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16. Abstract

Congestion on urban freeways impacts safety, motorist delay, air quality, and energy consumption. In areas where travel demand far exceeds capacity, some level of congestion will be inevitable. However, where imbalances in the freeway system exist, bottlenecks restrict the use of available capacity. Valuable capacity can be recaptured, congestion reduced, and impacts diminished if these bottlenecks can be removed. This research report defines bottlenecks, discusses methodologies for identifying and determining the cause(s) of a bottleneck, suggests appropriate ways to alter geometrics to diminish the impacts of a bottleneck, and provides a methodology to estimate the benefits to be expected from implementing a bottleneck improvement. Examples of implemented projects where before and after data have been collected are also discussed.

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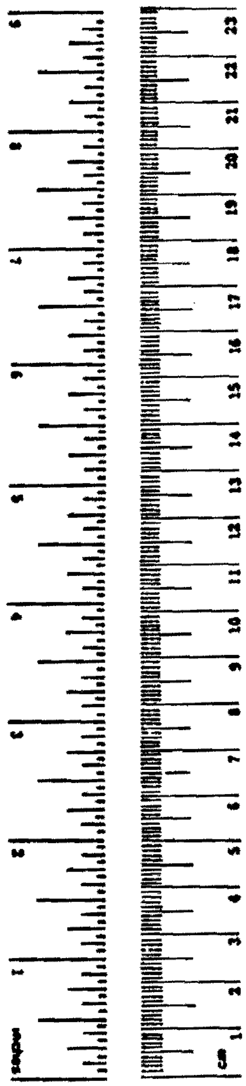
METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	2.54	centimetres	cm
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	centimetres squared	cm^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

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
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
TEMPERATURE (exact)				
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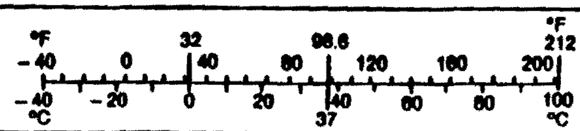

These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

METHODOLOGY FOR ASSESSING FEASIBILITY OF BOTTLENECK REMOVAL

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ABSTRACT

Congestion on urban freeways impacts safety, motorist delay, air quality, and energy consumption. In areas where travel demand far exceeds capacity, some level of congestion will be inevitable. However, where imbalances in the freeway system exist, bottlenecks restrict the use of available capacity. Valuable capacity can be recaptured, congestion reduced, and impacts diminished if these bottlenecks can be removed. This research report defines bottlenecks, discusses methodologies for identifying and determining the cause(s) of a bottleneck, suggests appropriate ways to alter geometrics to diminish the impacts of a bottleneck, and provides a methodology to estimate the benefits to be expected from implementing a bottleneck improvement. Examples of implemented projects where before and after data have been collected are also discussed.

DISCLAIMER

This study, Urban Highway Operations Research and Implementation Program, was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views of the Texas Department of Transportation or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permit purposes.

Engineer in Charge: Carol H. Walters, P.E.
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INTRODUCTION

Placing a kink in a hose restricts the flow of water, regardless of the capacity of the hose. Similarly, a "kink" in a freeway system (referred to as a bottleneck), usually occurring at a ramp junction, causes the available capacity to be under-utilized, with congestion (stored demand) upstream and free flow conditions at a volume reflecting the bottleneck capacity downstream. The bottleneck may limit flow downstream to less than the available freeway capacity. In this era of maximizing the efficiency of our existing traffic systems, bottlenecks need to be understood, and where appropriate, eliminated. Often the constriction can be removed through a relatively low-cost improvement to a short section of the freeway, within existing right-of-way, perhaps requiring only conversion of a shoulder to a driving lane with slight narrowing of mainlanes from 12 feet to 11 feet.

Not every site with recurrent congestion is caused by a bottleneck. Demand on some freeways is simply over capacity, and unstable flows frequently break down into stop-and-go conditions. This report will 1) define bottlenecks, 2) discuss methodologies for identifying a bottleneck and discovering its causes (there may be more than one, and they can be deceptive), 3) suggest appropriate ways to alter geometrics to better fit the demand, and 4) provide a methodology to estimate benefits expected from bottleneck removals, as a means of determining the feasibility and priority of a proposed project. Examples of implemented projects where before and after data have been collected are included, along with the lessons learned.

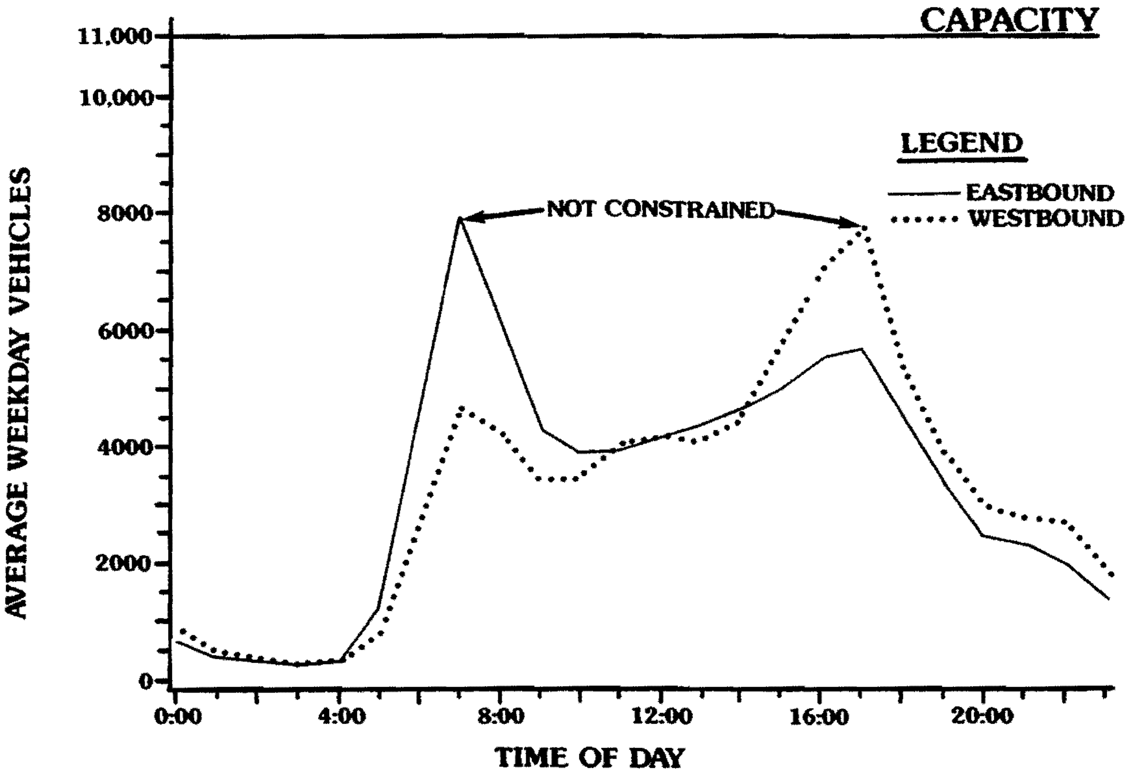
IDENTIFYING A BOTTLENECK

A bottleneck is defined, for the purposes of this report, as a short section of freeway for which the demand, in one or more lanes, exceeds capacity, resulting in congestion upstream and freeflow conditions downstream. The reasons bottlenecks occur in our freeway systems are two-fold. First, design hour volumes for ramps are not well predicted by simple use of K and D factors provided for freeway design. The Highway Design Manual suggests use of the formula "$DHV = 2 \times K \times D$" to convert twenty-four hour volume projections for ramps into design hour volumes. In reality, actual ramp volumes have little correlation to the adjacent freeway K and D values and indicate that local land use patterns are of much greater significance in peak hours. Thus, accomplishing a good interchange design to meet future peak hour demands is difficult.

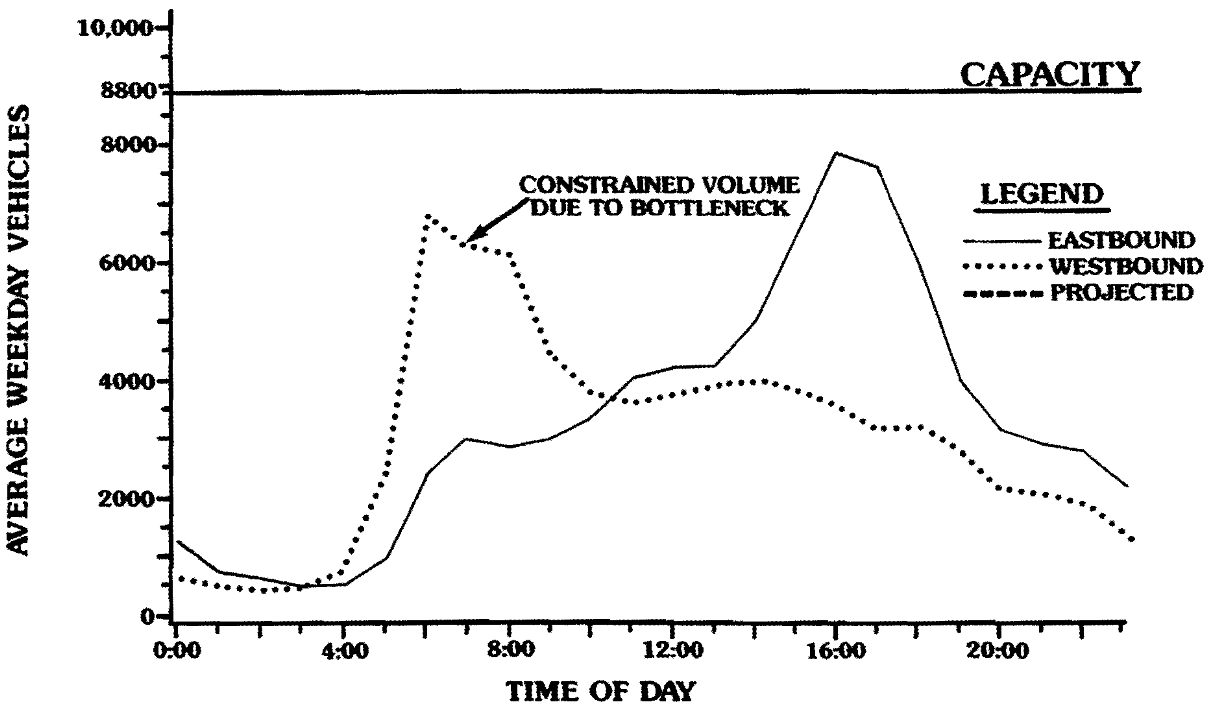
The second reason bottlenecks occur is that facilities are designed for volumes expected in the design year, perhaps as much as twenty-five years in the future; and land use changes may not be easily predicted that far into the future, so even the twenty-four hour projections may eventually prove to be highly inaccurate. It should therefore be no surprise that bottlenecks develop, and every attempt should be made to fix them when they do.

Obvious candidates for inspection for possible bottlenecks are areas of recurrent congestion; these may be discovered via traffic reports, complaints to the districts, or personal contacts or experience. The presence of a bottleneck may be detected by observing the typical daily profile from the Automatic Traffic Recorder (ATR) station on that freeway. The ATR stations are operated and maintained by TxDOT (D10), and books of ATR data are published yearly. Two typical data profiles are shown in Figure 1. The first profile, at a location in Houston where capacity is not reached, exhibits a normal peak in both of the peak periods. The second profile, at a location in Dallas, is truncated short of capacity in the morning peak period, indicating the possible presence of a bottleneck either upstream or downstream of the count station. (An upstream bottleneck will create "metered flow" conditions at the count station, while a downstream bottleneck will cause stop-and-go conditions which may extend past the count station location; either will result in lower peak hour volume counts over the count station, which do not reflect demand.)

Other data is often needed to identify a bottleneck and to determine its cause(s).



Traffic Volume Profile, Free-Flow Operation
IH-610 (South), Houston, Texas



Traffic Volume Profile, Eastbound Bottleneck
IH-30 (East), Dallas, Texas

Figure 1. Daily Traffic Volume Profiles

DETECTING CAUSES: DATA COLLECTION

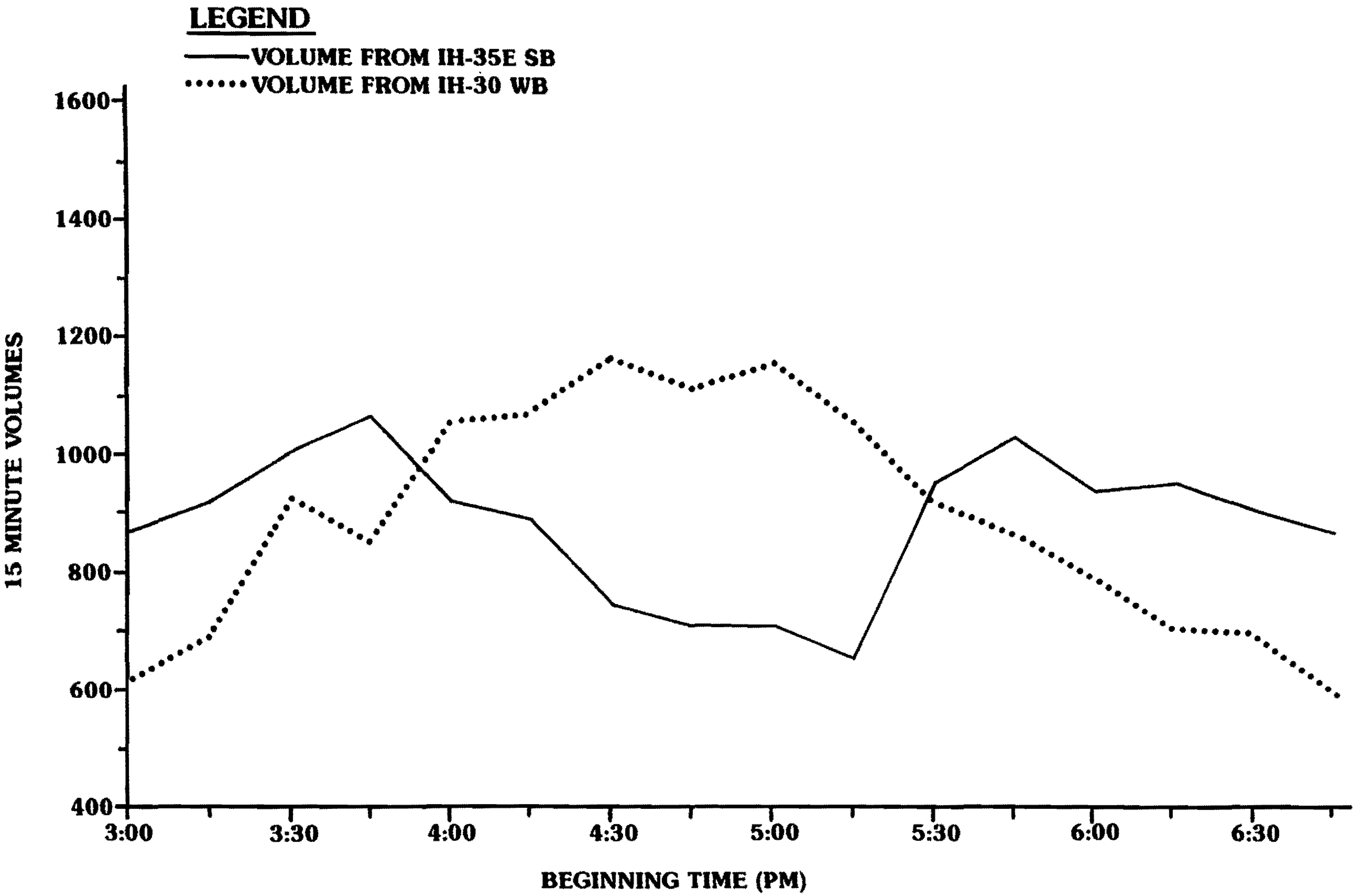
Five types of data collection are recommended at a suspected bottleneck site, and these are each discussed in more detail in the following section.

1. Traffic volume counts by *fifteen minute periods*.
2. Travel time runs throughout the congested corridor on fifteen minute headways.
3. Videotape of the operation at the bottleneck.
4. Drive-through video on each approach through the congestion.
5. Origin-destination data if a weave is involved.

TRAFFIC VOLUMES

Manual counts, with vehicle classification, are needed on the freeway; these can be made with video cameras and reduced in the office. Machine counts, to collect twenty-four hour volume data, should be conducted on any ramps upstream or downstream of the potential bottleneck, in the direction of congested flow; this may allow detection of a hidden bottleneck within the queue. The time period should be for as long a period as congestion is known to occur, plus thirty minutes either side. For example, if congested conditions typically begin at 4:00 PM and last until 6:00 PM, data collection should cover the period from 3:30 to 6:30 PM. This is because it is necessary to see both the pre-breakdown conditions to determine what is actually triggering the breakdown and the recovery conditions to see what is making the difference. It is also helpful in assessing the extent of benefits (length of peak) expected if improvements are made. Three days of machine counts (including the day of the freeway manual count) should be obtained, if at all possible, to rule out data that is not typical, i.e. caused by incidents or weather related.

The fifteen minute time periods will be sufficient to show patterns developing which can further show the existence of a bottleneck. Often, a look at hourly volumes alone will seem to suggest that ample capacity is provided for each movement in a bottleneck, because the counts measure the volume actually getting *through* on each movement, not the vehicles stacked up waiting to get through. Figure 2 is a peak period volume plot of two major freeway ramps that merge together. An inside merge occurs as the three lane ramp from IH-30 merges with the two



15-Minute Volumes for IH-35E SB and IH-30 Ramp

NOTE: VOLUMES COLLECTED IN OCTOBER 1990

Figure 2. IH-35E Southbound PM Volumes

lane ramp from IH-35E to form four lanes. The volume from IH-35E (shown with a solid line) illustrates a typical pattern in a bottleneck situation; volumes actually *drop* during the peak hour as capacity becomes constrained, perhaps by another competing movement. Clearly, the demand is not being served in this case. On the other hand, the volume from IH-30 (dotted line) shows a typical peaking pattern, indicating that demand is reasonably well served on that approach. Twenty-four hour volumes show the IH-35E approach (actually the mainlanes of the freeway, in this case) to be the higher volume movement, but the IH-30 approach is robbing IH-35E of its share of capacity during the peak hour.

TRAVEL TIMES

Travel time runs in the direction of congestion are needed by 15 minute time periods as well, and these should start at least a quarter of a mile beyond the farthest extent of congestion during the peak hour, and continue until speeds reach free flow conditions on the mainlanes. The time period should be the same as for the volume counts, and these should be conducted on the same day as the freeway manual counts, if at all possible. Each ramp gore should be used as a reference point, and careful measurement of distance between each point should be made prior to data collection, and included on the data sheet. The floating car method is used, but it is important to stay within the congestion. For instance, some lanes may move faster because they do not lead into the bottleneck. While they may be used by "queue-jumpers" who cut back into the congested lanes at the last minute, data based on this maneuver will not show congestion patterns accurately. However, the existence of queue-jumping should be noted in the travel time logs, since this behavior may be one of the causes of the bottleneck. Any incidents, such as accidents or disabled vehicles, which may affect the data should also be noted, and if severe, the affected data should be retaken.

Travel time data yield speed patterns that both allow the quantification of delay and provide insight into the extent of imbalance in congestion on approaches at a given junction. Figure 3 illustrates the speed profiles of the two converging ramps used in the example in Figure 2. Vehicles driving the IH-35E approach, the freeway mainlanes, are enduring over ten minutes of heavily congested conditions, while those using the IH-30 approach are encountering only three or four minutes of fairly light congestion.

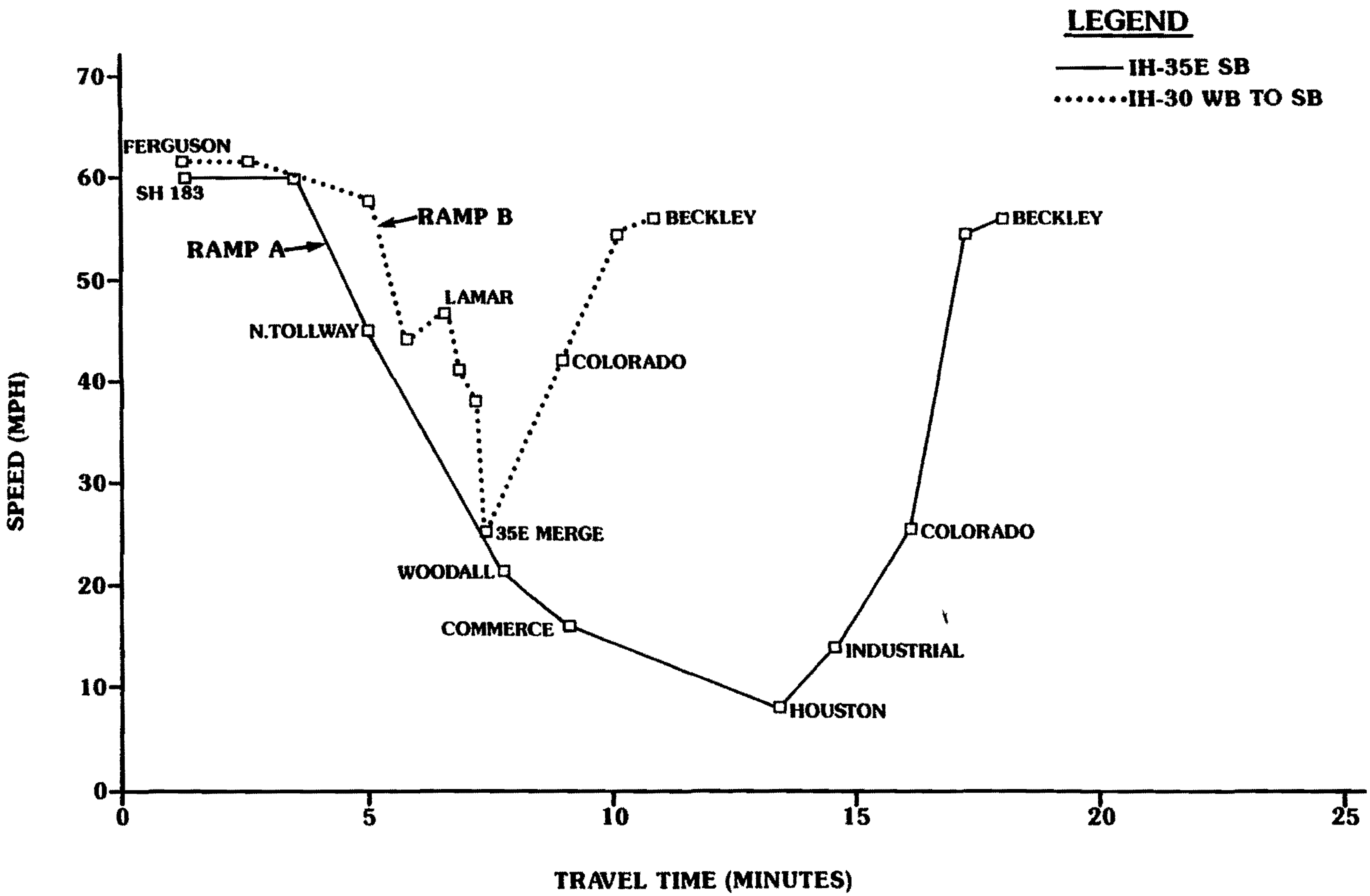


Figure 3. Typical Travel Speeds on IH-35E Southbound and IH-30 Ramp
PM Peak Period

Figure 4 shows another, highly useful, type of plot which may be made when travel times and volumes are collected on the same day. The data shown in Figure 4 are from a major freeway interchange in Dallas where Loop 12 merges with IH-35E. As shown, the volumes on the Loop 12 approach are obviously constrained, demonstrated both by the flat pattern during what should be the peak and by the depressed speeds as the peak progresses. Once again, the demand for the Loop 12 approach is not served by the existing geometry. The IH-35E approach, however, demonstrates adequate capacity and unconstrained operation with a modest peak in volumes and corresponding speeds around 50 mph.

VIDEOTAPE OF BOTTLENECK

The use of videotape recorders at a stationary location allows the problem of a bottleneck to be brought into clear focus both for those on the analytical team and for those to whom the proposed improvement must be justified. Videotaping reveals the sometimes extreme, unsafe, and often illegal, maneuvers drivers will make to "solve" the bottleneck, at least for themselves, and may even reveal the cause of the bottleneck, and perhaps suggest a solution. It also provides a useful record that allows the team's questions to be answered as they arise, without repeated field trips, simply by reference to the video. Thirty minutes of videotape during the busiest time period will be sufficient in most cases.

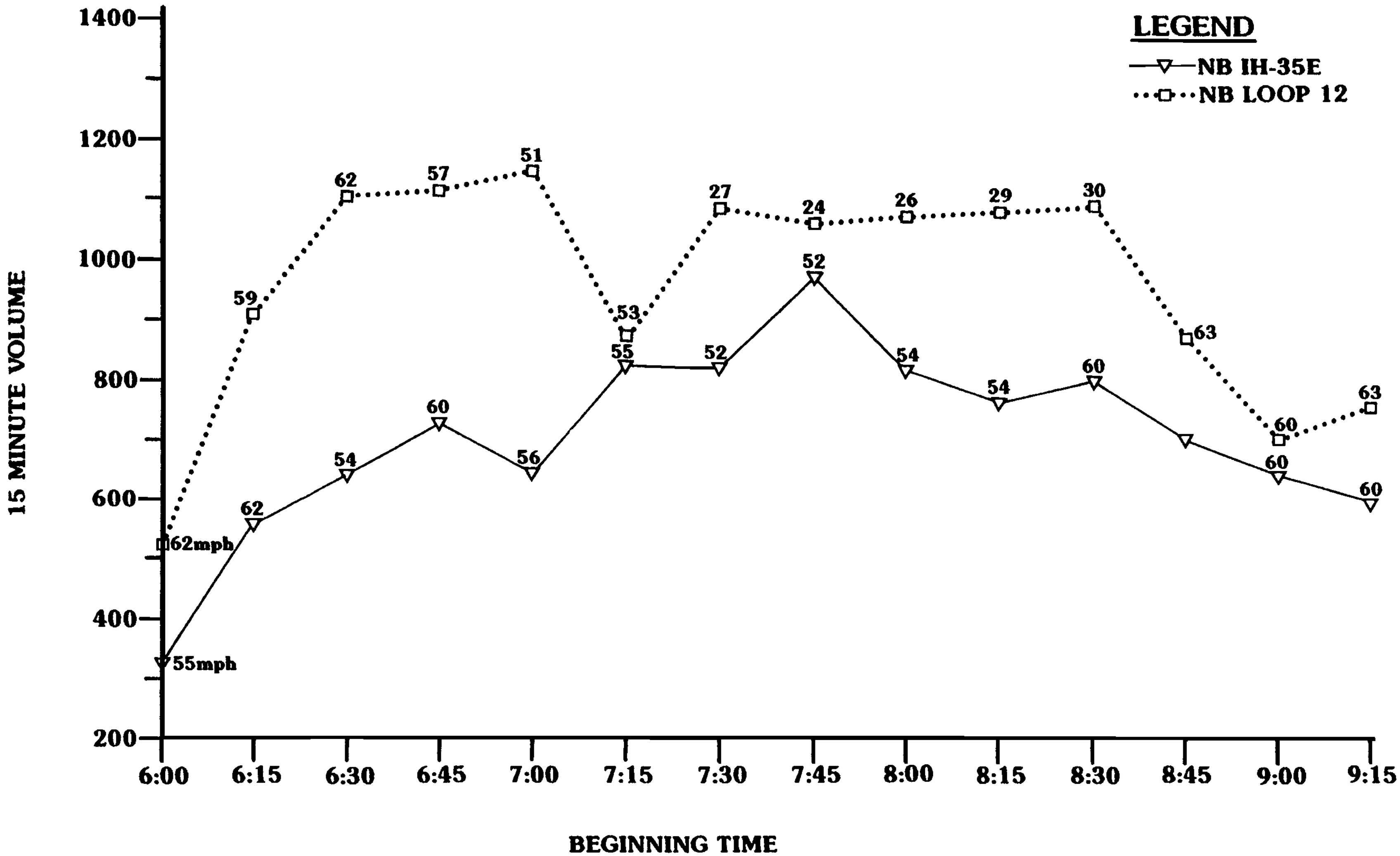
DRIVE-THROUGH VIDEO

Videotaping from the drivers perspective is necessary for several reasons. First, it documents on video at least one travel time run for each approach through the bottleneck. It also allows the driver's eye view of the congestion, the sight distance available, provides a record of signing and striping and its effectiveness, the number of lanes available as well as shoulder availability and condition, and the relative difficulty in merging or weaving. Videotaping should occur at one of the most congested time periods. This data will be used as a constant reference throughout development of improvement alternatives.

ORIGIN-DESTINATION DATA

In the case of a weaving section, information on weaving volumes is essential. Often a vantage point can be found to videotape the entire weaving area, with the data later reduced in

AM PEAK PERIOD 15 MINUTE VOLUMES AND AVERAGE SPEEDS



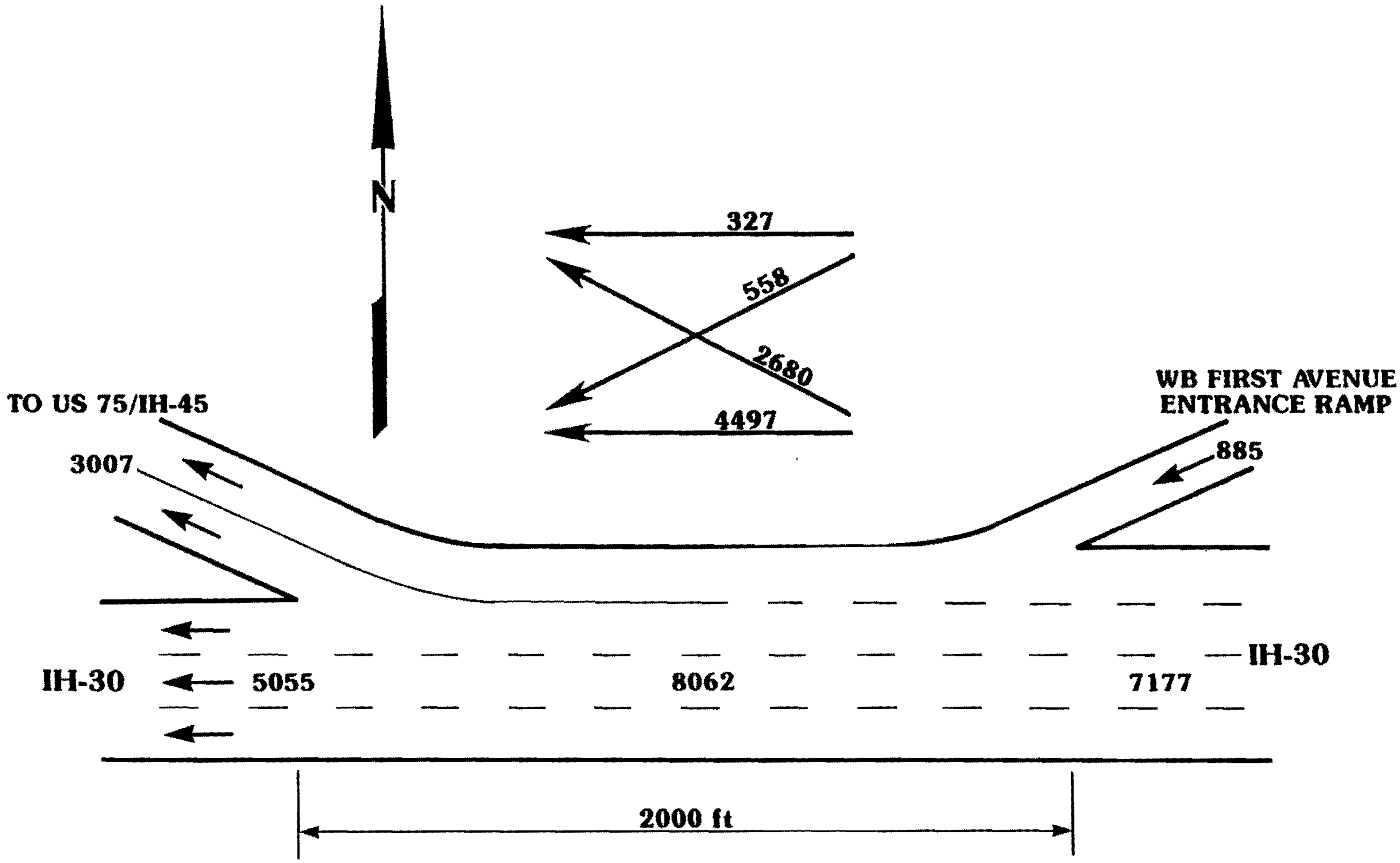
NOTE: NB IH-35E - AVERAGE SPEED FROM STOREY TO WALNUT HILL
NB LOOP 12 - AVERAGE SPEED FROM NW HWY TO WALNUT HILL

Figure 4. Northbound IH-35E Bottleneck at Loop 12

the office by viewing the videotape. In other cases, two cameras may be needed, with cars matched later by simultaneously running both tapes, and matching individual vehicles or license plates from the two traffic streams. If video is not available, audio tape recording the license plates allows later matching, but the result is often imprecise, because the process is so subject to human error at each stage -- from proper reading of both tags, to enunciation, to listening, to transcribing, and finally to matching.

Another type of origin-destination data may be needed in some instances, for example, if there is a need to know who is using a high volume ramp, where they came from, and where they are going. In this case, videotaping of the ramp, transcribing license plates, obtaining addresses from the Department of Motor Vehicles, and mailing out a postage-paid survey form may yield sufficient data.

Figure 5 shows the weaving volumes between two high volume ramps in Dallas. A mail-back survey showed that most of the vehicles using the First Avenue entrance ramp had originated several miles out in the corridor and had apparently driven the freeway until congestion was encountered, diverted to arterial streets, and rejoined the freeway at the First Avenue ramp, causing a weaving problem. The effect of this queue-jumping was to convert localized congestion at two points into stop-and-go conditions for six miles upstream. Ramp metering or a peak hour ramp closure might be considered in such a case.



NOTE: WEAVING VOLUME = 3238vph;
MAXIMUM WEAVING VOLUME
FOR TYPE B WEAVE = 3000vph

Figure 5. Example of Weaving Volumes (IH-30 East at First Avenue)

DEVELOPING IMPROVEMENT ALTERNATIVES

DEFINING THE PROBLEM

The first step in finding solutions is accurately defining the problems. With the help of graphic displays of the data collected, analysis of the data, as well as viewing the video, it should become clear what is happening. The types of questions that can be answered from the data collection and an analysis of the existing operations are: Is it an entrance ramp that is forced to merge when it needs its own lane? Is it a lane drop where too little volume exits, causing a merge problem into the next continuing lane? Is it a merge where the lower volume commands the right of way, constraining the major volume? Is it a weave whose design (i.e., Type A) provides too little capacity to accommodate the demand? Is it a one lane exit ramp where two lanes are needed? Is it a one lane entrance where two are needed? Or is it a combination of several of these?

Using methodology from the 1985 Highway Capacity Manual (HCM), incorporated in the FHWA Highway Capacity Software (HCS), and peak fifteen minute flow rates through the analysis area, existing theoretical levels of service can be obtained. Two problems occur, however. First, some elements will be working better than the analysis predicts. This is because Texas urban drivers are finding greater capacity by driving closer together; Urbanik (1) has established that a value of 2200 vehicles per hour per lane (vphpl) is a more appropriate value for capacity for Texas' urban freeways than is the traditional 2000 vphpl. For analytical purposes here, it is suggested that observed traffic flow rates be reduced by 10% prior to using the HCS software, to adjust for this difference in capacity. (Or, if possible, change the capacity value from 2000 to 2200 vphpl in the program itself. This is consistent with the HCM's emphasis of use of local data, when available, over default values.)

The second problem is that levels of service values will probably indicate that the system is operating right at capacity, suggesting little urgency for improvement. However, as mentioned earlier, in cases of constraint, the *capacity of the bottleneck* is indicated by the measured traffic volumes, while the *unmet demand* waits in queues upstream.

Often, a hidden bottleneck exists within the queue caused by an identified downstream bottleneck; solving the downstream one will have benefits only until the upstream one is reached. At other times, a potential bottleneck lies downstream, undiscovered because of the metering effect of the one upstream. Detective work is needed, and this is the stage at which it should be done. If there is more than one problem, they should all be solved at once, while retaining the low-cost nature of the improvement.

IDENTIFYING OPPORTUNITIES

This is the stage at which solution options are assessed. Typical low cost improvements include:

1. Using a short section of shoulder as an additional lane.
2. Restriping merge or diverge areas to better serve demand.
3. Reducing lane widths to add a lane.
4. Modifying weaving areas.
5. Metering or closing entrance ramps.

Many of these options require use of more pavement, to some degree. Is there an inside shoulder that would create a usable traffic lane for a short section of freeway? If there are bridges, are they wide enough to accommodate the extra lane while allowing adequate clearance to barriers (2 feet) and an outside shoulder? If not, are they short enough that loss of a shoulder as a breakdown lane would not be critical (less than 500 feet)? If changes to an entrance or exit ramp or weaving area are considered, will adjusting the position of ramp gores cause geometric problems which must be resolved? Are vertical clearance issues, grade-matching, and sight distance problems created? If a shoulder is considered for removal, is there right-of-way to allow adding one back for part of the length of the project?

The issue of shoulder removal has safety implications. Although loss of a breakdown lane can sometimes result in a disabled vehicle blocking a travel lane, which is obviously hazardous, the alternative of allowing a bottleneck to continue causing recurrent stop-and-go congestion on a freeway is perhaps more hazardous. Research by Urbanik (2) suggests that shoulder conversion to remove bottlenecks has an overall positive effect on safety. There remains the possibility that congestion could develop again, and that the loss of the shoulder would create a worse condition than before. This lends greater emphasis to the need for certainty that the proposed improvement is actually elimination of a bottleneck, and not simply a capacity improvement which is likely to induce more overall freeway traffic, and break down again.

If a shoulder can be safely eliminated, moving the travel lanes over to the inside and creating an additional lane for a short distance may be feasible, providing there is a reasonable place where the lane can be dropped downstream without creating a new bottleneck. Wherever possible, it is preferable to remove an *inside* rather than an outside shoulder, for several reasons. First, drivers expect full size outside shoulders, while inside shoulders are sometimes not provided; second, outside shoulders provide greater safety when leaving the vehicle and seeking assistance; and third, re-entry into a slower lane of traffic is easier.

Many times modifications using a shoulder introduce the added lane at an entrance ramp on the right side of the freeway and drop the lane at a downstream exit ramp on the right. There is, therefore, reason in some cases to convert the outside shoulder to a travel lane: if the modified section is short, if the added lane is needed between an entrance and exit ramp, and if the area beyond the outside shoulder offers space for emergency stops.

If the bottlenecked movement itself cannot be fixed reasonably, can the other traffic which is affected by it be better accommodated? Finally, will this improvement invite enough new traffic to cause immediate breakdown again? Or is this truly a clearing up of a "kink" in the system, without being a capacity addition which will overload some other part of the facility?

ANALYSIS OF IMPROVEMENT ALTERNATIVES

To perform an analysis of the improved design, it is necessary to estimate the unmet demand for the bottleneck movement. One rough estimate can be obtained by using the average delay per vehicle during the peak hour, and equating that to an incremental demand flow proportional to 2200 vphpl. For instance, a 10 minute average delay over the peak hour would mean 10 minutes worth of additional vehicles would have gotten through the bottleneck during that hour, had the delay not been there, or 367 additional vphpl. If the bottleneck capacity is two lanes, an additional flow rate of 733 vph may be expected at the peak, if it could be handled. This in no way accommodates the induced volumes improved freeway operations might attract, both peak and off-peak; it only estimates the effects of smoother operation for the existing volumes.

Following this adjustment, the improved system should be analyzed to be sure it will work adequately with the estimated demand flow rates, as far as weaving, merging, and diverging are concerned. One caution is that use of an auxiliary lane may create a weaving section where there once was a simple, over-capacity merge. It is necessary to analyze the improvement both as a *weave*, unless the length of auxiliary lane puts it out of the realm of weaving, and as a *merge*, after subtracting any volumes which may now exit before the merge is required. If the freeway is full, precluding a successful merge, use of a short auxiliary lane will only help if sufficient volumes have exited to allow the merge to take place. Otherwise, the bottleneck has simply been moved to the lane drop, which will provide only limited relief to the system.

ESTIMATING BENEFITS

In order to establish feasibility of a bottleneck improvement, estimates are needed of both implementation cost and expected benefits. Quantifiable benefits accrue from reduction in motorist delay. Other benefits in air quality, energy consumption, and vehicle operating costs are less easily quantified and normally are not needed in order to justify economic feasibility of a project.

Simply put, for a given time period, the calculated improvement in travel time is multiplied by the number of vehicles counted plus the number in queue, as mentioned earlier. The resulting value, in vehicle-hours, is assessed a dollar benefit by the use of a factor developed in earlier research by McFarland and Chui (3). This research surveyed drivers on a number of factors, such as propensity to speed versus the likelihood and cost of speeding tickets, to determine the value motorists place on their own time. Adjusting for inflation, that value for 1991 was listed as $10.25 per hour per person. Adjusting for a typical occupancy rate of 1.15 during peak hours, a value of $11.79 per vehicle hour is obtained.

There are two complications in this process. First, there is some difficulty in estimating improved speeds. It is tempting to assume speeds will increase to the 55 mph speed limit on most freeways. However, if there is any congestion downstream of the bottleneck, the new speeds will not be able to exceed the downstream speeds. Also, as mentioned earlier, there may be hidden bottlenecks within the queue which will continue to limit speeds. If a weave is involved, the HCS procedures will define speeds to be expected for weaving and non-weaving vehicles. For a Type C weave, this may well control the entire section. A good rule of thumb would be to assume no greater speeds following bottleneck removal than the downstream speed of 45 mph, whichever is lower during the peak period.

Second, there is often no improvement in travel time at all during the peak <u>hour</u>. There is, instead, an increase in traffic <u>volume</u>. Obviously, any new traffic attracted to the facility will have changed routes due to an improvement in trip time over its old routes; and if speeds on alternate routes before the improvement are collected, this benefit can be estimated. Without this data, a conservative approach would be to credit improvement only to the <u>original</u> traffic volumes and their expected improved travel times, over the entire peak period. Figure 6 shows the before and after travel speeds for a bottleneck improvement in Dallas; note that there is no

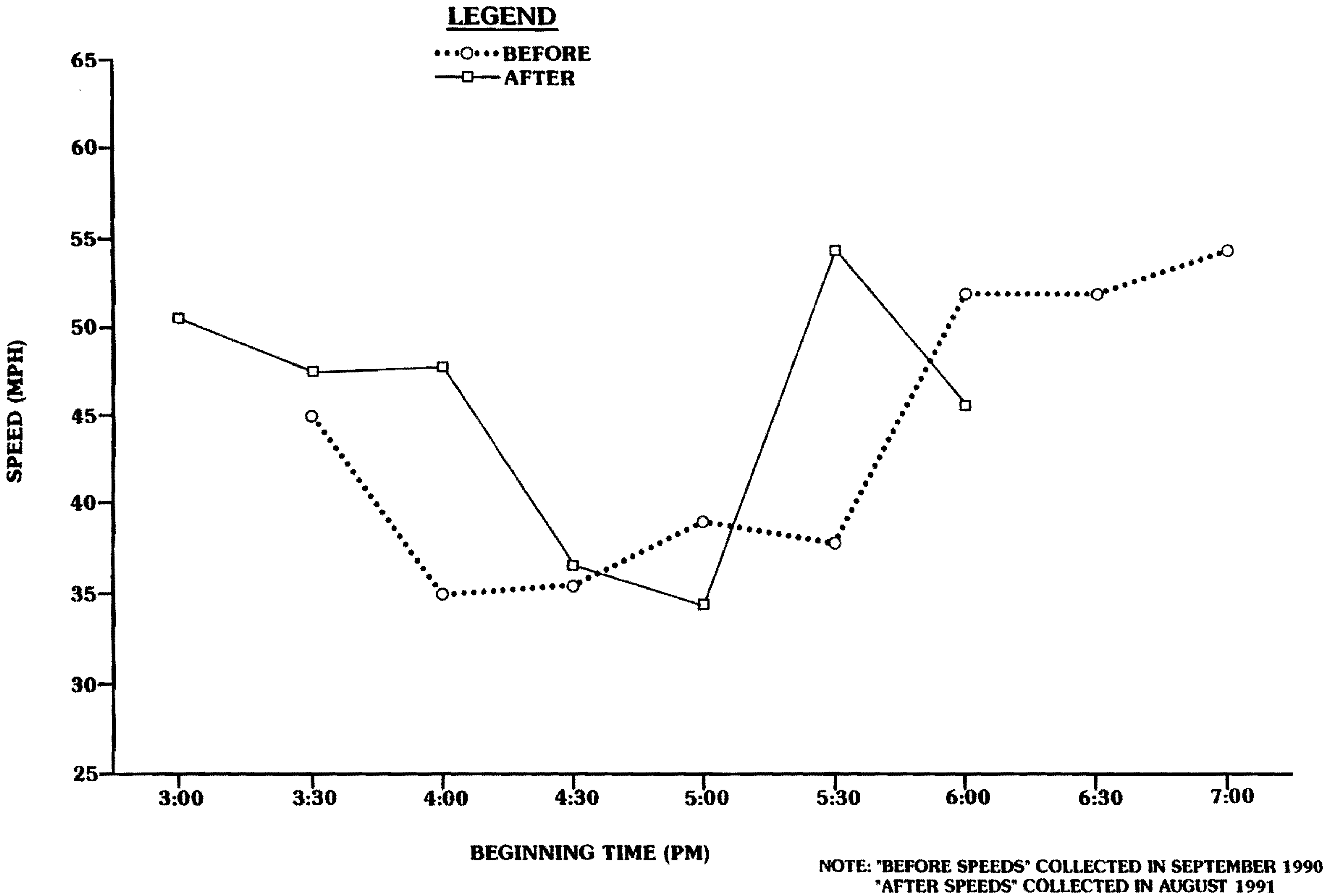


Figure 6. August Travel Speeds for IH-35E SB between Commerce and Industrial

speed improvement during the peak half hour, but significant improvement accrues during the remainder of the peak period. A less conservative approach in the absence of speed data on alternate routes would be to assume a 25 mph average speed on alternate routes, and credit any new traffic diverted with this amount of improvement.

Finally, benefits should be aggregated for each thirty minutes, considering volumes and travel time improvements expected. (Once again, the original volumes should be increased by the queued volumes upstream, both in calculating new level of service after improvement and in estimating benefits.) Typically, while off-peak operations will be improved, these benefits will not be counted. If it is estimated that there will be 200 work days per year during which no delay-causing incident occurs during the peak period, and if an estimate is available of the useful life for the improvement (prior to a permanent improvement), then assuming a reasonable discount rate will allow calculation of a present worth value for benefits of the improvement.

Determination of the useful life can obviously have a major impact on feasibility. An interim improvement on a facility expected to undergo capacity addition in the next few years will have to be much less costly to implement than one which will improve a facility for many years, when no major expansion is planned. This consideration again brings up the issue of design standard and safety, as the FHWA is more likely to approve a design exception (i.e. shoulder removal) for an interim project than for a semi-permanent one.

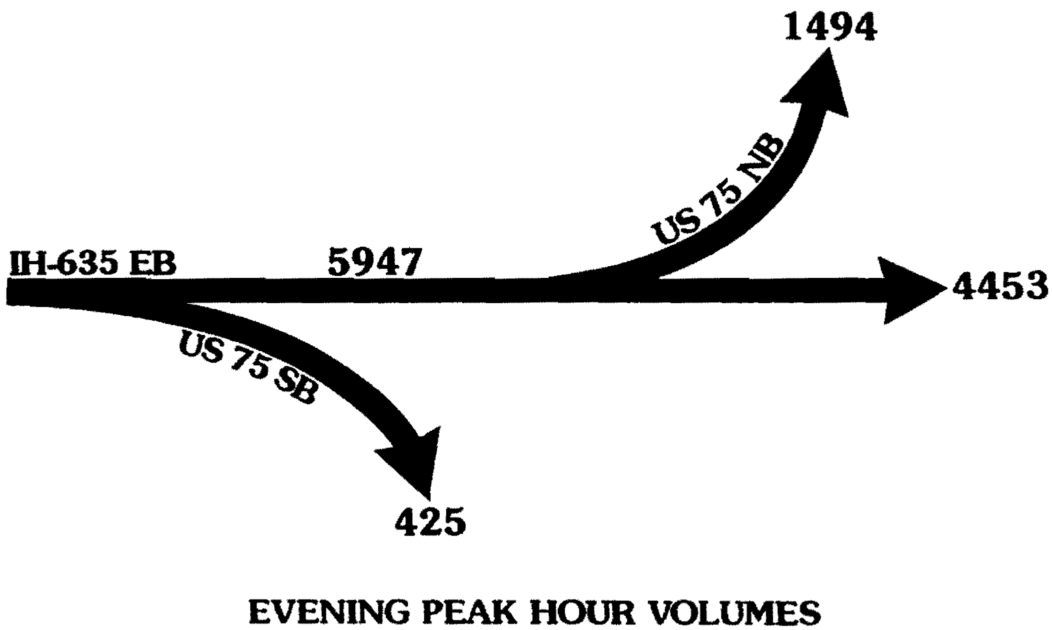
CASE STUDIES

IH 635/US 75 INTERCHANGE, DALLAS, TEXAS

An example of a successful bottleneck removal project is detailed below. The interchange of IH 635 and US 75 in Dallas has been the site and the cause of recurrent congestion for several years. Demand for the eastbound IH 635 to northbound US 75 movement was clearly under-served, with eastbound queues during much of the day, particularly during the evening peak. There were problems in the westbound direction as well, but this example will focus on the eastbound problems, solutions, and benefits achieved.

Figure 7 indicates the geometry before improvement, along with the traffic counts during the evening peak hour, the most congested time frame. A lane drop from eastbound IH 635 to southbound US 75 was utilized by less than 500 vehicles per hour, while an option lane to northbound US 75 carried almost 1500 vehicles per hour. The volumes were known to be capacity constrained, which was evident by the upstream queuing. Videotape confirmed that through vehicles escaping from the lane drop were forcing their way in to the three continuing lanes, in effect "queue-jumping" by traveling at higher speeds in the lane which was an exit-only. Vehicles exiting northbound were forced to wait in queue in the left lane because the downstream geometry for the exit ramp caused right-of-way to be granted to another traffic stream (from the westbound to northbound ramp), limiting capacity to less than a full lane. Thus, two of the four eastbound lanes were stop-and-go, and vehicles escaping into the two middle lanes created stop-and-go conditions for them as well. Indeed, the downstream traffic volume (eastbound through vehicles) was higher than expected capacity for the two lanes effectively available for that movement.

Figure 8 shows the improved geometry, and the resulting evening peak hour volumes. An inside shoulder was converted to a travel lane, as shown, and the lane was added at the point where the former lane drop had caused congestion, eliminating the need for the lane drop. Existing lane markings were moved to the left to maintain a smooth transition for all four continuing lanes. At the exit to northbound, the newly created left lane was dropped, the ramp was converted to two lanes, and the third lane became an option lane. Downstream on the exit ramp to northbound US 75, the yield to the US 75 mainlane traffic was eliminated, allowing free flow for the new two-lane exit.



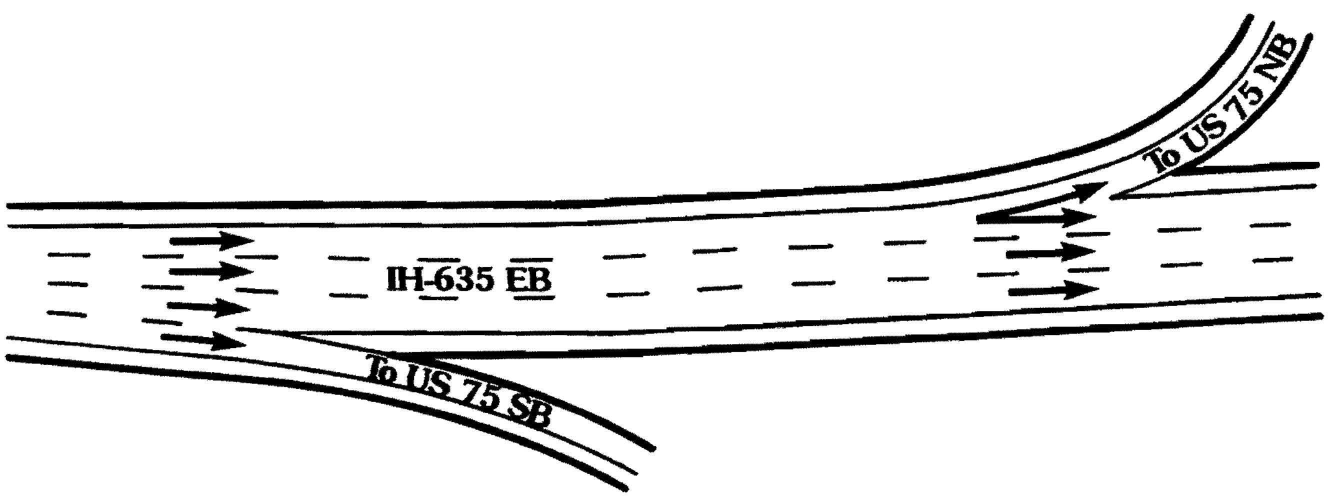
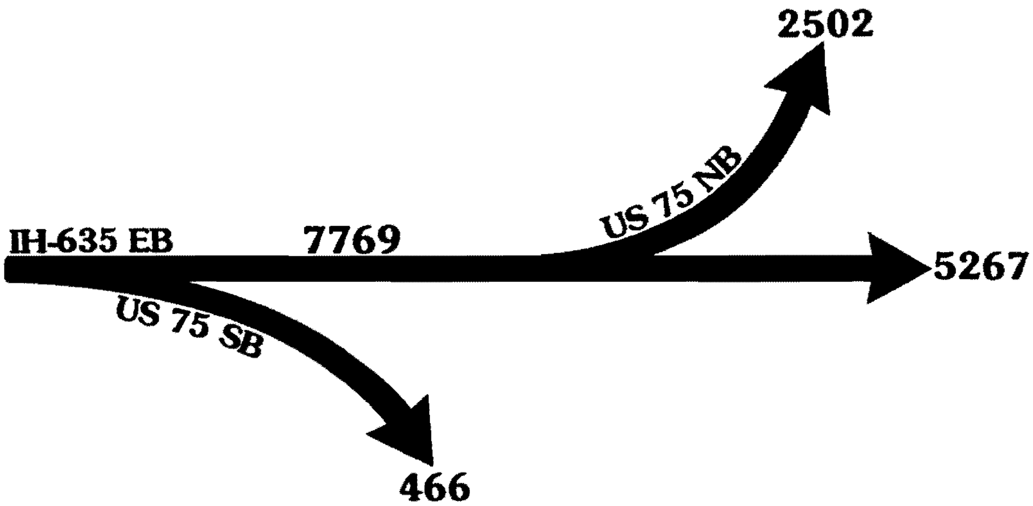


Figure 7. Eastbound IH-635 Traffic Volumes and Geometric Design before Improvement



EVENING PEAK HOUR VOLUMES

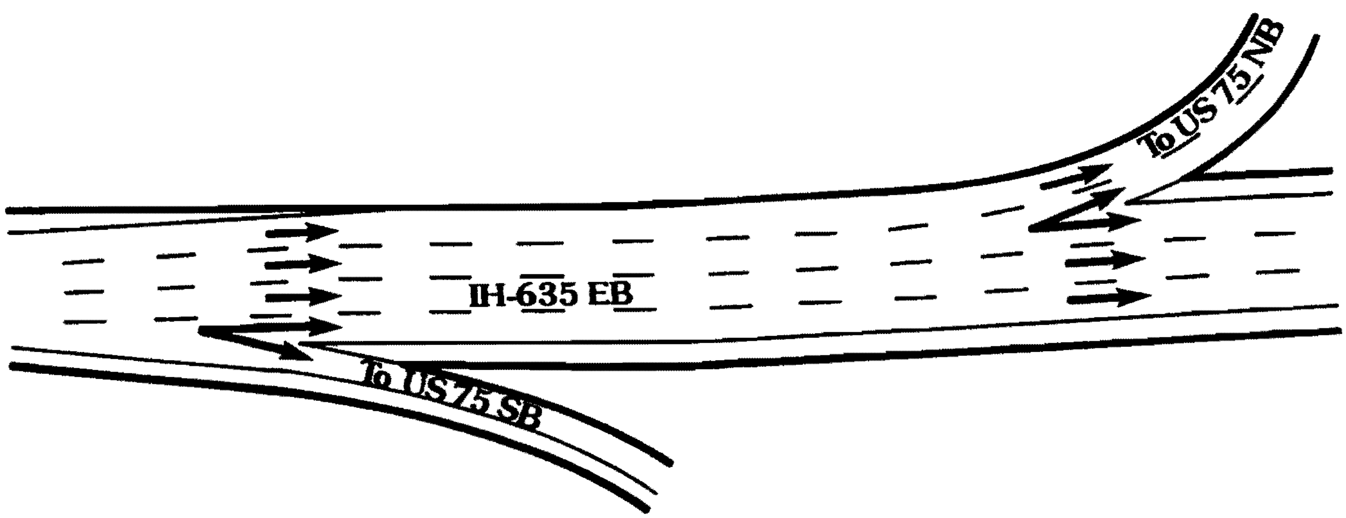


Figure 8. Eastbound IH-635 Traffic Volumes and Geometric Design after Improvement

Traffic volumes immediately increased to take advantage of the new capacity, both for the ramp and the through lanes. Figure 9 shows the daily volume profile on the improved ramp, both before and after improvement. Truncated demand is obvious in the before condition, while peaks have appeared both during the morning (the minor peak) and the evening. Ramp volumes increased over 50% during the evening peak hour. Figure 10 shows the traffic volumes and speeds on IH 635 eastbound during the evening peak. In every time period, except for the fifteen minutes beginning at 6:00 PM when a downstream bottleneck intervened, traffic volumes increased, and speeds increased for <u>every</u> time period. Volumes were up almost 20% during the evening peak hour, and speeds increased over 50% during the peak period. Speed data were available for two miles upstream of the former bottleneck, and average speeds doubled, but only from 10 mph to 20 mph. Clearly, other capacity deficiencies exist, but a remarkable improvement in operation has resulted. The volume increases indicate both that some vehicles are spending less time in queue, and thus are appearing at the count location sooner, and that others must be diverting from elsewhere in the system.

Benefits have been assessed based only on the travel time savings of the original traffic volumes, and have been found to be $3.6 million per year during the morning and evening peak periods combined. Benefits for the westbound improvement mentioned earlier were $3.8 million per year, for a total annual project benefit of $7.4 million. The cost of the project was $2.45 million, yielding a benefit/cost ratio of 24.5 (with a 4% discount rate and a ten year life).

As is frequently the case for bottleneck improvement projects, this benefit/cost ratio is already so high that further quantification of additional benefits is not needed. However, it should be noted that additional benefits are accruing to the diverted traffic, as well as to the arterials from which they diverted, and to the off-peak traffic. These improvements in travel also result in environmental and energy benefits.

IH 35E SOUTHBOUND/IH 30 EASTBOUND RAMP, DALLAS, TEXAS

This bottleneck location, discussed earlier, underwent some restriping during a pavement overlay project, with virtually no expense associated to the striping change. The modifications, however, have had mixed impacts. Figures 2 and 3 show the volumes and speeds, indicating the imbalance in the demand versus the capacity. As shown in Figure 11, the mainlane volume on IH-35E was served by two lanes, but was required to merge with three lanes coming from

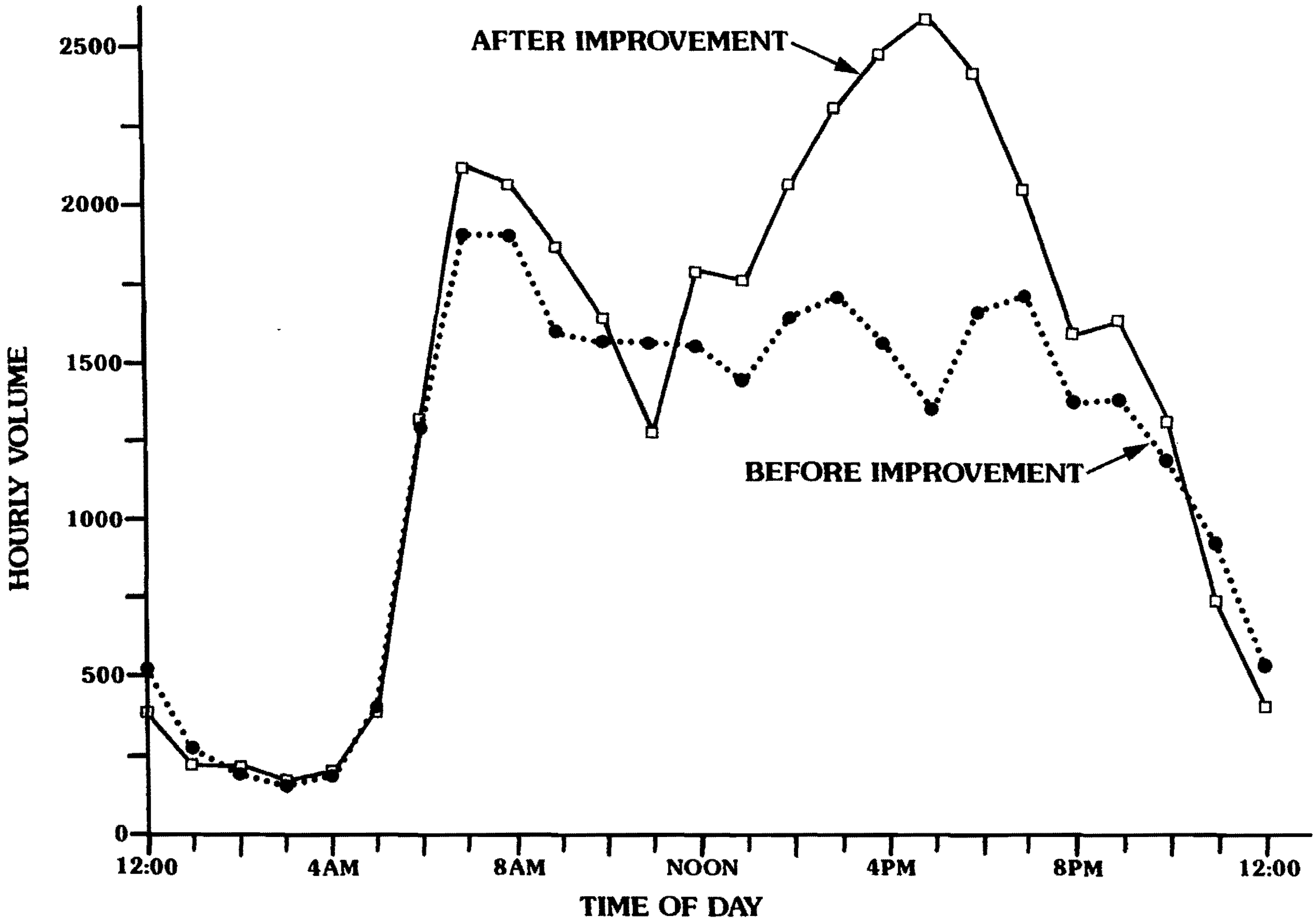
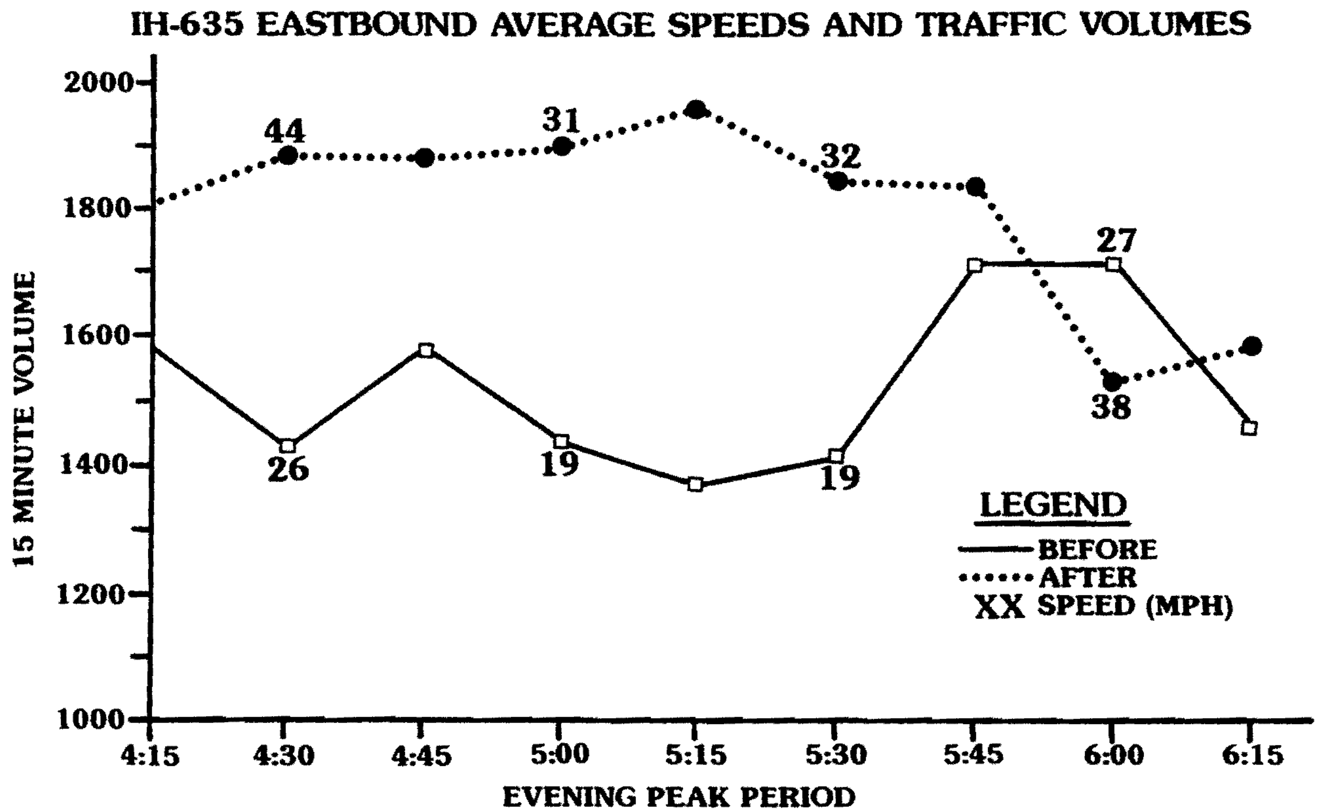


Figure 9. Volume Profile on IH-635 Eastbound Ramp to US 75 Northbound



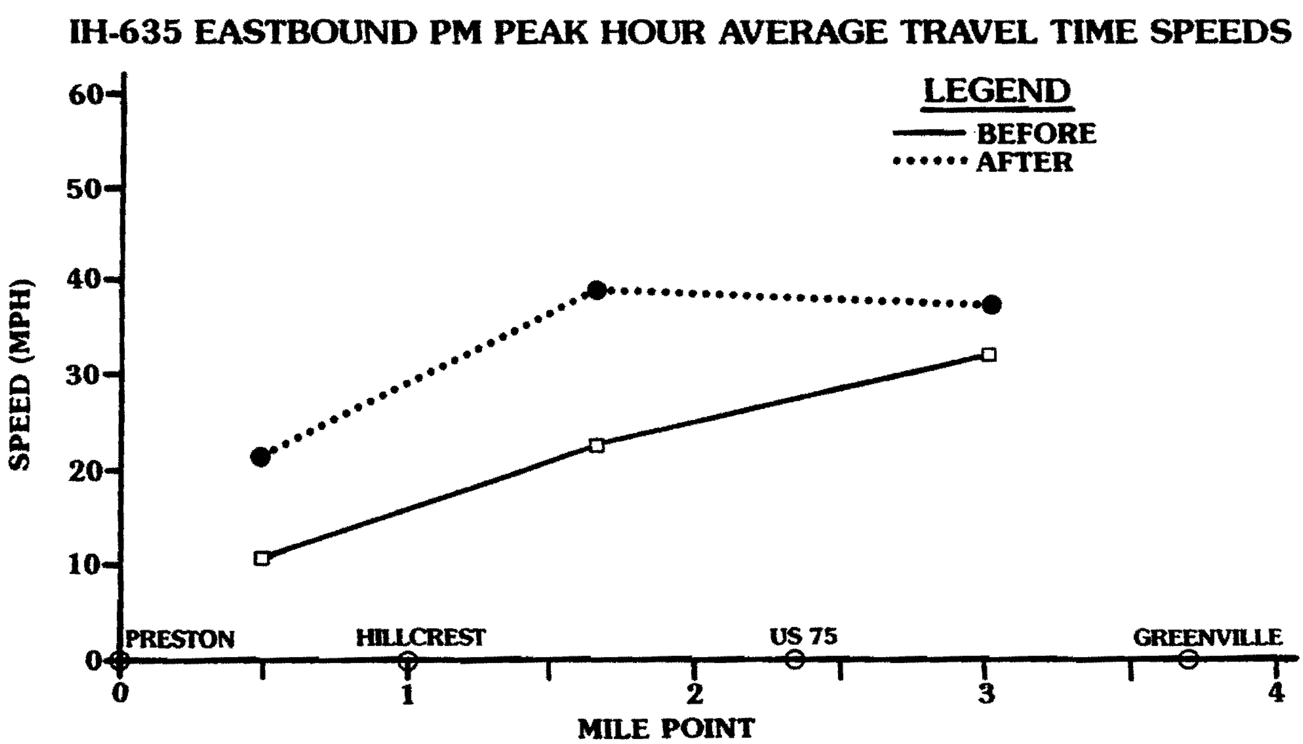


Figure 10. Speed Profile on IH-635 Eastbound

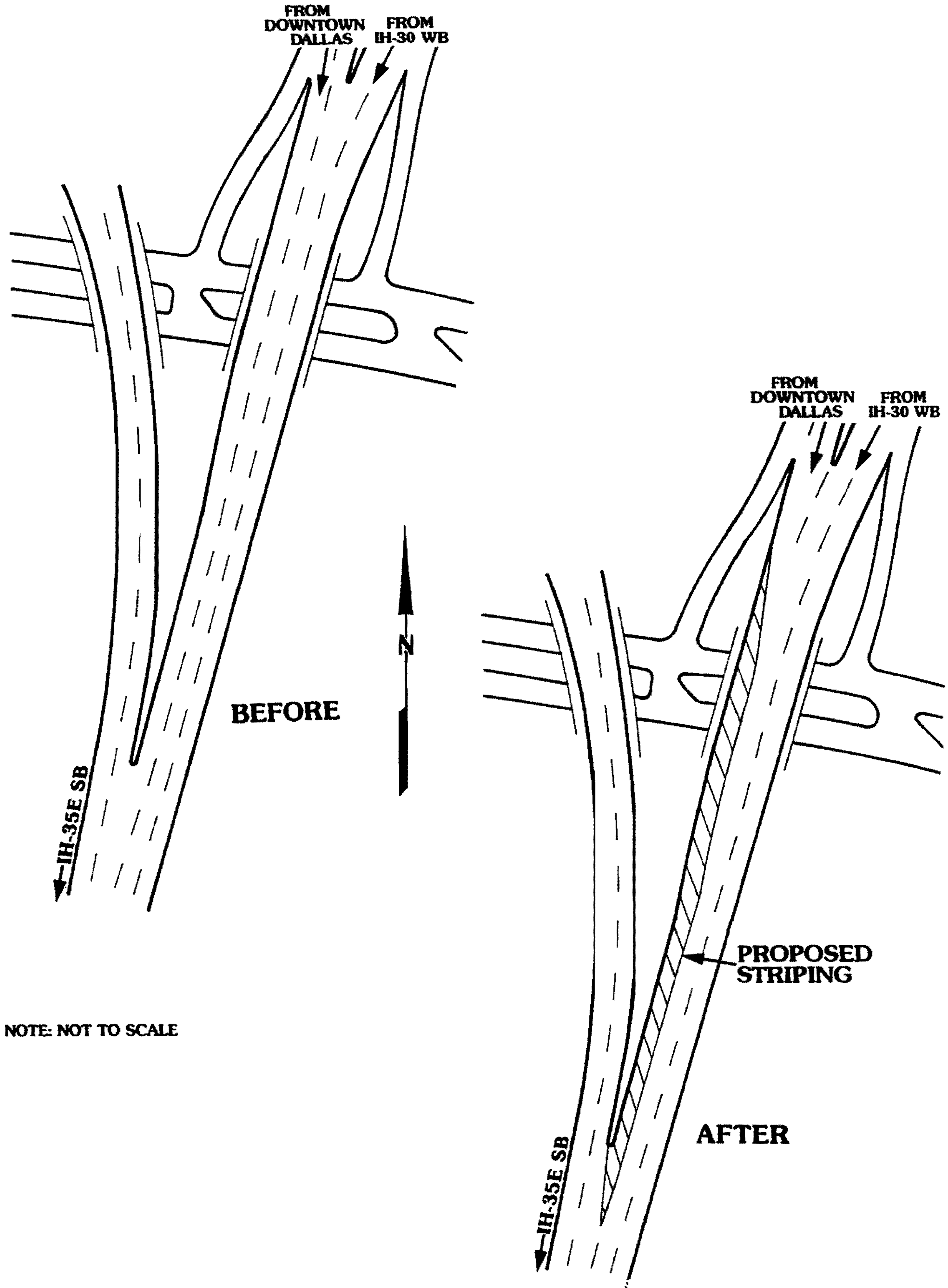


Figure 11. Geometry of IH-35E Freeway at Merge with IH-30

IH 30. Because the merge was on the right, IH 30 traffic assumed the right-of-way, effectively limiting IH 35E to one and a half lanes. It was proposed to restripe IH-30, eliminating the inside merge, and giving both ramps two lanes. This would slightly under-serve the peak hour on the IH 30 ramp, but vastly remove the constraint on IH 35E. Traffic volumes downstream of the merge were already at capacity, but speeds were relatively high, and not expected to change.

Figure 6 showed the changes in the speed profile, which reflect higher speeds for IH 35E, except during the peak hour itself. However, the change was not as great as had been expected, and long queues still exist upstream. The problem may lie partly in changes in travel patterns of downtown commuters, in response to the geometric change, and partly in the on-going existence of a "hidden bottleneck." Almost a full lane of traffic from downtown Dallas previously merged fairly easily into the three lane ramp from IH 30. When it was reduced to two lanes, the merge became more difficult, and queues developed upstream on a collector-distributor road leading out of downtown. Due to congestion, volumes have dropped by almost 500 vehicles on the ramp from downtown; some of these vehicles may have begun to enter IH 35E upstream of the original bottleneck location, at a left-hand ramp, where it is necessary to weave across three lanes in order to reach the southbound lanes. This weave was not analyzed originally, and it is possible that the weave itself could be constraining speeds through that section, regardless of the downstream bottleneck. This would limit the extent of improvement in speeds to the segment between the bottlenecks (approximately a half mile), rather than for the two miles of the original queue. Figure 12 shows the changes in volume at the improved merge. Clearly, the capacity better fits the demand now, and benefits have been calculated at almost $200,000 per year, with virtually no cost. However, disbenefits to the under-served downtown ramp have not been quantified. Alternatives to improve the merge for that ramp are being evaluated at this time.

This example is inserted to demonstrate first that intuitively obvious improvements need to be carefully assessed, because it is possible to miss potential impacts, particularly if even a slight capacity reduction for an existing traffic movement is proposed. Second, the existence of a hidden bottleneck upstream can greatly reduce the projected benefits. The weaving problem occurred within a slow moving queue, and so was not detected.

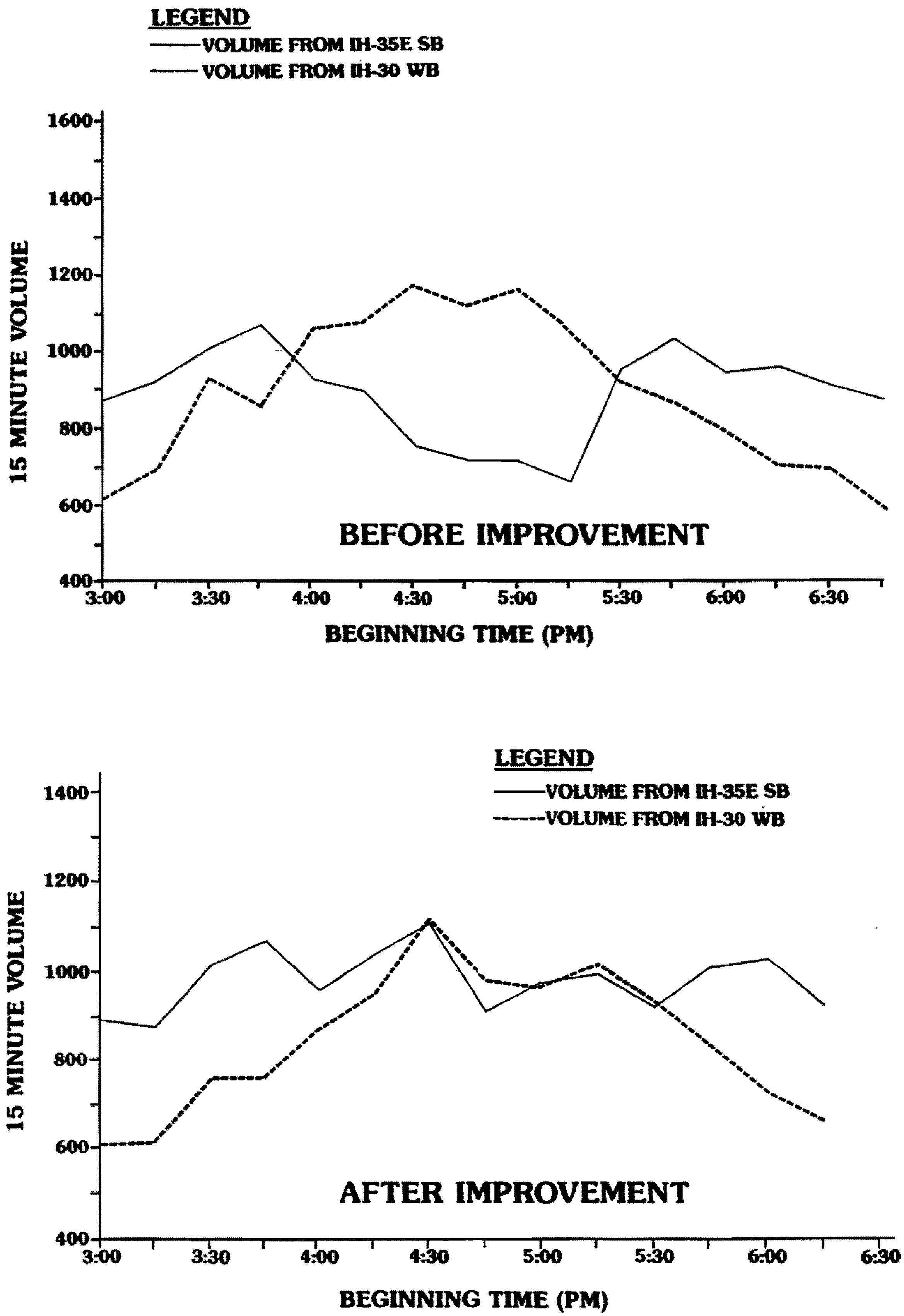


Figure 12. IH-35E Southbound Bottleneck

SPUR 366 (WOODALL RODGERS) WESTBOUND/IH 35E NORTHBOUND

A one lane exit from Spur 366 westbound was congested for much of the day, causing stop-and-go conditions on the mainlanes, queue-jumping to reach the exit at the last minute, and creating a difficult merge/weave problem at an upstream entrance ramp. However, except for a short span, sufficient width existed on the ramp for two lanes. It was decided to change the gore area and remove an inside shoulder for a short distance to allow two lanes of traffic to exit from Spur 366, as shown in Figure 13.

Again, results have been mixed. Volumes have risen on the exit by almost 20% during the morning peak period, but speeds have dropped during the morning peak hour, although average peak period speeds have remained the same. The problem now is the one lane entrance (tapered design) to IH 35E. During the evening peak, when IH 35E is not peaking northbound, ramp speeds have increased. However, if the two peak periods are taken together, a net disbenefit is recorded, based on original traffic volumes and changes in travel speeds. (Off-peak benefits are not assessed.) A second bottleneck project is under consideration to add a second lane to the entrance to IH 35E, which will be dropped approximately one mile downstream at a major exit to the Dallas North Tollway.

This example serves to illustrate three issues discussed earlier. First, the original bottleneck was serving as a meter that kept the downstream merge from failing during the morning peak hour. The bottleneck has moved downstream. Second, the additional traffic attracted to the new ramp must be receiving a benefit because of diversion, but it is not possible to quantify it. Third, safety problems have been lessened on Spur 366, as queuing is now taking place on the ramp instead of the freeway mainlanes; however, it is difficult to quantify these benefits, since many property-damage-only accidents are not recorded. Clearly, this project has produced benefits beyond its $71,000 cost, but full benefits are not yet realized.

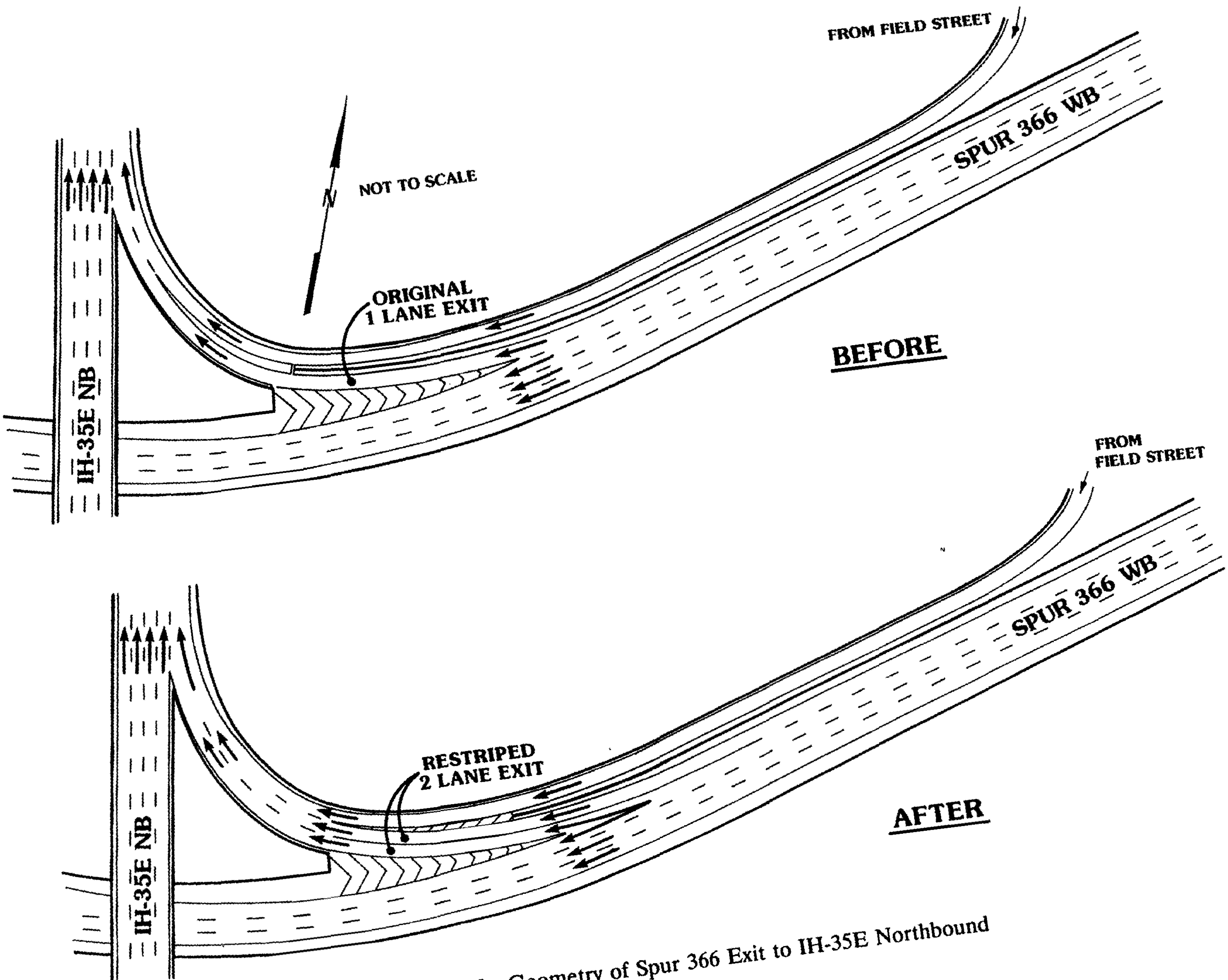


Figure 13. Geometry of Spur 366 Exit to IH-35E Northbound

CONCLUSIONS

In a time of fiscal constraints, when construction costs are rising and right-of-way availability is disappearing, with increased attention to environmental issues, and greater public involvement in project development and prioritization, it has become more difficult to add needed capacity to our urban freeway systems. It therefore becomes more imperative that we obtain the most efficiency from our existing investment in freeway facilities. One way to do that is to eliminate bottlenecks that waste capacity. Benefits accrue from increased travel speeds, lowered emissions (where stop-and-go traffic is improved), and reduced energy usage, as well as improved safety in many cases.

Bottleneck removal involves careful detective work, and time spent on data collection and analysis will pay off handsomely; inadequate investigation of the specific causes and potential system effects can lessen the intended benefits. However, this type of improvement generally has an extremely high benefit/cost ratio. Many improvements can be made with simple restriping, while others may require more major construction, but can still be funded for a fraction of normal capacity improvements. Bottleneck removal is analogous to intersection improvements in an arterial system; money spent on adding extra turning lanes for a short distance may preclude the need for widening an entire thoroughfare.

The following summarizes the key points to bottleneck removal:

1) Traffic volumes alone will not detect (but may suggest) locations of bottlenecks; vehicle speeds, local traffic patterns, and field observations are needed to detect the existence and the causes of freeway bottlenecks.

2) The amount of congestion on different approaches at freeway interchanges can be very imbalanced; distributing the capacity to reflect the demand can significantly reduce the overall congestion in the system.

3) Improvements such as restriping lanes, using shoulders, and modifying weaving areas produce primary benefits of reduced congestion and improved safety, as well as

secondary benefits in emission reduction, vehicle operating costs, and congestion on alternate routes.

4) These benefits can be obtained, not by adding freeway capacity, but by *recapturing design capacity* within the freeway system; this becomes an increasingly important distinction as regular capacity improvements are becoming more difficult to justify, environmentally and politically.

5) Additional checks must confirm that implementation of a bottleneck improvement will not simply move the congestion to another location (which may have further safety implications).

If design exceptions, such as shoulder conversions, can be approved, low-cost improvements to remove freeway bottlenecks can provide significant benefits.

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