Abstract

hEART 2018 – 7th Symposium of the European Association for Research in Transportation

March 2018

Autonomous Intersection Management Including Pedestrians

Tanja Niels[a], Klaus Bogenberger[a], Aleksandar Stevanovic[b], Nikola Mitrovic[b], Robert Bertini[c]

[a]Bundeswehr University Munich, Werner-Heisenberg-Weg 39, 85579 Neubiberg, Germany
[b]Florida Atlantic University, 777 Glades Rd, Boca Raton, FL 33431, USA
[c]University of South Florida, 4202 E Fowler Ave, Tampa, FL 33620, USA

Keywords: Autonomous Driving, Urban Transportation, Autonomous Intersection Management, Pedestrians

1. Introduction

In recent years, the development of connected and automated vehicles (CAVs) is improving worldwide. CAVs are currently being tested on public roads and they offer several new technologies and possibilities that could revolutionize transportation. On the one hand, autonomous driving is promising for both logistics and enhanced personal mobility options, especially for persons with disabilities. Driving will not only be more accessible and comfortable, due to improved shared mobility options it will most likely also be cheaper. These developments might lead to a significant increase in vehicle miles travelled (VMT).

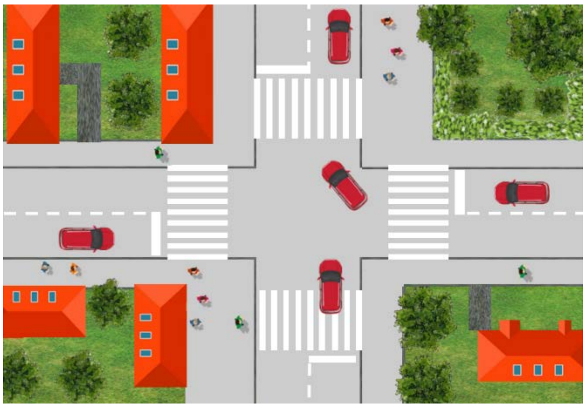
On the other hand, traffic congestion and air pollution have become significant problems, especially in cities. The worldwide population is still increasing, and an increasing share of the world's population resides in metropolitan areas (United Nations, 2014). While many recent studies conclude that autonomous driving has the potential to enhance the capacity of streets and intersections through shorter headways and faster reaction times, these capacity improvements might be overcompensated by the increase in VMT (Eisenkopf et al., 2017). Therefore, the advisory committee of the German Federal Ministry of Transportation is suggesting that the usage of the urban street network could be charged in the future (Eisenkopf et al., 2017). One possible way to combine the potentials that CAVs offer to improve capacity with a tolling system is to apply autonomous intersection management (AIM) algorithms that can dynamically charge fees for crossing an intersection.

AIM systems offer benefits for urban intersections and they can be designed in different ways in order to suit a variety of needs. First of all, it has been discussed in several papers that AIM can increase the capacity of intersections significantly (Dresner et al., 2008; Fajardo et al., 2011). Additionally, certain users can be prioritized by AIM, for example ambulance vehicles or public transportation (Dresner et al., 2006). AIM has also been studied in combination with bidding strategies, see e.g. Carlino et al. (2013), Isukapati et al. (2017) and Schepperle et al. (2008).

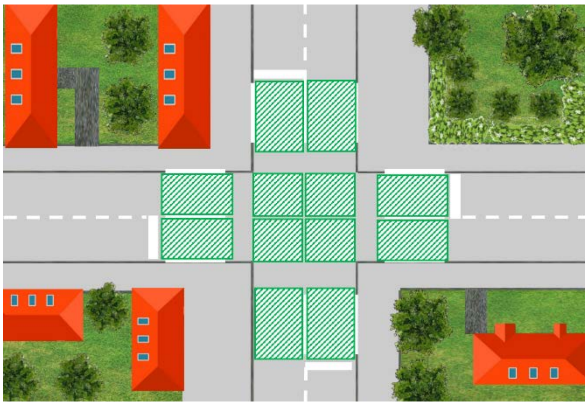
Chen et al. (2016) give a good overview of AIM models and projects. However, most studies consider intersections where only CAVs are present. When modelling urban intersections, it has to be taken into account that vehicles interact with other transportation modes, such as transit, bicycles and pedestrians. In this paper, we consider urban intersections with both CAVs and pedestrians. The research objective is to develop a model that minimizes the average delay time at the intersection for car passengers and pedestrians. It is possible to assign weights to the different road users, and thus a toll system can also be incorporated.

2. Model

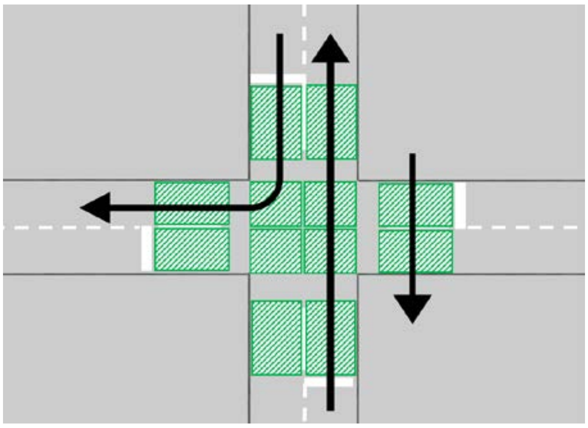
In this chapter, the objective and the constraints for the AIM are presented. First of all, the considered intersection is divided into eight different conflict areas. This procedure is shown in Figure 1, where an example intersection with pedestrians and vehicles is shown. Figure 1a shows the intersection situation and Figure 1b shows the partitioning into conflict areas. Only one vehicle or a group of pedestrians is allowed to pass a conflict area at a time as shown in Figures 1b and 1c. Dividing an intersection into a grid of conflict areas is common



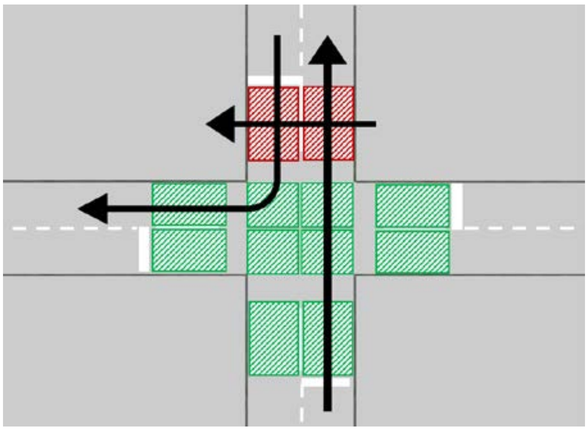
a) Image of an urban intersection with pedestrians.



b) The intersection is partitioned into different conflict zones.



c) Non-conflicting movements are allowed at the same time.



d) Conflicting movements are not allowed at the same time.

Figure 1: Image of an urban intersection including pedestrians and its discretization.

when developing AIMs. In our case, we consider not only the conflicting movements of vehicles, but also the conflicts between vehicles and pedestrians. The granularity of the partitioning is relatively low, considering that the inner part of the intersection (where vehicles' movements conflict) is only divided into four different tiles. This is done to keep the model simple and the computational complexity low. In general, the flexibility and efficiency improve when using a higher granularity – however, it was shown by Dresner et al. (2008), that a higher granularity does not always lead to shorter average waiting times and that a granularity of 2×2 is a good compromise for intersections that are approached by one lane from each direction.

In order to model the intersection control, we make the following assumptions:

1) The vehicles' positions, current speeds and destinations are available, as soon as the vehicle enters a range of 300m from the center of the intersection.
2) A speed limit of 30 km/h is imposed on all four approaches of the studied intersection which is respected by crossing vehicles.
3) All vehicles are identical. The vehicle's recommended path (and thereby speeds) obtained from the AIM are fully known before a vehicle crosses the intersection.
4) Pedestrians are detected via cameras at the intersection. This means they are not detected prior to arriving at the intersection, but when they are already there. The right of way is displayed to pedestrians via traffic signals.
5) Pedestrians are assumed to cross the intersection with a speed of 1.2 m/s. An additional clearance time is assigned and camera detection ensures that the intersection tile is cleared before a vehicle is allowed to cross.

The objective of the modeling approach is to minimize the average delay at the intersection. Let U be the set of all vehicles and pedestrians crossing the intersection. For each vehicle or pedestrian u in U, let $t_0(u)$ be the time that is needed for travelling from origin to destination assuming that crossing the intersection leads to no delay at all and let $t(u)$ be the time that is actually needed. We then aim at minimizing the average delay

$Delay_{avg} = \frac{1}{|U|} \sum_{u \text{ in } U} t(u) - t_0(u).$

It is possible to include priority, e.g. for highly occupied vehicles, pedestrians, or vehicles that pay an extra fee by assigning them a certain weight in the objective function. Let $w(u)$ be the weight of vehicle or pedestrian u. We then aim at minimizing the average weighted delay
$Delay_{avg,weighted} = \frac{1}{|U|} \sum_{u \text{ in } U} w(u) * (t(u) - t_0(u)).$

The average delay is minimized under the following constraints:

1) A tile in the middle of the intersection can only be used by one vehicle at a time.
2) A tile representing a conflict area between vehicles and pedestrians can only be used by one vehicle or by a group of pedestrians at a time.
3) Between the successive use of a conflict area, a minimum gap time G needs to be respected.
4) A minimum headway g is assumed for two successive vehicles, $g < G$.
5) Vehicles on the same intersection approach cross the intersection in the order "First In, First Out", this means that no overtaking is possible on the approach to or within the intersection.
6) Vehicles that have arrived at a stop line and pedestrians at the intersection are not allowed to wait for more than a limited amount of time $Wait_{max}$, in order to ensure that the goal of minimizing the average delay is not obtained by making few people wait for a very long time.

A basic intersection, as shown in Figure 1, is used to develop and demonstrate the AIM.

3. Conclusion and Outlook

The research goal of this paper is to present an AIM control algorithm including pedestrians given the assumptions and objectives stated in Chapter 2. The model will be further developed and implemented on a test intersection.

In future studies, the control shall be tested in a simulation of a real and more complex intersection in Munich, Germany, and other transportation modes shall be included.

References

Carlino, D., Boyles, S.D. and Stone, P., 2013. Auction-based autonomous intersection management. In: Proceedings of the 16th IEEE Intelligent Transportation Systems Conference (IEEE ITSC), pp. 529-534.

Chen, L. and Englund, C., 2016. Cooperative Intersection Management: A Survey. In: IEEE Transactions on Intelligent Transportation Systems, Vol. 17, No. 2, 2016.

Dresner, K. and Stone, P., 2006. Human-Usable and Emergency Vehicle–Aware Control Policies for Autonomous Intersection Management. In: The Fourth Workshop on Agents in Traffic and Transportation (ATT 06), 2006.

Dresner, K. and Stone, P., 2008. A Multiagent Approach to Autonomous Intersection Management. In: Journal of Artificial Intelligence Research 31 (2008), pp. 591-656.

Eisenkopf, A., Fricke, H., Gerike, R. et al., 2017. Automatisiertes Fahren im Straßenverkehr – Herausforderungen für die zukünftige Verkehrspolitik. Guachten des wissenschaftlichen Beirats beim Bundesminister für Verkehr und Digitale Infrastruktur.

Fajardo, D., Au, T.C., Waller, S.T. et al., 2011. Automated Intersection Control: Performance of Future Innovation Versus Current Traffic Signal Control. In: Transportation Research Record: Journal of the Transportation Research Board, No. 2259, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 223-232.

Isukapati, I.K. and Smith, S.F., 2017. Accommodating high value-of-time drivers in market-driven traffic signal control. In: IEEE Intelligent Vehicles Symposium (IEEE IV), 2017, (pp. 1280-1286).

Schepperle, H., Böhm, K., and Forster, S., 2008. Traffic Management Based on Negotiations between Vehicles - A Feasibility Demonstration Using Agents. In: AMEC/TADA 2007, LNBIP 13, pp. 90-104, 2008, Springer-Verlag Berlin Heidelberg.

United Nations, Department of Economics and Social Affairs, Population Division, 2014. World Urbanization Prospects: The 2014 Revision, Highlights. ISBN 978-92-1-123195-3