 5250 vehicles per hour, 4200 vehicles per hour, and 3150 vehicles per hour.

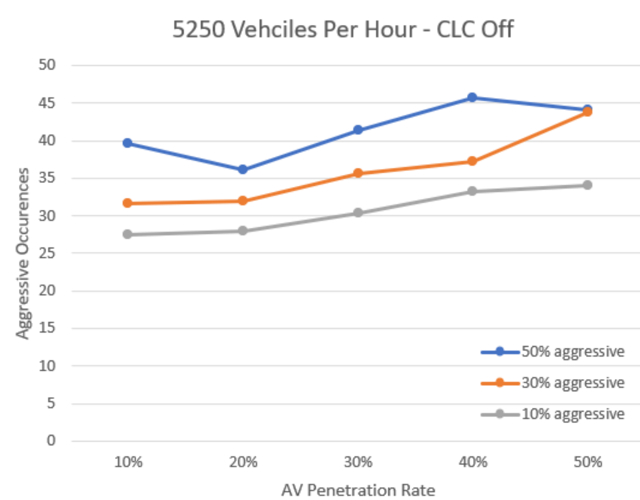
3 METHODOLOGY

We follow a few steps to determine which vehicles are not giving way and if there is an autonomous vehicle in range to report the situation. We start by tracking the top-most vehicle in the merging lane and label it as V1. If we recognize that V1 has stopped for more than two seconds, we check who is passing by V1 in the middle lane. For simplicity, every vehicle that is passing the merging point while V1 is stopped for more than two seconds is assumed to be not giving way, and the number of aggressive occurrences increments. We then check if there is an autonomous vehicle in range to record the aggressive occurrence. To do that we check if there are autonomous vehicles within a 50-meter range or 100-meter range from V1. If there is, we count the number of vehicles between the autonomous vehicle and V1. If there are 0 or one vehicles in between, then the aggressive case gets reported. We repeat the process with different penetration rates of autonomous vehicles for each penetration rate of aggressive human-driven vehicles, where each trial is run 10 times. We again repeat the process with 20% reduced traffic volume and 40% reduced traffic volume.

Since the sensor system is not unified across autonomous vehicles, we test for multiple settings. Some autonomous vehicles have mid-and long-range sensors all around, while others have mid- and long-range sensors only ahead. The strengths and reliability of the sensors are not uniform either, as sensor simulation for perception is still a new process and is undergoing much experimentation. For this reason, we take different variabilities into account and test for them, including whether the vehicle can see only ahead or all around, whether it can only see the vehicle ahead of it, or up to two vehicles ahead, and whether it can see up to 50 meters ahead or up to 100 meters ahead.



(a) Cooperative Lane Change Parameter Switched On



(b) Cooperative Lane Change Parameter Switched Off

Figure 2: Cooperative Lane Change On vs Off

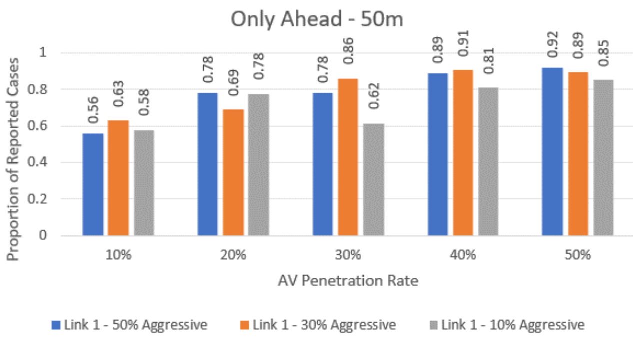
4 RESULTS AND DISCUSSION

4.1 Cooperative Lane Changing

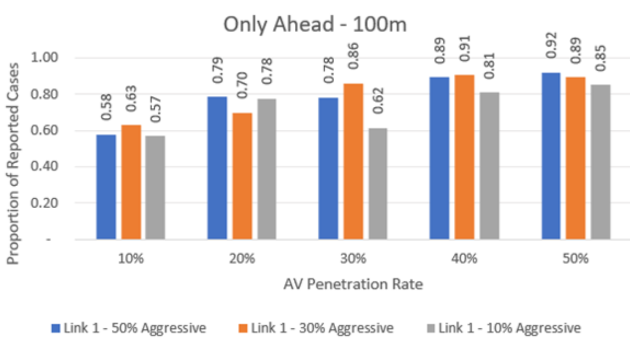
One of the main features of aggressive human-driven vehicles that we have defined is that they do not cooperatively change lanes. In order to assess the significance of this parameter, we tested all the simulation scenarios at 5250 vehicles per hour with the cooperative lane change parameter turned on for regular human-driven vehicles and autonomous vehicles and turned off for aggressive human-driven vehicles, and with the cooperative lane change parameter turned off for all vehicles in the simulation. Looking at the results in figure 2, it is evident that there is a small increase in the number of aggressive occurrences when the cooperative lane change parameter is switched off for all vehicles (fig. 2b) versus when it is on for non-aggressive vehicle types (fig. 2a).

4.2 Sensing Range

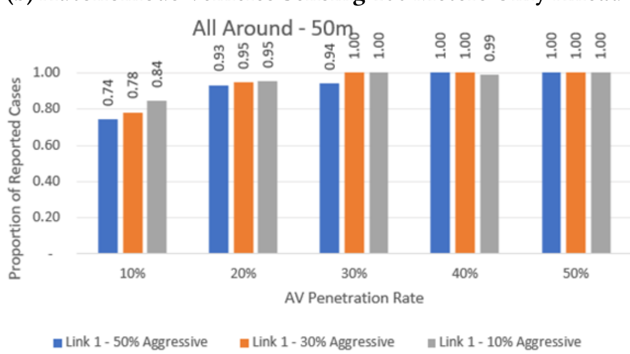
For not giving way to occur, the traffic must be dense. For this reason, only a small sensing range is required. In figure 3, we can see that with 4200 vehicles per hour, (20% reduction from the maximum traffic volume in our simulation), largest difference between a 50 meter sensing range and a 100 meter sensing range in all scenarios is only 1%. This difference only occurs in up to 30% autonomous vehicles penetration rate. However, the difference is too small that it is insignificant.



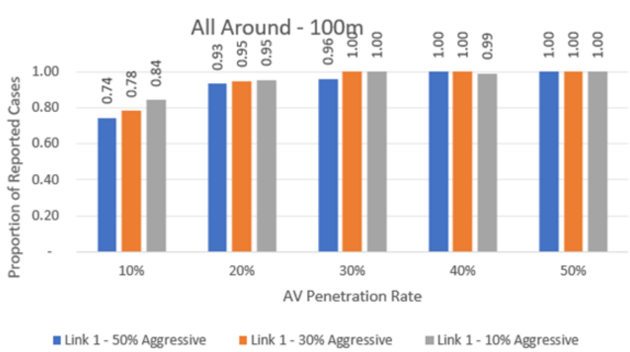
(a) Autonomous Vehicles Sensing 50 Meters Only Ahead



(b) Autonomous Vehicles Sensing 100 Meters Only Ahead



(c) Autonomous Vehicles Sensing 50 Meters All-Around



(d) Autonomous Vehicles Sensing 100 Meters All Around

Figure 3: Autonomous Vehicles Sensing Range vs Reported Cases for Traffic Volume of4200 Vehicles Per Hour

4.3 Monitoring Range

Comparing the autonomous vehicles' vehicle monitoring capability, we evaluate the difference in the proportion of aggressive cases recorded between the capability to monitor the vehicle ahead only versus the capability to monitor the vehicle ahead and the vehicle ahead of it.

Looking at the graphs in figure 4, there is a significant difference of up to 20% between the proportions of recorded aggressive cases between monitoring only the vehicle ahead (no vehicles in between) and monitoring the vehicle ahead and the vehicle ahead of it (0 or 1 vehicles in between) at 10% autonomous vehicles penetration rate.

The difference between the two monitoring schemes reduces as the penetration rate of autonomous vehicles increases, with the proportion of reported cases coming very close together at 50% autonomous vehicles penetration rate. Moreover, the proportion of aggressive occurrences reported with an all-around sensing is higher than the proportion of occurrences reported with only ahead sensing since more vehicles are being sensed.

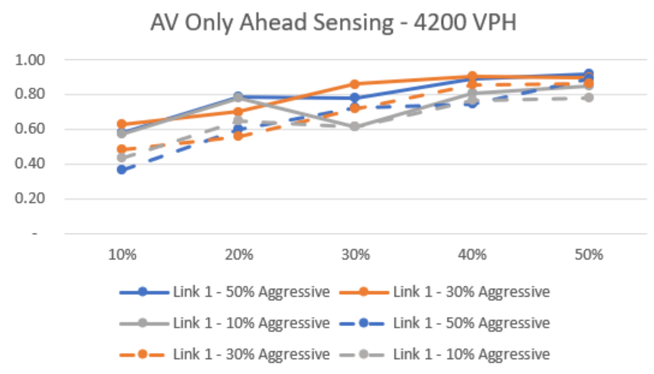
The results are fairly consistent with both traffic volumes, 5250 vehicles per hour and 4200 vehicles per hour, with only a slightly greater variability between the proportion of reported vehicles at each autonomous vehicle penetration rate at 4200 vehicles per hour (figure 4a and 4b), and that is due to the smaller number of cases, which results in a greater change in percentage. For example, if we have an average of 30 cases, each reported case is affecting the results by 3.33% percent. However, if we have an average of 8 cases, each reported case affects the results by 12.5%.

5 CONCLUSION

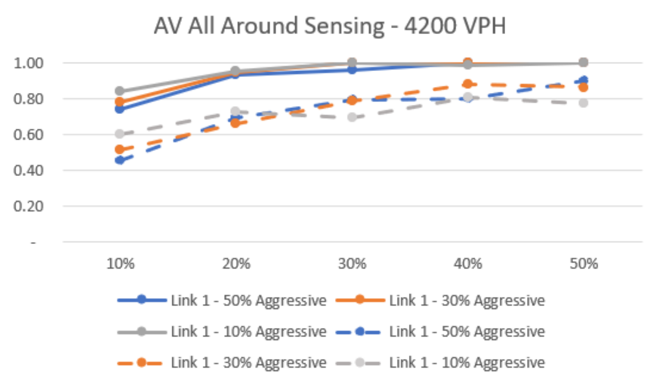
Autonomous vehicles provide a great potential to safer roads and reduced traffic congestion. If we exploit their technology creatively and effectively, we could greatly improve the efficiency of our roads.

Our research focused on reduction in roadway width, which is a common traffic bottleneck that can lead to severe traffic congestion. Our results that even with only 20% of autonomous vehicles on road we can cover nearly 80% of aggressiveness cases. With only 10% autonomous vehicles on road having an all-around sensing range and able to monitor 1 or 2 vehicles all around, 80% of aggressive cases can be reported. The minimum penetration rate to cover such a high percentage of aggressive cases is much lower than we anticipated, and shows that countries can go a long way greatly optimize their roads and push drivers to give way with if they invest a fairly small percentage of highly reliable autonomous vehicles with strong sensors.

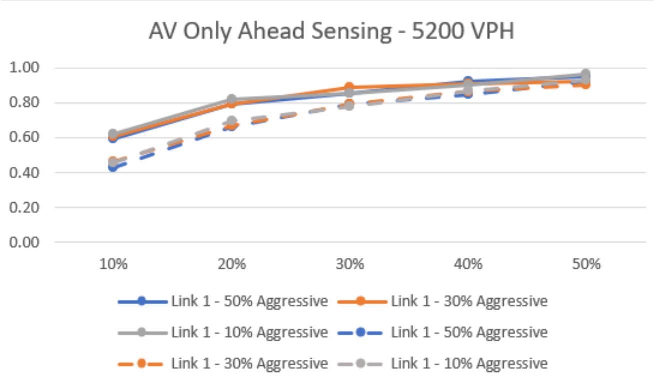
My work so far is only the first step of this project and there is still a long way to go. There is much to expand on



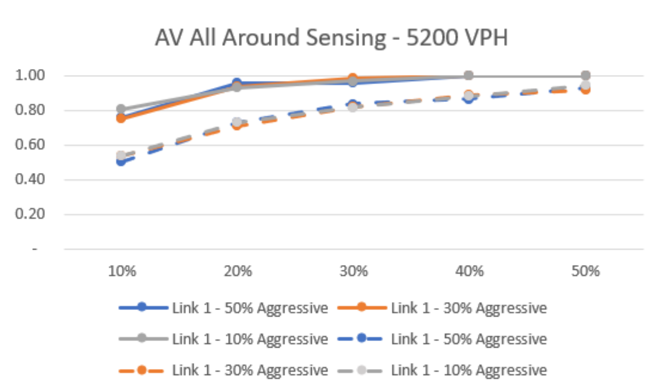
(a) Autonomous Vehicles Sensing Only Ahead, 4200 VPH



(b) Autonomous Vehicles Sensing All Around, 4200 VPH



(c) Autonomous Vehicles Sensing Only Ahead, 5250 VPH



(d) Autonomous Vehicles Sensing All Around, 5250 VPH

Figure 4: Cooperative Lane Change On vs Off

and import. Starting with tracking not giving way, where it is simply assumed when V1 is stopping for more than two seconds for the simplicity and time constraints of my project, is more complicated than just that. The point record system is also yet to be developed, but it has most of the tools ready. Our small layout is also ready to be scaled larger.

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