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Methodology for estimating capacity and vehicle delays at unsignalized multimodal intersections

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ABSTRACT

An uncontrolled intersection is one where neither traffic signs nor lights, are used to guide the traffic through the intersection, but instead the drivers decide on the right of way based on some standard priority rules. This paper establishes a methodology to systematically evaluate the expected average delays at multi-modal uncontrolled intersections. The methodology considers the demand values of different traffic streams, along with the priority and direction of each stream to determine the capacity available for each. Using this capacity and the formula for delay adapted from the highway capacity manual, the average delay for each vehicle stream can be determined. The methodology is tested using data collected at five locations in Zurich, Switzerland. The results show that the methodology can predict the delay of different vehicle streams to within 4 s/veh, and also can identify the streams for which large delays would be expected.

Introduction

An uncontrolled intersection is one where neither traffic signs nor lights are used to guide the traffic through the intersection, but the drivers decide on the right of way. To do so, they typically follow clear rules, such as public transportation having priority over cars, or cars inside a roundabout having priority over cars outside the roundabout.

Many of this type of intersections, including ones with multiple modes and relatively large demands can be found in Europe. However, without a systematic and practical method to assess their operation it is hard to determine whether an uncontrolled intersection would be able to satisfy the traffic demands with an acceptable level of service. Therefore, it is important to develop an analytical tool for estimating capacities and the resulting vehicle delays in the presence of multimodal streams, which may be encountered at uncontrolled intersections.

Two general approaches for determining capacity at uncontrolled intersections exist. The first approach utilizes gap acceptance concepts to determine the capacity of a low priority stream. This implies that a distribution of headways among vehicles in the high priority stream is assumed, and drivers trying to cross it accept or reject these gaps according to certain criteria. Some of the initial research on utilizing gap acceptance concepts to determine capacity at intersections was carried out by Harders (1968). Later research has shown how to use multiple variations of these concepts to analyze different problems such as: uncontrolled intersections (Tanner, 1967; Highway Capacity Manual, 2010), limited priority merges where

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major stream cars either allow minor stream cars to enter, or the minor stream cars push their way in even if they don't have the right-of-way (Ma et al., 2013; Menendez et al., 2015; Troutbeck, 1999), and highway merges (Bunker and Troutbeck, 2003; Troutbeck and Kako, 1999; Menendez, 2006). However, these papers do not present a systematic methodology for investigating multimodal uncontrolled intersections.

The second approach uses conflict theory, which was first introduced by Gleue (1972) for signalized intersections. The goal is to establish a conflict matrix for each traffic stream and calculate the additive conflict flows (ACF). The conflict matrix establishes the different streams that are in conflict with each other and could affect each other's capacity. Then, the main idea is that depending on the conflicting streams two factors can lead to larger capacity for each traffic stream: (1) the probability that the road is not blocked, and (2) the probability that the gap on the main stream is large enough. The ACF approach has been used to model all-way-stop-controlled intersections (Li et al., 2009; Wu, 2000), two-way-stop-controlled intersections (Brilon and Wu, 2001; Li and Deng, 2008; Li et al., 2009) also with multiple-lane approaches (Li et al., 2011), uncontrolled intersections (Li et al., 2009), and roundabouts (Qu et al., 2014). Multiple modes along with cars, such as pedestrians and bicycles can also be included in the analysis of capacity with this method (Brilon and Miltner, 2005; Li et al., 2009). However, the conflict theory approach has a pre-defined set of possible conflicts that are considered, and does not systematically consider different traffic streams. This bounds the analysis to the intersection configurations presented in those papers.

The goal of this paper is to develop a systematic methodology for determining capacities available for multimodal streams at uncontrolled intersections, which can be used for delay estimation of the vehicle streams. The methodology presented in this paper is systematic and easy to adapt to the local conditions if necessary. It is also tested with real data from five locations in Zurich, Switzerland.

The rest of the paper is organized as follows. First, an overview of the background research which forms the foundations of this work is provided. Second, the methodology employed to systematically analyze the capacities and resulting delays at uncontrolled intersections with multiple modes is described in detail. Next, the methodology is empirically evaluated using data from five locations in Zurich. Finally, some concluding remarks are presented.

Background

This work uses the principles of ACF, but develops a systematic methodology to determine the equivalent of a conflict matrix at complex uncontrolled intersections with multiple modes, and then the resulting capacity of each traffic stream. The results are systematically obtained following two consecutive iterative algorithms. The advantage of the methodology developed in this paper is that it can be applied to many different intersections with different geometrical and operational properties, and due to its systematic nature is programmable. This work builds on the work of Pitzinger and Spacek (2009) which identified a methodology for assessing delays at uncontrolled intersections. The methodology presented in Pitzinger and Spacek (2009) relies on some subjective judgements, which creates additional complications in the calculations. This work expands on Pitzinger and Spacek (2009) by developing a simpler, more systematic and comprehensive approach. A clear methodology is developed that does not require any judgement and hence can be programmed to quickly analyze multimodal intersections.

The first step of this work was to empirically determine the saturation flows (S) of different modes, with a special focus on car traffic, and how the other modes affect car traffic. To do so, 43 h of video data were collected across 20 intersections throughout Switzerland to estimate standard values for the saturation flow of different transport modes (cars, buses, trams, and pedestrians) at uncontrolled intersections. Notice that these values are slightly lower than those that would be observed at controlled intersections, as drivers typically behave more carefully in the total absence of traffic signs or signals. The results were used as default values in the subsequent calculations, and are provided in Table 1.

In the case of cars, two values were observed, one when cars enjoy the highest priority, and one when they do not. The latter is smaller than the former, as in this case cars tend to be even more careful when crossing the intersection. In the case of pedestrians, S represents the flow of pedestrians needed to completely block car traffic. For the pedestrian calculations, S was found to depend on ρ, the average number of pedestrians crossing the intersection simultaneously. This parameter ρ can take on the values 1 through 5, and if the average number of pedestrians passing together is greater than 5, $\rho = 5$. For the case of trams and buses, S was observed based on the actual operating constraints of these vehicles (e.g., minimum headways required). More details can be found in Menendez et al. (2015).

Table 1
Saturation flow values of different modes.

Mode		Saturation flows (S)
Car	Highest priority	1750 veh/h
	Not highest priority	1650 veh/h
Pedestrian		900ρ ped/h where ρ is the average number of pedestrians crossing the intersection together $\rho = [1–5]$
Trams		340 trams/h
Bus		600 buses/h