CHAPTER 18

Picoscopic Modeling

Suppose one is observing traffic 10,000 m above the ground, and the traffic behaves as a compressible fluid whose states (speed, flow, density, etc.) propagate back and forth like waves. This is a scenario of *macroscopic* modeling. If one goes to 3000 m above the ground, the sense of waves recedes and a scene of particles emerges. A vehicle behaves as a particle hopping from one cell to another governed by predetermined logic. This is a scenario of *mesoscopic* modeling. If one goes even lower to 1000 m above the ground, the scene is dominated by moving particles which interact with each other so as to maintain safe positions in the traffic stream. This is a scenario of *microscopic* modeling as well as the state of the art.

What is the next level of traffic flow modeling? Continuing with the above analogy, the next level should provide a perspective as if one were on the ground and driving in one of the vehicles in the traffic. What one sees now is neither a wave nor a particle, but a detailed picture incorporating drivers, vehicles, and the environment (e.g., roadway, signs, signals) (see Figure 18.1). Drivers collect information and make control decisions in terms of steering, acceleration, and deceleration. Vehicles dynamically respond to their drivers by executing their control decisions and moving on the ground accordingly. Feedback from vehicle dynamics, together with information from the environment, constitutes the basis for drivers to make control decisions in the next step. Traffic operation is simply the movement and interaction of all vehicles in the system over time and space. This is a scenario of *picoscopic* modeling.

18.1 DRIVER, VEHICLE, AND ENVIRONMENT

Traffic flow modeling at the picoscopic level should not only represent drivers, vehicles, and the environment in different models, but should also capture the interaction among these components. Therefore, a natural approach is to address the modeling problem as a driver-vehicle-environment closed-loop system [70, 71] as illustrated in Figure 18.2.

In a transportation system, drivers are active components which make decisions, while vehicles are passive components which execute decisions.

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Figure 18.1 A picoscopic view of a transportation system.

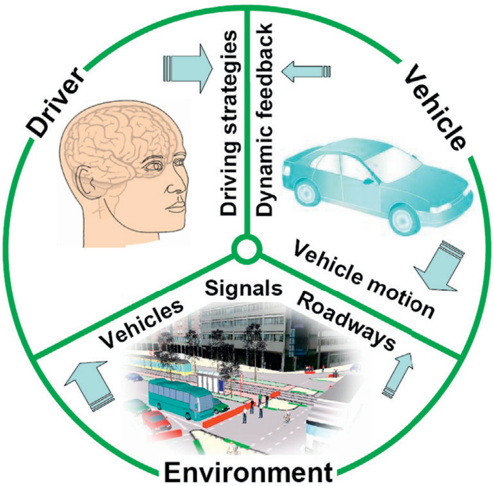

Figure 18.2 A driver-vehicle-environment closed-loop system.

The interaction between a driver and his/her vehicle constitutes a basic unit in a traffic stream. Therefore, a natural way to mimic the real-world system is to model drivers and vehicles separately but with interaction between them. Drivers are motivated by goals, act autonomously, and reason on the basis of their knowledge. Figure 18.3 presents the structure of such a driver modeling approach.

This approach involves three components: inputs, driver, and outputs. Inputs to the model are environment information and vehicle feedback. The environment loosely refers to the entire system, including drivers, vehicles, pedestrians, roadway infrastructure, traffic control devices, roadside, abutting lands, nearby business, etc. Vehicle feedback includes part of vehicle dynamic responses, such as vehicle speed, acceleration, and yaw

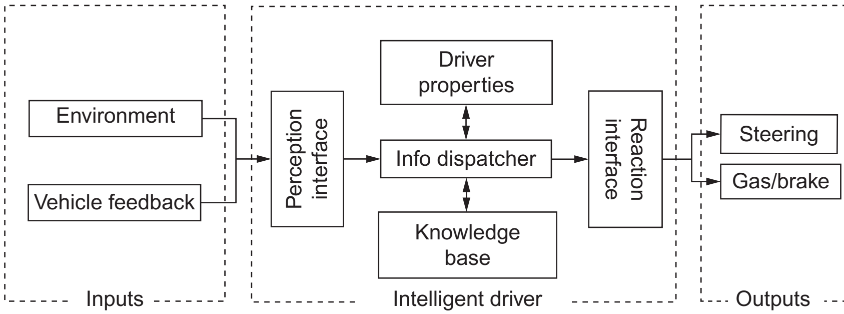

Figure 18.3 Picoscopic modeling: driver modeling.

velocity, perceived by the driver and affecting his/her driving decision. As an intelligent agent, a driver is able to (a) respond in a timely fashion to changes in the environment, (b) exercise control over his/her own actions, (c) pursue a goal which motivates his/her actions, (d) communicate with other agents, and (e) change his/her behavior on the basis of previous experience. With these considerations, the driver model consists of the following components: a perception interface which collects and transforms information before it enters the driver, a reaction interface which converts driver decisions to actionable instructions before they are executed by the vehicle, driver properties including driver's goals and characteristics, a knowledge base including experiences and decision rules that govern driving behavior, and an information dispatcher, which is the central processing unit of the driver. Outputs of the driver model are driving decisions, including steering, accelerating, and braking.

In Chapter 21, a field theory will be introduced that can serve as the basis for the intelligent driver. In this theory, highways and vehicles are perceived as a field by a subject driver whose driving strategy is to navigate through the field along its valley.

The approach to vehicle modeling needs to incorporate vehicle dynamics so that vehicle dynamic responses and lateral movement can be captured. Figure 18.4 illustrates such an approach which includes inputs, dynamic vehicle, and outputs. Inputs to the vehicle come from two sources: inputs from the driver, including steering, throttle position, and brake position, and inputs from environment such as roadway surfaces, lanes, curves, and resistances. The vehicle model consists of vehicle-specific information (i.e., vehicle properties such as mass, dimension, and engine power) and vehicle-generic information, including a set of dynamic equations describing the

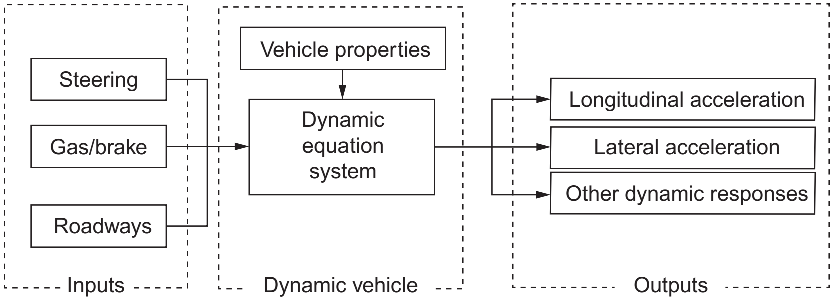

Figure 18.4 Picoscopic modeling: vehicle modeling.

dynamic performance of a class of vehicles, such as acceleration/deceleration and steering performance. Outputs of the dynamic vehicle are vehicle dynamic responses, of which longitudinal acceleration, lateral acceleration, and yaw velocity are of particular interest.

In Chapter 19, a simple engine model will be formulated with reasonable accuracy and excellent computational efficiency to facilitate vehicle modeling. In Chapter 20, a simple dynamic interactive vehicle model will be formulated that requires minimal calibration effort and computational resources.

Combining the above driver and vehicle models results in a driver-vehicle unit which constitutes a basic building block of roadway traffic. Such units as well as roadways, traffic control devices, and other transportation system components constitute a general environment in which a driver-vehicle unit operates. The interactions among drivers, vehicles, and the environment are summarized in the picoscopic transportation modeling architecture shown in Figure 18.5.

In this architecture, the driver receives information from the environment such as roadways, traffic control devices, and the presence of other vehicles. The driver also receives information from his/her own vehicle such as speed, acceleration, and yaw velocity. These sources of information, together with driver properties (such as characteristics and goals), are used to determine driving strategies (such as steering and accelerating/braking). The driving strategies are fed forward to the vehicle, which also receives roadway information from the environment. These sources of information, together with vehicle properties, determine the vehicle's dynamic responses on the basis of vehicle dynamic equations. Moving longitudinally and laterally, the vehicle constitutes part of the environment. Some of vehicle dynamic responses such as speed, acceleration, and yaw velocity are fed back

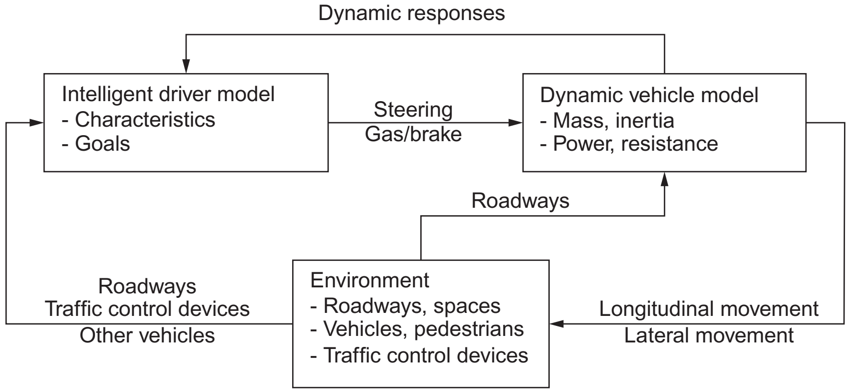

Figure 18.5 Picoscopic modeling: modeling architecture.

to the driver to determine driving strategies in the next step. Therefore, the architecture creates an environment, in which each vehicle is an autonomous agent which is driven by goals and is able to achieve the goals by moving through the environment. Thus, traffic operation is simply the motion and interaction of all vehicles in the environment.

18.2 APPLICATIONS OF PICOSCOPIC MODELING

Transportation modeling and simulation is characterized by two competing dimensions: scale (i.e., geographical scope covered in the modeling) and level of detail (i.e., resolution provided by the model). Because of the processing power of today's computers, a macroscopic model can achieve a very large modeling scale, such as the Commonwealth of Massachusetts, with relatively low resolution. A mesoscopic model strikes a balance between the two; a microscopic model is able to provide fine modeling resolution within a limited geographical area, such as the city of Boston. Following this trend, a picoscopic model would furnish ultrahigh modeling resolution but within a very limited geographical area, such as the roads surrounding Public Garden in Boston. With such a fine level of detail, picoscopic modeling can help address many transportation-related problems, among which the following are a few examples.

18.2.1 Interactive Highway Safety Design

Picoscopic transportation modeling can be used to assist highway design. For example, a highway design can be tested by different "drivers" and "vehicles" in a computer to check if the highway provides sufficient sight distance to avoid accidents or a curve is properly superelevated to allow safe turning. Such an interactive highway safety design not only ensures design quality but also saves time and resources to achieve the design goal.

18.2.2 Connected Vehicle Technology

Future vehicles will be equipped with dedicated short-range communications, along with sensing, positioning, and computing devices. As such, vehicles will be able to communicate with other vehicles as well as the roadside. Such a connected vehicle technology will transform future highways and streets into an environment that encompasses ubiquitous computing and communication (see Figure 18.6). Consequently, innovative applications can be deployed to dramatically increase safety, throughput, and energy efficiency. However, such systems elude mathematical analysis and conventional simulation because of the complexity and interdependency involved. Picoscopic modeling might be able to address these systems because it not only captures sufficient modeling details but also allows the incorporation of the effects of connected vehicle technology into modeling.

18.2.3 Transportation Forensics

Investigation of a traffic accident frequently requires the ability to decipher what happens shortly before, during, and after the accident. This involves reconstruction of the accident during which the driver perceives

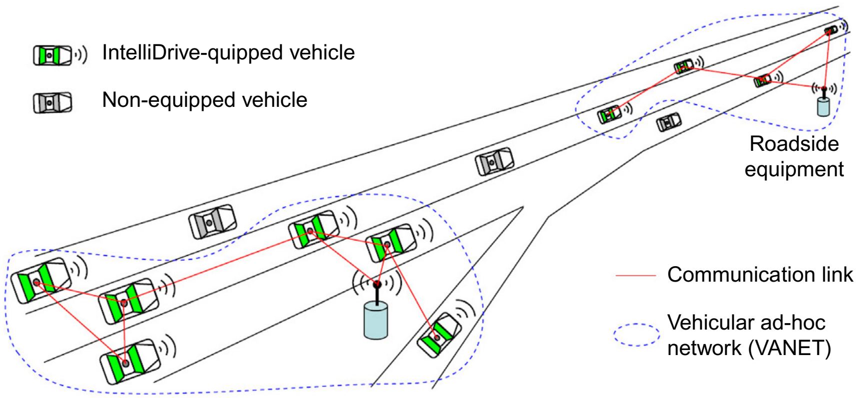

Figure 18.6 An illustration of connected vehicle technology.

an immediate hazard, makes a decision, and executes control, while the vehicle's dynamically responds to control instructions, moves on the ground, collides with another vehicle, and is redirected, potentially causing a second crash. Modeling at such a level of detail necessitates a picoscopic approach.

18.2.4 Emergency Management

In analyzing transportation systems under extreme conditions, one must have both the capability of overseeing the full picture (e.g., a regional transportation network) and the capability of zooming in for local details (e.g., a corridor or an intersection). Anyone who is familiar with Google Maps or Google Earth develops a sense of the importance of having global information yet being able to zoom in and view local details. The transportation modeling and simulation tools developed so far have offered only a single-level resolution. As such, they are suited for either solving large-scale transportation problems with coarse resolution or solving small-scale problems with fine details. Though these tools can provide a partial solution, efforts are needed to integrate them to provide an integral analysis with both scale and detail because emergency management involves addressing multiple aspects of the emergency.

Transportation modeling at the picoscopic level is essential to help achieve very fine modeling detail and address problems that are beyond the capabilities of conventional modeling tools. For example, conventional tools are developed for use under peaceful settings, and thus they are not suited for coping with unusual traffic operations. Under extreme conditions, drivers are under great pressure, and their driving behavior changes drastically from their usual ways. As a result, safety as a primary goal may give way to the need of getting out of the endangered site as quickly as possible. Traffic rules may not be observed, and consequently, unusual operations such as running a red light, violating priority rules, and off-road operations are possible. Existing modeling and simulation tools are based on the assumption of driving in a safe world, so they have difficulty to replicate situations under extreme conditions. Moreover, panic behavior is likely to result in more frequent accidents and crashes than usual. However, existing modeling and simulation tools are designed to guarantee "accident-free" situations, which prevents these tools from modeling and simulating transportation systems under extreme conditions.

PROBLEMS

1. Where do car-following models fit in the driver-vehicle-environment closed-loop system framework?
2. Comment on the potential benefits of picoscopic traffic flow modeling.
3. Comment on the potential costs of picoscopic traffic flow modeling.
4. Comment on the appropriate applications of picoscopic traffic flow modeling.