



CHAPTER 2

CAPACITY AND LEVEL-OF-SERVICE CONCEPTS

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I. INTRODUCTION

This manual presents methods for analyzing capacity and level of service for a broad range of transportation facilities. It provides procedures for analyzing streets and highways, bus and on-street light rail transit, and pedestrian and bicycle paths.

Facilities are classified into two categories of flow: uninterrupted and interrupted. Uninterrupted-flow facilities have no fixed elements, such as traffic signals, that are external to the traffic stream and might interrupt the traffic flow. Traffic flow conditions result from the interactions among vehicles in the traffic stream and between vehicles and the geometric and environmental characteristics of the roadway.

Interrupted-flow facilities have controlled and uncontrolled access points that can interrupt the traffic flow. These access points include traffic signals, stop signs, yield signs, and other types of control that stop traffic periodically (or slow it significantly), irrespective of the amount of traffic.

Uninterrupted and interrupted flows describe the type of facility, not the quality of the traffic flow at any given time. A freeway experiencing extreme congestion, for example, is still an uninterrupted-flow facility because the causes of congestion are internal.

Freeways and their components operate under the purest form of uninterrupted flow. Not only are there no fixed interruptions to traffic flow, but access is controlled and limited to ramp locations. Multilane highways and two-lane highways also can operate under uninterrupted flow in long segments between points of fixed interruption. On multilane and two-lane highways, it is often necessary to examine points of fixed interruption as well as uninterrupted-flow segments.

The analysis of interrupted-flow facilities must account for the impact of fixed interruptions. A traffic signal, for example, limits the time available to various movements in an intersection. Capacity is limited not only by the physical space but by the time available for movements.

Transit, pedestrian, and bicycle flows generally are considered to be interrupted. Uninterrupted flow might be possible under certain circumstances, such as in a long busway without stops or along a pedestrian corridor. However, in most situations, capacity is limited by stops along the facility.

Capacity analysis, therefore, is a set of procedures for estimating the traffic-carrying ability of facilities over a range of defined operational conditions. It provides tools to assess facilities and to plan and design improved facilities.

A principal objective of capacity analysis is to estimate the maximum number of persons or vehicles that a facility can accommodate with reasonable safety during a specified time period. However, facilities generally operate poorly at or near capacity; they are rarely planned to operate in this range. Accordingly, capacity analysis also estimates the maximum amount of traffic that a facility can accommodate while maintaining its prescribed level of operation.

Operational criteria are defined by introducing the concept of level of service. Ranges of operating conditions are defined for each type of facility and are related to the amount of traffic that can be accommodated at each service level.

The two principal concepts of this manual—capacity and level of service—are defined in the following sections.

Uninterrupted-flow facility defined

Interrupted-flow facility defined

Capacity analysis defined

Capacity defined

Capacity is defined on the basis of reasonable expectancy

Concepts of demand and volume

Quality and level of service defined

II. CAPACITY

The capacity of a facility is the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions.

Vehicle capacity is the maximum number of vehicles that can pass a given point during a specified period under prevailing roadway, traffic, and control conditions. This assumes that there is no influence from downstream traffic operation, such as the backing up of traffic into the analysis point.

Person capacity is the maximum number of persons that can pass a given point during a specified period under prevailing conditions. Person capacity is commonly used to evaluate public transit services, high-occupancy vehicle lanes, and pedestrian facilities.

Prevailing roadway, traffic, and control conditions define capacity; these conditions should be reasonably uniform for any section of facility analyzed. Any change in the prevailing conditions changes the capacity of the facility.

Capacity analysis examines segments or points (such as signalized intersections) of a facility under uniform traffic, roadway, and control conditions. These conditions determine capacity; therefore, segments with different prevailing conditions will have different capacities.

Reasonable expectancy is the basis for defining capacity. That is, the stated capacity for a given facility is a flow rate that can be achieved repeatedly for peak periods of sufficient demand. Stated capacity values can be achieved on facilities with similar characteristics throughout North America. Capacity is not the absolute maximum flow rate observed on such a facility. Driver characteristics vary from region to region, and the absolute maximum flow rate can vary from day to day and from location to location.

Persons per hour, passenger cars per hour, and vehicles per hour are measures that can define capacity, depending on the type of facility and type of analysis. The concept of person flow is important in making strategic decisions about transportation modes in heavily traveled corridors and in defining the role of transit and high-occupancy vehicle priority treatments. Person capacity and person flow weigh each type of vehicle in the traffic stream by the number of occupants it carries.

III. DEMAND

In this manual, demand is the principal measure of the amount of traffic using a given facility. Demand relates to vehicles arriving; volume relates to vehicles discharging. If there is no queue, demand is equivalent to the traffic volume at a given point on the roadway. Throughout this manual, the term volume generally is used for operating conditions below the threshold of capacity.

IV. QUALITY AND LEVELS OF SERVICE

Quality of service requires quantitative measures to characterize operational conditions within a traffic stream. Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.

Six LOS are defined for each type of facility that has analysis procedures available. Letters designate each level, from A to F, with LOS A representing the best operating conditions and LOS F the worst. Each level of service represents a range of operating conditions and the driver's perception of those conditions. Safety is not included in the measures that establish service levels.

SERVICE FLOW RATES

The analytical methods in this manual attempt to establish or predict the maximum flow rate for various facilities at each level of service—except for LOS F, for which the flows are unstable or the vehicle delay is high. Thus, each facility has five service flow rates, one for each level of service (A through E). For LOS F, it is difficult to predict flow due to stop-and-start conditions.

The service flow rate is the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a given period under prevailing roadway, traffic, and control conditions while maintaining a designated level of service. The service flow rates generally are based on a 15-min period. Typically, the hourly service flow rate is defined as four times the peak 15-min volume.

Note that service flow rates are discrete values, whereas levels of service represent a range of conditions. Because the service flow rates are the maximums for each level of service, they effectively define the flow boundaries between levels of service.

Most design or planning efforts typically use service flow rates at LOS C or D, to ensure an acceptable operating service for facility users.

PERFORMANCE MEASURES

Each facility type that has a defined method for assessing capacity and level of service (see Part III of this manual) also has performance measures that can be calculated. These measures reflect the operating conditions of a facility, given a set of roadway, traffic, and control conditions. Travel speed and density on freeways, delay at signalized intersections, and walking speed for pedestrians are examples of performance measures that characterize flow conditions on a facility.

SERVICE MEASURES

For each facility type, one or more of the stated performance measures serves as the primary determinant of level of service. This LOS-determining parameter is called the service measure or sometimes the measure of effectiveness (MOE) for each facility type.

Service flow rate defined

Service measure defined

V. FACTORS AFFECTING CAPACITY AND LOS

BASE CONDITIONS

Many of the procedures in this manual provide a formula or simple tabular or graphic presentations for a set of specified standard conditions, which must be adjusted to account for prevailing conditions that do not match. The standard conditions so defined are termed base conditions.

Base conditions assume good weather, good pavement conditions, users familiar with the facility, and no impediments to traffic flow. Other, more specific base conditions are identified in each chapter of Part III. Examples of base conditions for uninterrupted-flow facilities and for intersection approaches are given below.

Base conditions for uninterrupted-flow facilities include the following:

- Lane widths of 12 ft,

Base conditions defined

- Clearance of 6 ft between the edge of the travel lanes and the nearest obstructions or objects at the roadside and in the median,
- Free-flow speed of 60 mi/h for multilane highways,
- Only passenger cars in the traffic stream (no heavy vehicles),
- Level terrain,
- No no-passing zones on two-lane highways, and
- No impediments to through traffic due to traffic control or turning vehicles.

Base conditions for intersection approaches include the following:

- Lane widths of 12 ft,
- Level grade,
- No curb parking on the approaches,
- Only passenger cars in the traffic stream,
- No local transit buses stopping in the travel lanes,
- Intersection located in a noncentral business district area, and
- No pedestrians.

In most capacity analyses, prevailing conditions differ from the base conditions, and computations of capacity, service flow rate, and level of service must include adjustments. Prevailing conditions are generally categorized as roadway, traffic, or control.

ROADWAY CONDITIONS

Roadway conditions include geometric and other elements. In some cases, these influence the capacity of a road; in others, they can affect a performance measure such as speed, but not the capacity or maximum flow rate of the facility.

Roadway factors include the following:

- Number of lanes,
- The type of facility and its development environment,
- Lane widths,
- Shoulder widths and lateral clearances,
- Design speed,
- Horizontal and vertical alignments, and
- Availability of exclusive turn lanes at intersections.

The horizontal and vertical alignment of a highway depend on the design speed and the topography of the land on which it is constructed.

In general, the severity of the terrain reduces capacity and service flow rates. This is significant for two-lane rural highways, where the severity of terrain not only can affect the operating capabilities of individual vehicles in the traffic stream, but also can restrict opportunities for passing slow-moving vehicles.

TRAFFIC CONDITIONS

Traffic conditions that influence capacities and service levels include vehicle type and lane or directional distribution.

Vehicle Type

The entry of heavy vehicles—that is, vehicles other than passenger cars (a category that includes small trucks and vans)—into the traffic stream affects the number of vehicles that can be served. Heavy vehicles are vehicles that have more than four tires touching the pavement.

Trucks, buses, and recreational vehicles (RVs) are the three groups of heavy vehicles addressed by the methods in this manual. Heavy vehicles adversely affect traffic in two ways:

- They are larger than passenger cars and occupy more roadway space; and
- They have poorer operating capabilities than passenger cars, particularly with respect to acceleration, deceleration, and the ability to maintain speed on upgrades.

Impact of roadway conditions

Impact of traffic conditions

The second impact is more critical. The inability of heavy vehicles to keep pace with passenger cars in many situations creates large gaps in the traffic stream, which are difficult to fill by passing maneuvers. The resulting inefficiencies in the use of roadway space cannot be completely overcome. This effect is particularly harmful on sustained, steep upgrades, where the difference in operating capabilities is most pronounced, and on two-lane highways, where passing requires use of the opposing travel lane.

Heavy vehicles also can affect downgrade operations, particularly when downgrades are steep enough to require operation in a low gear. In these cases, heavy vehicles must operate at speeds slower than passenger cars, forming gaps in the traffic stream.

Trucks cover a wide range of vehicles, from lightly loaded vans and panel trucks to the most heavily loaded coal, timber, and gravel haulers. An individual truck's operational characteristics vary based on the weight of its load and its engine performance.

RVs also include a broad range: campers, both self-propelled and towed; motor homes; and passenger cars or small trucks towing a variety of recreational equipment, such as boats, snowmobiles, and motorcycle trailers. Although these vehicles might operate considerably better than trucks, the drivers are not professionals, accentuating the negative impact of RVs on the traffic stream.

Intercity buses are relatively uniform in performance. Urban transit buses generally are not as powerful as intercity buses; their most severe impact on traffic results from the discharge and pickup of passengers on the roadway. For the methods in this manual, the performance characteristics of buses are considered to be similar to those of trucks.

Directional and Lane Distribution

In addition to the distribution of vehicle types, two other traffic characteristics affect capacity, service flow rates, and level of service: directional distribution and lane distribution. Directional distribution has a dramatic impact on two-lane rural highway operation, which achieves optimal conditions when the amount of traffic is about the same in each direction. Capacity analysis for multilane highways focuses on a single direction of flow. Nevertheless, each direction of the facility usually is designed to accommodate the peak flow rate in the peak direction. Typically, morning peak traffic occurs in one direction and evening peak traffic occurs in the opposite direction. Lane distribution also is a factor on multilane facilities. Typically, the shoulder lane carries less traffic than other lanes.

CONTROL CONDITIONS

For interrupted-flow facilities, the control of the time for movement of specific traffic flows is critical to capacity, service flow rates, and level of service. The most critical type of control is the traffic signal. The type of control in use, signal phasing, allocation of green time, cycle length, and the relationship with adjacent control measures affect operations. All of these are discussed in detail in Chapters 10 and 16.

Stop signs and yield signs also affect capacity, but in a less deterministic way. A traffic signal designates times when each movement is permitted; however, a stop sign at a two-way stop-controlled intersection only designates the right-of-way to the major street. Motorists traveling on the minor street must stop and then find gaps in the major traffic flow to maneuver. The capacity of minor approaches, therefore, depends on traffic conditions on the major street. An all-way stop control forces drivers to stop and enter the intersection in rotation. Capacity and operational characteristics can vary widely, depending on the traffic demands on the various approaches.

Other types of controls and regulations can affect capacity, service flow rates, and LOS significantly. Restriction of curb parking can increase the number of lanes available on a street or highway. Turn restrictions can eliminate conflicts at intersections, increasing capacity. Lane use controls can allocate roadway space to component

Impact of control conditions

movements and can create reversible lanes. One-way street routings can eliminate conflicts between left turns and opposing traffic.

TECHNOLOGY

Emerging transportation technologies, also known as intelligent transportation systems (ITS), will enhance the safety and efficiency of vehicles and roadway systems. ITS strategies aim to increase the safety and performance of roadway facilities. For this discussion, ITS includes any technology that allows drivers and traffic control system operators to gather and use real-time information to improve vehicle navigation, roadway system control, or both.

To date, there has been little research to determine the impact of ITS on capacity and level of service. The procedures in this manual relate to roadway facilities without ITS enhancements.

Current ITS programs might have the following impacts on specific capacity analyses:

- For freeway and other uninterrupted-flow highways, ITS might achieve some decrease in headways, which would increase the capacity of these facilities. In addition, even with no decrease in headways, level of service might improve if vehicle guidance systems offered drivers a greater level of comfort than they currently experience in conditions with close spacing between vehicles.
- For signal and arterial operations, the major benefits of ITS would be a more efficient allocation of green time and an increase in capacity. ITS features likely will have a less pronounced impact on interrupted flow than on uninterrupted-flow facilities.
- At unsignalized intersections, capacity improvements might result if ITS assisted drivers in judging gaps in opposing traffic streams or if it somehow controlled gaps in flow on the major street.

Many of these ITS improvements—such as incident response and driver information systems—are occurring at the system level. Although ITS features will benefit the overall roadway system, they will not have an impact on the methods to calculate capacity and level of service for individual roadways and intersections.