

The less-than-perfect driver: a new model of car-following behavior

Imagine a world where drivers don't make mistakes. Everyone pays perfect attention to the movements of cars around them, and no one takes unnecessary risks like following too closely behind another vehicle. There are no distractions like cellular phone calls, too-hot cups of coffee, or annoying songs on the radio. In this world, it goes almost without saying that the smooth flow of traffic is not disrupted by vehicle crashes.

This utopian world really exists—at least in research labs where computer simulations model the movements of virtual vehicles. As the computing power required to simulate hundreds or even thousands of vehicles has become available in personal computers, such simulations have emerged as invaluable tools for understanding the effects of new traffic control systems and management technologies.

But like all utopias, these neat and tidy models are not as perfect as they appear. For researchers like civil engineering professor **Panos Michalopoulos** and traffic researcher **John Hourdos**, who are trying to understand how and why vehicle crashes happen and how crashes affect traffic, the behavior of virtual vehicles is frustratingly limited. Joined by civil engineering professor **Gary Davis** and graduate student **Wuping Xin**, the researchers set out to develop a more accurate and complete model of car-following behavior.

Understanding the causes and dynamics of vehicle crashes is a goal shared by many ITS researchers at the University of Minnesota, and the search for answers has spurred the development of new tools and techniques. In the case of the Minnesota researchers, the need for more realistic simulations led them to propose a novel model of car-following behavior—one that will give researchers a new insight into the quick and deadly world of traffic collisions.

Reflecting reality

The first attempts to mathematically describe the behavior of vehicles under simple traffic conditions were made in the 1950s, by scientists and engineers seeking to understand how disturbances in traffic flow propagate down a line of moving vehicles. Based on systems of linear differential equations, these models were strictly deterministic. Later, recognizing that chance and uncertainty play an undeniable role in traffic flow, models incorporated a limited stochastic element by adding a random noise term

to their equations. In addition, advanced models of vehicle movement began to incorporate reaction time delays to better mimic driver behavior.

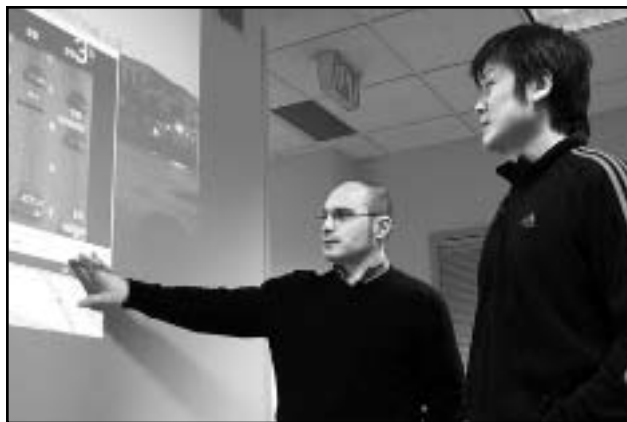
A significant advance occurred with the development of psycho-physical models that more accurately reflect the decision-making processes of drivers. Whereas in earlier models every vehicle adjusted its speed constantly based on distance to the vehicle ahead, vehicles in a psycho-physical model change their acceleration only when they reach an "action point"—for example, when distance to a vehicle ahead drops below a specified distance. Today, this principle is incorporated into the car-following models in several widely used commercial simulation systems.

Despite these advances and the success of current car-following models at reproducing many observed features of traffic flow, existing approaches fail to capture the intricacies of individual driver behavior. Even the best drivers are subject not only to reaction time delays but to distraction and errors in

judgment—factors that are too complex to be modeled as random noise.

Many researchers have used car-following models to understand the genesis of dangerous traffic conditions, by looking for evidence of instability within the systems of equations that govern car-following models. Points of instability, where the models "break down" and the virtual vehicles begin to collide, are

(continued)



John Hourdos and Wuping Xin.

Seminar addresses privacy, scalability of location-based systems

Privacy and scalability are key challenges facing the emerging field of location-based information services, said Mohamed Mokbel at an ITS Institute Advanced Transportation Technologies Seminar October 24.

Driven by improvements in consumer GPS and wireless communications, location-based information services have the potential to penetrate nearly every aspect of daily life. Mokbel, an assistant professor in the University of Minnesota's computer science and engineering department, is currently developing technologies to provide high-quality location-specific information while respecting privacy.

Interest in services that provide information based on a user's location is growing rapidly

among consumers and information providers, he said, but the technology cannot reach its full potential unless users' anonymity is protected. Mokbel outlined the development of "location anonymizer" software that protects privacy by obscuring users' precise locations while allowing them to electronically access information about the area around them.



Mohamed Mokbel

As more location-based services become available, Mokbel said, the ability of database systems to keep up with huge demands for spatial information will become a limiting factor. The second half of the seminar covered advanced server architectures designed to remove the bottlenecks that slow down current spatial information systems.

Less-than-perfect driver (continued)

indicators of accident-prone traffic conditions. One example is the formation of high-density “traffic waves” in which gaps between vehicles become too short for drivers to avoid rear-end collisions. This phenomenon, frequently observed in the real world and successfully reproduced using conventional car-following models, can arise naturally from the dynamic interaction between vehicles as traffic density increases.

However, data from real-world car-following experiments also point to another instability mechanism related to driver performance. Factors such as visual perception and decision errors appear to exert a significant influence on the car-following behavior of individual vehicles. This instability is not accounted for by conventional models, even those incorporating random noise terms into their linear equations. If traffic simulation is to provide a clear picture of crash mechanisms, car-following models must take both sources of instability into account.

Model behavior

Wuping Xin has spent a lot of time thinking about instability. Under the direction of Micholopoulos and Hourdos, Xin took on the challenge of implementing the research team’s conceptual model of driver behavior and vehicle response in the form of computer software that can be interfaced with traffic simulation systems. The model Xin developed is based on a highly flexible conceptual framework that improves its ability to simulate complex interactions between driver perception and response.

The framework divides the driving task into two major components—the external world and the driver-vehicle unit (DVU). Rather than conceiving of the driver and vehicle as a single entity, the DVU comprises three subsystems that work together to govern the movement of the virtual vehicle. A DVU acquires information about the external world through sampling, and compares this information to a target specification or reference input.

- The information acquisition stage comprises sampling of conditions in the external world. Information acquisition governs driver perception and thereby affects reaction time.

- During the decision-making stage, information about the external world is processed in order to determine what control inputs to the vehicle are required.
- Finally, vehicle control includes the implementation of control decisions such as whether to accelerate or decelerate. The output of this stage is fed back into the simulation as changes in vehicle position, affecting the traffic situation.

In the present model, each DVU is characterized by its own perceptual thresholds, resulting in an individual perception-response time dependent on traffic situations. Each DVU also seeks to maintain a desired following gap time subject to safety constraints. While the current model is not a complete implementation of their conceptual framework, it is designed so that additional factors can be added to it as detailed data on driver behavior becomes available from experimental research. The new car-following model offers a more realistic simulation of the driver’s perception-response process, because the response behavior of each driver-vehicle unit conditions varies according to external conditions. This differs from previous models, in which the perception-response process is defined independently of local conditions or prescribed within limited parameters.

In many car-following models, vehicles change their acceleration primarily in response to changes in the amount of headway separating them from other virtual vehicles; this headway is “perceived” with certainty through the direct evaluation of relative velocities. Driver-vehicle units in the new model, in contrast, rely on perceptual cues to determine when they are approaching too closely to a vehicle ahead. These perceptual cues take two forms, analogous to the visual cues used by drivers in the real world, and are governed by perceptual thresholds modeled on the limits of human perception. While the perceptual thresholds are constant for each DVU, different constant values may be assigned to different DVUs.

- The first visual cue is the rate of expansion of the apparent size of a vehicle ahead. In order to perceive relative motion, the change in apparent visual size of a leading vehicle must exceed a specified threshold rate.

- When the visual expansion rate is too low to be useful, the DVU evaluates the change in headway distance, again subject to limits modeled on human perception. Using these perceptual cues, each DVU attempts to maintain a desired following distance to the vehicle ahead. In a typical simulation scenario that mimics real-world observations, a DVU hovering near its desired following distance is unable to directly perceive relative motion through visual expansion rate or change of distance—the DVU enters a kind of “blind zone” and continues to accelerate or brake until the perceptual threshold of a visual cue is exceeded. This behavior implements the “action point” concept grounded in human perception and subject to realistic variation between drivers.

A crucial feature of the model is that acceleration and braking decisions are based on the amount of reaction time each DVU “believes” it has based on analysis of perceptual cues—this may differ from the DVU’s actual minimum perception-response time, which varies depending on traffic conditions. However, acceleration or braking maneuvers are carried out in accordance with the DVU’s actual perception-response time. This feature of the model allows it to emulate common decision errors.

While the development of the new car-following model was motivated by the research needs of Michalopoulos and Hourdos, future researchers may benefit as well. Implementing the model in such a way that it can interface with standard simulation packages used by traffic researchers makes it a powerful general tool for examining collisions.

Development of the model is ongoing, as the research team plans to improve its accuracy by adding new features such as the ability of a DVU to consider the movements of multiple DVUs ahead of it, if they are visible. This addition would bring DVU decision-making behavior more in line with that of human drivers, who frequently respond to braking or acceleration by cars further ahead in the lane.