Chapter 2
Trajectory and Floating-Car Data

Measure what is measurable, and make measurable what is not so.

Galileo Galilei

Abstract Different aspects of traffic dynamics are captured by different measurement methods. In this chapter, we discuss trajectory data and floating-car data, both providing space-time profiles of vehicles. While trajectory data captures all vehicles within a selected measurement area, floating-car data only provides information on single, specially equipped vehicles. Furthermore, trajectory data is measured externally while, as the name implies, floating-car data is captured inside the vehicle.

2.1 Data Collection Methods

Traffic can be directly observed by cameras on top of a tall building or mounted on an airplane. Tracking software extracts *trajectories* $x_\alpha(t)$, i.e. the positions of each vehicle α over time, from the video footage (or a series of photographs). If *all* vehicles within a given road section (and time span) are captured in this way, the resulting dataset is called *trajectory data*.

Thus, trajectory data is the most comprehensive traffic data available. It is also the only type that allows direct and unbiased measurement of the traffic density (see Sect. 3.3) and lane changes. However, camera-based methods involve complex and error-prone procedures which require automated and robust algorithms for the vehicle tracking, and thus are often the most expensive option for data collection. Furthermore, a simple camera can cover a road section of at most a few hundred meters since smaller vehicles are occluded behind larger ones if the viewing angle is too low.

A different method uses probe vehicles which "float" in the traffic flow. Such cars collect geo-referenced coordinates via GPS receivers which are then "map-matched" to a road on a map—the speed is a derived quantity determined from the spacing (on a map) between two GPS points. This type of data is called *floating-car data*

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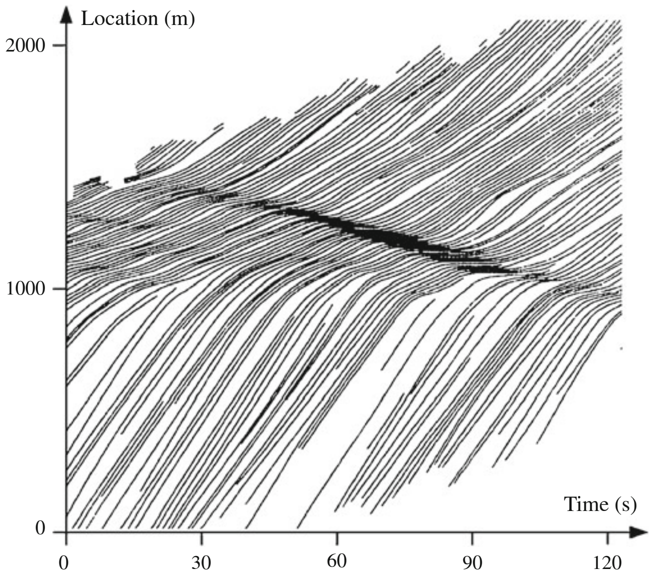


Fig. 2.1 Trajectories with moving stop-and-go waves on a British motorway segment [Adapted from: Treiterer et al. (1970)]

(FCD). Some more recent navigation systems also record (anonymized) trajectories and send them to the manufacturer. The probe vehicles can be equipped with other sensors (e.g. radar) to record distance to the leading vehicle and its speed (however, such equipment is expensive). FCD augmented in this way are also referred to as *extended floating-car data* (xFCD). One problem of FCD is that many equipped vehicles are taxis or trucks/vans of commercial transport companies which, due to their lower speeds, are not representative for the traffic as a whole. Fortunately, this bias vanishes just when the FCD information becomes relevant: In congested situations, free-flow speed differences do not matter.

Both trajectory and floating-car data record the vehicle location $x_\alpha(t)$ as a function of time, yet they differ substantially:

- Trajectory data records the spatiotemporal location of *all* vehicles within a given road segment and time interval while FCD only collects data on a few probe vehicles.
- Contrary to trajectory data, FCD does not record which lane a vehicle is using since present GPS accuracy is not sufficient for lane-fine map-matching.
- FCD may contain additional information such as the distance to the leading vehicle, position of the gas/brake pedals, activation of turning signals, or the rotation angle of the steering wheel (xFCD). In principle, every quantity available via the *CAN-bus*[1] can be recorded as a time-series. This kind of data is naturally missing in trajectory data due to the optical recording method.

[1] The CAN-bus is a micro-controller communication interface present in all modern vehicles.

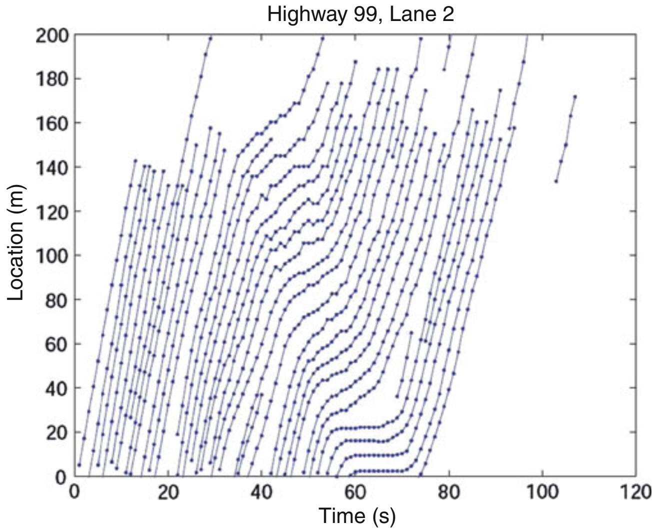


Fig. 2.2 Trajectories with moving stop-and-go waves on the California State Route 99 [From: www.ece.osu.edu/~coifman/shock]

2.2 Time-Space Diagrams

Figures 2.1 and 2.2 are examples of trajectory data of a single lane visualized in a *space-time diagram*. By convention, we will always plot time on the x-axis vs. space on the y-axis. The following information can be easily read off the diagrams:

- The local speed at (front-bumper) position x and time t is given by the gradient of the trajectory. A horizontal trajectory corresponds to a standing vehicle.
- The *time headway*, or simply *headway*, Δt_α between the front bumpers of two vehicles following each other (see Sect. 3.1) is the horizontal distance between two trajectories.[2]
- *Traffic flow*, defined as the number of vehicles passing a given location per time unit, is the number of trajectories crossing a horizontal line denoting this time interval. It is equal to the inverse of the time mean of the headways.
- The *distance headway* between two vehicles is the vertical distance of their trajectories. It is composed of the distance gap between the front and the rear bumpers plus the length of the leading vehicle.
- The *traffic density*, defined as the number of vehicles on a road segment at a given time, is the number of trajectories crossing a vertical line in the diagram and thus the inverse of the *space mean* of the distance headways (cf. Sect. 3.3).
- Lane changes to and from the observed lane are marked by beginning and ending trajectories, respectively.

[2] The time headway is composed of the (rear-bumper-to-front-bumper) time gap plus the occupancy time interval of the leading vehicle.

- The gradient of the boundary of a high-density area indicates the propagation velocity of a traffic jam. The congestions in the Figs. 2.1 and 2.2 are stop-and-go waves which are moving upstream and thus have a negative propagation speed.

If not only the longitudinal positions $x_\alpha(t)$ (along the road) but also the *lateral* positions $y_\alpha(t)$ (across the lanes) are recorded, one can generate a two-dimensional trajectory diagram from which one can deduce lateral accelerations and the duration of lane changes.

> Is it possible to estimate the time needed to pass through a given road segment using trajectory data? How would you calculate the travel time increase caused by a traffic jam? What additional assumption is needed to estimate the total time loss of all persons driving through the congestion?

Problems

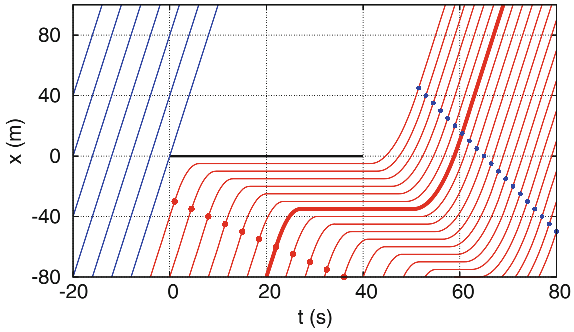
2.1 Floating-Car Data
Assume that some vehicles with GPS systems (accurate to approximately 20 m) send their (anonymized) locations to a traffic control center in fixed time intervals. Can this data be used to reconstruct (1) trajectories of single vehicles, (2) location and time of lane changes, (3) traffic density (vehicles per kilometer), (4) traffic flow (vehicles per hour), (5) vehicle speed, and (6) length and position of traffic jams? Justify your answers.

2.2 Analysis of Empirical Trajectory Data
Consider the trajectory data visualized in Fig. 2.2:

1. Determine the traffic density (vehicles per kilometer), traffic flow (vehicles per hour), and speed in different spatiotemporal sections, for example $[10, 30\,\mathrm{s}] \times [20, 80\,\mathrm{m}]$ (free traffic) and $[50, 70\,\mathrm{s}] \times [20, 100\,\mathrm{m}]$ (congested traffic).
2. Find the propagation velocity of the stop-and-go wave. Is it traveling with or against the direction of traffic flow?
3. Estimate the travel time increase incurred by the vehicle that is at $x = 0\,m$ at time $t \approx 50\,s$ due to the stop-and-go wave.
4. Estimate the average *lane-changing rate* (lane changes per kilometer and per hour) in the spatiotemporal area covered by the dataset. (Assume six trajectory beginnings or endings within $[0, 80\,\mathrm{s}] \times [0, 140\,\mathrm{m}]$.)

2.3 Trajectory Data of "Obstructed" Traffic Flow

Consider the trajectory data of city traffic shown in the diagram below:



1. What situation is shown? What does the horizontal bar beginning at $x = t = 0$ mean?
2. Determine the traffic demand, i.e. the inflow for $t \leq 20$ s.
3. Determine the density and speed in the free traffic regime upstream of the "obstacle".
4. Determine the density within the traffic jam.
5. Determine the outflow after the "obstacle" disappears. Also find the density and speed in the outflow regime after the initial acceleration (the end of which is marked by smaller blue dots).
6. Determine the propagation speed of the transitions "free traffic $\rightarrow$ jam" and "jam $\rightarrow$ free traffic".
7. What travel time delay is imposed on a vehicle entering the scene at $t = 20$ s and $x = -80$ m?
8. Find the acceleration and deceleration values (assuming they are constant). The start of the deceleration phase and the end of the acceleration phase of each vehicle are marked by dots.

Further Reading

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