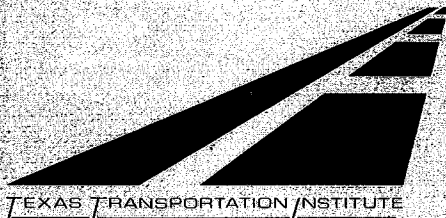




## DEPARTMENTAL INFORMATION EXCHANGE



In cooperation with  
Texas Department of Transportation  
and the FHWA

## Summary Report

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Summary Report 1196-2S

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# FREEWAY CAPACITY IN TEXAS

## PROBLEM STATEMENT

To effectively plan, design, and operate freeways, traffic engineers and transportation professionals need freeway capacity estimation procedures that are accurate and reliable *and* take into account the effects of congestion. A thorough understanding of today's traffic flows—the number of vehicles passing a point per unit of time—is necessary to develop those procedures.

When a freeway is moving as many cars as possible, *without* stop and go lines (queues) of traffic, by definition, it has reached capacity. Since 1950, the *Highway Capacity Manual* (HCM) has established average capacity values at 2000 passenger cars per hour per lane (pcphpl). Recent studies, however, have routinely measured flows in the field that exceed this established capacity. In addition to questioning the validity of the average value, also at issue is whether a reduction in capacity occurs when a queue forms. Detailed reevaluation of capacity and the speed-flow relationship will help develop a consensus on capacity values for the HCM and promote a better understanding of the flow processes on our increasingly congested urban freeways.

## OBJECTIVES

The Texas Transportation Institute (TTI) conducted study 1196, *Development of Planning and Capacity Values for Urban Freeways in Large Texas Cities*, in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). Part of the study focused on the following areas pertaining to freeway capacity:

- 1) the maximum observed flow rates;
- 2) the characteristics of flows prior to congestion, the flows as cars are speeding up out of a queue, and whether flows decrease once a queue has formed;
- 3) the variation in flows between selected study sites with differing geometric and traffic conditions; and
- 4) the development of an empirically-based speed-flow model for estimating freeway operating conditions and capacity in Texas.

Four out of the ten initial sites in Texas were chosen for detailed analysis and use in model development. All the selected sites had occurrence of congestion on a regular basis, varying geometrics, and a bottleneck unaffected by downstream congestion. The study focused on the characteristics and influences of freeway bottlenecks because they are known locations where flows exceed established capacity—the only condition which confirms that capacity has been reached. Data were collected using inductive loop detectors at the four primary sites

and video cameras at the other six sites.

Researchers first developed a preliminary empirical flow model from flow data at the primary study site—Houston's US 290 at Tidwell. Because of concerns about the affects of different geometric characteristics and traffic conditions, researchers then collected, analyzed, and compared flow data for three and four days at the following validation sites:

- Interstate 410 at West Ave. in San Antonio, Texas;
- U.S. 183 at Central in Fort Worth, Texas;
- Interstate 35E at U.S. 67 in Dallas, Texas.

All of the findings were then combined to build a generalized speed-flow model which more accurately estimates the values that should be assigned to freeway capacity, and to make some recommendations concerning flow processes and data collection procedures involved in determining freeway capacity.

## FINDINGS

### Maximum Flow Rates

While flow rates varied across individual lanes, a flow rate of approximately 2,200 pcphpl could be maintained in individual lanes and, on average, over the entire U.S. 290 study site. Although there were clear differences between all of the validation sites, the analysis and validation procedure supported the basic findings for the U.S. 290 facility. Based on the analysis in this report, the maximum sustainable flow—the number recommended for capacity—was determined to

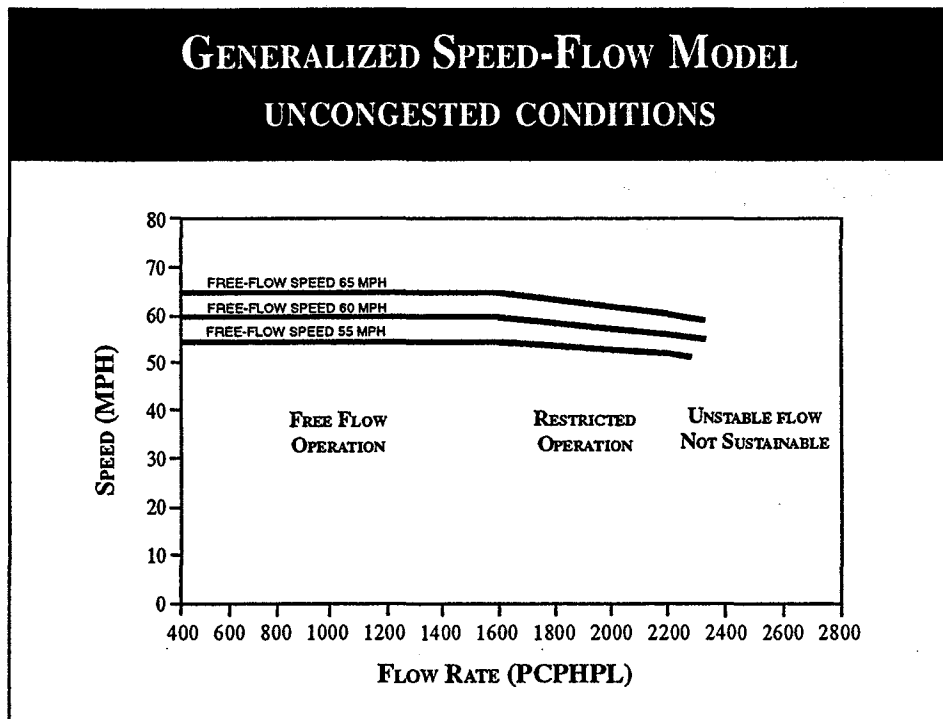


Figure 1

be 2,200 pcphpl (200 pcphpl over the value given in the HCM). This number is believed attainable at most locations in Texas with modern designs on level terrain with low truck percentages (less than 5%).

### Characteristics of Flow

Results of the study confirmed the following important points pertaining to flow:

- Because of imbalanced flow rates among individual lanes, due simply to driver preference and behavior, higher flows under free flow conditions (when drivers can select desired speed and easily maneuver) do not generally occur in all lanes at once. Thus these varying speed and lane choices can cause congestion before capacity has been reached. *Therefore, freeway bottlenecks, where flow rates are more consistent, are the best locations for measurement of freeway capacity.*

- Secondly, the flow rates

taken as cars are accelerating out of a bottleneck (queue discharge) are more consistent because speed and lane choice equally redistribute in bottlenecks. *Thus the best estimate for maximum sustainable flow, and the value recommended for use as capacity, is queue discharge at bottlenecks.*

### Variation in Flows Under Different Geometric and Traffic Conditions

► Of particular importance is the fact that individual site characteristics play an important role in the flow processes at specific sites. Because a bottleneck is a location on a freeway where demand exceeds capacity, the operation is influenced by both the type and location of the bottleneck. The type of bottleneck influences the distribution of traffic across lanes, determining the shape of the speed-flow relationship for each lane and the entire facility.

## MAXIMUM FLOW RATES FOR OPERATIONAL CONDITIONS

Flow Condition	Flow
Free-Flow Operation	0 – 1600 pcphpl
Restricted Operation	1600 – 2200 pcphpl
Unstable	> 2200 pcphpl

Table 1

For example, a change in the number of lanes does not affect the distribution of traffic the same as a high volume right hand merge, which adds vehicles to a single lane. High volume traffic added to a single lane may cause the lane to break down, resulting in congestion on the entire facility. *The concept of lane interaction is very important and may explain the variety of results obtained in earlier studies which attempted to find a single speed-flow relationship for the overall facility.*

▶ Another major factor which influences flow processes at a given bottleneck is its location with respect to other bottlenecks. In some large urban areas, congestion occurs for miles, extending through many interchanges that may themselves not be bottleneck locations. There are two types of effects from adjacent bottlenecks—those produced by upstream congestion and those produced by downstream congestion. Upstream congestion (before the subject bottleneck) effectively meters the flow, and thus locations

downstream may actually experience a reduction in flow as the traffic backs up in the upstream bottleneck. Under these conditions, the subject location never breaks down. Downstream congestion causes queues to back up *through* the subject bottleneck location, resulting in lower service rates. For example, a downstream slowdown at the I-410 site caused a drop in flow of over 400 vphpl.

Since demand changes at different freeway locations throughout the peak period and causes different bottlenecks to break down at different times, sites with no upstream or downstream congestion effects are rare. The speed-flow relationship and maximum sustainable flow rates proposed in this study are for independent bottlenecks. When extensive congestion exists, accurate analysis requires the use of computerized techniques to account for the effects of upstream or downstream bottlenecks. *The current procedures for determining capacity in the Highway Capacity Manual are*

*not accurate for extensive congestion or multiple bottlenecks.*

### Proposed Speed-Flow Model

This study's generalized speed-flow model for uncongested conditions is shown in figure 1. Although it is possible to sustain flows as high as 2,400 pcphpl in high-speed, non-merge lanes, it is not possible to sustain this high capacity in all bottleneck configurations. However, a flow rate of 2,200 pcphpl can be achieved in almost any type of lane, as well as over an entire bottleneck facility. Table 1 shows the maximum flow rates associated with each operational level.

Although, theoretically, if there is no stop and go activity, the facility will remain uncongested, this does not generally occur in practice, primarily due to merging and weaving activity. This lane changing causes traffic to slow down and line up before the actual capacity has been reached. In addition, lane preference alone causes lane imbalances which may result in the facility's breakdown before the established capacity has actually been reached. Nevertheless, the capacities found in this study are sustainable under queue discharge conditions. Although the capacities are applicable in both uncongested and congested conditions, the curves shown in Figure 1 illustrate the operation assuming the facility remains uncongested. Again, more complex relationships, which are largely site specific, occur when traffic demand exceeds capacity.

## CONCLUSIONS

Report 1196-2F may be used by officials involved in the planning, design, or operation of freeway facilities. Based on this analysis, the speed-flow model was developed with a maximum sustainable flow rate of 2,200 pcphpl, which is the value recommended to replace the current freeway design capacity in Texas.

It should be noted, however, that if a site does not match the conditions listed below (on which the model was based), the results may vary from those predicted by the model:

- conditions directly downstream of the bottleneck, which is usually some type of merge location;
- no downstream congestion;
- uncongested traffic conditions;

- nearly level terrain;
- low heavy vehicle percentages (less than 5%).

Adjustments for grades and heavy vehicles should be made using the current *Highway Capacity Manual* procedures. When assessing traffic conditions and estimating capacity, engineers can no longer rely on simple analysis; if traffic demands exceed capacity, they must account for congestion effects. If conditions exceed a capacity of 2,200 pcphpl, the only practical analysis requires the use of a computer simulation model to accurately assess the problem. A capacity value of 2,200 is appropriate for computer simulation.

The data used for this analysis has also been used by the Highway Capacity and Quality Service Committee of the Trans-

portation Research Board to study freeway traffic flow and produce revised analytical procedures. In addition, this data will also be considered by an upcoming National Cooperative Highway Research Project (NCHRP) to update chapter 3 of the *Highway Capacity Manual*.

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The information in this summary is reported in detail in TTI Research Report 1196-2F, "An Evaluation of Freeway Capacity in Texas," John Ringert and Thomas Urbanik II, October 1992. The contents of this summary do not necessarily reflect the official views of TxDOT or the FHWA.

