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Fuzzy model of vehicle delay to determine the level of service of two-lane roads

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ABSTRACT

The level of service (LOS) on two-lane highways and, therefore, the quality of traffic flow, is currently estimated based on the delay of the vehicles and, in certain types of roads, the average travel speed. Speed is relatively easy to measure. However, it is important, and not so simple, to determine whether a vehicle is delayed. Traditional methods, generally based on quantitative measurements of average time between vehicles and thresholds, fail to take into account the inherent vagueness of the driving process. In this paper, we have developed a fuzzy model that gives a new and reliable method for determining such vehicle state on two-way two-lane roads, based on drivers' perceptions. The proposed system is composed of seven fuzzy subsystems that take into account imprecise knowledge, human factors, and subjective perceptions regarding the road, the car, the driver, environmental conditions, etc. Simulation results of the system have been successfully compared with the behavior of two-lane road drivers who were interviewed. The level of service of these facilities is obtained using the estimated vehicle delay state and the overtaking maneuver. Therefore, this proposal makes it possible to introduce these existing driving experiences into LOS assessment and accordingly, it is potentially a step forward since LOS must be related, by definition, to user experience. These results could be used in future frameworks. In addition, an extension of the possible states of a vehicle is defined. This approach takes into account the drivers point of view regarding overtaking desire and in this sense, it is closer to reality.

1. Introduction

Both traffic engineers and road users are concerned with the quality of traffic flow. The concept of level-of-service (LOS) is commonly accepted in traffic engineering as a way to assess the quality and flow characteristics on various facilities (Cohen & Polus, 2011). The level-of-service gives an idea of the comfort of drivers while driving and reflects the traffic flow and traffic congestion. But only a quantitative description of traffic quality is not enough. In fact, transportation has increased the need for reliable descriptions of traffic quality flow using measures and concepts that are easily understood by road users. After a century, this search is not over.

The level of service on two-lane roads and, therefore, the quality of traffic flow, is currently estimated based on the delay of the vehicles and, in certain types of roads, the average travel speed. Speed is relatively easy to measure (Corcoba & Muñoz, 2014). On the contrary, being vehicle delay a key factor to calculate the level of service on roads, its estimation depends largely on technical and non-technical parameters. Therefore, it is a very complex task because it is influenced by many different factors and most of them present uncertainties and inaccuracies.

Traditional methods use a few parameters (hardly two) to calculate the delay, and do not deal with uncertainty. Vehicle delay typically consists of two parts, uniform and non-uniform (Dion, Rakha, & Kang, 2003). Most studies focused on the uniform delay, estimated by signal timings and traffic volumes. They are based on historical data, use the statistical approach, and work on urban environments where there are traffic lights and other type of signals. However, the determination of non-uniform delay has been a problem for researchers, as it involves random and uncertain factors. Conventional approaches do not handle many variables and interactions that cannot be defined properly by mathematical models. Indeed, following headway, driver conditions, perception times, weather conditions, among others, are not being used in the existing delay formulas due to the imprecise nature of these variables, while it is obvious that vehicle delay can increase on rainy days or when sight distance is very low. These conditions are not considered in those estimations (Murat, 2006). Furthermore, these traditional approaches do not provide a method for estimating vehicle

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delay for two-lane roads or for multilane highways. They usually calculate the delay only for signalized intersections. Therefore, a model of the vehicle delay that takes into account not only quantitative but also qualitative factors and that can be applied to two-way roads is required.

In this paper, we have used approximate reasoning to develop a fuzzy model that gives a new and reliable method to estimate if a vehicle is delayed, based on imprecise variables. This knowledge based model aims at better understanding drivers' perception, including subjective factors. The motivation of using approximate reasoning is because one of the main features of human decision-making and response processes is their inherent approximate nature. Deterministic models of driver behavior fail to take into account the inherent vagueness of the driving process (Chakroborty & Kikuchi, 1999). Besides, we are interested in two-way two-lane roads (T-W T-L), with typically very few road signals.

The proposed fuzzy model is made up of several fuzzy subsystems. It is structured in three levels. In the first one, three fuzzy systems estimate the quality of the environment as perceived by the driver, the car performance, and the driver conditions. The outcomes of these systems allow the determination of the level of safety while driving and the estimation of the available gap in order to overtake. At the third level, two fuzzy systems estimate the driver willingness to overtake and if the driver perceives he can overtake. Finally, based on this information, the fuzzy system estimates if the individual car is delayed.

We have used this vehicle state to estimate the level of service of the two-lane roads. Furthermore, as the overtaking maneuver has been considered as the combination of these two subjective perceptions of the driver, the intelligent system provides guidance on whether to overtake, thus reducing delays and consequently, improving driving comfort and the level of service.

Additionally, this approach has led to an extension of the possible states of a delayed vehicle considering passing desire as a new factor.

Surveys were conducted to T-W T-L road drivers to test the system. Their answers were compared with those of the system itself, being the expected on more than 90% of the cases.

To summarize, the main contributions of this paper are the following. We have design a fuzzy model of the vehicle delay in two-lane roads completely different from how the delay is defined in most of the previous papers, including many of the subjective variables that are involved in the driving. As far as we know, the estimation of vehicle delay in two-lane two-way roads using fuzzy logic has not been proposed before and, therefore, the fuzzy perception of the level of service of these types of highways is novel. We have also proposed a new categorization of the delayed vehicles based on the subjective consideration of overtaking.

The rest of the paper is organized as follows. Section 2 summarizes how the vehicle delay is estimated by traditional methods, particularly in two-lane roads, and the literature regarding the application of fuzzy logic to traffic flow. Section 3 describes in detail the design and implementation of the fuzzy model of the vehicle delay, showing most of the fuzzy subsystems it includes. Section 4 presents the determination of the level of service of two-lane roads based on drivers' subjective perceptions such as the overtaking desire. In Section 5, simulation results are compared to real data obtained from surveys conducted to two-way road drivers, and an extension of the possible states of vehicles is proposed. The paper ends with the conclusions.

2. Background

The Transportation Research Board (1985), in the *Highway Capacity Manual* (HCM), first defined the level-of-service (LOS) as a mere reflection of the comfort of drivers and, later, in a more specific way including conditions such as speed, timings, safety, signaling, etc. The level-of-service depends largely on the type of road. In fact, it can be calculated as the ratio between traffic flow and road capacity. This may be true for high capacity roads, where the chance of overtaking at any time is supposed to be uniform for all drivers. However, this is not the case for two-lane roads, where some drivers may be delayed despite their desired speed because it is not always possible to overtake another vehicle. Therefore, vehicle delay must be included as a crucial factor to estimate the level of service of multilane roads.

In 2015, the first large research project funded by NCHRP (National Cooperative Highway Research Program) on operational considerations in two-lane roads, project 17-65, has gone under way. The results of the research presented here may be used by the project team in revising the existing framework for measuring LOS in these facilities.

2.1. Vehicle delay calculation by traditional methods

Delay calculations have not been prevalent in uninterrupted flow facilities for individual vehicles. The trend has been to measure delay comparing actual trip times with free flow travel times. This way, an aggregate delay can be measured, and is routinely reported as hours of congestion spent by users in a facility. Therefore, in order to consider the delay of a single vehicle in a facility, the best resource is to compare it with data from interrupted flow facilities.

In conventional models for estimating vehicle delay, only statistical data are usually taken into account, with little consideration of nontechnical factors, as the latter cannot be directly represented in analytical models. The Webster (1958), Highway Capacity Manual (Transportation Research Board, 1985) and its subsequent updates, or the Akcelik's (1981) delay calculation methods have been preferred by traffic engineers for many years. In these studies, the average delay of vehicles is calculated based on deceleration, stopping, acceleration times and queues, and they are mainly focused on signalized intersections or urban traffic flow.

The first and most general model for estimating the delay is given by:

$$d = d_u + d_o \tag{1}$$

In Eq. (1), the first term represents the average delay assuming uniform vehicles arrivals, that is, the uniform part. The second term represents the additional delay due to the randomness of vehicle arrivals and over-saturation queues. This non-uniform delay, also called the overflow term, is attributed to the probability of sudden surges arrivals and cycle failures. A third term can be considered, meaning a semi-empirical adjustment term that is introduced into the model to account for specific field conditions.

The Webster well-known delay formula to estimate the delay for isolated intersections is:

$$d = \frac{c(1-\lambda)^2}{2(1-\lambda x)} + \frac{x^2}{2q(1-x)} - 0.65\left(\frac{c}{q^2}\right)^{1/3} x^{2\,+\,5\lambda} \tag{2}$$

where:

- d = Average delay per vehicle on the particular approach of the intersection (seconds)
- c = Cycle length in seconds
- q = Flow
- λ = Proportion of the cycle which is effectively green for the phase under consideration, that is, the ratio of effective green to cycle time
- x = Degree of saturation (volume to capacity ratio)

The values of the parameters give particular forms to the delay expressions depending on the specific traffic situation (country, urban flow, etc.).