CHAPTER 12

Microscopic Modeling

The models presented in Chapters 4-11 emphasize collective and average behavior of vehicles (e.g., flow, speed, and density), and consider traffic flow as a compressible fluid. Central to these models are the relationships among flow, speed, and density as well as how they vary dynamically over time and space. Such models are termed *macroscopic*, and they are capable of capturing the amount of "fluid" (i.e., number of vehicles) flowing into and out of roadway segments over time, rather than tracking each and every vehicle as it moves along the roadway.

In contrast, *microscopic* models emphasize the behavior of individual vehicles, and are capable of capturing the motion of and interaction among these vehicles. Unlike macroscopic models, which treat vehicles as a fluid, microscopic models represent a driver-vehicle unit as a particle without mass. Such a particle is sometimes referred to as an "active" particle since it is capable of making decisions based on rules stipulated in microscopic models.

12.1 MODELING SCOPE AND TIME FRAME

Depending on the geographical scope and time frame involved, driving decisions can be categorized at three levels—namely, strategic, tactical, and operational. Driving decisions at the *strategic* level involve a large geographical scope and a long time frame. For example, Figure 12.1 illustrates the decision-making scenario faced by a driver who is about to travel from the University of Massachusetts Amherst (point C) to Boston (point D). The driver has at least three options:

1. Interstate 90 (Massachusetts Turnpike). The bottom route, which is the fastest route if there is no congestion, and the toll is about $5.
2. Route 2. The top route, which is a scenic, rural highway that is rarely congested.
3. Route 9. The middle route, which is the shortest route, but it goes through many town centers and traffic signals.

This scenario constitutes a **route-choice** decision that involves a geographical scope of about 100 km and a time frame of a few hours. A

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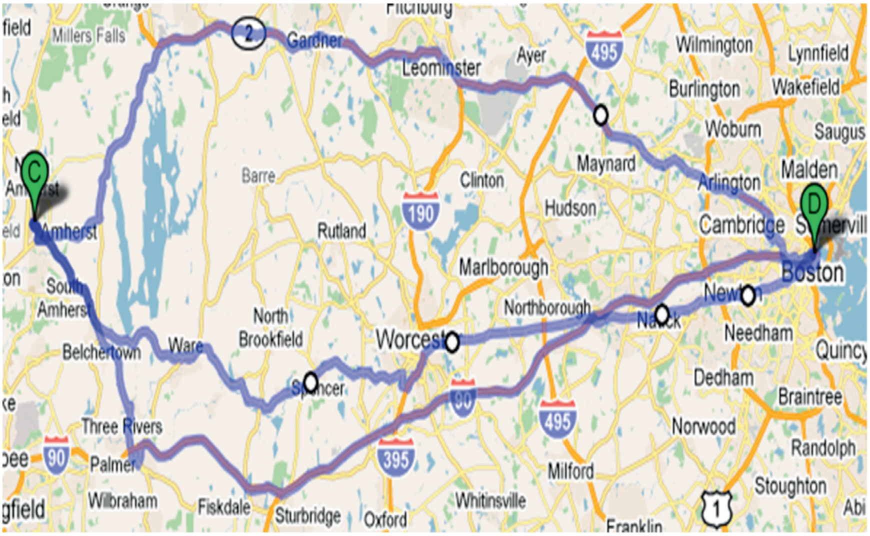

Figure 12.1 Making a decision at the strategic level.

microscopic model that describes how drivers make a route choice decision is called a route-choice model. Such a model is typically a discrete choice model which chooses one of a set of options based on some utilities and constraints.

After the driver has chosen a route (e.g., Massachusetts Turnpike) and is traveling down the road, a *tactical* decision will have to be made sooner or later that involves a medium geographical scope and a medium time frame. For example, Figure 12.2 illustrates that the driver needs to decide when and where to change to the side lane in preparation for using the upcoming exit. Such a case constitutes a **lane-changing** decision with a geographical scope of a few kilometers and a time frame of a few minutes. Again, a lane-changing model is typically a discrete choice model that determines the choice of a target lane from available options based on the driver's objective and constraints.

An *operational* decision involves the driver's operational control of the vehicle in order to ensure safety and maintain mobility within a small geographical scope and a short time frame. For example, Figure 12.3 illustrates that the driver (in the circled vehicle) is following another vehicle in a context of a geographical scope of tens of meters and a time frame of a few seconds. The driver needs to make a **car-following** decision on how

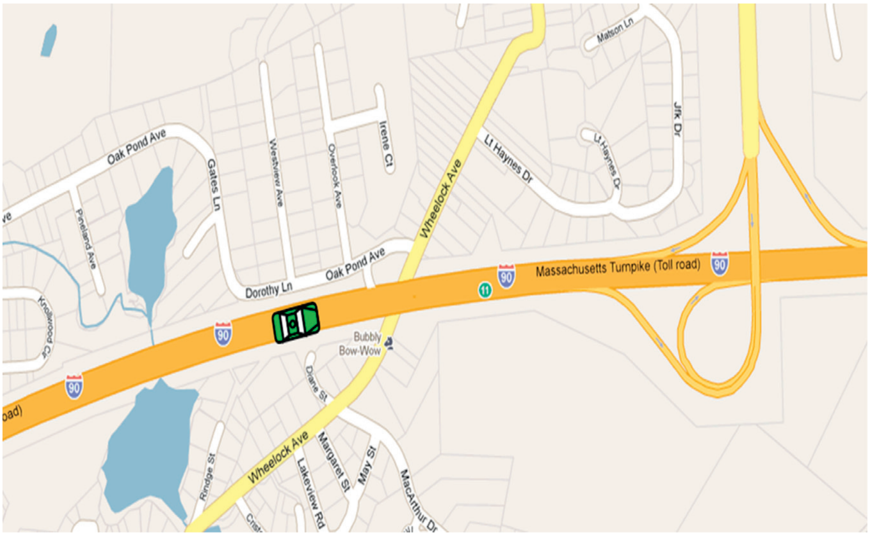

Figure 12.2 Making a decision at the tactical level.

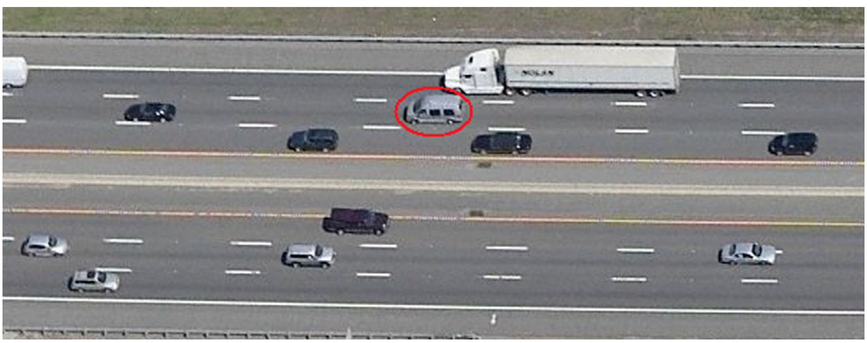

Figure 12.3 Making a decision at the operational level.

to operate his or her vehicle (e.g., determine speed and acceleration in the next second) so as to avoid colliding with the leading vehicle. Meanwhile, if the driver feels stressed following the slow leading vehicle, the driver may want to change to another lane to improve his or her mobility. As such, the driver makes a **gap-acceptance** decision by looking for gaps in the adjacent lane and switching to that lane when an acceptable gap becomes available.

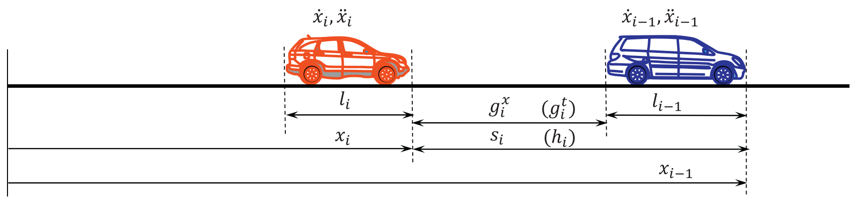

Figure 12.4 A car-following scenario.

Therefore, on the basis of the geographical scope and time frame involved, microscopic models can fall into one of the following three broad categories:

1. at the strategic level: route-choice models;
2. at the tactical level: lane-changing models;
3. at the operational level: car-following and gap-acceptance models.

12.2 NOTATION

The chapters that follow will emphasize car-following models. More specifically, drivers' operational control when following another vehicle on a single-lane highway will be considered where no passing is allowed. Before the formal discussion of car-following models, it is helpful to summarize the notation to be used. Figure 12.4 illustrates two vehicles traveling on a one-lane highway. These vehicles $(1, 2, \ldots, i-1, i, i+1, \ldots, I)$ are numbered cumulatively with lower-numbered vehicles in front—for example, vehicle 1 leads vehicle 2. The locations or displacements of vehicles are measured from a common but arbitrary reference point.

i	vehicle ID, $i = 1, 2, \ldots, I$.
$x_i(t)$	the location of vehicle i at time t.
$\dot{x}_i(t)$	the speed of vehicle i at time t.
v_i	desirable speed that driver i is willing to travel at whenever possible.
$\ddot{x}_i(t)$	the acceleration of vehicle i at time t.
A_i	the maximum acceleration that vehicle i is able to apply. $A_i > 0$.
B_i	the maximum deceleration that vehicle i is able to apply. $B_i < 0$.
l_i	the length of vehicle i.
τ_i	the perception-reaction time of driver i.
$s_i(t)$	the spacing between vehicle i and the leading vehicle $i-1$ at time t.
$g_i^x(t)$	the distance between vehicle i and the vehicle in front of it at time t.
$h_i(t)$	the headway between vehicle i and the vehicle in front of it at time t.
$g_i^t(t)$	the time gap between vehicle i and the vehicle in front of it at time t.

12.3 BENCHMARKING SCENARIOS

The upcoming chapters will introduce some microscopic car-following models. These models were formulated with a variety of modeling philosophies and appeared in different forms. It would be very interesting and informative if these models could be cross-compared on the basis of a common ground. Such a process is called benchmarking, two scenarios of which are set up here, one being microscopic and the other macroscopic.

12.3.1 Microscopic Benchmarking

Microscopic benchmarking employs a concrete example consisting of a set of hypothetical driving regimes. The purpose of microscopic benchmarking is to illustrate the performance of these car-following models in different regimes so that their operational control under various conditions can be examined.

The example involves two vehicles: a leading vehicle $i-1$ and a following vehicle i. The motion of the leader is predetermined and that of the follower is governed by the car-following model under study. Initially ($t = 0$), vehicle $i - 1$ stands still at 5000 m from the reference point ($x_{i-1}(0) = 5000$ m, $\dot{x}_{i-1}(0) = 0$ m/s, and $\ddot{x}_{i-1}(0) = 0$ m/s^2). Vehicle i, which is also still ($\dot{x}_i(0) = 0$ m/s and $\ddot{x}_i(0) = 0$ m/s^2), stands somewhere near the reference point, with the exact location to be determined case by case in different car-following models. When the scenario starts ($t > 0$), vehicle $i - 1$ remains still, while vehicle i starts to move. Since vehicle $i - 1$ is far ahead, vehicle i is entitled to accelerate freely to satisfy its driver's desire for mobility. At time $t = 100$ s, vehicle i is at somewhere about $x_i(100) \approx 2770$ m. At this moment, a third vehicle previously moving in the adjacent lane at 24 m/s changes to the subject lane at location 2810 m and takes over as the new leading vehicle, assuming ID $i - 1$—that is, $x_{i-1}(100) = 2810$ m, $\dot{x}_{i-1}(100) = 24$ m/s, and $\ddot{x}_{i-1}(100) = 0$ m/s^2. This change is designed to mimic the effect that a vehicle cuts in in front of another vehicle with a spacing of about 40 m. Meanwhile, the previous, stationary leading vehicle is removed from the road. The new leading vehicle keeps moving at that speed up to $t = 200$ s, and then undergoes deceleration at a rate of $\ddot{x}_{i-1} = -3$ m/s^2 until it comes to a complete stop. After that, vehicle $i - 1$ remains stopped up to $t = 300$ s. Then, it begins to accelerate at a constant rate of $\ddot{x}_{i-1} = 2$ m/s^2, and eventually settles at its full speed of $\dot{x}_{i-1} = 36$ m/s. At time $t = 400$ s, the vehicle starts to decelerate again at a constant rate of $\ddot{x}_{i-1} = -3\,\text{m/s}^2$ until it comes to another full stop, and remains there. During all the time, the motion of the follower i is completely stipulated by the car-following model. The above scenario is formulated as follows.

$$\begin{cases} x_{i-1} = 5000\,\text{m}, \dot{x}_{i-1} = 0\,\text{m/s}, \ddot{x}_{i-1} = 0\,\text{m/s}^2 & \text{when } 0\,\text{s} \le t < 100\,\text{s}, \\ x_{i-1} = 2810\,\text{m}, \dot{x}_{i-1} = 24\,\text{m/s} & \text{when } t = 100\,\text{s}, \\ \ddot{x}_{i-1} = 0\,\text{m/s}^2 & \text{when } 100\,\text{s} \le t < 200\ \text{s}, \\ \ddot{x}_{i-1} = -3\,\text{m/s}^2 & \text{when } 200\,\text{s} \le t < 208\ \text{s}, \\ \ddot{x}_{i-1} = 0\,\text{m/s}^2 & \text{when } 208\,\text{s} \le t < 300\,\text{s}, \\ \ddot{x}_{i-1} = 2\,\text{m/s}^2 & \text{when } 300\,\text{s} \le t < 318\,\text{s}, \\ \ddot{x}_{i-1} = 0\,\text{m/s}^2 & \text{when } 318\,\text{s} \le t < 400\,\text{s}, \\ \ddot{x}_{i-1} = -3\,\text{m/s}^2 & \text{when } 400\,\text{s} \le t < 412\,\text{s}, \\ \ddot{x}_{i-1} = 0\,\text{m/s}^2 & \text{when } t \ge 412\,\text{s}. \end{cases}$$

The driving regimes involved in the above process include the following:

- Start-up: Vehicle i starts to move from standstill, when the process begins ($t > 0$ s).
- Speedup: After start-up, vehicle i continues to accelerate to higher speeds ($0\,\text{s} < t < 100$ s).
- Free flow: As vehicle i speeds up, it settles at its desired speed if it is unimpeded ($0\,\text{s} < t < 100$ s).
- Cutoff: A sudden decrease in spacing owing to the new leader $i - 1$ cutting in ($t = 100$ s).
- Following: Vehicle i has to adopt vehicle $i - 1$'s speed so as to avoid a collision ($100\,\text{s} < t < 200$ s).
- Stop and go: Vehicle i is forced to stop and go owing to vehicle $i - 1$'s brief stopping ($200\,\text{s} \ge t \le 300$ s).
- Trailing: Vehicle i is following a speeding leader ($300\,\text{s} < t < 400$ s).
- Approaching: Vehicle i is getting close to a slower or stationary leader ($400\,\text{s} \ge t < 420$ s). item Stopping: Vehicle i tries to stop behind a stationary object separated by a minimum spacing ($t \ge 420$ s).

This scenario involves a series of tests in a single driving process. Rather than seeking "the best" model, our focus here is to analyze whether a model makes physical sense by facing these tests. Therefore, the reality check includes the following items:

- Start-up: Whether the model itself is sufficient to start the vehicle up without involving any additional, external logic.

- Speedup: Whether the model generates speed and acceleration profiles that make physical sense.
- Free flow: Whether the model settles at its desired speed without overshooting or undershooting.
- Cutoff: Whether the model loses control or, if not, responds with a reasonable control maneuver.
- Following: Whether the model is able to adopt the leader's speed and follow the leader at a reasonable distance.
- Stop and go: Whether the model is able to stop the vehicle safely behind its leader and start moving again when the leader resumes motion.
- Trailing: Whether the model is able to speed up normally without being tempted to speed up by its speeding leader—that is, a vehicle is attracted to excessively high speeds by its speeding leader.
- Approaching: Whether the model is able to adjust the vehicle properly when the intervehicle spacing closes up.
- Stopping: Whether the model is able to stop the vehicle properly behind a stationary object separated by a minimum spacing, without overshooting or undershooting, and causing speed and acceleration to return to zero naturally when stopped, etc.

Note that the starting position of the follower i is determined by trial and error such that the vehicle moves to $x_i \approx 2770\,\text{m}$ at $t = 100\,\text{s}$, at which point the vehicle should have reached its desired speed $v_i = 30\,\text{m/s}$. The sudden appearance of the new leader $i-1$ at $x_{i-1} = 2810\,\text{m}$ leaves a spacing of about 40 m between the two vehicles, which is a little more than the distance traversed during one perception-reaction time. Drivers would normally back up a little in this situation and then identify a comfortable spacing to start car following.

12.3.2 Macroscopic Benchmarking

Macroscopic benchmarking employs a set of empirical data obtained from Georgia 400, a toll road with freeway by design located in Atlanta, Georgia, USA. The data contain 1-years' worth of field observations at one station across four lanes. The fundamental diagram (i.e., mathematical and/or graphical presentation that illustrates the collective behavior of traffic flow) observed at this station is depicted in Figure 12.5. This figure contains a set of four plots that illustrate speed-density, speed-flow, flow-density, and speed-spacing relationships. The "cloud" contains field observations of flow, speed, and density aggregated to 5 min intervals. To highlight the average

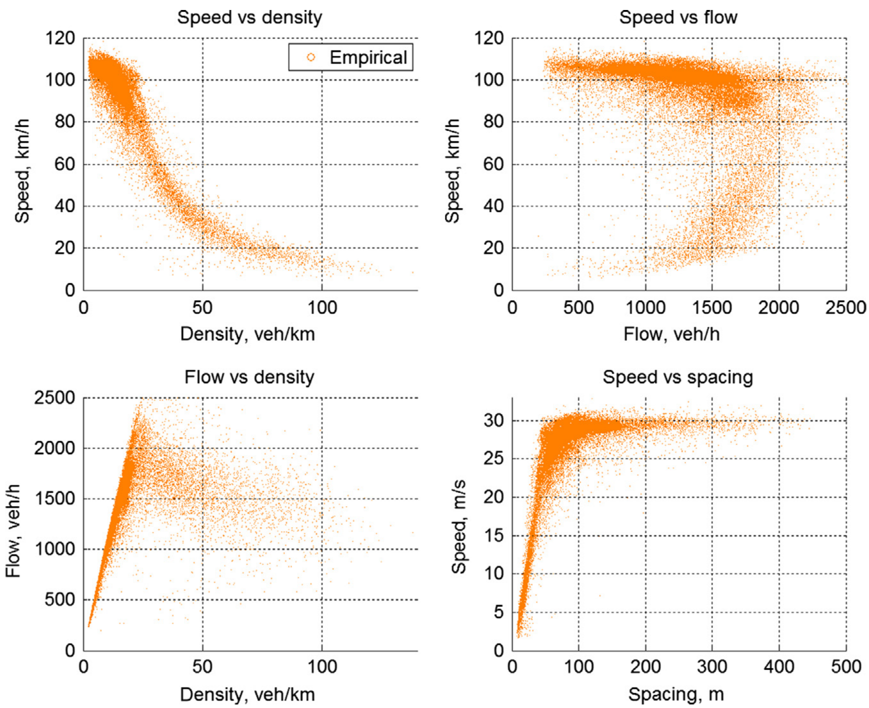

Figure 12.5 Empirical fundamental diagram observed from the field.

behavior of traffic flow, the observations in the cloud are further aggregated with respect to density, and the result is shown as circles.

PROBLEMS

1. What are the major differences between microscopic modeling and macroscopic modeling?
2. Route choice, lane change, and car following are all about decision making. Elaborate the difference among these decision making processes.
3. Identify the following traffic flow characteristics with use of of the empirical fundamental diagram illustrated in this book:
   a. Free-flow speed
   b. Capacity condition (capacity, optimal speed, and optimal density)
   c. Jam density