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A Stochastic Car Following Model

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Abstract
This paper describes a data-driven, stochastic car-following model. From a data-base of car-following episodes, the acceleration a of the following vehicle is modeled as drawn from a distribution that is sampled directly from the data. To make this work, the input variables speed v, speed difference Δv, net space headway g (gap), and acceleration A of the lead vehicle are discretized, and in each of the resulting bins a different acceleration distribution $F_{v,\Delta v,g,A}(a)$ is estimated. In most cases, the acceleration values are distributed according to a Laplace distribution. Missing data-bins are interpolated. This model is then tested; it is found, that the resulting distributions of safety surrogate measures reproduce the ones found in reality.

Keywords: Car following, stochastic model, modelling car accidents

1 The Concept

Most existing car following models are deterministic and do not consider the uncertainty and fluctuation of human perception and behavior (Helbing, 2001), (Nagel, et al., 2003), (Treiber, 2013). Therefore, safety-relevant aspects may differ from reality in simulations which could also be seen by the fact that car following models are designed to be accident free. This constraint reduces the usability of these models for traffic safety research significantly. Nevertheless, some investigations regarding traffic safety are still possible. For example, the model of Krauß (Krauß, 1998), (Krauß, et al., 1997) allows very strong braking deceleration in critical situations, which can be used for traffic safety related investigations.

Note also, that the overwhelming majority of car-following models are essentially one-dimensional, which restricts traffic safety analyses to rear-end-crashes. This is also the case for the considerations here. However, surrogate safety measures (SSM) like TTC (time-to-collision, Eq. (1)

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and DRAC (deceleration rate to avoid a crash, Eq. (2)) which are used here have a similar limitation. For reference, these two SSM are defined as:

$$T := TTC = \frac{g}{\Delta v} \qquad (1)$$

$$D := DRAC = \frac{(\Delta v)^2}{2g} \qquad (2)$$

where g is the net headway between the lead and the following vehicle, and $\Delta v = V - v$ is the speed difference with V the speed of the lead and v the speed of the following (subject) car.

Here, we follow the approach of (Yang, et al., 2010), in which a non-deterministic car following model was developed based on a huge data set. We developed a stochastic car following model that enables reasonably realistic simulations of the human driving behavior, in particular with respect to traffic safety relevant aspects. That means, for example, that the distributions of the SSM reflect the ones found in reality.

In this model, the acceleration a of a following vehicle will be determined. It is assumed that a depends on the velocity v of the following vehicle, the velocity difference Δv between the subject and the proceeding vehicle, the gap g between the two, and finally, on the acceleration A of the lead car. The acceleration a will be drawn from a probability distribution, whereby this distribution depends on $v, \Delta v, g$ and A. That means, for every tuple $(v, \Delta v, g, A)$ there exists a distribution function $F_{v,\Delta v,g,A}(x)$, and a will be drawn from it. These distribution functions will be determined by the mentioned data set of the naturalistic driving study (see Section 2). For that, the data for $v, \Delta v, g$ and A will be binned. For each bin, the expected value, the standard deviation as well as the distribution class of the acceleration a will be determined. However, this will be done only if the bin contains at least 100 data-points. If the bin has a smaller number of values, the expected value will be determined by an alternative car following model. For the standard deviation, a constant will be assigned and a Laplace distribution will be chosen for this bin. The parameters of the reference model will also be determined from the data-set under consideration.

The Laplace distribution is defined as:

$$L_{\mu,\sigma}(a) = \frac{1}{2\sigma}\, exp(-|a - \mu|/\sigma) \qquad (3)$$

where μ and σ are two parameters, its center and its width, respectively. For the data-set below, the type of the distribution has been found by testing in each of the bins the empirical distribution against a several distributions via a g-test and a χ^2-test. In 86% of the cases, a Laplace distribution was found to provide the best test-result.

2 The data set

For determining the distribution function described in Section 1, the data of the *Intelligent Cruise Control Field Operational Test* (Fancher, et al., 1998) was used. This field operational test was conducted between 1996 and 1997 in Michigan, USA. For that, 10 vehicles were equipped with various sensors and instruments to measure driving dynamic parameters as well as the distance to the preceding vehicle. The vehicles were given to 108 volunteers for two to five weeks, in which the data was constantly recorded. Although the purpose of the experiment was to investigate the comfort of adaptive cruise control (ACC), a sufficiently large amount of recorded trips without ACC was present. (Originally, they were used to compare the performance of the ACC against natural conditions.) More precisely, there are 8,690 trips of 102 drivers adding up to 1,821 driving hours and 88,000 kilometers, in which no ACC was used. 80% of the trips were used to create the model and 20% to verify it.

The following data was extracted from the trips:

- Running time: time since ignition switch was turned on