6 TRAFFIC FLOW AND CAPACITY
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6.1 Introduction

The design of highways, runways, ports or any transportation facility is guided by knowledge and theory of the traffic streams they serve. A facility’s scale, its geometry and its control measures are selected to affect certain properties of its traffic, such as the travel delay, the separation between vehicles, etc. In the case of highway traffic, the emphasis of this chapter, these are usually properties that are collected from, or averaged over, some number of vehicles. This is because the behavior of one driver differs from that of another, sometimes in complicated or even unexpected ways, and the traffic engineer typically seeks properties that are reproducible or predictable; i.e., properties that are not sensitive to driver variations.

Chapter 6 is devoted to methods of measuring traffic stream properties and of predicting how these properties evolve over time and space. Certain emphasis is given to flow restrictions, or bottlenecks, and to the estimation of their capacities since traffic streams are often impacted by these restrictions.

Section 6.1 provides some important definitions along with descriptions of some graphical tools for analyzing the motion of objects on transport systems. Most of what is presented here is applicable to any mode of transportation. Moreover, this information is necessary background for the treatment of highway traffic offered in the remaining sections of the chapter. Section 6.2 describes methods of processing traffic data measured, for example, by loop detectors to identify bottleneck locations along highway facilities without traffic signals or other exogenous controls. The use of these methods to estimate bottleneck capacities is likewise shown here. Section 6.3 presents methods of estimating capacities and vehicle delays at highway intersections controlled by traffic signals or stop signs. Theories for predicting the evolution of highway traffic are the subject of section 6.4. A simple theory is described here in some detail and other theories are briefly noted.

The chapter provides references for all of the topics covered. Notes on the historical developments and future research directions are likewise included for many of the subjects.
Basic Concepts

This first section includes definitions for some of the properties commonly used to characterize traffic streams. So-called generalized definitions, which preserve useful relations between the properties, are part of this discussion. Also described in section 6.1 is a three-dimensional representation of traffic streams. This representation makes clear the conservation concepts that are fundamental to theories of traffic evolution. In particular, it illustrates the relation between two important graphical tools for presenting and interpreting traffic data: 1) curves of cumulative vehicle count and 2) trajectories plotted on time-space diagrams. A description of the latter tool is the starting point for this section.

Before embarking on this discussion, however, there are two points that deserve mention. First, the subjects covered in section 6.1 do not involve theory or conjecture. Rather the concepts are true by definition. Secondly, the discussion in this section owes much to notes composed by Newell (unpublished) for a graduate course in transportation engineering and to a book written by Daganzo (1997).

The Time-Space Diagram. Objects are commonly constrained to move along a one-dimensional guideway, be it, for example, a highway lane, walkway, conveyor belt, charted course or flight path. Thus, the relevant aspects of their motion can often be described in cartesian coordinates of time, \( t \), and space, \( x \). Figure 6-1 illustrates the trajectories of some objects traversing a facility of length \( L \) during time interval \( T \); these objects may be vehicles, pedestrians or cargo. Each trajectory is assigned an integer label in the ascending order that the object would be seen by a stationary observer. If one object overtakes another, their trajectories may exchange labels, as shown for the fourth and fifth trajectories in the figure. Thus, the \( \ell \)th trajectory describes the location of a reference point (e.g. the front end) of object \( \ell \) as a function of time \( t \), \( x_\ell (t) \).

The characteristic geometries of trajectories on a time-space diagram describe the motion of objects in detail. These diagrams thus offer the most complete way of displaying the observations that may have actually been measured along a facility. As a practical matter, however, one is not likely to collect all the data needed to construct trajectories. Rather, time-space diagrams derive their (considerable) value by providing a means to highlight the key features of a traffic stream using only coarsely approximated data or hypothetical data from “thought experiments.”

The literature includes numerous illustrations of how these diagrams, even when drawn approximately, can be used in solving problems that frequently arise in transport. As examples, Daganzo (1997) shows how trajectory plots can help to select desirable scheduling policies in rail and in sea transportation; Newell (1979) used them in deriving expressions of airport runway capacity; and they are a widely used tool for synchronizing traffic signals along an arterial (Newell, 1989).