

4. ESTIMATION OF HIGHWAY CAPACITY

The ability of the road network to service vehicle demand is a major factor in determining how rapidly an evacuation can be completed. The capacity of a road is defined as the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane of roadway during a given time period under prevailing roadway, traffic and control conditions. (From the 2000 Highway Capacity Manual)

In discussing capacity, different operating conditions have been assigned alphabetical designations, A through F, to reflect the range of traffic operational characteristics. These designations have been termed "Levels of Service" (LOS). For example, LOS A connotes free-flow and high-speed operating conditions; LOS F represents a forced flow condition. LOS E describes traffic operating at or near capacity.

Because of the effect of weather on the capacity of a roadway, it is necessary to adjust capacity figures to represent the prevailing conditions during inclement weather. Based on limited empirical data, weather conditions such as rain reduce the values of free speed and of highway capacity by approximately 10 percent. Over the last decade new studies have been made on the effects of rain on traffic capacity. These studies indicate a range of effects between 5 and 20 percent depending on wind speed and precipitation rates.

Given the population density of Gaffney and the roadway grid system along US Highway 29, congestion arising from evacuation is likely to be significant within the city. As such, estimates of roadway capacity must be determined with great care. Because of its importance, a brief discussion of the major factors that influence highway capacity is presented in this section.

Capacity Estimations on Approaches to Intersections

At-grade intersections are apt to become the first bottleneck locations under local heavy traffic volume conditions. This characteristic reflects the need to allocate access time to the respective competing traffic streams by exerting some form of control. During evacuation, control at critical intersections will often be provided by traffic control personnel assigned for that purpose, whose directions may supersede traffic control devices. The Traffic Management Plan identifies these locations (Traffic Control Points, TCP) and the management procedures applied.

The per-lane capacity of an approach to a signalized intersection can be expressed (simplistically) in the following form:

$$Q_{cap,m} = \left(\frac{3600}{h_m} \right) \cdot \left[\frac{G-L}{C} \right]_m = \left(\frac{3600}{h_m} \right) \cdot P_m$$

where:

- $Q_{cap,m}$ = Capacity of a single lane of traffic on an approach, which executes movement, m , upon entering the intersection; vehicles per hour (vph)
- h_m = Mean queue discharge headway of vehicles on this lane that are executing movement, m ; seconds per vehicle
- G_m = Mean duration of GREEN time servicing vehicles that are executing movement, m , for each signal cycle; seconds
- L = Mean "lost time" for each signal phase servicing movement, m ; seconds
- C = Duration of each signal cycle; seconds
- P_m = Proportion of GREEN time allocated for vehicles executing movement, m , from this lane. This value is specified as part of the control treatment.
- m = The movement executed by vehicles after they enter the intersection: through, left-turn, right-turn, diagonal.

The turn-movement-specific mean discharge headway h_m , depends in a complex way upon many factors: roadway geometrics, turn percentages, the extent of conflicting traffic streams, the control treatment, and others. A primary factor is the value of "saturation queue discharge headway", h_{sat} , which applies to through vehicles that are not impeded by other conflicting traffic streams. This value, itself, depends upon many factors including motorist behavior. Formally, we can write,

$$h_m = f_m (h_{sat}, F_1, F_2, \dots)$$

where:

- h_{sat} = Saturation discharge headway for through vehicles; seconds per vehicle
- F_1, F_2 = The various known factors influencing h_m
- $f_m(\cdot)$ = Complex function relating h_m to the known (or estimated) values of h_{sat}, F_1, F_2, \dots

The estimation of h_m for specified values of h_{sat}, F_1, F_2, \dots is undertaken within the PC-DYNEV simulation model and within the TRAD model by a mathematical model¹. The resulting values for h_m always satisfy the condition:

$$h_m \geq h_{sat}$$

¹ Lieberman, E., "Determining Lateral Deployment of Traffic on an Approach to an Intersection", McShane, W. & Lieberman, E., "Service Rates of Mixed Traffic on the far Left Lane of an Approach". Both papers appear in Transportation Research Record 772, 1980.

That is, the turn-movement-specific discharge headways are always greater than, or equal to the saturation discharge headway for through vehicles. These headways (or its inverse equivalent, “saturation flow rate”), may be determined by observation or using the procedures of the Highway Capacity Manual.

Capacity Estimation Along Sections of Highway

The capacity of highway sections -- as distinct from approaches to intersections -- is a function of roadway geometrics, traffic composition (e.g. percent heavy trucks and buses in the traffic stream) and, of course, motorist behavior. There is a fundamental relationship which relates service volume (i.e. the number of vehicles serviced within a uniform highway section in a given time period) to traffic density. Figure 4-1 describes this relationship.

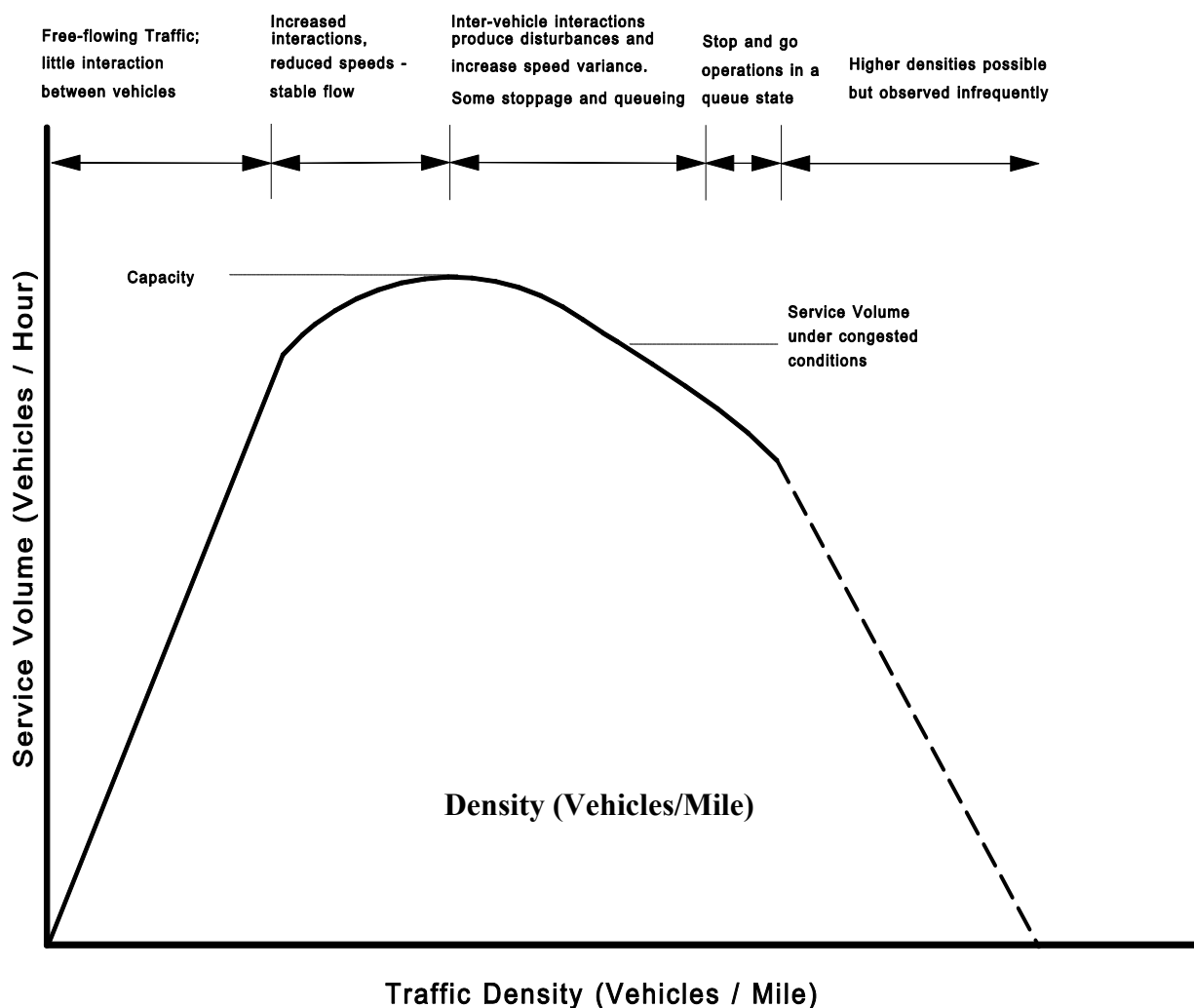


Figure 4-1. Fundamental Relationship Between Volume and Density

As indicated, there are two flow regimes: (1) Free Flow (left side of curve); and (2) Forced Flow (right side). In the Free Flow regime, the traffic demand is fully serviced; this service volume increases as demand volume and density increase, until the service volume attains its maximum value, which is the capacity of the highway section. As traffic demand and the resulting highway density increase beyond this "critical" value, the rate at which traffic can be serviced (i.e. the service volume) can actually decline below capacity. Therefore, in order to realistically represent traffic performance during congested conditions (i.e. when demand exceeds capacity), it is necessary to estimate the service volume, V_F , under congested conditions.

The value of V_F can be expressed as:

$$V_F = R \times \text{Capacity}$$

where R = Reduction factor which is less than unity.

Based on empirical data collected on freeways, we have employed a value of $R=0.85$. It is important to mention that some investigators, on analyzing data collected on freeways, conclude that little reduction in capacity occurs even when traffic is operating at Level of Service, F . While there is conflicting evidence on this subject, we adopt a conservative approach and use a value of service volume, V_F , which is applied during LOS F conditions; V_F is lower than the specified capacity.

The estimated value of capacity is based primarily upon the type of facility and on roadway geometrics. Sections of roadway with adverse geometrics are characterized by lower free-flow speeds and lane capacity.

The procedure used here was to estimate "section" capacity, V_E , based on observations made traveling over each section of the evacuation network, by the posted speed limits and travel behavior of other motorists and by reference to the 2000 Highway Capacity Manual. It was then determined for each highway section, represented as a network link, whether its capacity would be limited by the "section-specific" service volume, V_E , or by the intersection-specific capacity. For each link, the model selects the lower value of capacity.

Application to the Lee Nuclear Station EPZ

As part of the development of the WLS EPZ traffic network, an estimate of roadway capacity is required. The source material for the capacity estimates presented herein is contained in:

2000 Highway Capacity Manual (HCM)
Transportation Research Board
National Research Council
Washington, D.C.

The highway system in the WLS EPZ consists primarily of three categories of roads and, of course, intersections:

- Two-lane roads: Local, State
- Multi-lane Highways (at-grade)
- Freeways (Interstate-85)

Each of these classifications will be discussed.

Two-Lane Roads

Ref: HCM Chapter 20

Two lane roads comprise the majority of highways within the EPZ. The per-lane capacity of a two-lane highway is estimated at 1700 passenger cars per hour (pc/h). This estimate is essentially independent of the directional distribution of traffic volume except that, for extended distances, the two-way capacity will not exceed 3200 pc/h. The HCM procedures then estimate Level of Service (LOS) and Average Travel Speed. The evacuation simulation model accepts the specified value of capacity as input and computes average speed based on the time-varying demand: capacity relations.

Based on the field survey and on expected traffic operations associated with evacuation scenarios:

- Most sections of two-lane roads within the EPZ are classified as “Class I”, with “level terrain”; some are “rolling terrain”.
- “Class II” highways are mostly those within city limits.

Multi-Lane Highway

Ref: HCM Chapter 21

Exhibit 21-23 (in the HCM) presents a set of curves that indicates a per-lane capacity of approximately 2100 pc/h, for free-speeds of 55-60 mph. Based on observation, the multi-lane highways outside of urban areas within the EPZ service traffic with free-speeds in this range. The actual time-varying speeds computed by the simulation model reflect the demand: capacity relationship and the impact of control at intersections.

Freeways

Ref: HCM Chapters 22-25

Chapter 22 of the HCM describes a procedure for integrating the results obtained in Chapters 23, 24 and 25, which compute capacity and LOS for freeway components. The

discussion also references Chapter 31, which presents a discussion on simulation models. The simulation model, PC-DYNEV, automatically performs this integration process.

Chapter 23 of the HCM presents procedures for estimating capacity and LOS for “Basic Freeway Segments”. Exhibit 23-3 of the HCM2000 presents capacity vs. free speed estimates.

Free Speed:	55	60	65	70+
Per-Lane Capacity (pc/h):	2250	2300	2350	2400

The inputs to the simulation model are highway geometrics, free-speeds and capacity based on field observations. The simulation logic calculates actual time-varying speeds based on demand: capacity relationships.

Chapter 24 of the HCM presents procedures for estimating capacity, speed, density and LOS. The simulation model contains logic that relates speed to demand volume: capacity ratio. The value of capacity obtained from Exhibit 24-8 (of the HCM2000), depends on the "Type" and geometrics of the weaving segment and on the "Volume Ratio" (ratio of weaving volume to total volume).

Chapter 25 of the HCM presents procedures for estimating capacities of ramps and of "merge" areas. The capacity of a merge area "is determined primarily by the capacity of the downstream freeway segment". Values of this merge area capacity are presented in Exhibit 25-7 of the HCM2000, and depend on the number of freeway lanes and on the freeway free speed. The KLD simulation model logic simulates the merging operations of the ramp and freeway traffic. If congestion results from an excess of demand relative to capacity, then the model allocates service appropriately to the two entering traffic streams and produces LOS F conditions (The HCM does not address LOS F explicitly).

Intersections

Ref: HCM Chapters 16, 17

Procedures for estimating capacity and LOS for approaches to intersections are presented in Chapters 16 (signalized intersections) and 17 (un-signalized intersections). These are the two longest chapters in the HCM 2000, reflecting the complexity of these procedures. The simulation logic is likewise complex, but different; as stated on page 31-21 of the HCM2000:

“Assumptions and complex theories are used in the simulation model to represent the real-world dynamic traffic environment.”