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OPTIONS FOR MANAGING TRAFFIC VOLUMES AND SPEEDS ON THE KATY TRANSITWAY

RESEARCH REPORT 484-6

COOPERATIVE RESEARCH PROGRAM

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION

METROPOLITAN TRANSIT AUTHORITY
OF HARRIS COUNTY

in cooperation with the
U.S. Department of Transportation
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16. Abstract

Houston has made a major commitment to developing freeway transitways--special lanes designated for the use of high-occupancy vehicles. These lanes are beginning to become operational, and a major effort is being undertaken to evaluate these initial facilities in order to learn from the early experience. This research project is jointly funded by the two operating agencies -- the Metropolitan Transit Authority of Harris County and the State Department of Highways and Public Transportation.

A major concern involves what vehicles will be allowed to utilize the transitway. After 2+ carpools were allowed onto the priority facility, demand grew rapidly. Volumes began to approach capacity. In response to this situation, Texas Transportation Institute evaluated alternative approaches for managing vehicular demand on the Katy Transitway. That analysis is documented in this research report.

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An Evaluation of the Impact of Permitting Carpools
to Use the Katy Transitway
Research Study 2-10-85-484

Sponsored by
Metropolitan Transit Authority of Harris County
and
State Department of Highways and Public Transportation
In Cooperation with
U.S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843

April 1988

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha

MASS (weight)

oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

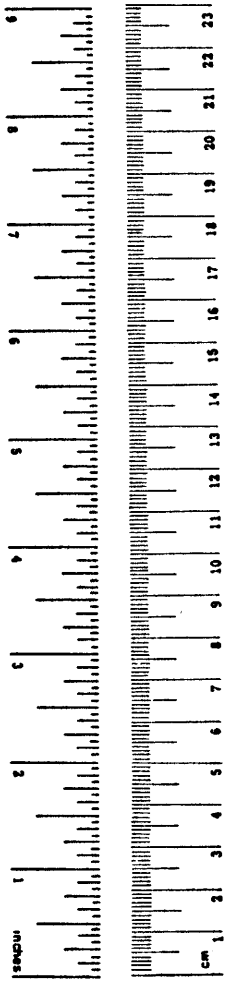
VOLUME

fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac

MASS (weight)

g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

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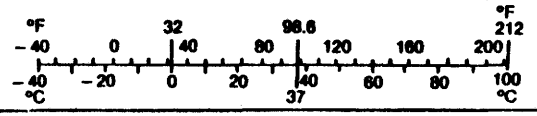

These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

ABSTRACT

Houston has made a major commitment to developing freeway transitways--special lanes designated for the use of high-occupancy vehicles. These lanes are beginning to become operational, and a major effort is being undertaken to evaluate these initial facilities in order to learn from the early experience. This research project is jointly funded by the two operating agencies -- the Metropolitan Transit Authority of Harris County and the State Department of Highways and Public Transportation.

A major concern involves what vehicles will be allowed to utilize the transitway. After 2+ carpools were allowed onto the priority facility, demand grew rapidly. Volumes began to approach capacity. In response to this situation, Texas Transportation Institute evaluated alternative approaches for managing vehicular demand on the Katy Transitway. That analysis is documented in this research report.

Key Words: Authorized vehicle lanes, Transitways, High-occupancy vehicle lanes, Priority treatment, Carpools, Demand management.

IMPLEMENTATION STATEMENT

Since there is relatively little experience with operating exclusive, reversible high-occupancy vehicle lanes, many of the operating procedures and approaches to be used in Houston are being developed through experience. This study was undertaken to assist the Metropolitan Transit Authority of Harris County and the State Department of Highways and Public Transportation in the implementation and operation of the transitways. The information presented in this report specifically addresses operating issues that have developed as a result of allowing carpools to use the transitways. Alternative approaches for managing demand are identified and evaluated.

DISCLAIMER

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SUMMARY

Summary of Recommendations

The a.m. peak hour is the critical operating period on the Katy Transitway; the a.m. peak-hour volume is approximately 1450 vehicles per hour (vph), resulting in a volume/capacity ratio of approximately 0.95. The following actions are recommended.

1. Expedite the completion of the eastern transitway extension through I-610.

2. Develop and implement procedures for incident management. These procedures will primarily involve ramp metering and/or closure.

3. Undertake an experiment to determine whether overhead cameras can effectively be used to enforce transitway operating regulations.

4. If a.m. peak-hour volumes begin to approach 1450 to 1500 vph, undertake a second mail-out (a first mail-out was sent in September) to transitway users encouraging a voluntary spreading of the peak-hour.

5. If demand begins to exceed 1500 to 1600 vph, more stringent demand management strategies will be required.

   A. Reject the alternative of requiring 3+ carpool occupancy during the peak-hour.

   B. At this time, develop procedures for implementing authorization for peak-hour transitway users. This may be the preferred approach for "routine" demand management.

   C. At this time, develop procedures for metering and/or closing ramps to control transitway volumes. This may be an acceptable approach for "routine" demand management and is definitely needed for incident management.

Introduction

Demand on the Katy Transitway during the a.m. peak-hour, as measured in September 1987, is approximately 1450 vehicles per hour (vph). As defined in the 1985 Highway Capacity Manual, at this volume the transitway is operating at level-of-service C to D.

Due to characteristics of the design, operation and demand for the Katy Transitway, congestion and delay problems on the main lane of the transitway are currently evident during only the a.m. peak hour. The locations that

influence the a.m. peak-hour capacity of the transitway are: 1) the merge volume where the Gessner slip ramp enters the transitway; 2) the geometry on the flyover ramp approaching the Post Oak intersection; and 3) the Post Oak intersection. Any actions taken to manage demand at this time should address a.m. peak-hour conditions; until the eastern transitway extension opens, it is not likely that significant congestion problems will develop on the transitway in the p.m. There is considerable unused capacity on either side of the a.m. peak hour; thus, a goal is to manage peak-hour demand without adversely impacting traffic operations outside of the peak hour.

Critical Volume Levels

Transitway Mainlane

Based on 5-minute flow rates, once flow on the transitway exceeds 1000 vph to 1200 vph, free-flow (55 mph) speeds begin to be impeded. However, it is estimated that, as long as volumes are not greater than 1200 vph and as long as an incident does not occur, the average a.m. peak-hour transitway speed between Gessner and Post Oak (the critical transitway section) will be at least 50 mph. The average speed between SH 6 and Gessner is free flow, but minor speed reductions do occur at the Addicks park-and-ride intersection.

Once transitway volume exceeds 1450 vph, average transitway speeds between Gessner and Post Oak decline to approximately 45 mph; at a volume of approximately 1500 vph, average transitway speeds drop below 40 mph. Also, as transitway volumes increase, the delay that results from transitway incidents increases substantially.

An estimated relationship between average speed on the transitway and 5-minute flow rates is depicted in Figure S-1. This graph assumes that the speeds and volumes depicted are not influenced by downstream bottlenecks.

Post Oak Flyover Ramp

Transitway traffic approaching the flyover ramp at Post Oak must reduce speed to 35 to 40 mph to safely drive through the curves and grades. As flow rates increase, the probability increases that vehicles will be queued at the signal, which requires even slower approach speeds by vehicles coming to the flyover. This speed reduction at flow rates in excess of 1200 vph causes a breakdown of operations on the approach to the flyover. However, after a queue forms at this location, a capacity of 1500 vph can be maintained on the flyover.

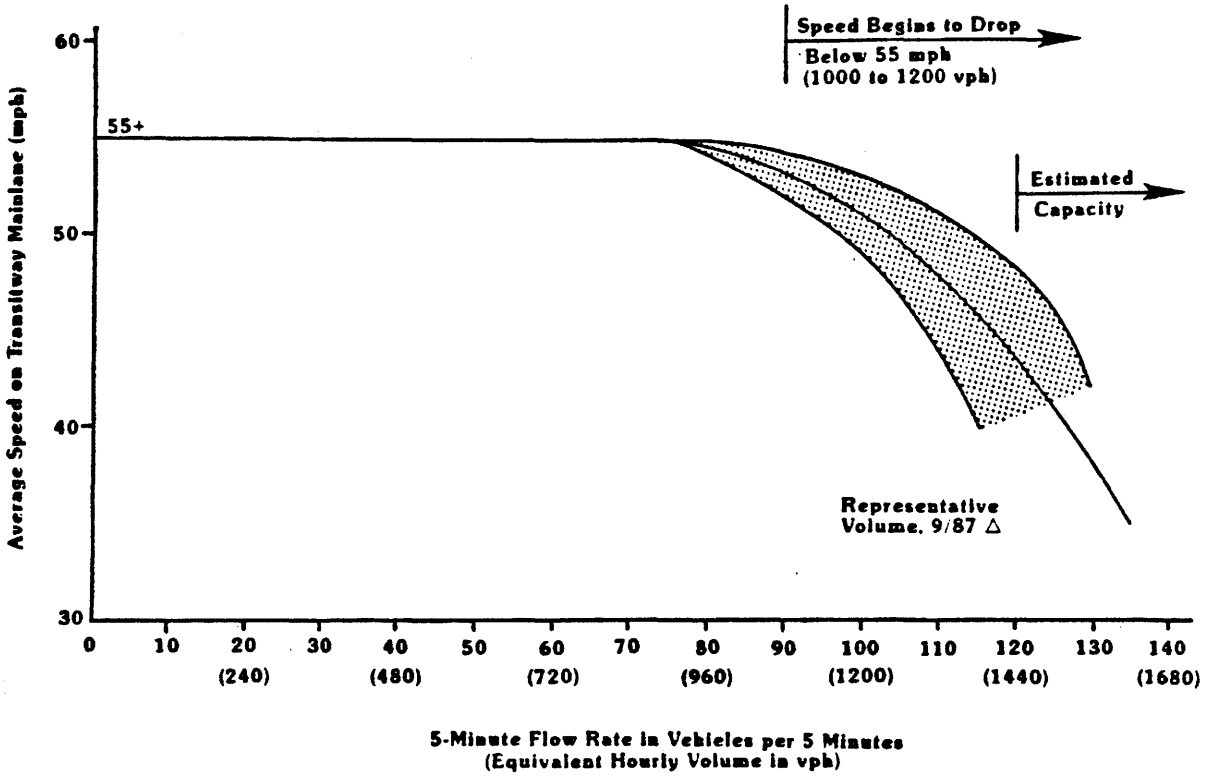


Figure S-1. Estimated Speed-Volume Relationship for Katy Transitway, Transitway Volume Not Impacted by Downstream Bottleneck

Post Oak Intersection

During the a.m. peak hour, the Post Oak intersection represents a constraint on capacity. Based on an a.m. peak-hour volume of just less than 1300 vph, stopped delay per vehicle at the Post Oak intersection was found to be 21 seconds per vehicle; a 10% increase in this a.m. volume is estimated to result in 30 seconds of stopped delay per vehicle, approximately a 45% increase in delay.

Conclusions Regarding Capacity and Speed

Once volumes exceed 1200 vph, average speeds on the transitway between Gessner and Post Oak will be less than 55 mph. An hourly volume of 1500 vph appears representative of "capacity" conditions for the Katy Transitway. This value, calculated using Katy Transitway data, is in agreement with the

observed capacity of HOV lanes throughout the United States as estimated by the agencies responsible for operating those lanes[1]. As volumes exceed this level, average speeds will begin to decline noticeably (Figure S-1), and the stability of flow will be greatly reduced; that is, incidents will occur more frequently, and the delay impacts of the incidents can become substantial. This will be particularly true if incident management techniques are not developed and implemented.

Alternative Actions to Manage Peak-Hour Volumes

The fact that congestion concerns have developed on the Katy Transitway is not unexpected; once 2+ unauthorized vehicles were allowed onto the transitway, this condition was anticipated. Relative to the other Houston transitways being constructed, managing volumes on the Katy Transitway is difficult. Only one of the a.m. entrance ramps is grade-separated. Managing volumes at the "slip" ramp locations is considerably more difficult than managing volumes at grade separated ramps.

At present, peak-hour volumes on the transitway are still just less than the estimated capacity. However, those volumes are in the 1400 to 1450 vph range, resulting in a volume/capacity ratio in the range of 0.95 for the a.m. peak hour. Modest increases in demand will create congestion problems, particularly during the a.m. peak hour. Desirably, volumes can be "managed" to maintain an a.m. peak-hour volume less than 1500 vph.

In addition to the actions that can be taken to control peak-hour volumes, the following changes in the design and/or operation of the transitway are currently being pursued.

1. Eastern extension of the transitway through I-610. This will eliminate the capacity constraints caused by the flyover ramp geometry and by the Post Oak intersection; it will also eliminate the added travel time that currently occurs on the Katy Road section from Post Oak to Washington Avenue. Its completion should be expedited. However, implementation of this improvement will make enforcement more difficult.

2. Optimize signal operation at Post Oak. This effort is currently underway and should result in some reduction in delay to transitway vehicles at the intersection by providing a more efficient timing sequence to raise the capacity of the transitway approach.

Available Management Alternatives

There are several options that can be taken to manage demand during the peak hour. The first alternative, voluntary spreading of the peak-hour, is

[1]Institute of Transportation Engineers. 1985 Survey of Operating Transitway Projects.

already being encouraged. During the first week in September 1987, post cards were mailed to carpoolers using the transitway requesting that, if possible, they use the transitway either before 7:00 a.m. or after 8:00 a.m.

The estimated impact of the alternative demand management actions on a.m. peak-hour transitway demand is shown in Table S-1. Based on expectations of transitway demand that may occur in the near future, it is estimated that, to maintain peak-hour volumes below 1500 vph, it may be necessary to reduce peak-hour demand by, at most, 10% to 20%.

Table S-1. Estimated Impact of Alternative Demand Strategies on Peak-Hour Carpool Volumes

Alternative Peak-Hour Management Action	Estimated % Reduction in 2+ Carpool Volume at the Maximum Load Point
1. Voluntary Spreading of the Peak Hour • Post card mailouts, Use of changeable message signs	0% - 3%
2. Impose a 3+ Carpool Definition During the Peak Hour	75%
3. Require Vehicle Authorization During the Peak Hour	20-40%
4. Close and/or Meter Entrance Ramps During the Peak Hour	25+%

Recommendations

At present, a.m. peak-hour volumes are in the range of 1400 to 1450 vph, resulting in volume to capacity ratios close to 1.0. It is the opinion of the Texas Transportation Institute staff that, at this volume level, each new vehicle attempting to enter the transitway is going to become part of a queue at some location. Since queues already exist on the transitway, adding 50 to 100 vehicles to these queues during peak-hour operation will result in unacceptable queueing and travel delay on the transitway.

Recommended Actions as Peak-Hour Volumes Exceed 1450 vph

As the peak-hour volume approaches and begins to exceed 1500 vph, it will be necessary to take action to manage (reduce) demand. As a minimum, the following should be pursued.

1. If volumes increase to the 1450 to 1500 vph level, undertake a second mail-out to transitway users encouraging voluntary spreading of travel patterns; this mail-out should be more direct than the initial mail-out. It should indicate that a severe congestion problem has developed and, unless voluntary spreading of the peak occurs, substantive measures such as authorization

and/or selected ramp closures will be implemented to manage transitway volume during the peak hour. A draft of such a post card is presented subsequently in this report.

2. Begin immediately to develop strategies for more effectively managing incidents on the transitway. At the high transitway volumes currently being experienced, incidents occurring on the transitway can result in severe delay and congestion problems. Appropriate strategies can significantly minimize the impact of these incidents.

3. As volumes remain high and as actions are taken to manage demand, enforcement will become more difficult. This problem will be further exacerbated when the eastern transitway extension opens; this action greatly reduces the effectiveness of the current Post Oak enforcement station. It is recommended that consideration be given to the use of overhead cameras to enforce transitway operating regulations. It would be appropriate to test the viability of this concept in the near future. Camera technology, similar to that which has been used recently in speed enforcement, should be considered for installation in the near future on the transitway for testing purposes.

Recommended Actions As Peak-Hour Volumes Exceed 1500 to 1600 vph

If volumes exceed 1500 to 1600 vph, it is unlikely that the problem will be solved through voluntary actions only. Any more substantive action taken to reduce a.m. peak-hour carpool demand can be expected to: 1) be relatively difficult to implement; 2) be relatively difficult to operate and enforce; and 3) be relatively unpopular with at least some current users of the transitway. There are no "easy" solutions.

It is recommended that the alternative of changing the peak-hour carpool definition to 3+ be rejected at this time. The impacts of this alternative on demand are too drastic for implementation at any time in the foreseeable future. The alternative of a 3+ carpool definition could reduce demand by up to 75% to 80%, far in excess of the demand reduction (10%-20%) needed to effectively manage volumes.

Two other basic options exist. One involves implementing authorization during the a.m. peak hour. The other involves selected ramp closures and/or metering during the a.m. peak-hour. Both can result in a reduction in peak-hour demand in the range of 25% to 40%. Given current demand projections, this level of reduction in a.m. peak-hour demand should satisfactorily address the transitway congestion problem.

In the opinion of the TTI research staff, at the level of knowledge that currently exists, neither is obviously superior to the other. Either can effectively address the problem that may develop. It may be that authorization is a preferred approach for "routine" demand management, and that ramp closures and/or metering represent a preferred approaching for

managing incidents and unusual operational experiences. At the volumes currently using the transitway, it is essential that incident management strategies be developed and implemented.

Given that it may be necessary to implement one of these alternatives or some combination of the two alternatives in the near future, it is recommended that a detailed plan for the implementation of both alternatives be developed by Metro and the State. Such a plan would detail procedures to follow in the implementation as well as more closely defining operating and enforcement costs. Techniques for using the available surveillance, communications and control system to assist in the implementation of the alternatives would be defined. This more detailed analysis should help identify which approach is more preferable.

INTRODUCTION

Phase 1 of the Katy Transitway opened in October 1984. At that time, only authorized buses and vans were allowed to use the transitway, and fewer than 100 vehicles used the transitway during the peak hour.

In order to address a public perception that the transitway was underutilized, the following actions have been taken to increase vehicular volumes on the transitway.

- April 1985; 4+ authorized carpools were allowed to use the transitway.
- July 1985; authorized 4+ carpools were allowed to use the transitway with only 3+ occupants in the vehicle.
- September 1985; authorized 3+ carpools were allowed to use the transitway.
- August 1986; 2+ carpools were allowed to use the transitway, and authorization requirements were eliminated.

Removing authorization and allowing 2+ carpools to use the transitway significantly increased transitway usage (Figure 1). In addition, the completion of Phase 2 of the transitway in July 1987 generated approximately a 15% increase in the a.m. peak hour carpool volume; data collected in early September indicate that, with the reopening of school, the peak-hour demand on the transitway has increased by an additional 5% to 10%; approximately 1350 to 1450 2+ carpools now use the transitway during the a.m. peak hour.

The objective of the transitway is to provide a reliable, high-speed travel alternative; the travel time savings and reliability offered by the transitway provide the incentive for travelers to use high-occupancy vehicles. It is imperative that traffic volumes using the transitway be managed at a level that avoid the creation of significant congestion on the transitway.

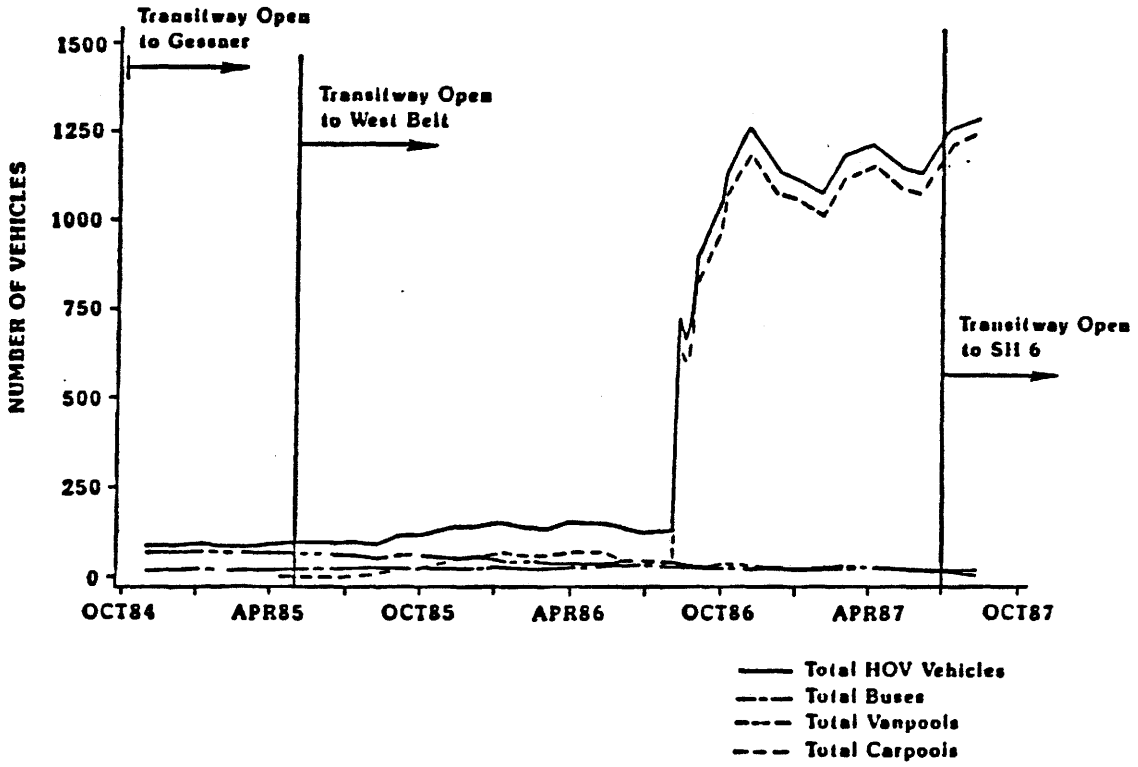


Figure 1. A.M. Peak-Hour Vehicular Volume on the Katy Transitway

Existing transitway volumes are beginning to create concerns regarding congestion on the transitway. The intent of this report is to: 1) relate transitway operating conditions to traffic volumes; and 2) identify and overview approaches that might be considered for managing the volume of vehicles using the Katy Transitway.

CURRENT TRANSITWAY OPERATING CONDITIONS

Data collected by Texas Transportation Institute in July through September, 1987, are used to define the current operating condition of the Katy Transitway.

Traffic Volumes

A.M. Operating Period

A.M. peak-hour and peak-period vehicular volumes are shown in Table 1. A maximum peak-hour volume of 1266 vph was recorded on July 8; carpools comprise approximately 95% of that volume. These volumes are depicted in Figure 2. Peak-hour volumes in the range of 1350 to 1450 have been counted since school opened in September. A 4-day analysis noted the consistent pattern of demand in that the peak-hour, as measured at Silber, began at 6:56, 6:59, 6:54 and 6:59.

Table 1. A.M. Vehicle Volumes, Katy Transitway, July 8, 1987

Time Period	Vehicle Volume			
	Total Approaching Post Oak	Entering at Gessner	Entering at Addicks P/R	Entering from I-10 West of SH6
A.M. Operating Period (5:45-11:15 a.m.)				
Bus	77	35	25	17
Vanpool	53	15	20	18
Carpool	2569	1206	515	848
Total	2699	1256	560	883
A.M. Peak Hour (7:00-8:00 a.m.)				
Bus	32	14	13	5
Vanpool	23	2	15	6
Carpool	1211	541	293	377
Total	1266	577	321	388

Note: Counts conducted in September 1987 suggest that the volumes shown in this table increased by approximately 10% with the re-opening of school; 2+ carpool volumes of 1350 vph to 1450 vph have been recorded.

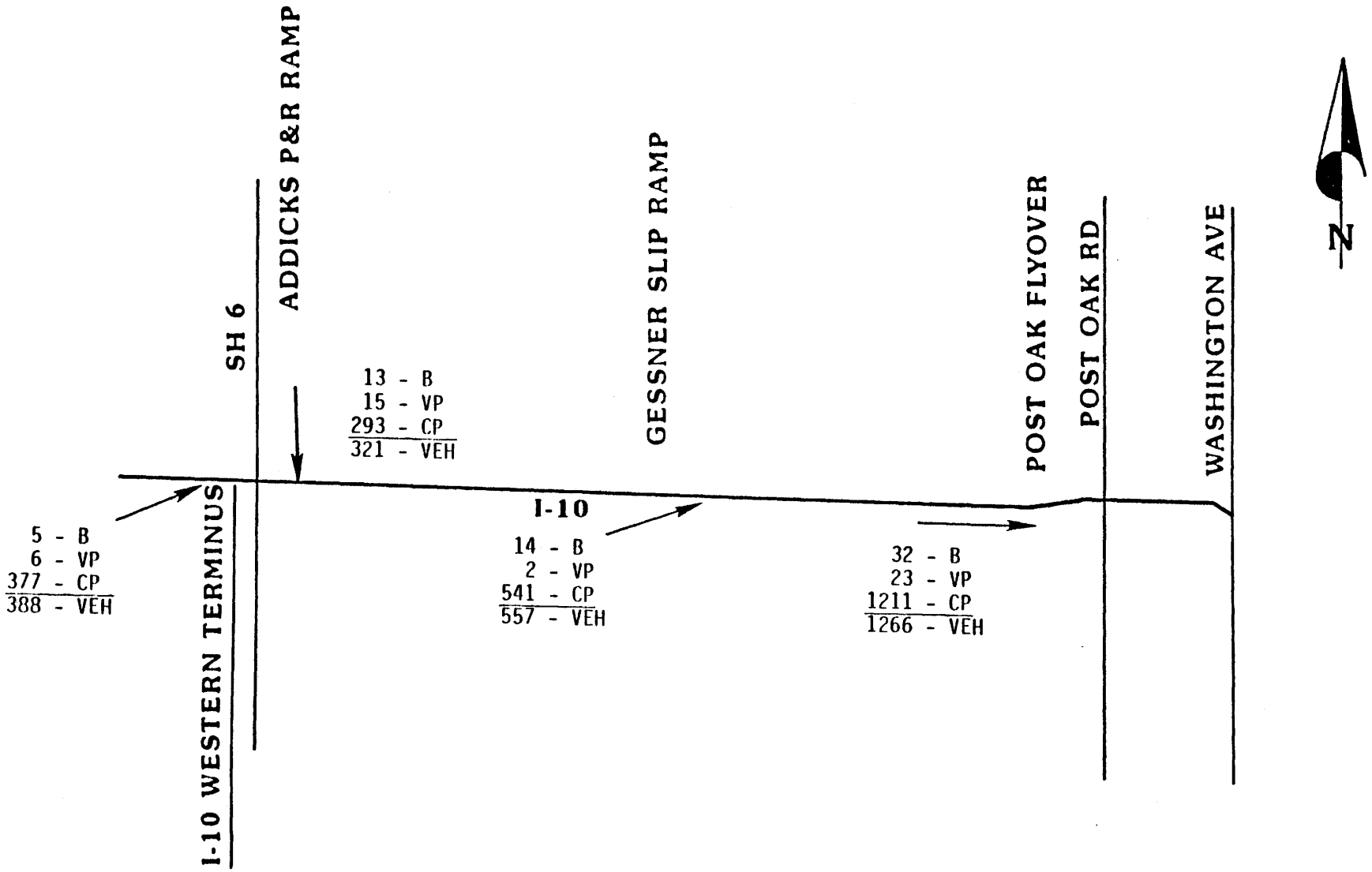


Figure 2. Katy Transitway Eastbound A.M. Peak-Hour Volumes, July 8, 1987

The transitway does experience significant peaking. While the peak-hour (7-8 a.m.) 2+ carpool volume, as measured in July, is in the range of 1200 vph, the volume from 6-7 a.m. is approximately 600 vph, and the volume from 8-9 a.m. is approximately 700 vph. A plot of 5-minute volumes (all vehicles), as measured in July, on the transitway is depicted in Figure 3. At that time, five-minute flow rates approaching Post Oak were generally in excess of 100 vehicles (equivalent 1200 vph) throughout the peak-hour. A maximum 5-minute flow rate of 131 (equivalent 1572 vph) was recorded during an August 1987 count.

P.M. Operating Period

P.M. peak-hour and peak-period volumes, as counted on July 8, 1987, are shown in Table 2. The p.m. peak-hour volume of 1111 vph is 12% lower than the a.m. peak-hour volume. The lower volume is partly the result of the p.m. peak-period demand being spread over a longer time period and partly the result of demand being metered by the traffic signal at the intersection of Post Oak and Old Katy Road. P.M. vehicle volumes are depicted in Figure 4. A 4-day analysis noted that the peak-hour, as measured at Silber, began at 4:47, 5:00, 4:57 and 4:54.

Table 2. P.M. Vehicle Volumes, Katy Transitway, July 8, 1987

Time Period	Vehicle Volume			
	West of Post Oak	Exiting at Gessner	Exiting at Addicks P/R	Exiting to I-10 West of SH6
P.M. Operating Period (2-7 p.m.)				
Bus	66	34	18	14
Vanpool	66	25	22	19
Carpool	2431	960	522	949
Total	2563	1019	562	982
P.M. Peak Hour (4:45-5:45 p.m.)				
Bus	31	15	8	8
Vanpool	22	5	11	6
Carpool	1058	426	188	444
Total	1111	446	207	458

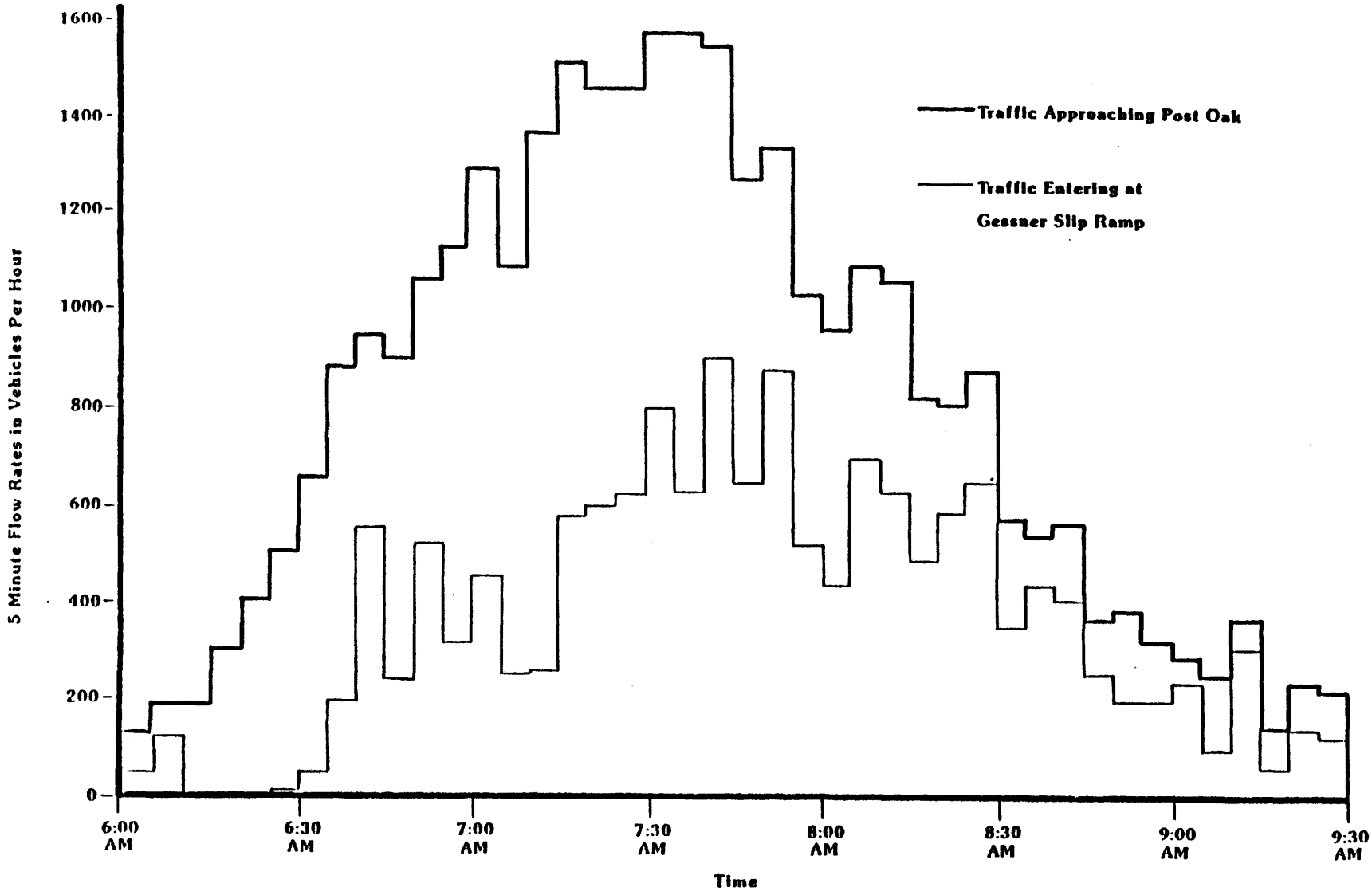


Figure 3. A.M. 5-Minute Flow Rates Approaching the Post Oak Intersection, July 8, 1987

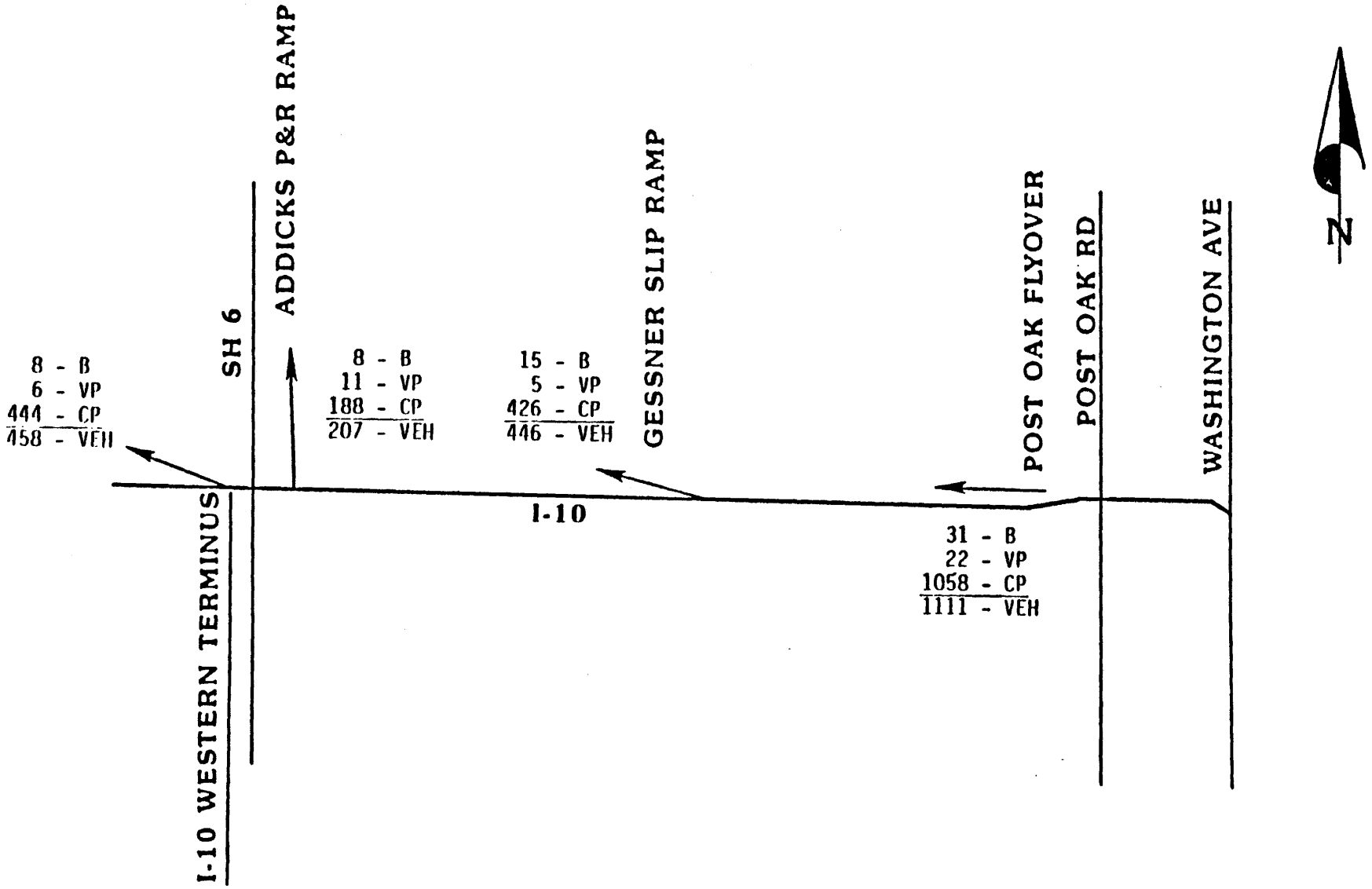


Figure 4. Katy Transitway Westbound P.M. Peak-Hour Volumes, July 8, 1987

As was the case in the a.m., the transitway experiences significant peaking in the p.m. A plot of 5-minute volumes (all vehicles as counted on July 8, 1987) on the transitway is depicted in Figure 5. The transitway volume from 3:45 to 4:45 p.m. is approximately 550 vph; the volume from 5:45 to 6:45 p.m. is approximately 750 vph.

Travel Time and Speed

A.M. Operating Period

Average speeds and travel time, by access location, have been measured for the a.m. peak period (Table 3). A plot of transitway running speeds from the western I-10 terminus to the Post Oak intersection, as measured in August 1987, is shown in Figure 6; average running speed was in excess of 45 mph during all periods of operation at that time.

Table 3. A.M. Eastbound Katy Transitway, Travel Time and Speed

Distance, Speed and Travel Time	Transitway Access Location		
	Western I-10 Terminus[1]	Addicks P/R[2]	Gessner Slip Ramp[1]
Trip Distance to Post Oak (mi.)	12.0	11.6	4.9
Average Speed in mph			
High	51	50	51
Low	46	45	36
Average	49	47	45
Travel Time in Minutes			
Short	14.1	13.9	5.8
Long	15.5	15.5	8.2
Average	14.7	14.8	6.5

[1]Measured from the slip ramp entrance.
[2]Measured from the location in the park-and-ride lot where the ramp comes to grade level.

A delay study at the Post Oak intersection, conducted during August, determined a stopped delay of 21 seconds per vehicle during the peak hour.

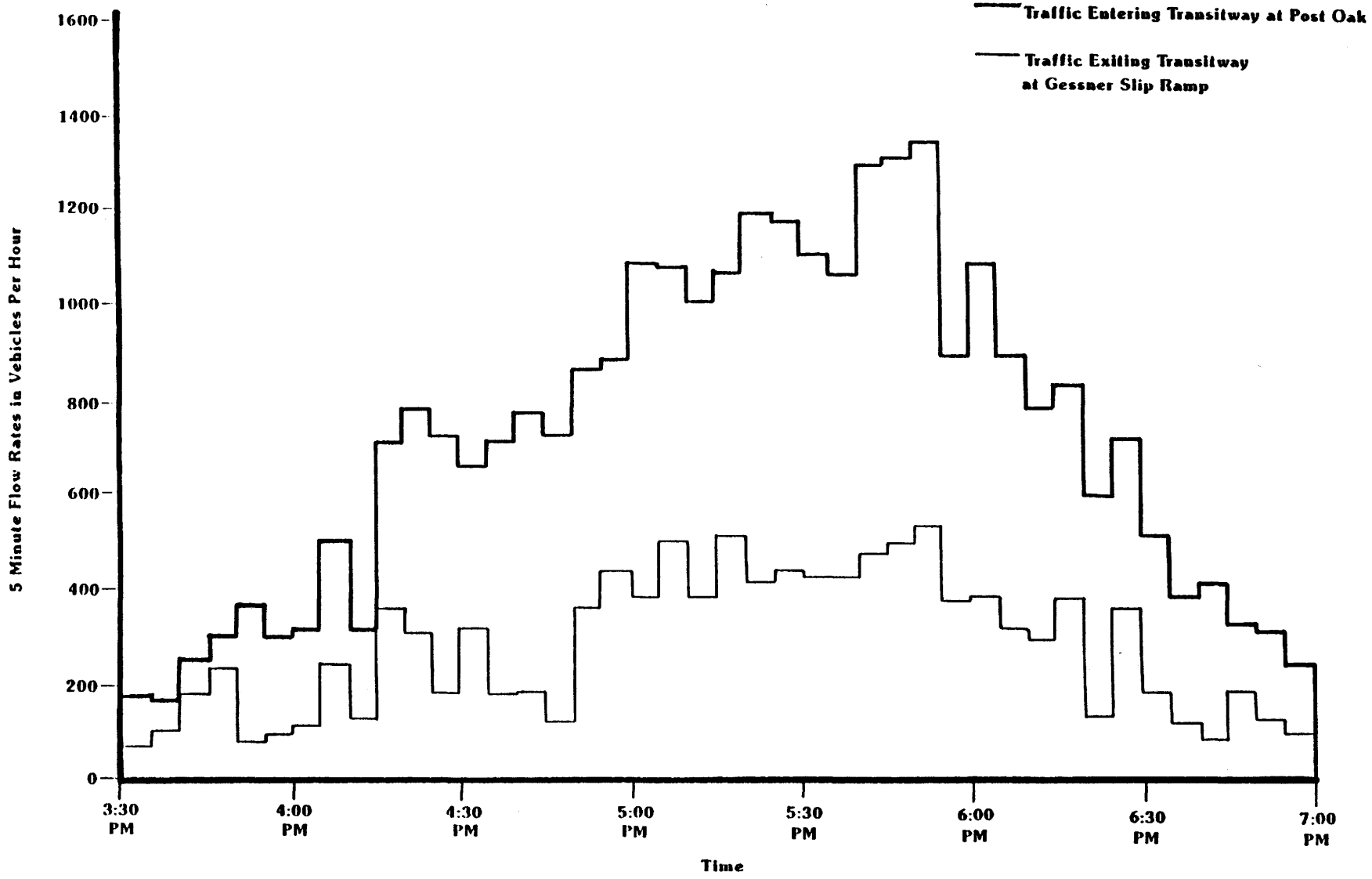


Figure 5. P.M. 5-Minute Flow Rates Entering the Transitway at Post Oak, July 8, 1987

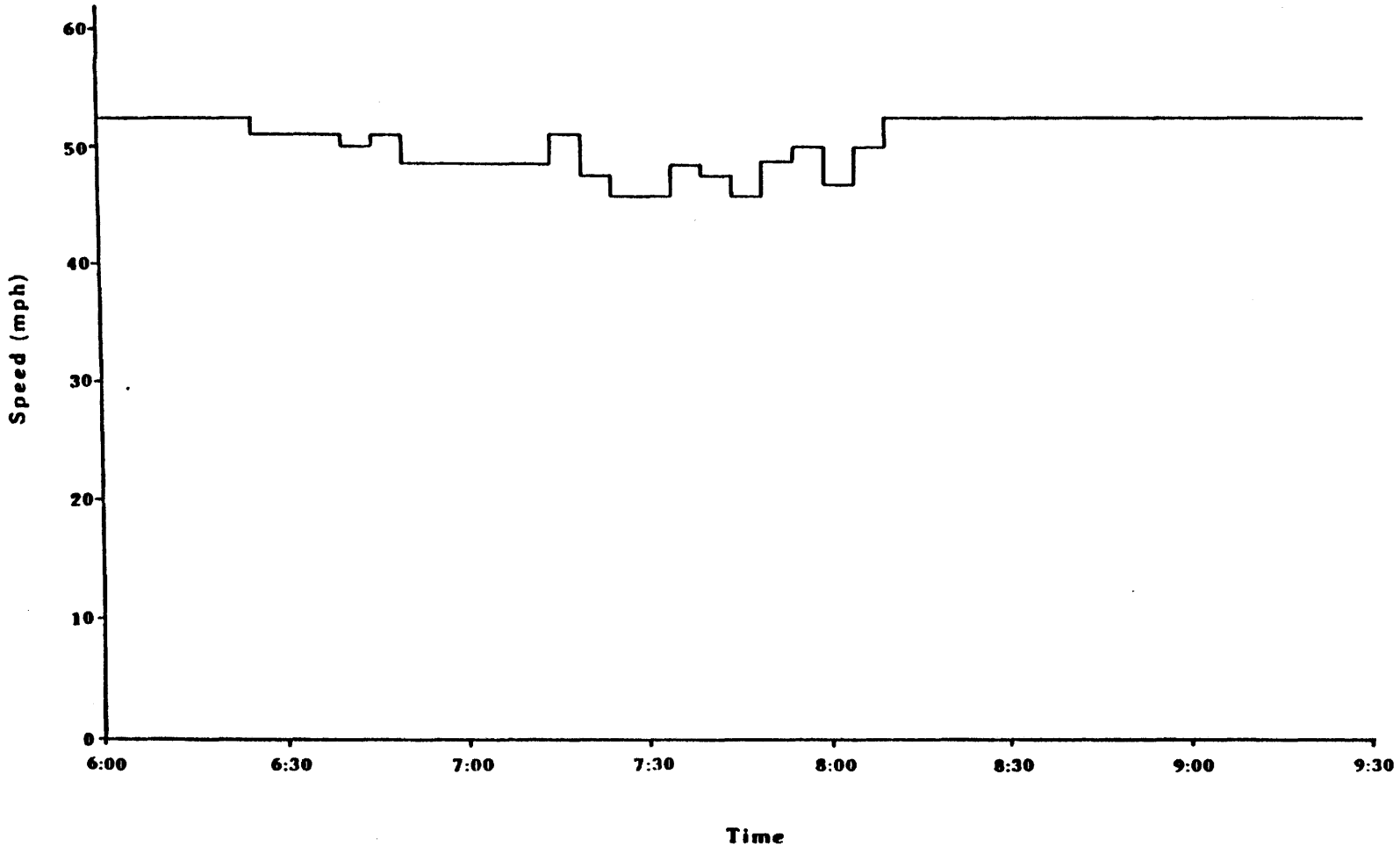


Figure 6. A.M. Average Transitway Running Speeds From Western Terminus to Post Oak Intersection, July 15, 1987

Of the 50 cycles observed, 3 were considered to have failed. The highest flow rate through the intersection was 1350 vph.

Additional analysis of travel time data is included in a subsequent section of this technical memorandum.

P.M. Operating Period

Since there is no access to the transitway west of Post Oak and since the capacity of the Post Oak intersection is similar to the capacity of the line-haul transitway, noticeable delay does not occur on the transitway in the p.m. Delay does occur on the approach to the intersection. This condition should continue at least until the eastern Katy Transitway extension is opened.

General Impacts of an Eastern Transitway Extension

Plans are currently being developed to extend the transitway through the I-610 interchange. For the vehicles that would use this extension (approximately two-thirds of the a.m. volume), an additional time savings of approximately 2 minutes will be realized. Implementation of this improvement will make enforcement of transitway regulations more difficult.

The eastern extension will have the following general impacts.

1. In the a.m., the capacity constraint at Post Oak created by both the intersection and the geometry of the flyover ramp will be eliminated, and delay reduced. Many of the a.m. congestion problems will be significantly alleviated. However, the resulting travel time savings will also provide some incentive for vehicles to be willing to incur delay at the Gessner transitway ramp in order to use the transitway. Congestion at that ramp merge location should increase.

2. In the p.m., two major transitway access locations will exist, and a merge will occur where the existing flyover ramp enters the

transitway. These merge volumes will be higher than the transitway mainlane volumes now experienced during the p.m. (Figure 5). This will create a possible capacity constraint; it would appear that this problem can be addressed through metering of the traffic entering the transitway from the Post Oak intersection. This could be accomplished either through timing of the signal or through installation of a ramp meter in advance of the flyover.

Conclusions

Based on current operations, the following conclusions appear valid.

1. To the extent that a volume/capacity problem exists, the problem is a peak-hour problem; at present, it is essentially an a.m. peak-hour problem. Although there is significant delay on the approach to the Post Oak intersection in the p.m., once traffic enters the transitway little delay is experienced. The peak-hour volume is 50% to 100% greater than the volume for an hour on either side of the peak hour. The a.m. peak hour is from 7-8 a.m.; the p.m. peak hour is from 5-6 p.m. The goal is to be able to manage a.m. peak-hour volumes without adversely affecting volumes outside of the peak-hour.

2. Volume and "congestion" problems are most apparent during the a.m. peak hour; the a.m. peak-hour volume is 10% to 15% greater than the p.m. peak-hour volume. A.M. congestion problems can occur primarily at three locations: 1) at the Gessner access location; 2) on the flyover ramp approaching the Post Oak intersection; and 3) at the Post Oak intersection. Implementation of the eastern transitway extension will significantly alleviate problems at two of these locations and will intensify problems at the third location (Gessner access ramp).

TANSITWAY DEMAND/CAPACITY RELATIONSHIPS

Current Level-of-Service

Level-of-service on the transitway is estimated using the 1985 Highway Capacity Manual at the following locations: 1) basic section; 2) ramp merge at Gessner; and 3) Post Oak intersection. Observation is used to estimate the capacity of the flyover ramp. These levels-of-service calculations are based on the a.m. peak-hour volumes observed during July and August 1987.

Basic Section

At the maximum load point, an a.m. peak-hour volume of approximately 1350 to 1450 pcph (passenger cars per hour) occurs. As shown previously, this volume travels at a speed in the range of 45 to 50 mph. The resulting density (27 vehicle/mile) equates to level-of-service C.

Ramp Merge at Gessner

Assuming the transitway to be a freeway section with a one-lane ramp entering at Gessner, the a.m. peak-hour merge volume would be 1350 to 1450 pcph. This equates to level-of-service C.

Post Oak Intersection

Analyses conducted by Texas Transportation Institute found a.m. peak-hour average stopped delay per vehicle to be 21 seconds. This is also equivalent to level-of-service C.

Flyover Ramp Approaching Post Oak

This ramp has a combination of horizontal and vertical curves that influence capacity. Observation suggests that a 5-minute flow rate of approximately 125 vehicles (equivalent to 1500 vph) represents capacity of this flyover ramp. This volume cannot, however, be sustained at free-flow speeds. Flow rates of 1300 vph at free-flow speeds will cause a breakdown in

operations, the formation of a queue, and a reduction in speeds to less than 35 mph. This is equivalent to a level-of-service of D to E.

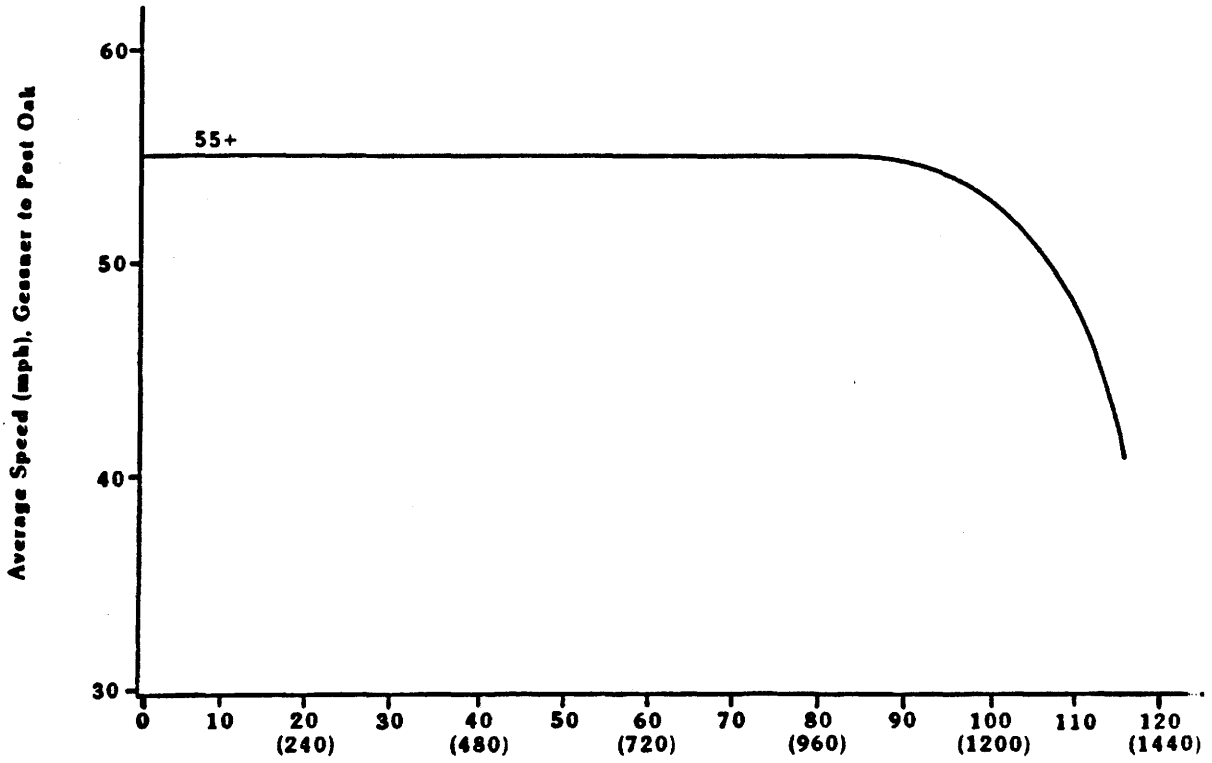
Conclusions

Assuming that the transitway is essentially equivalent to a freeway lane and using the 1985 Highway Capacity Manual, during July and August the transitway was operating at level-of-service C. As shown previously (Table 3), that operation resulted in relatively little delay to transitway traffic. Since September, the level-of-service appears to have declined to the C to D range.

Speed/Volume Relationship

Based on observation of the transitway operation, the speed/volume relationship shown in Figure S-1 was developed. This relationship applies to operation on the transitway in locations not influenced by downstream bottlenecks. Once volumes begin to exceed 1000 to 1200 vph, operating speeds begin to drop below 55 mph. That condition has already developed on the transitway.

Based on current volumes and peaking characteristics, Figure 7 was developed. This figure presents average travel speed between Gessner and Post Oak. This relationship does not consider delay incurred in passing through the intersection; it does, however, consider the bottleneck and associated delay created by the geometry of the flyover ramp. Observation suggests that the capacity of the flyover ramp is in the range of 125 vehicles per 5 minutes (equivalent 1500 vph). Once transitway volumes exceed this level, some queueing can be expected to occur at this location.



Note: This Relationship Includes the Bottleneck Created by the Geometry of the Flyover Ramp. It Does Not Include Delay Experienced at the Post Oak Intersection.

Figure 7. Estimated Average Travel Speed as Related to Volume, Katy Transitway, A.M. Operation Between Gessner and Post Oak

Transitway Volume/Capacity Ratio

Based on the analyses and data presented previously, it is the opinion of the Texas Transportation Institute research staff that the "capacity" of the Katy Transitway is essentially 1500 vph. This estimated capacity is consistent with observed capacities for other high-occupancy vehicle lane projects[1].

[1]Institute of Transportation Engineers. 1985 Survey of Operating Transitway Projects.

The estimated capacities of the bottleneck features of the Katy Transitway are as follows:

- Transitway Mainlane 1500 vph
- Flyover Ramp 1300 - 1500 vph
- Post Oak Intersection 1500 - 1600 vph

At present, a.m. peak-hour volumes in the range of 1400 to 1450 vph are being observed on the transitway. In effect, the volume/capacity ratio is currently in the range of 0.95; the Katy Transitway is presently operating at capacity.

Delay Impacts of Additional Volume Increases

Since the transitway is presently operating near capacity, as additional vehicles enter the system during the peak hour, these vehicles are going to end up in a queue in at least one of the bottleneck locations. Partly for this reason, the relationship between transitway volume and delay time becomes exponential.

Texas Transportation Institute calculations indicate that, in the range in which current transitway volumes occur, 10% increases in volume result in significantly greater increases in delay (Table 4).

Table 4. Estimated Relationships Between a.m. Volume and Increases in Travel Time and Delay

Location	Change in Volume		Change in Travel Time or Delay		
	Initial Volume vph	% Increase in Volume	Travel Time at Initial Volume	Travel Time @ 10% Greater Volume	% Increase in Travel Time
Travel Speed Between Gessner and Post Oak	1230	+10%	53 mph	41 mph	+23%
Stopped Delay Time at Post Oak Intersection	1230	+10%	21 seconds	30 seconds	+43%

As a result of these non-linear relationships, as volumes begin to exceed 1500 vph, it will become important to take actions designed to manage demand levels.

Conclusions

- The transitway in July and August was operating at level-of-service C during the critical a.m. peak hour.

- Once volumes exceed 1000 to 1200 vph, speeds on the transitway will begin to fall below 55 mph.

- Capacity of the transitway is estimated to be 1500 vph.

- Given the need to keep the transitway operating at a high speed and the presence of several bottlenecks, the peak-hour volume/capacity ratio on the transitway in September is greater than 0.9.

- Some queueing already occurs on the transitway. As volumes begin to exceed 1500, additional vehicles entering the system will end up in a queue in at least one bottleneck location. If volumes exceed 1500 vph, significant queues and delay may develop unless actions are taken to manage demand.

ALTERNATIVE ACTIONS TO MANAGE VOLUMES AND SPEEDS

Data presented previously suggest that the transitway is presently operating near capacity. Some queueing currently develops and, as additional traffic attempts to enter the transitway during the a.m. peak hour, that traffic is going to end up in a queue at some location; queue lengths could become substantial. Thus, if volumes continue to increase and exceed 1500 vph, it will be necessary to take action to manage demand.

In addressing the problem, the following need to be recognized.

- Based on current operation of the transitway, the problem is an a.m. peak-hour concern. The goal should be to manage a.m. peak-hour demand without adversely impacting the traffic operations that occur outside the peak hour. This condition will exist at least until the eastern transitway extension is opened.

- Based on the best available information on demand for the Katy Transitway, it does not appear that demand will exceed 1700 to 1800 vph in the near future. Thus, demand management techniques may be needed to reduce peak-hour demand by, at most, 10% to 20%.

- Demand management is synonymous with demand reduction. Altering existing travel habits through regulatory action, while possibly necessary, can nevertheless be controversial.

The following alternative demand management actions are overviewed in this document.

1. Voluntary spreading of peak-hour demand.
2. Imposing a 3+ carpool definition during the peak hour.
3. Requiring authorization during the peak hour.
4. Closing and/or metering entrance ramps during the peak hour.

Voluntary Spreading of Peak-Hour Demand

Since the transitway does experience sharp peaking, if a relatively small percentage of the traffic using the transitway could be encouraged to alter its trip time in order to not be on the transitway during the peak hour, the congestion problem could be "solved". Efforts to accomplish this have already been instigated. The following post card was sent to 1500 carpoolers in September.

> "It is the intent of the Metropolitan Transit Authority and State Department of Highways and Public Transportation to maintain a 55 mph operation on the Katy Transitway. This makes the transitway an attractive alternative to the mainlanes.
>
> The introduction of two person carpools has significantly increased traffic volumes. We are concerned about the additional traffic that may result when school starts. If further increases do occur, the transitway could become congested during the peak hour (7:00 a.m. to 8:00 a.m.) and speeds could be sharply reduced.
>
> Therefore, we seek your assistance in addressing this problem. The highest volume of vehicles use the transitway between 7:00 a.m. and 8:00 a.m. If you can adjust your morning travel to either use the transitway before 7:00 a.m. or after 8:00 a.m., we may be able to avoid congestion on the transitway and maintain 55 mph operations.
>
> Thank you for your cooperation. Note: Effective August 24, the afternoon hours for the Katy Transitway have been extended from 2-7 p.m. to 2-8 p.m.
>
> If there are any questions, please call METRO at 227-0003."

However, since, relative to the freeway, the transitway operates well even during the peak hour, it is estimated that this post card will have minimal impacts. It does accomplish the purpose of making the users aware that a problem may exist and offering them a voluntary approach for solving the problem.

If a.m. peak-hour volumes continue to increase and approach 1500 vph, it is recommended that a second post card be mailed. The general thrust of that post card should be to say that a problem has developed and, unless travel is voluntarily adjusted to reduce peak hour demand, more stringent actions will be taken by the operating agencies to assure that satisfactory operations are maintained on the transitway. Such a post card might read as follows ...

> "It is the intent of the Metropolitan Transit Authority and the State Department of Highways and Public Transportation to maintain a 55 mph operation on the Katy Transitway. That makes the transitway an attractive alternative to the mainlanes.
>
> As you are probably aware, at present during the a.m. peak hour (7-8 a.m.), we are experiencing significant congestion on the transitway. We seek your assistance in addressing this problem.
>
> If you can adjust your morning travel to either use the transitway before 7:00 a.m. or after 8:00 a.m., we may be able to reduce the peak-hour congestion on the transitway. If this voluntary approach is not successful in accomplishing this objective, more stringent regulatory measures will be imposed.
>
> Thank you for your cooperation. If there are any questions, please call METRO at 227-0003."

It is also recommended that consideration be given to manners in which the changeable message signs might be used to encourage traffic to voluntarily not enter the transitway during at least portions of the peak hour.

If transitway demand exceeds 1550 to 1600 vph, it is unlikely that the problem can be solved through voluntary action only. However, voluntary action should be pursued in conjunction with any other actions taken.

Imposing a 3+ Carpool Definition During the Peak Hour

The occupancy requirement to use the transitway could be adjusted to reduce vehicular volume during the peak hour. While the approach of varying occupancy requirements for a transitway by time of day has not been done before, with the surveillance, control and communication system and adequate enforcement, such a system could be implemented. Previous TTI research (Table 5) has estimated the impacts that a 3+ carpool definition would have on demand.

It is recommended that this alternative be rejected at this time. This approach may reduce demand by 75% to 80% and, since it appears that it will only be necessary to reduce demand by 10% to 20%, this alternative action would be an "overkill" for the problem. Indeed, it could cause the lane to appear seriously underutilized during the peak hour which might antagonize the regular motorists on the freeway mainlanes as well as the carpoolers no longer eligible to use the transitway.

Require Authorization During the Peak Hour

The authorization concept would be reintroduced. Carpools using the transitway during the peak hour would have to display a permit (possibly a permit that hangs from the rear view mirror). With appropriate use of enforcement and the surveillance, communications and control system, implementation of this alternative appears feasible.

Previous TTI research (Table 6) has estimated the impacts of authorization on transitway demand. It is estimated that implementation of authorization would reduce demand by 40%. This estimate may be somewhat high in that the authorization procedure used was more stringent than would be employed were this concept reintroduced; however, since the operating agencies have control over the number of authorization permits issued, they can, in effect, assure that at least an acceptable demand reduction is achieved through this approach.

Table 5. Estimated Impact on Carpool Vehicle Demand of Changing From a 2+ to a 3+ Carpool Definition

Data Source	Ratio of Estimated 3+ to 2+ Vehicular Demand[1]
Nationwide Experience[2]	
Portland, Oregon; Banfield Freeway	
3+ = 200/hr., 2+ = 900/hr.	0.22
Miami, Florida; I-95	
3+ = 200/hr., 2+ 800/hr.	0.25
New Jersey; Garden State Parkway	
3+ = 300/hr., 2+ = 900/hr.	0.33
Katy Freeway; Houston (Change from 3+ to 2+)	
3+ authorized = 100/peak period	0.05
2+ unauthorized = 2100/peak period	
Katy Freeway; Houston (Transitway volumes after change to 2+)	
3+ = 260/peak period, 2+ = 2100/peak period	0.12
Katy Freeway Carpool Survey	
• Response to question "Prior to allowing 2-person carpools onto the transitway in August, did you use the transitway?" Yes, Bus = 6%; Yes, Van = 3%; Yes, 3+ Carpool = 9%, No = 82%	0.09
• Response to question "Would you be using the transitway if 2-person carpools were not allowed on the transitway?" Yes = 13%; No = 82%; Not Sure = 6%	0.16
Houston Freeways, Mainlane Peak-Period Carpool Volumes	
• North; 2+ = 1878, 3+ = 240	0.13
• Gulf; 2+ = 1305, 3+ = 157	0.12
• Southwest; 2+ = 1424, 3+ = 124	0.09
• Northwest; 2+ = 1139, 3+ = 73	0.06
Range of Values	0.05 to 0.33
Average Value	0.15
Suggested Range for Houston Planning	0.10 to 0.25
Suggested Value for Houston	0.20 to 0.25

[1]Assuming an average vehicle occupancy of 3.2 with a 3+ definition and 2.2 with a 2+ definition, to convert 2+ person demand to 3+ person demand, the suggested value would be approximately 0.3 (0.20 x 3.2/2.2)

[2]HOV lane experiences where the eligible carpool definition was changed from 3+ to 2+.

Source: "The Houston Transitway System, Preliminary Carpool Demand Estimation," prepared for State Department of Highways and Public Transportation by Texas Transportation Institute, February 1987.

Table 6. Estimated Factors For Converting Unauthorized Carpool Demand to Authorized Carpool Demand

Data Source	Authorized as a Percent of Unauthorized
Katy Transitway, Houston (Change from Authorized to Unauthorized in August 1986)[1]	44%
3+ Volume During Authorization (12/85-5/86) = 187/day 3+ Volume Without Authorization (9/86-2/87) = 428/day	
Katy Transitway Carpool Survey (10/86)	
• Response to question "If it were still necessary to be issued a permit by Metro to be authorized to use the transitway, would you be using the transitway?" Yes = 55%; No = 23%; Not Sure = 22%	66%
• Response to question "If Metro finds it necessary to issue permits to maintain free flow, would you be willing to get a permit?"	76%
Katy Transitway Carpool Survey (4/87)	
• Response to question "If you carpooled prior to August 1986 but did not use the transitway, why did you choose to not use the transitway (responses from 3+ carpools)?" 58% Authorization process was too cumbersome 48% Other	62%
Range of Values	44% to 76%
Average Value	62%
Suggested Value for Houston Planning	60%

[1]At the time authorization was eliminated, the eligible carpool definition was also reduced from 3+ to 2+.

Source: "The Effects on Transitway Utilization of the Vehicle Authorization Process." Prepared for the State Department of Highways and Public Transportation by Texas Transportation Institute, August 1987.

Since the 40% estimate may be high with a less stringent authorization procedure, a range of 20% to 40% is assumed to be representative of the demand reduction implications of authorization.

This approach appears viable and should be considered for possible implementation. The following difficulties need to be realized.

1. Adequately informing the public of the strategy will be difficult. In addition to other means of notifying the public, adequate signing will need to be provided to inform motorists of the requirements for using the transitway.

2. Metro will need to develop procedures and commit resources for authorizing large volumes of vehicles.

3. Strict enforcement will need to be provided.

4. Since all demand management strategies are intended to adversely impact some current users of the transitway and since some confusion will exist over peak-hour only authorization, adverse public reaction may be generated.

Nevertheless, this is possibly the most viable strategy available for handling "routine" demand management. It is recommended that detailed procedures be developed for its implementation. Once those procedures are developed, it should be easier to ascertain whether this is the preferred alternative.

Close and/or Meter Entrance Ramps During the A.M. Peak Hour

A final option involves reducing access to the transitway for all or part of the peak hour by either closing ramps or metering ramp volumes. Given the current operation of the transitway, ramp metering is only possible at the ramp from the Addicks park-and-ride lot.

A problem involved with restricting volumes entering the transitway in the vicinity of SH 6 is that most of that traffic would still use the Katy Freeway and could enter the transitway at Gessner. To achieve a significant reduction (5+%) in carpool volumes on the transitway through altering ramp operations, it would probably be necessary to close the Gessner access ramp during at least portions of the peak hour. It is estimated that such an action would reduce transitway volumes by 25% to 30%. Thus, to achieve a 5% reduction in peak-hour volume, the ramp would have to be closed 15% to 20% of the time, or 9 to 12 minutes.

This action has the following problems.

1. Adequately informing the public of the strategy will be difficult. Again, adequate signing will need to be provided.

2. If the ramp is left open for buses but closed to carpools, enforcement will be difficult.

3. Extreme opposition can be expected from current users of the ramp.

4. Such an action discriminates against shorter trips in favor of longer trips, which can raise questions of equity.

Before the alternative is rejected in favor of authorization, development of a more detailed operational plan seems appropriate. Such a plan would develop and evaluate strategies for a variety of possible actions, including the following.

1. Close the slip ramp to the west of SH 6, either to all traffic or maintain bus access only.

2. Close the ramp to, or meter, carpool traffic using the ramp from the Addicks park-and-ride lot.

3. Close the slip ramp at Gessner, either to all traffic or maintain bus access only.

4. Some combination of the above listed alternatives.

Regardless of whether these strategies are employed on a routine basis to manage demand, operational plans should be developed that would allow use of these approaches during incident management. Indeed, these approaches are essential to effectively handle incidents. It should also be noted that, on other Houston transitways where most access locations are grade separated, ramp metering will be a more viable alternative.

CONCLUSIONS

Managing demand, in effect, means reducing demand. Any regulatory actions taken to reduce demand can be expected to generate at least some public opposition. Adequate operating and enforcement personnel will need to be available to implement any demand management strategy.

It is anticipated that the demand management strategies will need to reduce peak-hour demand by, at most, 10% to 20%. Table 7 summarizes the estimated impact of the demand management strategies considered.

Table 7. Estimated Impact of Alternative Demand Strategies on Peak-Hour Carpool Volumes

Alternative Peak-Hour Management Action	Estimated % Reduction in 2+ Carpool Volume at the Maximum Load Point
1. Voluntary Spreading of the Peak Hour • Post card mailouts, Use of changeable message signs	0% - 3%
2. Require 3+ Carpool Occupancy During the Peak Hour	75%
3. Require Vehicle Authorization During the Peak Hour	20-40%
4. Close and/or Meter Entrance Ramps During the A.M. Peak Hour	25+%