

---

## A model of car-following behavior at sags

Bernat Goñi Ros, Victor L. Knoop, Wouter J. Schakel, Bart van Arem, and Serge P. Hoogendoorn

Delft University of Technology, Department of Transport & Planning, Stevinweg 1, 2628CN Delft, The Netherlands.

{b.goniros,v.l.knoop,w.j.schakel,b.vanarem,s.p.hoogendoorn}@tudelft.nl

Sags are freeway sections along which the gradient changes significantly from downwards to upwards. Sags are often bottlenecks in freeway networks. The main cause is that the change in slope has a negative effect on vehicle acceleration, which influences longitudinal driving behavior at the beginning of the uphill section and reduces traffic flow capacity. Available car-following models are not capable of reproducing vehicle dynamics at sags in a sufficiently realistic way. This paper presents a car-following model that aims to fill that gap. In our model, acceleration ( $\dot{v}$ ) is determined by a two-term additive function. The first term is based on the *Intelligent Driver Model* and accounts for the influence of speed ( $v$ ) and spacing ( $s$ ). We added the second term to account for the influence of changes in gradient.

$$\dot{v}(t) = a \cdot \left[ 1 - \left( \frac{v(t)}{v_0(t)} \right)^4 - \left( \frac{s^*(t)}{s(t)} \right)^2 \right] - g \cdot [G(t) - G_c(t)] \quad (1)$$

In the second term,  $g$  is the gravitational acceleration,  $G(t)$  is the road gradient at time  $t$ , and  $G_c(t)$  is the compensated gradient at time  $t$ . The *compensated gradient* ( $G_c$ ) is a variable that accounts for the fact that drivers have a limited ability to compensate for the negative effect that an increase in gradient has on vehicle acceleration. Drivers are assumed to compensate for that negative effect linearly over time (the maximum gradient compensation rate is defined as a parameter).

The paper presents the results of a microscopic traffic simulation study using the proposed car-following model. The simulation output data are compared to empirical traffic data from a sag on the Tomei Expressway (Tokyo, Japan). Similar vehicle dynamics and traffic flow patterns are observed in the simulation output data and the empirical data. Particularly, the model is capable of reproducing the decrease in traffic flow capacity and the bottleneck location at the study site. The proposed car-following model could be used to evaluate the effectiveness of possible control measures aimed at reducing congestion at sags.