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16. Abstract

This study examines three types of relatively minor freeway improvements (ramp additions, ramp relocations and grade-separated ramps) to determine the magnitude of road user benefits accrued.

Total benefits were broken down into primary and secondary benefits. Primary benefits are those that accrue to the original target group of vehicles. Secondary benefits are those incidental to the improved conditions (e.g., improved intersection operation when ramp vehicles are eliminated).

Delay and travel time data were collected at the site of the ramp additions. Volumes at the new ramp were higher than expected, indicating a latent demand. Annual primary benefits of $162,000 accrued to the users of the new ramps. Secondary benefits in improved upstream intersection operations yielded $7,000 annually. No significant change in accidents resulted.

An exit ramp was relocated to eliminate queues onto the main lanes. Main lane conditions improved to produce $10,750 in primary benefits. Because the relocation allowed better lane distribution at the downstream intersection, secondary benefits of $34,500 accrued. Accidents were reduced, but not significantly.

A grade-separated ramp was constructed to provide new access between arterials that are too closely spaced for at-grade entrance and exit ramps. An annual savings of $143,000 accrued to the users of the new ramp. Because this study was based on historical data, no analysis of secondary benefits was possible. The improvement reduced the accident rate, but not significantly.

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EVALUATION OF MINOR FREEWAY MODIFICATIONS

An Interim Report

by

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Research Report Number 210-11

Evaluations of Urban Freeway Modifications

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INTRODUCTION

The growth in the metropolitan areas in the state of Texas has placed a tremendous demand on urban freeways for both mobility and access. When freeway facilities were originally constructed, their capacity was sufficient to handle the anticipated traffic demands for 20 years. Continued urban growth with attendant travel demands has out-stripped the intended freeway capacities in many locations. The primary response to increased travel demand in past decades has been to construct new facilities. Unfortunately, the cost of providing new facilities and maintaining old ones has risen faster than inflation. The State Department of Highways and Public Transportation (SDHPT) has implemented relatively low-cost programs to increase the utilization of the existing capacity of urban freeways.

Background

The results of increased development along freeway corridors have been increased traffic congestion, increased accident potential, and reduced operating speeds at frontage road-arterial intersections, at exit and entrance ramps, and on the main lanes. Additionally, corridor development along freeways has created access problems at certain locations. In response, the SDHPT has constructed relatively low-cost improvements to the freeway right-of-way such as new ramps, grade-separated ramps, and frontage road U-turns, and has also relocated ramps in order to reduce traffic queues at critical points. The intent of these types of modifications is to make maximum use of existing freeway capacities at a minimum cost.

The need for a tool or methodology to measure the cost-effectiveness of minor freeway modifications has become necessary. That these low-cost improvements can ease freeway congestion is generally accepted. However, because of funding and personnel constraints, the ability to select and prioritize various improvements or alternative solutions to freeway bottlenecks is crucial. The techniques currently employed to prioritize improvements tend to concentrate on the impacts on the primarily-affected traffic stream. Routinely, additional indirect benefits accrue to other portions of the traffic stream that result from these low-cost modifications. These secondary impacts are not typically included in evaluations because of the lack of adequate documentation and quantification of the secondary effects and the lack of an inexpensive tool to measure secondary impacts.

Study Purpose

The purpose of this study is twofold. The first objective is to identify, document and quantify all road user benefits that accrue from minor freeway modifications. Road user benefits include any savings in time and operating costs because of decreases in delay, idling, and travel time for all affected drivers, as well as benefits associated with decreases in accidents and accident potential as a result of decreased congestion.

The second objective of this study is to develop streamlined procedures to estimate the benefits to be derived from a particular improvement. These procedures will aid in the identification of those types of improvements that offer the highest potential benefit under given volume and geometric conditions.

Study Orientation

Most of the research conducted thus far in Study No. 210 has been related to modifications to the main lanes of a freeway. Such modifications included narrow lanes and extended auxiliary lanes. This portion of the study focuses on those improvements that can be made outside of the main lanes. While such modifications are typically implemented to solve problems that originate on the frontage road or at the downstream intersection, they frequently lead to reduced queues and improved freeway operation. It is unlikely that any of these minor modifications will produce the magnitude of benefit of freeway widening. However, for the cost involved, they offer some distinct advantages and can serve as an interim improvement until major improvements can be implemented.

Study Procedure

The road user benefits derived from minor freeway modifications include savings in four distinct areas: a) vehicle running costs, b) travel time costs, c) delay costs, and d) idling costs. In addition, the benefits derived from decreases in accidents are included. Quantification of the elements involves placing dollar values on time and on running, idling, and accident costs. The evaluations of all of the specific modifications made in this study are based on the dollar values defined by the 210-5 report, An Economic and Environmental Analysis Program Using the Results from a FREQ Model (1). Road user benefits are a compilation of both primary and secondary effects. Savings in running costs and travel time costs generally comprise the majority of the primary benefits, while savings in delay and idling costs typically comprise the bulk of the secondary benefits. However, the classification of road user savings into primary and secondary benefits varies with the type of freeway improvement implemented.

Running Cost Savings - These savings are based on the cost of operating a vehicle at the predominant operating speed, plus the cost of slowing or stopping at any intersection within the study area. Winfrey's (2) speed change cycle costs are used in determining additional running costs associated with stopping or slowing at intersections. Running cost savings are calculated as the difference between the running cost to vehicles before the construction of a given modification and the running cost after the construction.

Travel Time Cost Savings - The savings in travel time from each freeway improvement are based on travel time runs made before and after construction. This difference in time is assigned a dollar value using the 210-5 report's findings.

Delay and Idling Cost Savings - These savings are derived from the decrease in standing delay experienced at study area intersections. The average delay and idling times per delayed vehicle are recorded both before and after construction. The time savings are then converted to dollar savings.

Accident Cost Savings - Accident analyses that include relative changes in accident severity are performed. Ideally, each accident analysis should include accident data for at least two years prior to the completion of an improvement and two years after the completion of the project. Because of time constraints of this study, the accident analyses do not always span the two years before and two years after the completion of a project.

Data Collection Techniques

To achieve the objectives of this study, detailed operational data have been collected on several low-cost improvements. All of these data have been collected during the peak periods, which vary slightly from site to site, but generally fall between 7:00 to 9:00 a.m. and 4:00 to 6:00 p.m. Two types of field studies have been conducted - speed profile studies and intersection delay studies.

Speed Profile Study

In order to calculate running cost and travel time cost savings, a speed profile study is conducted. A speed profile study involves determining the average operating speed (typically on the main lanes) of vehicles traveling through the study area. Travel times are recorded on several segments of the freeway (see Figure 1), and are converted into operating speeds. Both the travel times and operating speeds for the before and after construction conditions are collected.

Intersection Delay Study

The calculations of both delay and idling cost savings are based on data collected during an intersection delay study. An intersection delay study involves determining the average vehicular delay experienced at a study area intersection.

Throughout the course of this research study two different techniques for measuring intersection delay have been used. Each technique has its own set of advantages. The first approach involves using an input-output method. The arrival and departure times of each vehicle are recorded on an event recorder. Knowing the length of time that each vehicle is delayed, it is

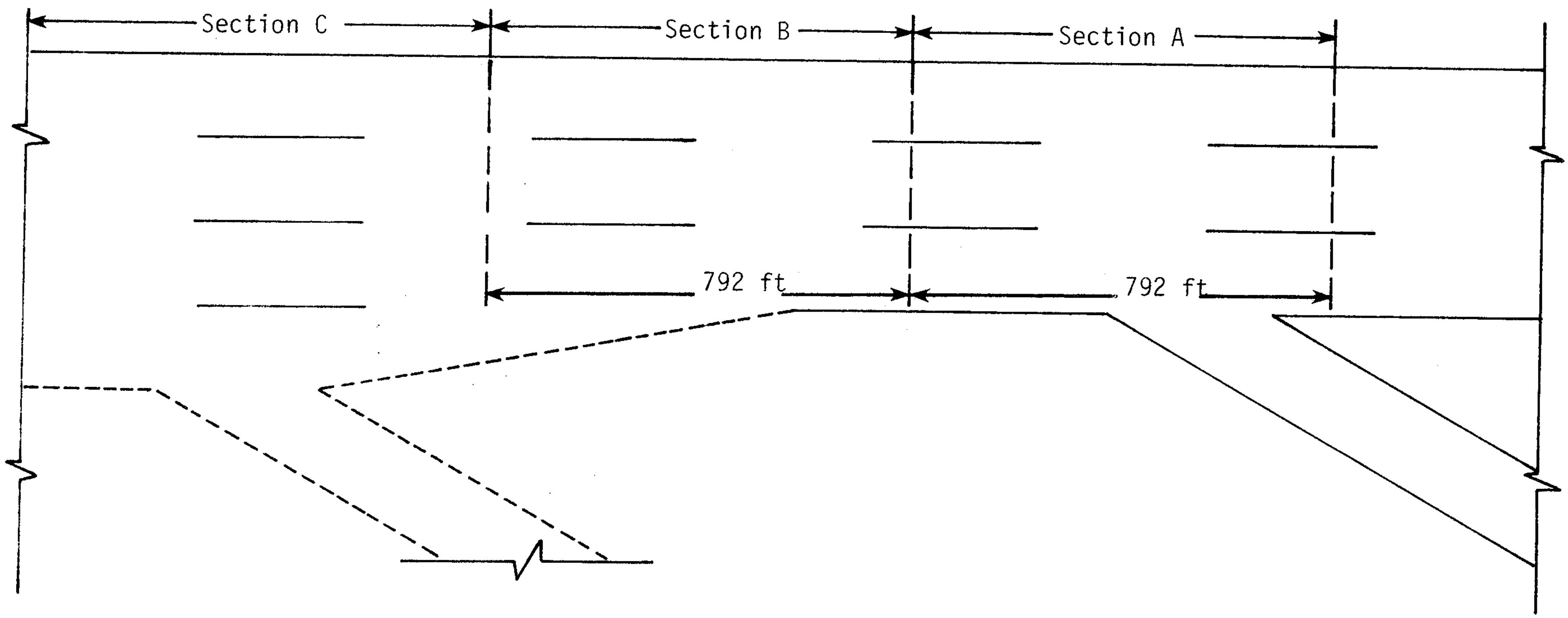


Figure 1. Typical Layout for Speed Profile Study

possible to determine very accurately the average delay experienced at each approach. The paper tape, upon which the times are recorded, serves as a permanent record of the intersection's delay characteristics.

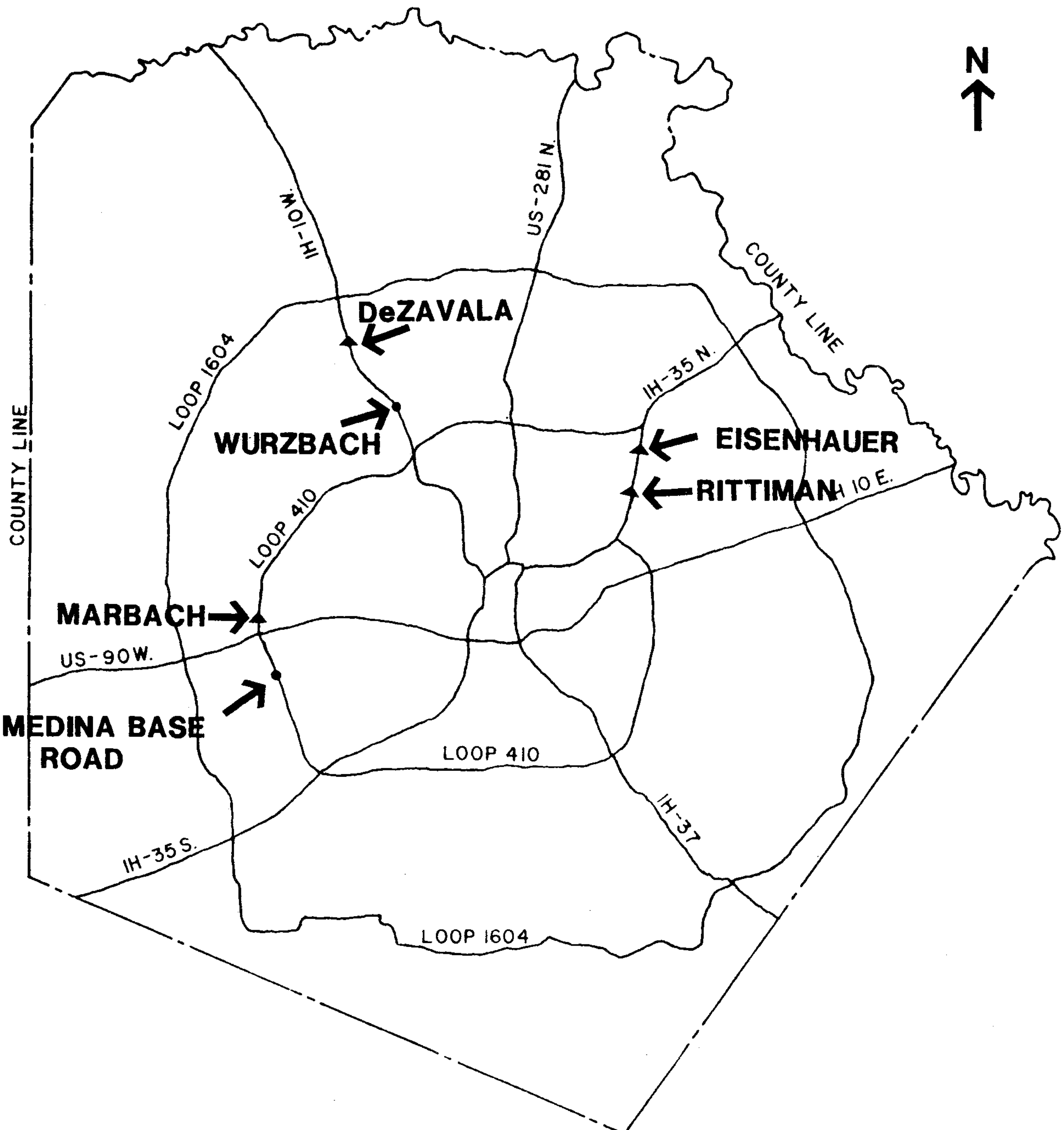
The primary disadvantage associated with using the event recorder technique is the excessive data reduction time required. In an effort to decrease this data reduction time, a second technique has been employed. This method, called a point sample method, is described in detail in Reilley's report A Technique of Measurement of Delay at Intersections (3). The technique involves making counts of all stopped vehicles on an approach at 15-second intervals. The 15-second counts approximate a weighted average of delay time per stopped vehicle. This weighted average serves as the average delay and idling time necessary to calculate delay and idling cost savings. The data reduction time for the point sample method is approximately one-eighth that of the time necessary to reduce the input-output data.

Of concern was the accuracy that would be lost if the 15-second point sample data collection method were used. When the two techniques were compared for the same sample, the accuracy of the point sample technique was determined to be not less than ± six percent of that of the event recorder. This error rate was considered acceptable and the 15-second point sample method was adopted for the remaining intersection delay field studies.

Portion of Study Covered by This Report

Thus far, the evaluations of two minor freeway modification projects have been completed. These projects include the Medina Base Road ramp additions to I-410 and the relocation of the Wurzbach exit ramp to I-10 (see Figure 2). The before and after construction field data have been collected and analyzed for both sites.

Bexar County, Texas



● Study sites for which the analysis is complete

▲ Study sites for which pre-construction data has been collected

Figure 2. Study Site Locations

Other field study locations where construction is planned or ongoing include: a U-turn addition at Eisenhauer and I-35; an exit ramp relocation frontage road widening, and U-turn addition at Rittiman and I-35; and relocation of the Marbach exit ramp to I-410 (see Figure 2). Only the before construction field data have been collected at these three San Antonio sites. As construction is completed, the after construction data collection and subsequent analysis will be performed.

RAMP ADDITIONS

Ramp additions refer to the construction of ramps at freeway locations where no direct access existed previously. Prior to ramp additions, drivers desiring to access a site (either a frontage road attraction or an intersecting arterial) generally are required to exit the freeway upstream of the desired point and to travel along the frontage road to their destination. Also, drivers wishing to access the freeway from their destination typically are forced to travel along the frontage road to an upstream entrance ramp. This type of access normally entails traveling through an upstream intersection (see Figure 3).

The benefits of ramp additions to the drivers desiring access are obvious. These direct benefits include: a) the savings in running costs (frontage road running speed versus freeway running speed), b) travel time savings, and c) savings in upstream intersection delay and idling costs.

The indirect benefits derived from ramp additions are not always as obvious as the direct benefits. Most likely, traffic demand at upstream intersections will decrease as a result of the new access points. The decrease in demand should improve the operation of these intersections and thereby should decrease standing delay. The decrease in demand may also decrease the number or severity of accidents at the upstream intersections through reduced exposure.

Another possible indirect benefit may be the alleviation of exit ramp queues onto the main lanes at upstream exit ramps. High demand for a given downstream destination may result in congested frontage road approaches and exit ramp queues onto the main lanes. With the addition of new access

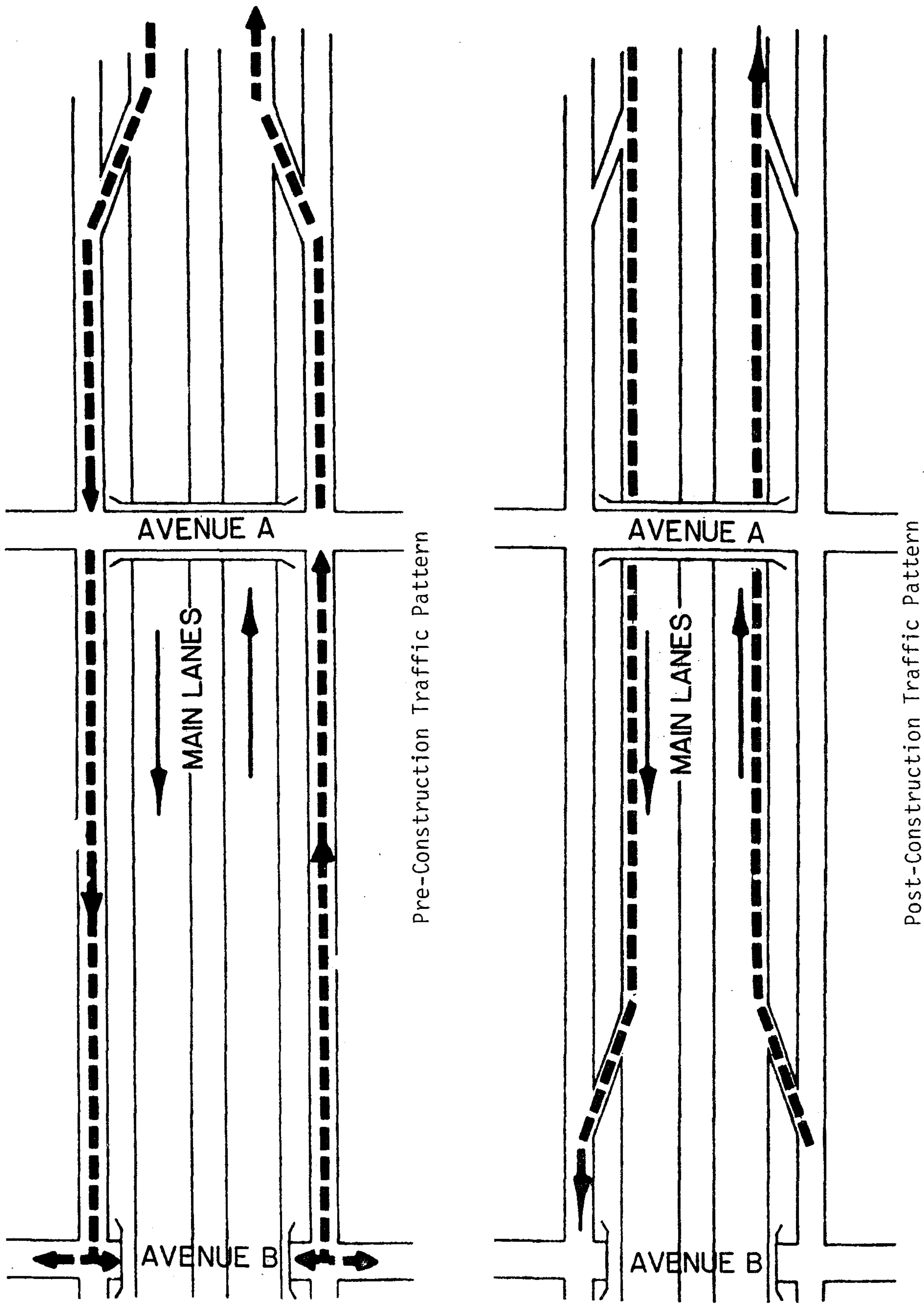


Figure 3. Typical Before and After Travel Patterns for Ramp Additions

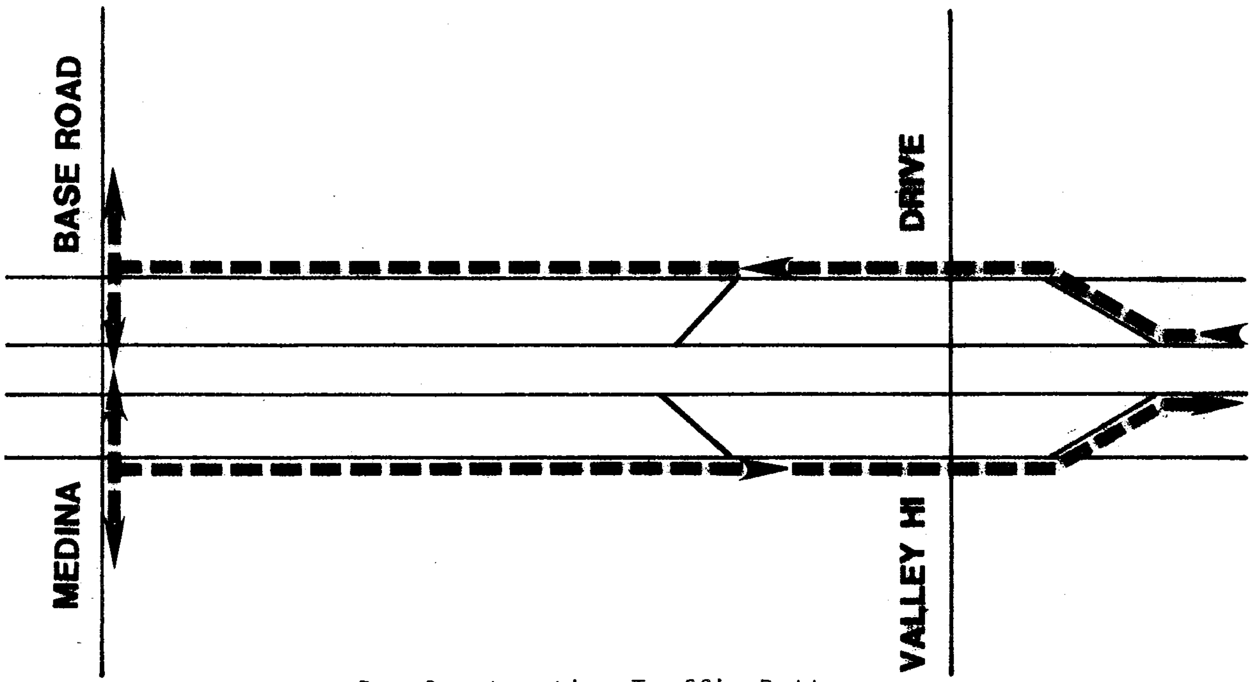
points these queues can be eliminated and delay and accident potential can be decreased.

Medina Base Road Ramp Additions

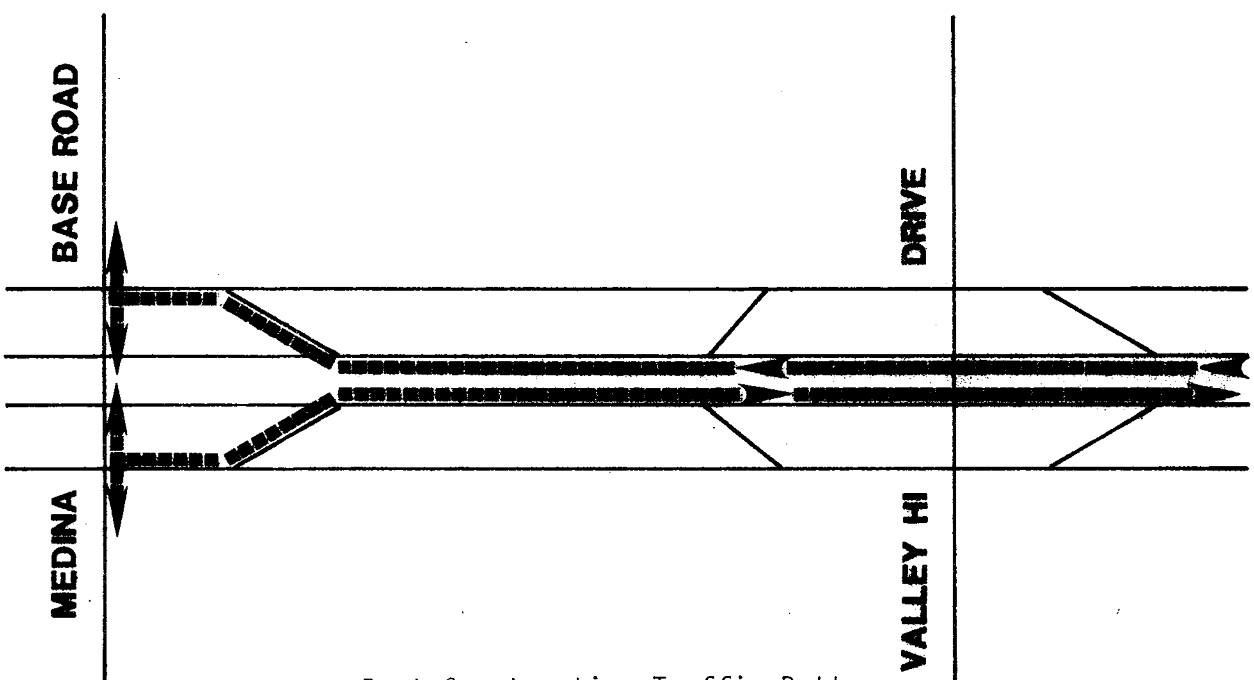
The addition of an entrance and an exit ramp to Medina Base Road at I-410 in San Antonio is a minor freeway modification made to improve access. The Medina Base Road ramps were completed and opened to the public on July 31, 1981. Before the Medina Base ramps were completed, drivers wishing to use Medina Base Road had to exit I-410 at Valley Hi Drive. Also, drivers wishing to access I-410N from Medina Base Road had to wait through the Valley Hi intersection signal before entering the freeway (see Figure 4). The obvious benefits of the new ramps were the elimination of the delay at the Valley Hi intersection and the decrease in travel time and running cost to the Medina Base Road drivers. The secondary benefits from the new ramps were the decrease in intersection delay for Valley Hi drivers and the elimination of exit ramp queues from the main lanes of I-410 and the Valley Hi exit.

Selection of Appropriate Improvement

Prior to the construction of the Medina Base Road ramps, the Valley Hi interchange at I-410 operated at capacity during the peak hours. Figure 5 shows the average daily approach volumes at this intersection. These volumes created an unacceptable level-of-service (LOS D to E) at this intersection during both the a.m. (7:00 to 8:00) and p.m. (4:00 to 5:00) peaks. Additionally, during the a.m. peak, the southbound exit traffic to Valley Hi queued onto the main lanes of I-410 for approximately 10 to 15 minutes (4).

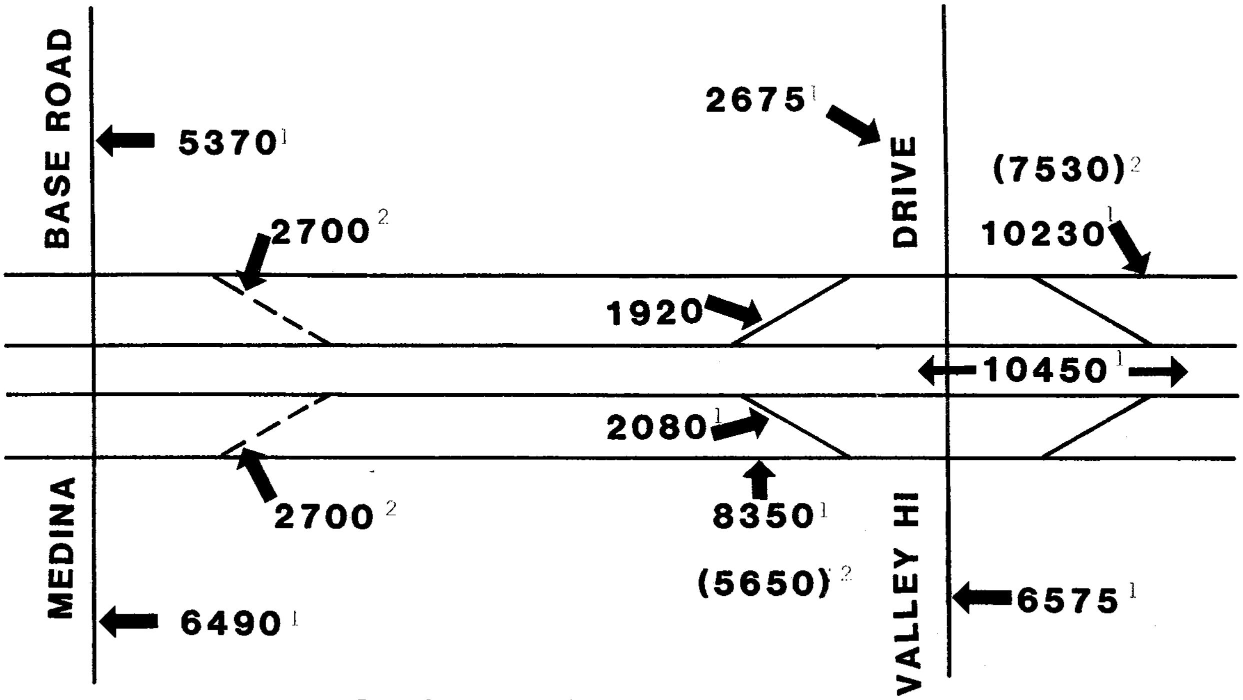


Pre-Construction Traffic Pattern



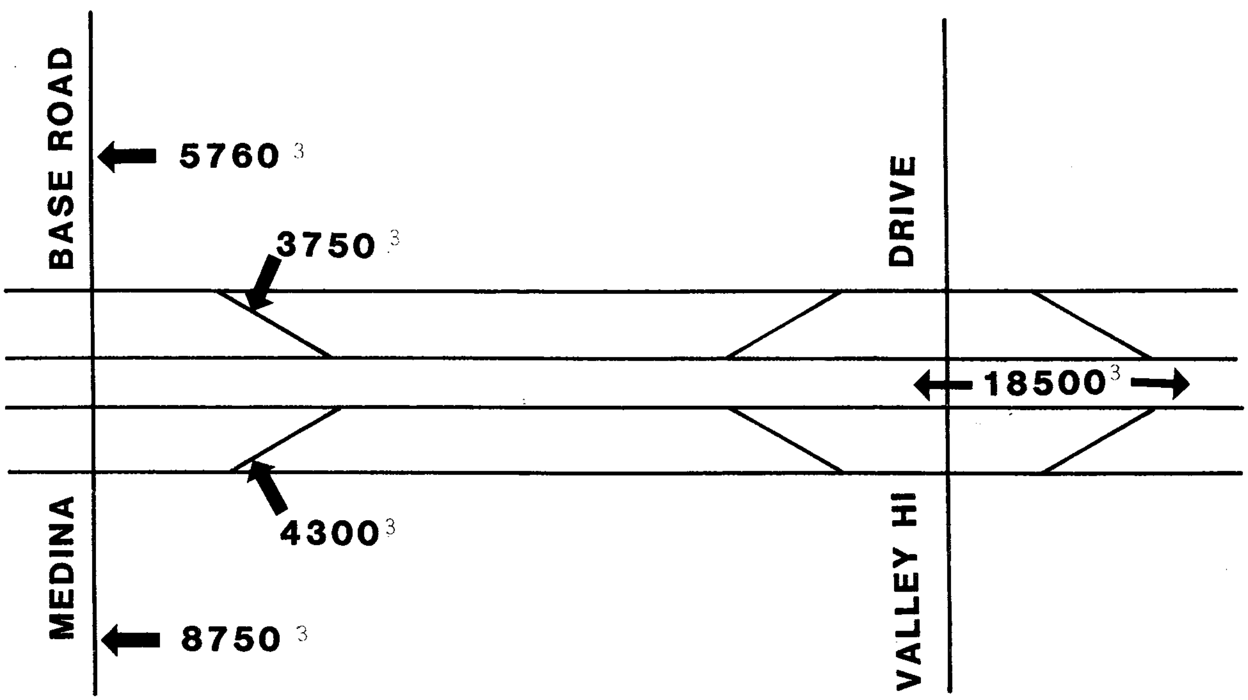
Post-Construction Traffic Pattern

Figure 4. Before and After Travel Patterns



Pre-Construction Traffic Volumes

Source: Freeway Operations Report, District 15, SDHPT



Post-Construction Traffic Volumes

Notes: [1]Before volumes, [2] Predicted volumes,
[3]Actual volumes after construction

Figure 5. Before and AFter Volumes Data

District 15 of the SDHPT recognized that a moderate amount of traffic could be removed from the Valley Hi intersection by constructing ramps to and from Medina Base Road (see Figure 5). The new ramps would provide direct access to Medina Base Road, could ease the congestion at Valley Hi, and possibly could eliminate the main lane queues at the Valley Hi exit. However, because the new ramps would cost $295,000 to construct, a quantification of the anticipated benefits from these ramps had to be made.

In justifying the cost of the new ramps, the District performed the economic analysis outlined in the <u>Operations and Procedures Manual</u> (<u>5</u>). The analysis included calculating an estimate of running cost savings and delay cost savings for potential ramp users. If, as anticipated, at least 5,400 vehicles used the new ramps daily, approximately $13,500 per year could be saved in running costs and approximately $45,750 per year could be saved in delay cost. Tables 5 and 6 of Appendix A detail how these dollar figures were derived.

Based on the economic analysis, the District estimated that the Medina Base Road ramp additions would save the motoring public approximately $60,000 per year. This savings translates to a benefit/cost ratio of 2:1 (n = 20, i = 10%) and less than seven years necessary to amortize the project. The economic analysis provided sufficient justification to construct the new ramps. Although it was recognized that secondary benefits (improved Valley Hi operation) would accrue from the Medina Base ramps, no abbreviated procedure existed to quantify these benefits.

Pre-Construction Conditions

Traffic Patterns

Valley Hi Drive is one of the three main entrances into Lackland Air Force Base (a major traffic generator) (see Figure 6). During the a.m. peak the major traffic flow is southbound on the I-410 frontage road turning eastbound onto Valley Hi Drive towards Lackland A.F.B. The major traffic flow during the p.m. peak is westbound on Valley Hi Drive away from Lackland. The most critical operational problem occurs during the a.m. peak on the southbound I-410 frontage road at the Valley Hi exit ramp. The combination of high peak-hour volume on the southbound frontage road (1565 vehicles) and the signal timing (which favored Valley Hi) caused queues of vehicles on the Valley Hi exit ramp and at times onto the main lanes of I-410.

Prior to any improvements, delay and travel time studies were conducted. The travel time (from Valley Hi to Medina Base Road) for potential ramp users was 65.6 seconds. Approximately 90 percent of the southbound frontage road vehicles experienced some delay at the upstream Valley Hi intersection during the a.m. peak with average delays exceeding two minutes per vehicle. During the p.m. peak the westbound Valley Hi traffic also experienced congestion and average delays of 30 seconds per vehicle. The overall Valley Hi intersection delay exceeded 80 vehicle-hours each day. The detailed data collected at Valley Hi are shown in Table 7 of Appendix A.

In order to ease the critical a.m. peak main lane queuing problem prior to the completion of the new ramps, the upstream intersection signal was retimed by District 15 personnel. The primary result of the retiming was the elimination of queues on the Valley Hi exit ramp and the I-410 southbound main lanes. The signal retiming also resulted in drastically reduced delay

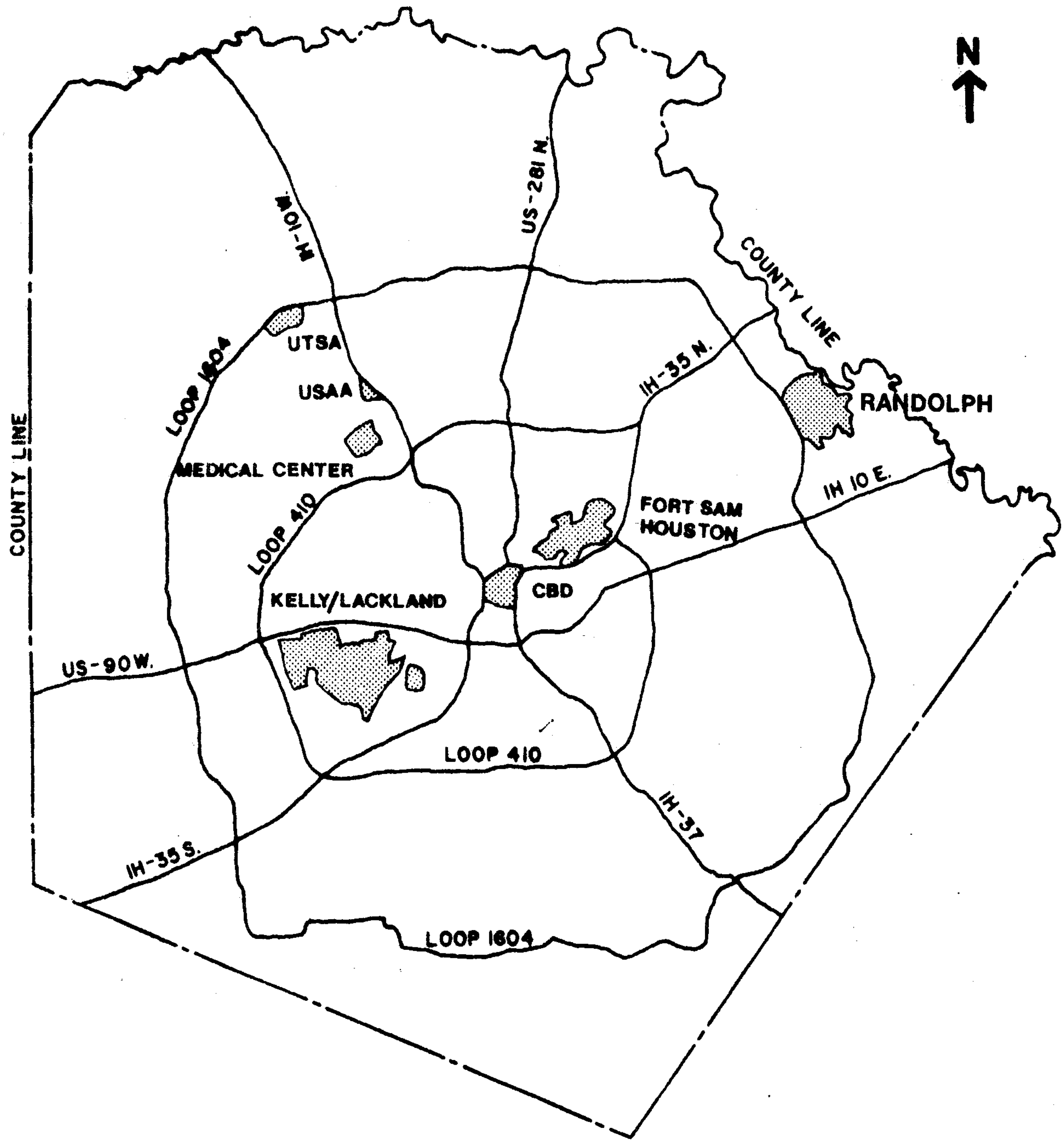


Figure 6 . Major Traffic Generators in Bexar County

experienced at all four approaches of the Valley Hi intersection during the peak periods. Overall intersection delay was reduced to just over 30 vehicle-hours of delay daily (a 62 percent improvement). The benefits from this signal timing improvement can be expected to last up to five years.

Accident Data

A one-mile section of I-410 adjacent to Valley Hi was the study section for accident data (Control-section: 521-5; milepoints 5.0-6.0, see Figure 7). The accident rate for this study area for 17 months prior to the completion of the new ramps was 2.62 accidents per million vehicle miles (MVM).

The accident rate for the northbound exit ramp to Valley Hi for the 17 months prior to construction was 4.02 accidents per million entering vehicles (MEV). The southbound exit ramp experienced no accidents during the before construction period.

The Valley Hi intersection experienced a 2.95 accidents per MEV accident rate during the 17 months prior to construction of the new ramps.

Surprisingly, the main lane milepoint sections directly upstream of the exit ramps were devoid of accidents for two years prior to the new ramp construction. Three years prior to the ramp additions the southbound main lanes experienced six accidents near the Valley Hi exit ramp; however, the average accident rate for the three years is lower than the average rate for four lane freeways with similar volumes

Post Construction Conditions

Traffic Patterns

The primary result of the addition of the Medina Base Road ramps was the elimination of the delay associated with using the upstream intersection

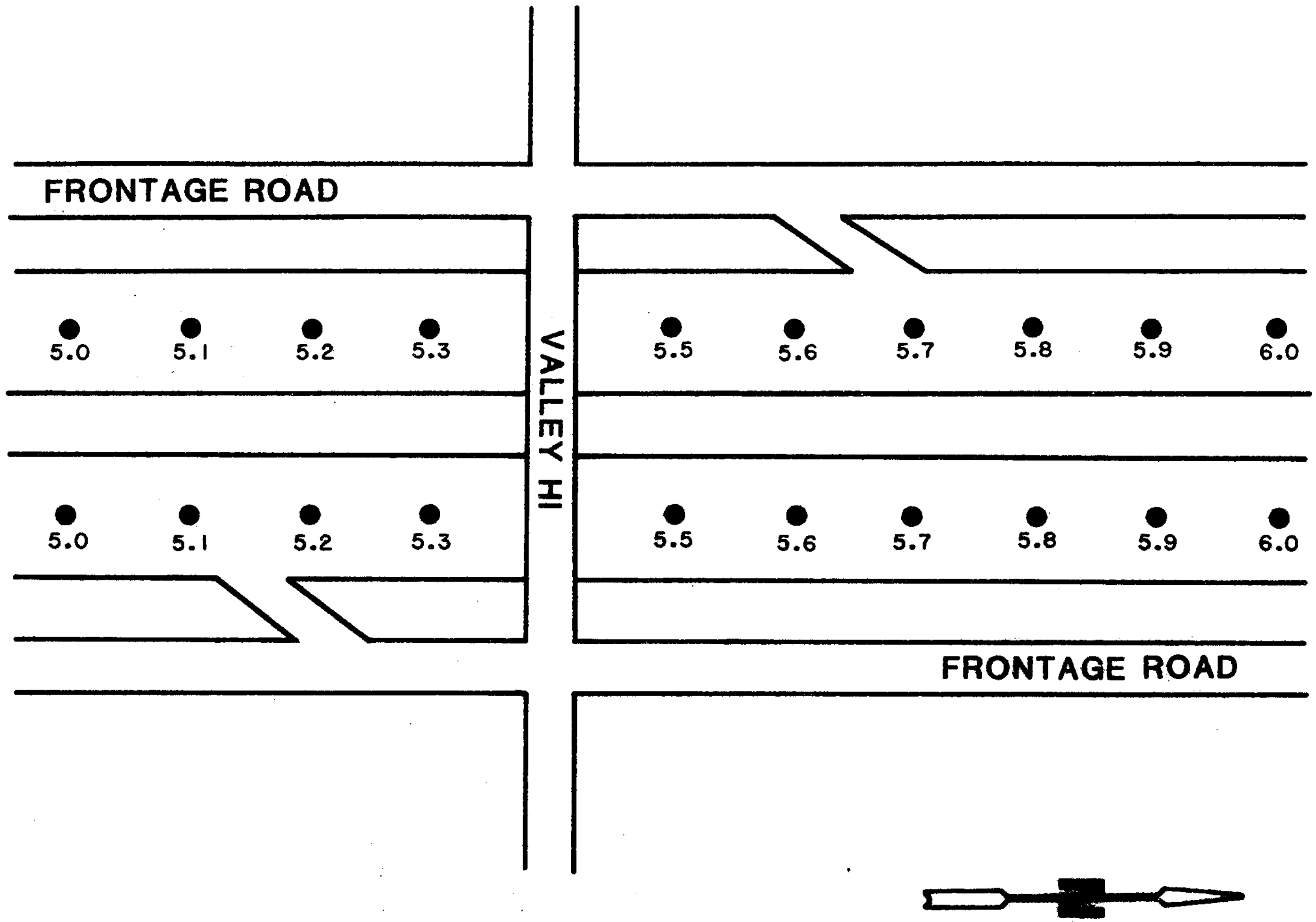


Figure 7. Control-Section 521-5; Milepoints 5.0-6.0

for some 8,050 ramp vehicles each day. Additional benefits from the new ramps were seen at the upstream interchange. The peak period volume on the northbound and southbound frontage road approaches to the intersection were decreased by 27 percent, further reducing the standing delay at the upstream intersection. The standing delay during the peak periods was reduced from 30 vehicle-hours to 16 vehicle-hours daily. This change represents an additional 46 percent improvement in operation over the improved signal operation.

An analysis of the I-410 frontage road volumes from before and after ramp construction and the new ramp volumes indicates the existence of some latent demand for the new ramps. It was anticipated that approximately 5,400 vehicles would use the new ramps each day. This estimation was based on the through traffic volume on the frontage roads upstream of the new ramp location (see Figure 5). The actual daily volume on the new ramps is 8,050 vehicles (an increase of 2,650 vehicles over that expected). Since the Medina Base Road ramps provided a new access point to Lackland AFB, it is suspected that most of the increase is due to a shift from the congested upstream interchanges (Valley Hi, U.S. 90). The possibility of an increase in demand for access to a given point should be recognized when estimating usage of an improvement.

Accident Data

During the 17 months after the construction of the new ramps, the accident rate for the study section was 2.50 accidents per MVM. This rate indicates a slight overall decrease in accident frequency during the after construction period.

The accident rate for the northbound exit ramp to Valley Hi during the after construction period was 2.29 accidents per MEV. The southbound exit ramp experienced one accident during the after construction period (1.10 accidents per MEV).

The Valley Hi intersection experienced a 2.42 accidents per MEV accident rate during the 17 months after the new ramps were completed.

Main lane accidents at the exit ramps did not increase during the after construction period.

Analysis of Improvement

The analysis of the ramp addition project involved a quantification of the total benefits (both primary and secondary) accrued to the motoring public. The monetary value of the total benefits was then used to calculate a benefit/cost ratio for the ramp addition project and the length of time necessary to amortize the project was estimated. The steps of this analysis format are demonstrated using the Medina Base Road ramp addition data and may be found in Tables 7 through 12 in Appendix A.

Primary Benefits

The estimated monetary value of the primary benefits derived from the Medina Base Road ramp addition project is $162,000 per year (see Figure 8). This dollar figure is based on several elements. The first element, running cost savings, is the difference in the cost of operating vehicles on the frontage road (through the upstream intersection) before ramp construction and the cost of operating vehicles on the freeway after the new ramps were opened. This running cost savings amounts to an approximate annual savings of $86,000.

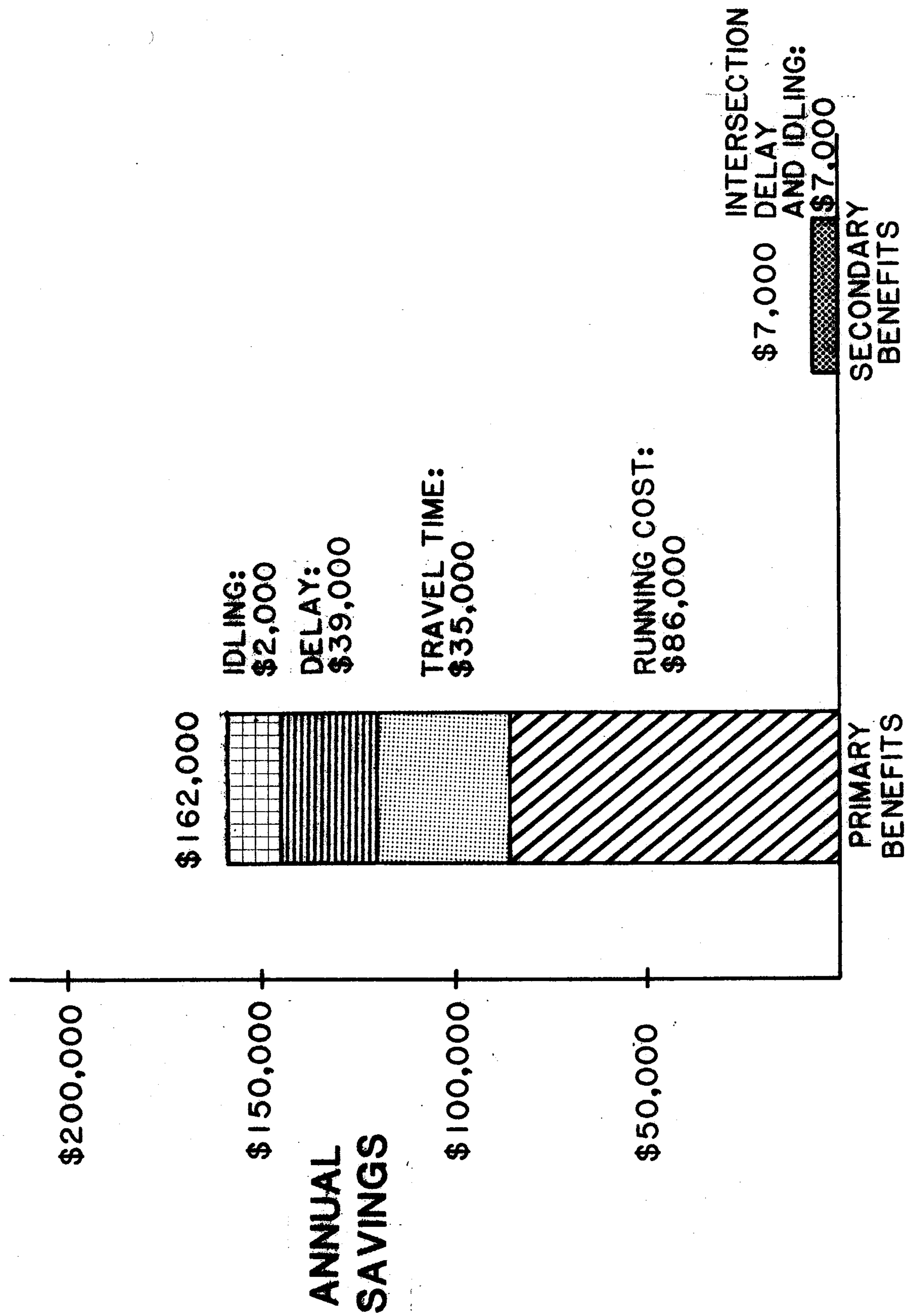


Figure 8. Total Benefits Derived from the Medina Base Road Ramp Additions

The travel time cost savings derived from the new ramps are the dollar values of time saved by using the freeway after the ramps were constructed. The travel time cost savings of 15.3 seconds per vehicle translates to an annual savings of approximately $35,000.

The delay and idling cost savings are based on the delay and idling time at the upstream intersection that were eliminated for ramp drivers by the new ramps. Approximately 21 seconds per vehicle of delay and idling time were eliminated for the new ramp drivers. These savings total $41,000 annually.

Secondary Benefits

The secondary benefits of the improvement in upstream intersection operation are measured in decreased delay and idling costs at the intersection. The decrease in delay and idling are a direct result of decreases in traffic volumes on the frontage road approaches to the intersection. The upstream intersection improved an average of eight seconds per vehicle on all four approaches. This improvement in operation yields an approximate annual savings of $7,000.

Adding all of the savings components together, the total annual savings from the ramp addition project is $169,000. The secondary benefits from this project represent four percent of the total benefits. The cost of constructing the new ramps was $295,000. The benefit/cost ratio for this project is in excess of five to one. The new ramps should pay for themselves in benefits to the public within two years.

Accident Analysis

The study area experienced a lower accident rate after the Medina Base road ramps were completed. Table 1 summarizes the accident data. The

Table 1. Valley Hi Accident Data Summary

LOCATION	"BEFORE" ACCIDENT RATE	"AFTER" ACCIDENT RATE	PERCENT CHANGE
Entire Study Area	2.62 acc./MVM	2.50 acc./MVM	- 5%
NB Exit Ramp to Valley Hi	4.02 acc./MEV	2.29 acc./MEV	-43%
SB Exit Ramp to Valley Hi	0 acc./MEV	1.10 acc./MEV	+100%
Valley Hi Intersection	2.95 acc./MEV	2.42 acc./MEV	-18%

overall decrease was not, however, satistically significant. Although the accident history improved slightly, this improvement alone is not sufficient to justify the ramp additions.

Summary of Findings

The process of analyzing the Medina Base Road ramp addition project provides a framework for evaluating other potential ramp addition projects. The applicability of these findings to other situations is, of course, dependent upon the traffic and geometric conditions of each site. The following summary of the Medina Base Road project indicates the type and amount of influence that each variable may have on total benefits.

Primary Benefits

Running Cost Savings - The average savings in running cost was 6.4¢ per vehicle. The majority of this savings was derived from the elimination of the cost of slowing or stopping at the upstream intersection. Overall, the elimination of the cost of slowing or stopping was the single largest road user benefit. Therefore, it is doubtful that ramp additions can be justified economically in the absence of a major, controlled upstream intersection.

Travel Time Cost Savings - This factor, which averaged 2.6¢ per vehicle in the Medina Base Road case, is essentially travel distance and operating speed related. In general, as travel distance and the difference in operating speed increases, there is a corresponding increase in the relative contribution to total benefits that travel time cost savings generates.

Delay Cost Savings - In terms of primary benefits, the average delay cost savings was 4¢ per vehicle. This component, the second highest road user savings, was a function of the cycle length and the volume of vehicles delayed at the upstream intersection. In this study, 73 percent of the potential ramp users were delayed. Higher proportions could be expected at more heavily-traveled locations.

Idling Cost Savings - The average savings in idling cost was only 0.2¢ per vehicle. It is unlikely that the economic impact of this component would ever be consequential. Idling cost savings is determined from the same base as delay, but it has a value about 1/25th that of delay.

Secondary Benefits

Delay Cost Savings - The secondary delay cost savings at the upstream intersection averaged 1¢ per vehicle. While this savings was basically related to the volume of traffic removed from the upstream intersection, it cannot be unequivocally stated that reduction of 2700 vehicles (instead of the actual 5400) would have produced a four second savings in delay per vehicle instead of the measured 8 seconds. The total intersection volume and the proportion of traffic removed are integral factors in this analysis. Unless dramatic results are anticipated, it is recommended that moderate changes in delay (5 - 10 seconds) be used for estimation purposes.

Idling Cost Savings - with respect to secondary benefits, idling cost savings plays an essentially negligible role in justifying ramp addition projects.

Impact on Other Facilities

To ensure that all aspects of the rerouting of vehicles were addressed, the impact on the I-410 main lanes and on Medina Base Road were assessed. Figure 5 shows the pre- and post-construction traffic volumes pertinent to these analyses.

A weaving and level-of-service (LOS) analysis of before and after conditions indicated that the volumes present are outside of the realm of weaving and that LOS "A" conditions prevail on the main lanes during the peak hour.

The increase in traffic on Medina Base Road was approximately 1100 vehicles per day. No change in peak hour level-of-service occurred due to the additional vehicles. Since the southbound frontage road must stop for Medina Base Road (two-way stop), there was some impact on these rerouted vehicles. It is estimated that the increase in volume added 4-5 seconds of waiting delay to rerouted traffic in the peak hour.

Conclusion

The obvious objective of any ramp addition is to improve access. However, other operational problems such as congested upstream intersections and exit ramp queues forming on the main lanes can be eased or eliminated by adding downstream ramps. The degree to which these operational problems can be alleviated and the magnitude of the road user benefits depends on the pre-construction traffic conditions. The benefits from the addition of the Medina Base Road ramps totaled approximately $170,000 per year. Although this project represents only one example of a successful ramp addition, the analysis of this project can serve as a guide for evaluating future ramp addition projects.

RAMP RELOCATIONS

A ramp relocation project typically involves removing an existing exit ramp and reconstructing it upstream of its original location (see Figure 9). During peak travel periods when the demand for a specific exit ramp exceeds storage capacity on the frontage road, slow moving or stopped queues can form on the main lanes in the vicinity of the ramp. By relocating the ramp further upstream from the arterial intersection, additional storage space on the frontage road can be utilized. Essentially, the main lane queues can be shifted to the frontage road.

The primary benefits from a ramp relocation project are derived from improvement in main lane operation when queues are reduced or eliminated. These benefits accrue from savings in main lane running costs and travel time costs. The secondary benefits from a ramp relocation project may be improved operations at the frontage road and arterial intersection. If the ramp relocation allows a more efficient use of frontage road storage, the intersection operation should improve.

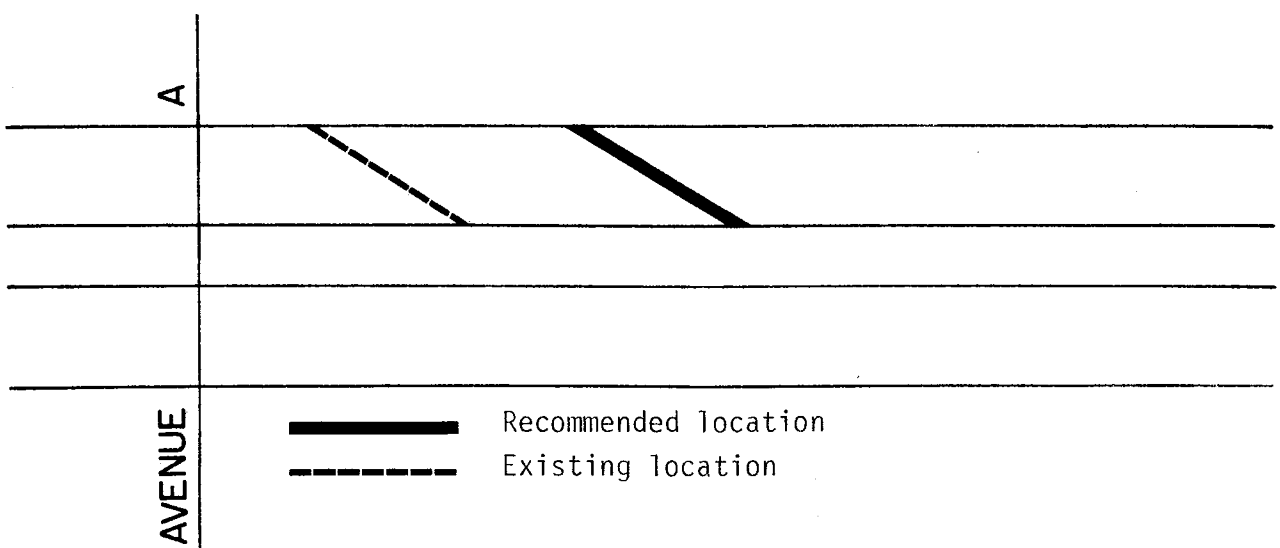


Figure 9 . Exit Ramp Relocation Project

Wurzbach at I-10: Exit Ramp Relocation

The exit ramp relocation project at Wurzbach and I-10 was completed and opened to the public by June 1, 1982. The westbound exit ramp was relocated approximately 0.5 mile east of its original location. This minor freeway modification was made because, during the p.m. peak, extremely slow moving exit ramp queues were forming on the westbound main lanes of I-10. Prior to the relocation project, the operating speed of the right main lane (WB) dropped to 20 mph for at least 15 minutes during the p.m. peak.

In conjunction with the ramp relocation project, the signal equipment and timing at the frontage road and arterial (Wurzbach) intersection were upgraded. The primary reason for the signal upgrade was the need to ease the incidence of main lane queues at the exit ramp. However, it was recognized that the signal upgrade would also improve the overall operation of the heavily congested intersection.

The primary benefits from both the ramp relocation project and the signal upgrading were the elimination of main lane exit ramp queues and the subsequent decrease in main lane running cost and travel time. The secondary benefit from these improvements was the improvement in both the frontage road and arterial operation. Standing delay at all four approaches to the intersection was decreased substantially.

Selection of Appropriate Improvement

The original location of the westbound exit ramp from I-10 to Wurzbach Road did not allow the existing frontage road capacity to be utilized fully. As a result, the traffic volumes exiting to Wurzbach caused traffic to back up onto the main lanes. It was recognized that the high exiting volumes (1500 to 2000 vph) during the p.m. peak also exceeded the capacity of a one lane exit ramp. The initial improvement plan called for the exit ramp to be relocated further upstream and to be expanded to two lanes (4).

Only the ramp relocation recommendation was implemented. Because a ramp relocation is not considered to be new construction work, no formal economic justification for the project was necessary. The rationale for moving the exit ramp was that previous relocation projects were effective in eliminating exit ramp queues. The signal upgrading was part of the overall planned signal equipment improvements for District 15. The ramp relocation project cost $172,000 to complete and the signal work cost approximately $14,000.

Pre-Construction Conditions

Traffic Patterns

Wurzbach Road is a very heavily traveled arterial that provides access to the South Texas Medical Center and to a large residential area north of I-10. The p.m. peak traffic volume exiting at Wurzbach approaches 1650 vehicles. Prior to the relocation of the exit ramp, the queue from the left lane of the frontage road frequently blocked the exit ramp. This blockage resulted in an inefficient use of the frontage road storage and caused extremely slow moving queues to form on the westbound main lanes.

Prior to any improvements, the average operating speed during the p.m. peak was 40 mph on the I-10 westbound main lanes. At times the operating speed in the right lane dropped to 20 mph or lower. Main lane level-of-service (LOS) fell below D for one-third to one-half mile east of the Wurzbach exit ramp.

The frontage road and arterial intersection also operated at low LOS (D to E) during the p.m. peak. All four approaches carry high traffic volumes during the peak. The average delay per stopped vehicle prior to any improvements was 125 seconds. This translates to approximately 113 vehicle-hours of delay each day.

The intersection signal retiming was implemented before the exit ramp relocation and signal detector work were completed. The signal retiming greatly improved both the Wurzbach intersection operation and the main lane queuing problems. Standing delay at all four approaches of the Wurzbach intersection was reduced by 50 percent to 56 vehicle-hours of delay. The incidence of main lane exit ramp queues was reduced, allowing the main lane operating speed to increase to 50 mph average speed.

Accident Data

A 1.2 mile section of I-10 adjacent to Wurzbach Road was the study section for accident data (Control-section: 72-12; milepoints 16.5-17.7; see Figure 10). The accident rate for this study area for six months prior to the relocation of the Wurzbach ramp was 5.16 accidents per MVM.

The accident rate for the east side of the Wurzbach interchange (northbound frontage road/westbound Wurzbach) during the before construction time period was 2.45 accidents per MEV. The west side of the interchange (southbound frontage road/eastbound Wurzbach) had an accident rate of 5.26 accidents per MEV during the six months prior to the ramp relocation.

The main lane sections that were affected by the ramp relocation experienced no accidents during the six months prior to construction.

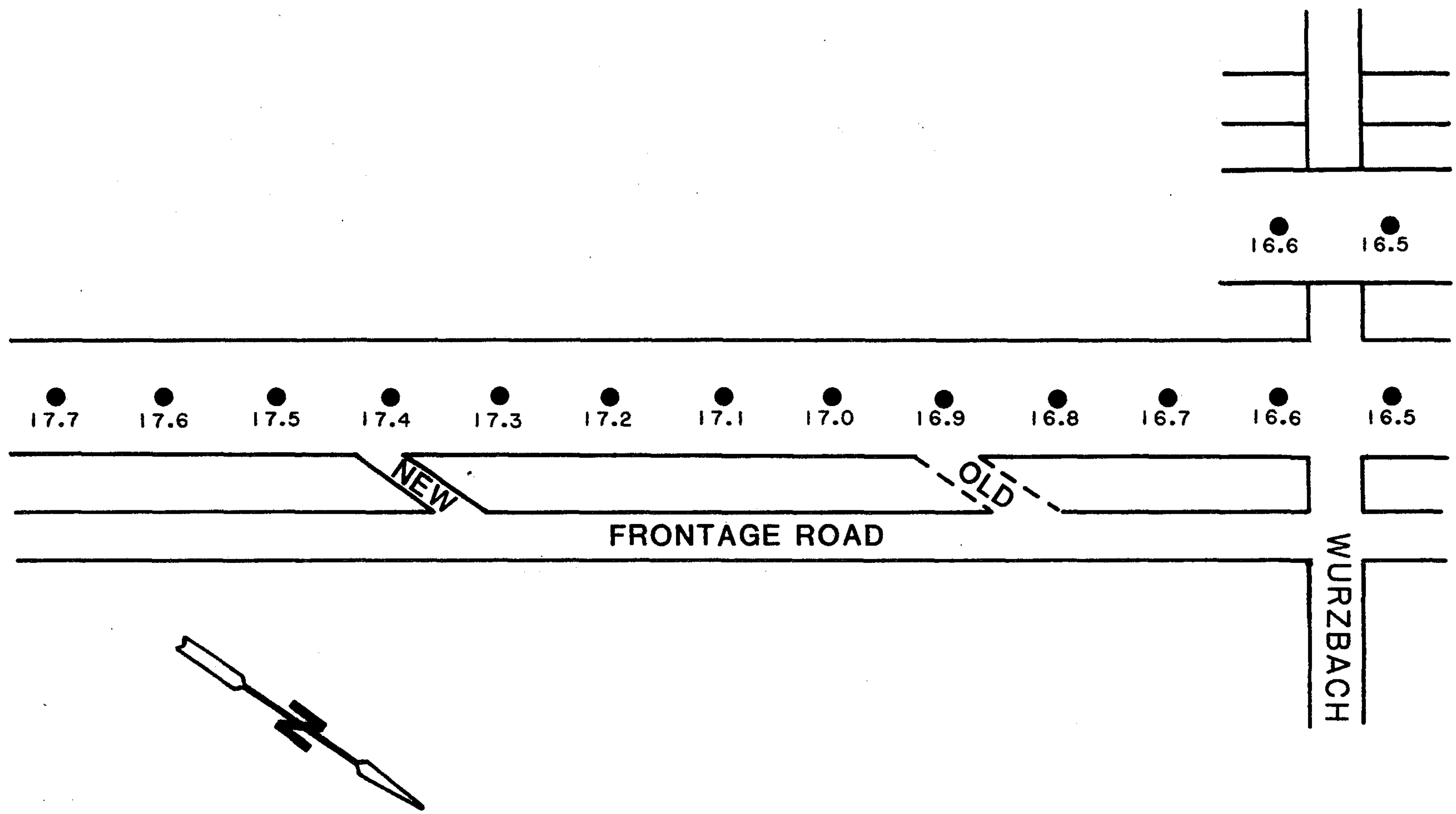


Figure 10. Control-Section 72-12; Milepoints 16.5-17.7

Post-Construction Conditions

Traffic Patterns

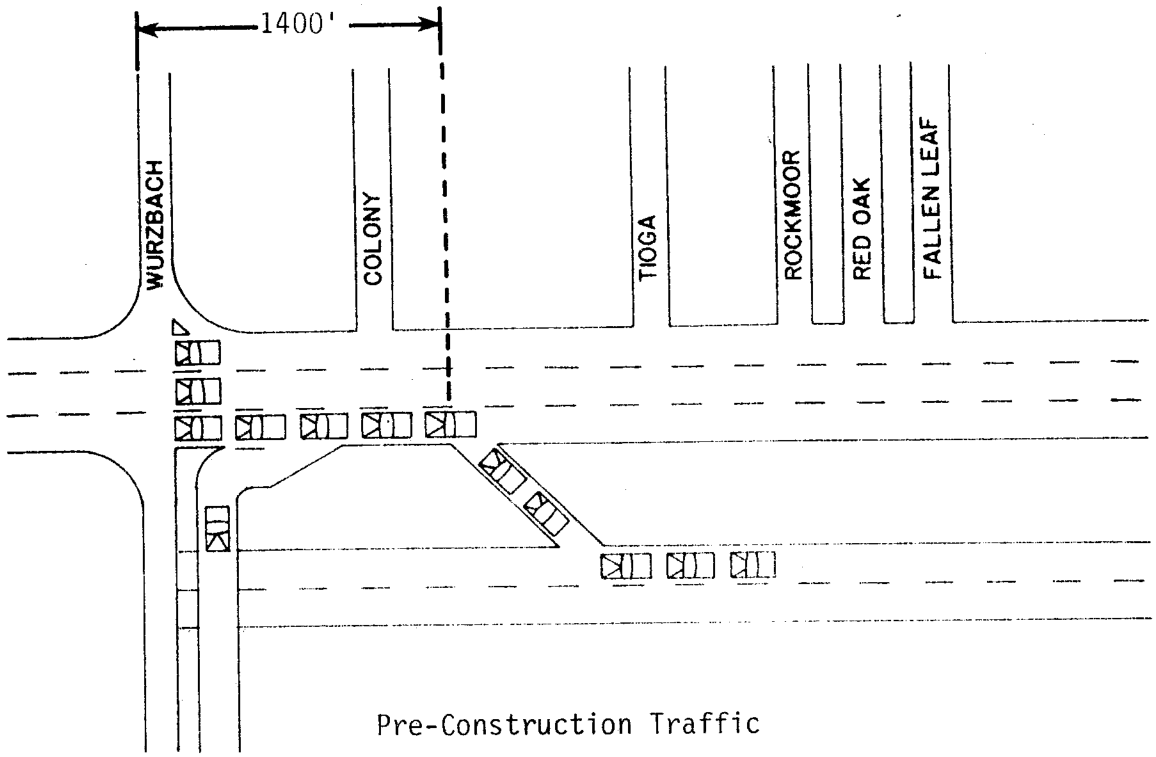
The primary result of the signal equipment upgrade and the ramp relocation was better operation of the diamond interchange which removed exit ramp queues from the main lanes. After the improvements were implemented, the storage capacity on the frontage road could be utilized more fully and the intersection operated more efficiently (see Figure 11). The average main lane operating speed returned to 55 mph after the improvements were completed (see Figure 12). The secondary result of these modifications was the reduced delay at the frontage road and arterial intersection. Standing delay was further decreased from 56 vehicle-hours to 35 vehicle-hours, an additional 37 percent improvement.

Another by-product of the ramp relocation was improved access to the residential area north of I-10 from the Wurzbach exit ramp. Figure 13 demonstrates this change in access.

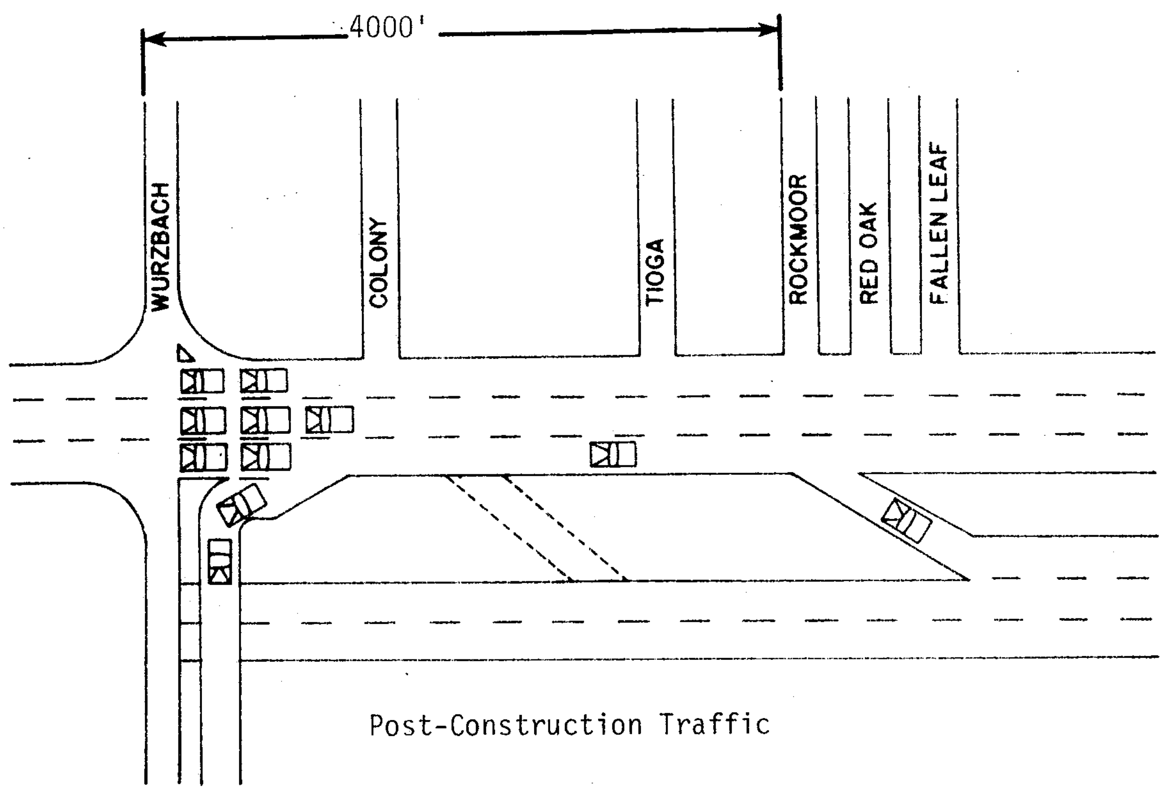
Accident Data

During the six months after the relocation of the Wurzbach exit ramp, the accident rate for the study section was 3.22 accidents per MVM. This rate indicates an overall decrease in accident frequency during the after construction period.

The accident rate for the east side of the Wurzbach interchange remained unchanged from the before relocation time period. The west side of the interchange improved substantially from five accidents to zero during the after construction period.



Pre-Construction Traffic



Post-Construction Traffic

Figure 11. Before and After Travel Patterns

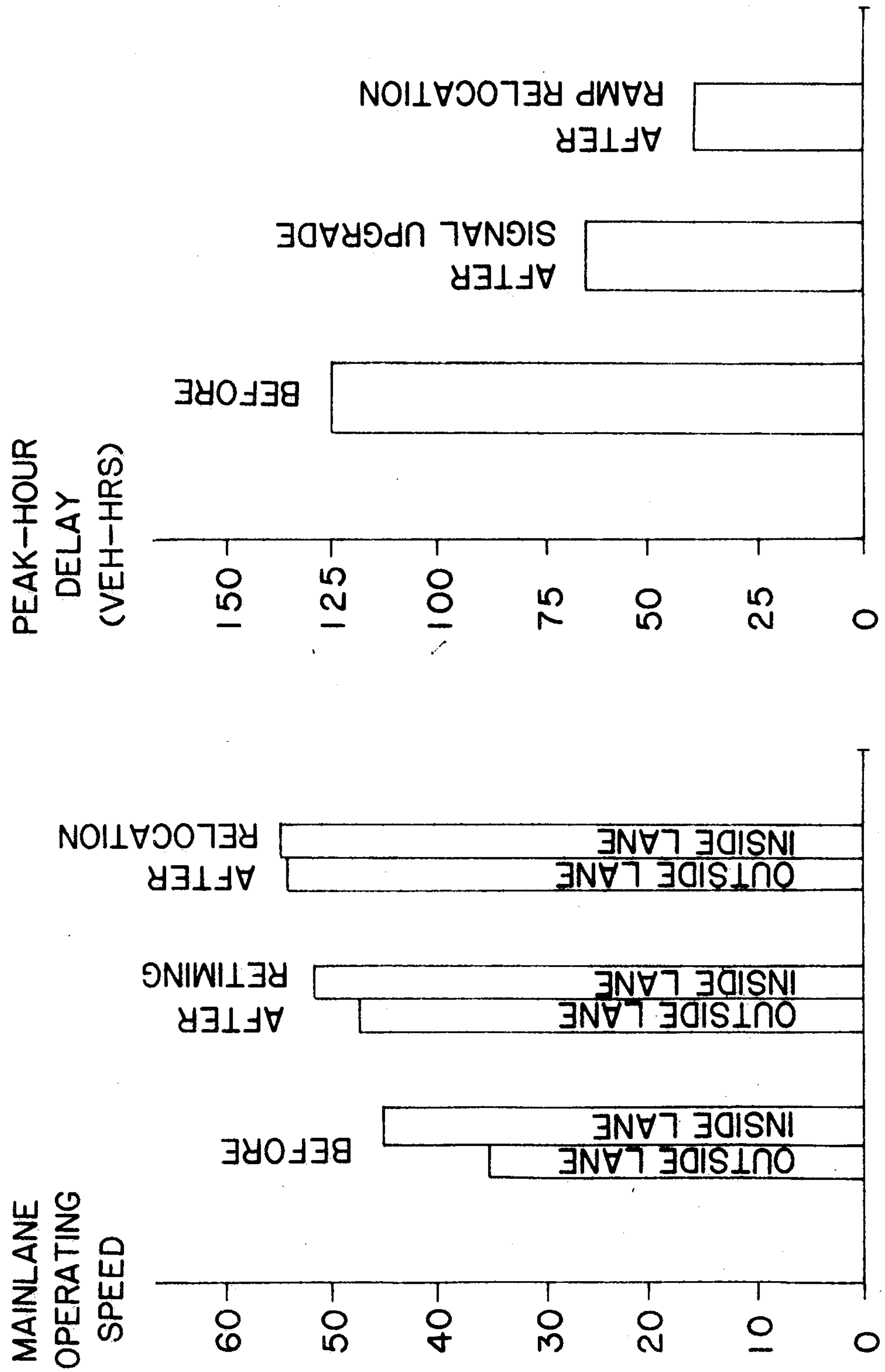
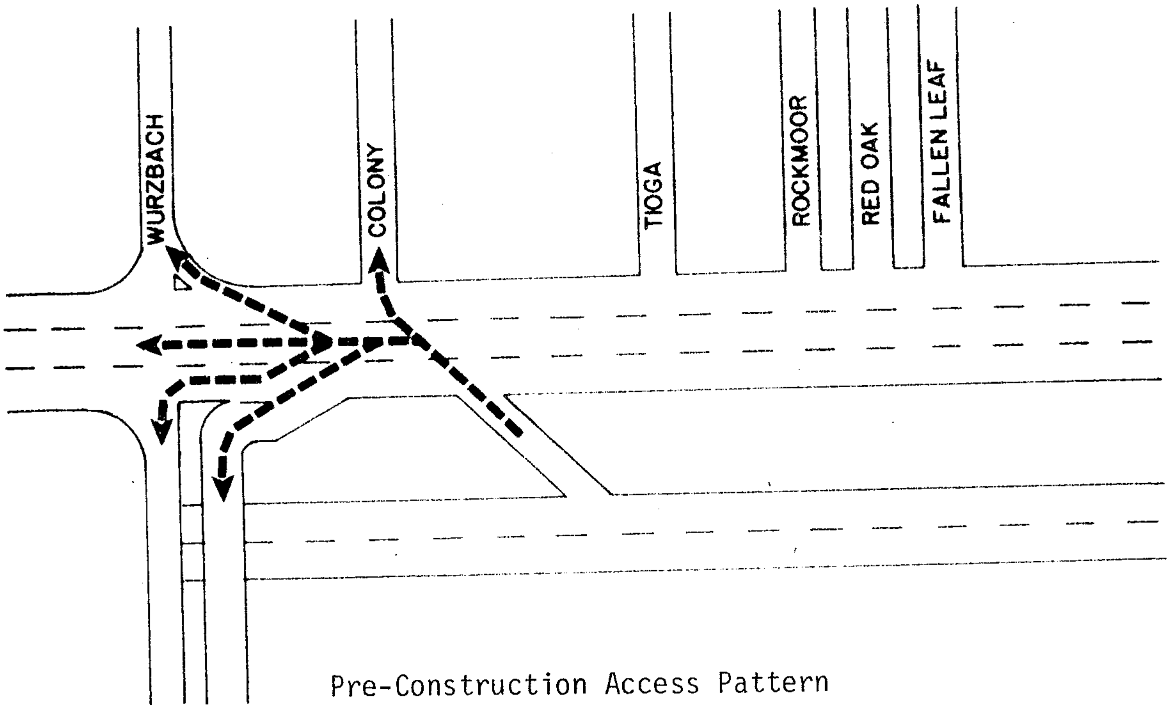


Figure 12. Post-Construction Improvements;
Ramp Relocation, I-10 at Wurzbach Road



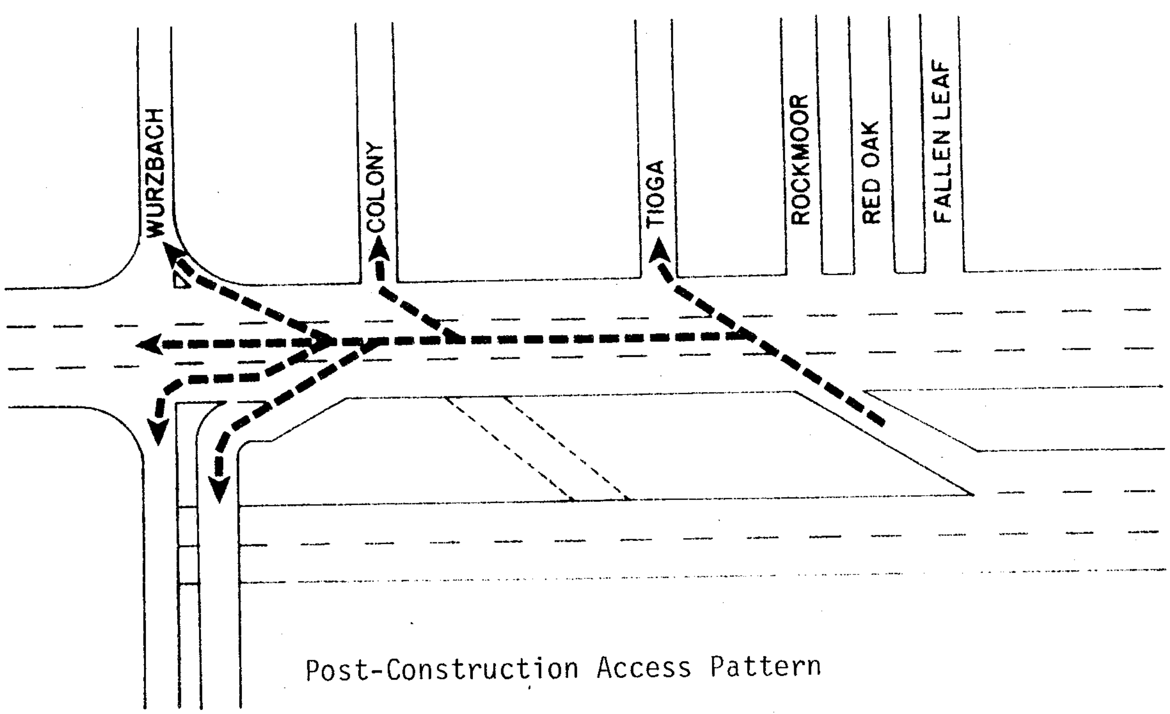


Figure 13. Before and After Access Patterns

Two accidents occurred on the northbound main lanes during the first three months after the exit ramp was moved. Both accidents occurred at the milepoints (17.1, 17.0) where the old ramp used to be located.

Analysis of Improvement

The monetary value of the primary and secondary benefits from both improvements combined is about $177,000 per year. This dollar figure is based on several elements. Since two improvements were made at Wurzbach, a separate analysis of each was made. The steps of these analyses are presented in Tables 13 through 20 in Appendix B.

Signal Upgrade - The signal equipment improvements and signal retiming produced approximately $132,000 annually including both primary and secondary benefits (see Figure 14). The primary benefits from the signal upgrade are derived from savings in running costs and travel time costs on the main lanes (10 mph improvement on main lanes). These amount to $25,250 and $12,250 per year respectively. These primary benefits constitute approximately 28% of the total benefits from the signal upgrade. The remaining 72% of the benefits are the secondary effects from the improved frontage road and arterial intersection operation. Improved operation of the intersection is measured in substantial decreases in standing delay and idling costs. These decreases (from 125 seconds per vehicle to 62 seconds per vehicle) translate to an approximate annual savings of $94,000. Again the benefits from the signal upgrade can be expected to last up to five years.

Ramp Relocations - the relocation the exit ramp completely eliminated the incidence of exit ramp queues on the main lanes. The main lane operating speed improved to 55 mph during the p.m. peak. The ramp relocation also enhanced the positive impact of the signal upgrading at the arterial

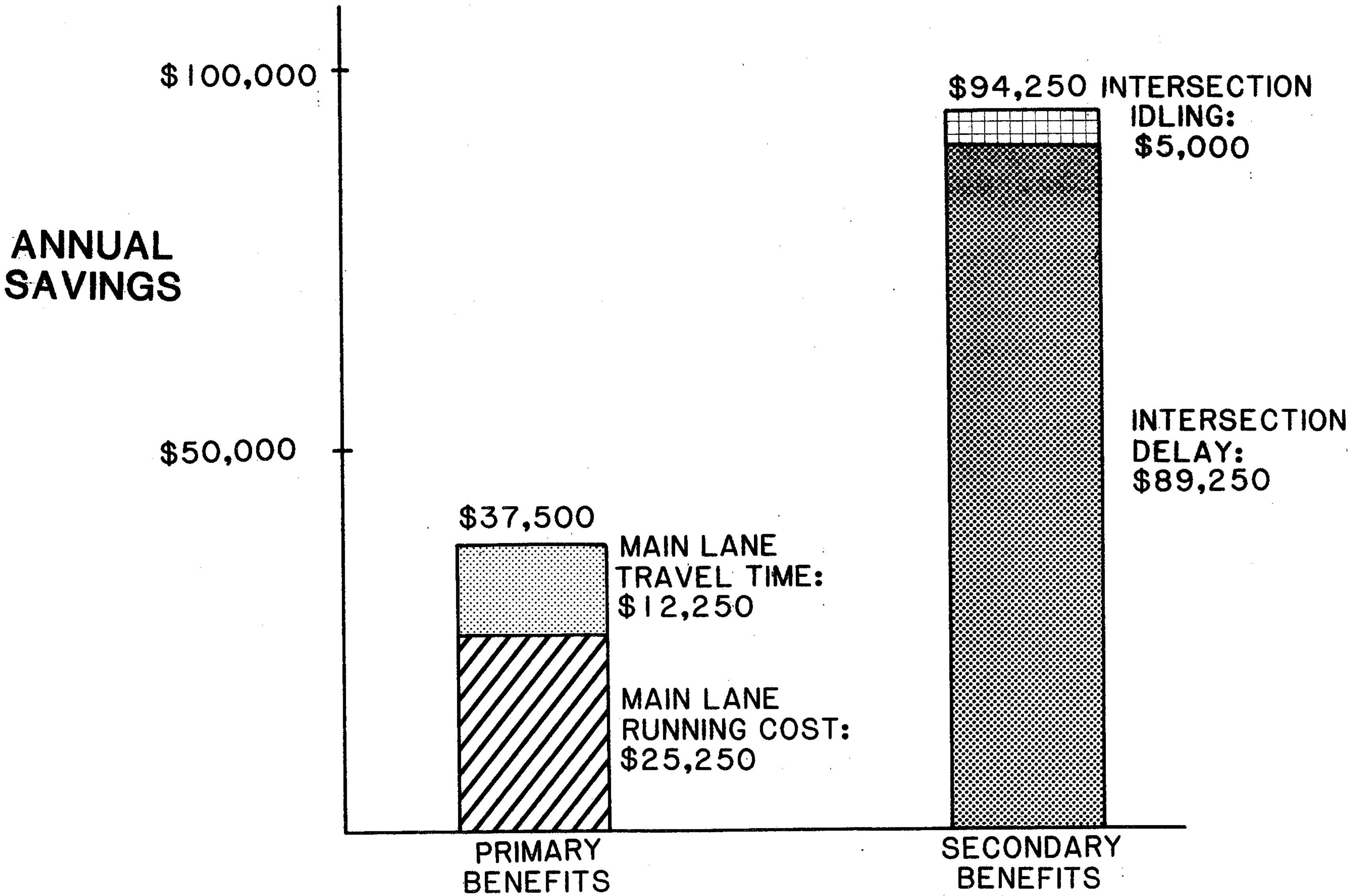


Figure 14. Total Benefits Derived from the Wurzbach Signal Upgrade

intersection, since the increase in intersection storage capacity allows the new signal timing to operate efficiently. The total benefits accrued from this modification translate to an annual savings of $45,000 (see Figure 15). The primary benefits of decreased main lane running costs and travel time costs are $11,000 annually (24% of total benefits). The remaining 76% of the benefits are attributed to secondary effects. Delay and idling time decreased from 62 seconds per vehicle to 39 seconds per vehicle. This decrease amounts to a $34,000 per year savings.

The combined dollar savings from the signal upgrade and the ramp relocation project are $177,000 per year. The combined cost of the two improvements was $186,000. Based on a 20-year amortization schedule for the ramp relocation and a five-year amortization schedule for the signal upgrade, the benefit/cost ratio for these improvements is approximately 10:1. The improvements will pay for themselves within two years of their completion. This combination of improvements successfully solved the storage capacity problem at the Wurzbach and I-10 interchange. These modifications, taken together, will provide future storage capacity for this location.

Accident Analysis

The study area experienced a lower accident rate after the Wurzbach exit ramp was relocated. Table 2 shows a summary of the accident data. The decrease in total accidents due to the ramp relocation was 38 percent. However, a statistical analysis of the improvement did not indicate the decrease is significant. Again, the accident decrease alone is not sufficient to justify the ramp relocation.

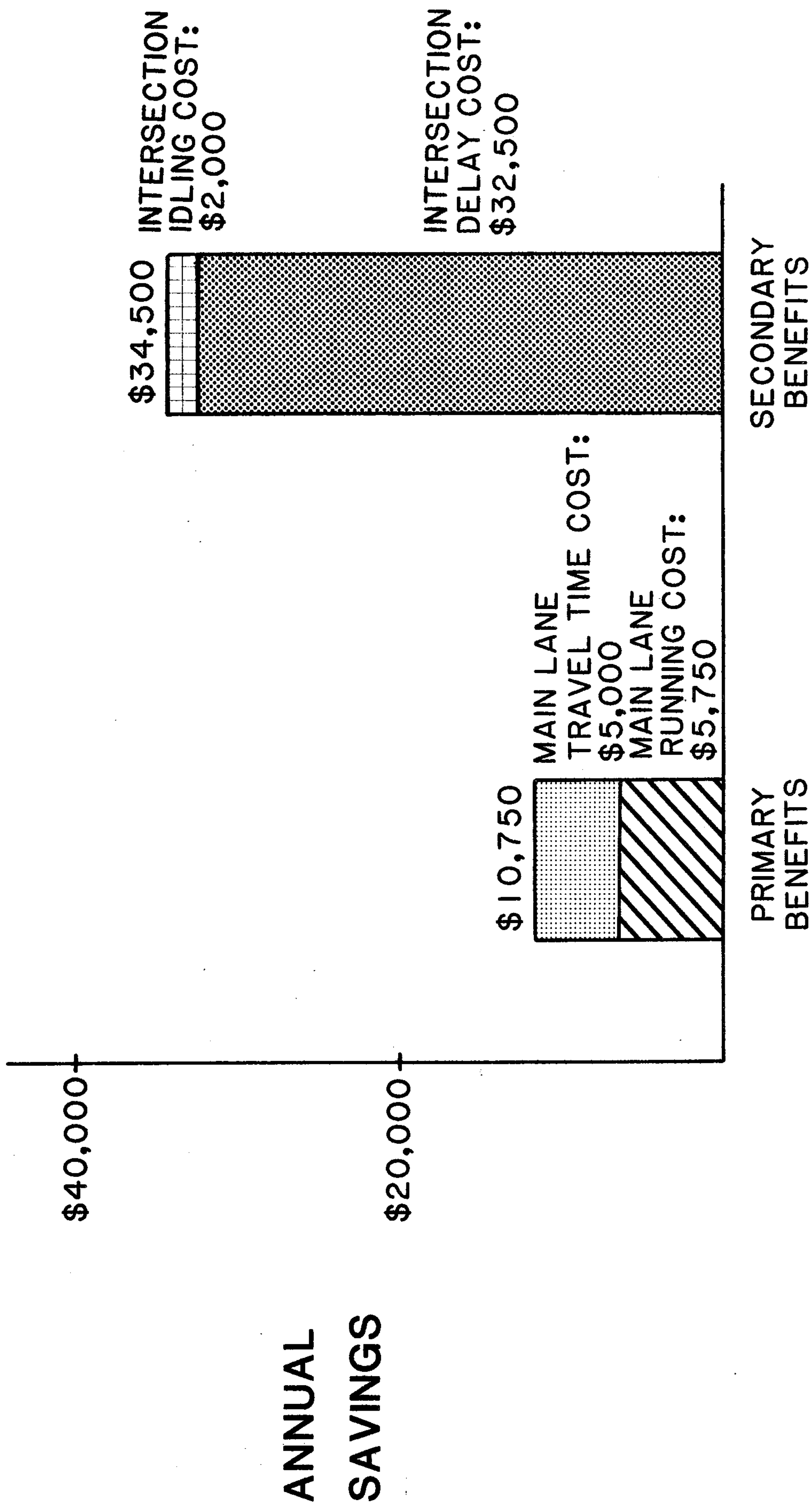


Figure 15. Total Benefits Derived from the Wurzbach Ramp Relocation

Table 2. Wurzbach Accident Data Summary

LOCATION	"BEFORE" ACCIDENT RATE	"AFTER" ACCIDENT RATE	PERCENT CHANGE
Entire Study Area	5.16 acc./MVM	3.22 acc./MVM	-38%
East Side of Wurzbach Interchange	2.45 acc./MEV	2.45 acc./MEV	0%
West Side of Wurzbach Interchange	5.26 acc./MEV	0 acc./MEV	-100%
Main Lanes	0 acc./MVM	0.9 acc./MVM	+100%

Summary of Findings

The process of analyzing the ramp relocation project at Wurzbach and I-10 provides a framework for evaluating other potential ramp relocation projects. The applicability of the Wurzbach findings to other ramp relocations is dependent upon the geometric conditions and traffic patterns at each site. The following summary indicates the type and amount of influence that each type of road user savings may have on total benefits.

Primary Benefits

Running Cost Savings - The average savings in main lane running cost was 2.7¢ per vehicle from the signal upgrading and 0.6¢ per vehicle from the ramp relocation. These savings were a direct result of eliminating the main lane exit ramp queues. Ramp relocation projects will only generate running cost savings if exit ramp queues are present on the main lanes prior to construction.

Travel Time Savings - This factor, which averaged 1.3¢ per vehicle from the signal upgrading and 0.5¢ per vehicle from the ramp relocation, is travel distance and operating speed dependent. As travel distance and the difference in operating speed increases, there is a corresponding increase in the relative contribution to total benefits that travel time savings generates.

Secondary Benefits

Delay Cost Savings - The delay cost savings at the Wurzbach intersection averaged 11¢ per vehicle from the signal upgrading and 4¢ per vehicle from the ramp relocation. This component was the largest singel road user savings from the Wurzbach project. Dramatic reductions (80 to 90 seconds) in intersection delay will produce very large road user benefits.

Idling Cost Savings - The average savings in idling cost were 0.65¢ per vehicle from the signal upgrading and 0.25¢ per vehicle from the ramp relocation. It is unlikely that the economic impact of this component would ever be consequential. Idling cost savings is determined from the same base as delay, but it has a value about 1/25th that of delay.

Conclusion

The primary objective of a ramp relocation project is to ease or eliminate the operational problems caused by exit ramp queues forming on the main lanes. By retiming and upgrading the signal equipment at the downstream frontage road intersection, exit ramp queues may be reduced also. The degree to which a ramp relocation can alleviate exit ramp queues depends on the preconstruction geometric and volume conditions. The total benefits from the Wurzbach exit ramp relocation project totaled approximately $177,000 per year. Although this project represents only one example of a successful ramp relocation project, the analysis of this project can serve as a guide for evaluating future relocation projects.

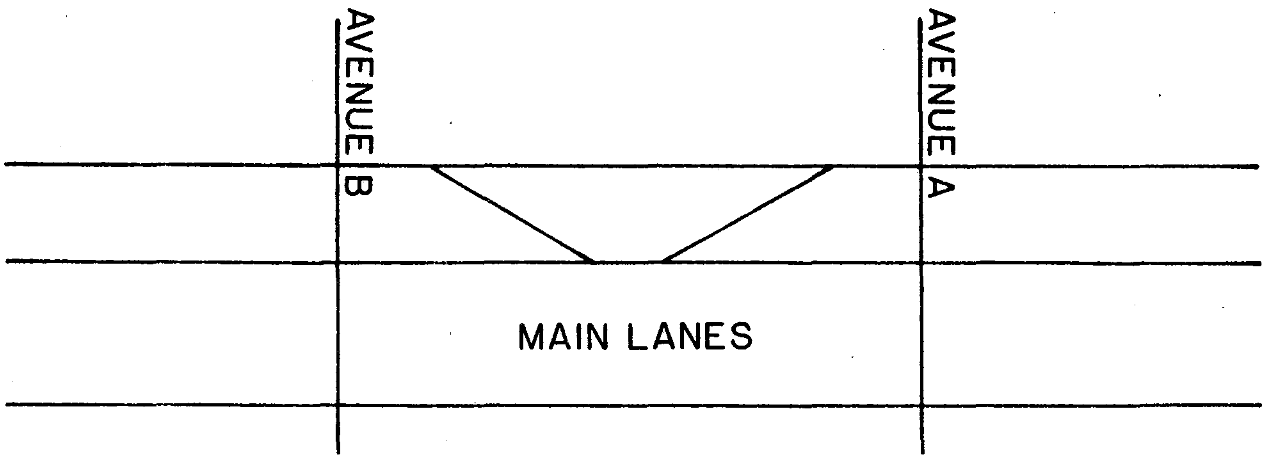
GRADE-SEPARATED RAMPS

Access to and from urban freeways sometimes requires both entrance and exit ramps between two arterial streets (see Figure 16). If both ramps cannot be accommodated at grade (due to insufficient weaving distance), then it may be feasible to elevate one of the two ramps such that one passes over the other. In this design, the entering and exiting traffic streams are kept completely separated. While this alternative provides for vastly improved operating conditions, it is costly and therefore requires careful analysis of potential benefits.

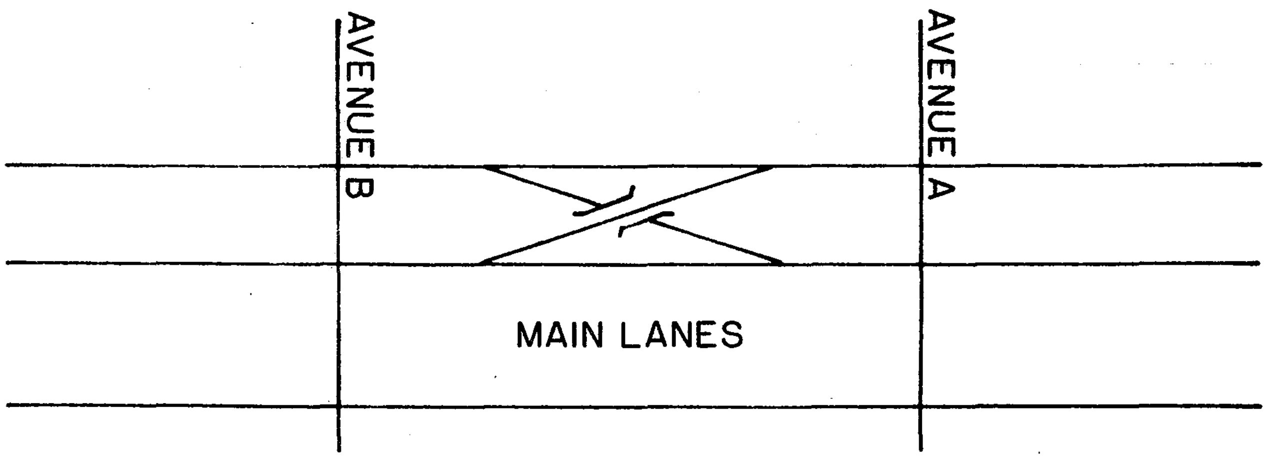
McCullough Grade-Separated Exit Ramp Addition

A grade-separated ramp was constructed at the McCullough Avenue exit from westbound I-410 in San Antonio. North Star Shopping Mall, a major traffic generator, is located in the southwest quadrant of the McCullough/410 interchange. Prior to 1977, westbound I-410 traffic desiring access to North Star Mall (and other destinations along McCullough) had to exit at Airport Blvd. and traverse the frontage road to McCullough (see Figure 17). This trip often required stops at Airport Blvd. and Jones-Maltsberger Road. The construction of the grade-separated exit ramp significantly reduced actual travel time because of the higher speed on the freeway (55 mph vs. 45 mph), and it eliminated stopped delay experienced at the two upstream intersections.

Unfortunately, the detailed field data available on the two previous types of freeway improvements are not available for this grade-separated ramp. Historical traffic volumes are shown in Figure 18. Other data necessary for analyzing this grade-separated ramp were reconstructed from various sources,

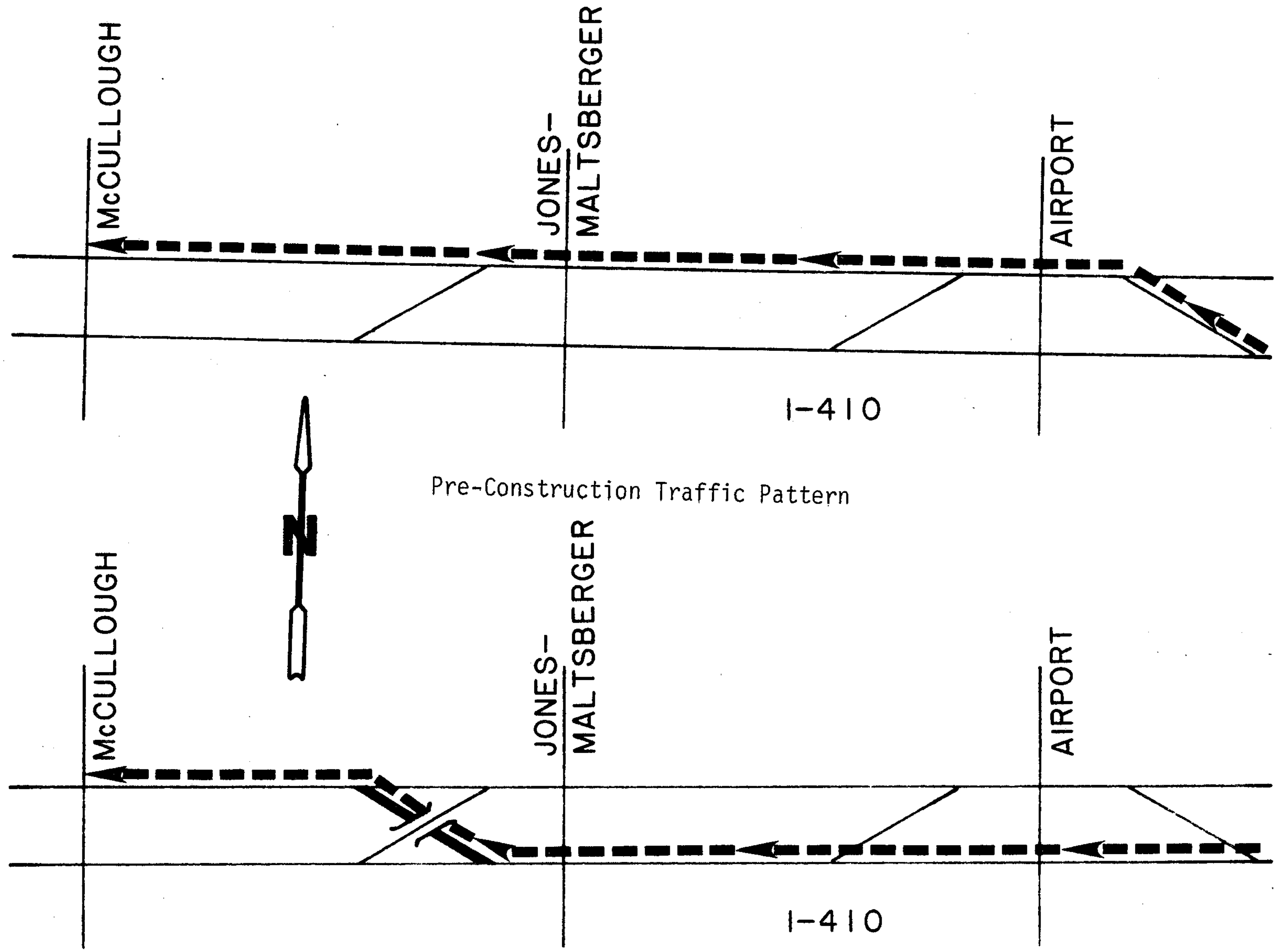


Ramp Pair with Insufficient Weaving Distance



Grade-Separated Ramp Pair

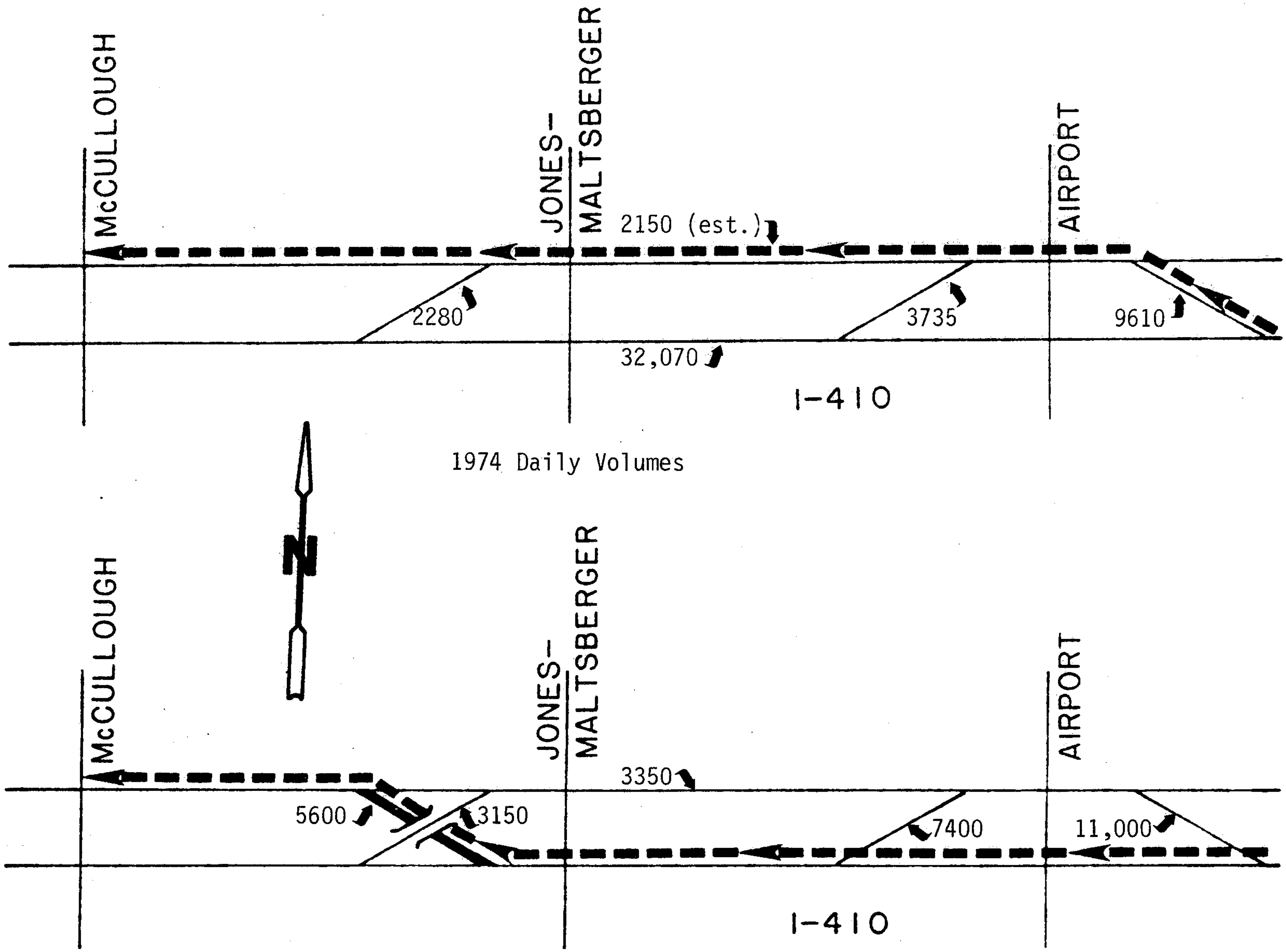
Figure 16. Before and After Construction Geometries



Pre-Construction Traffic Pattern

Post Construction Traffic Pattern

Figure 17. Before and After Traffic Patterns



1974 Daily Volumes

Project 1982 Daily Volumes

Figure 18. Daily Volumes in Study Area

and represent very conservative estimates of actual conditions. One important aspect of this modification that cannot be reconstructed is secondary benefits to motorists other than those using the new ramp. While these benefits are important, it is estimated that secondary benefits in this analysis would be a fairly small fraction of the total benefits.

Typical "Before" Conditions

During the peak four hours of the day, approximately 800 vehicles made the subject maneuver. Based on historical information and recent field studies, it is estimated that about 55 percent of all westbound traffic was delayed at Airport Blvd., and 60% delayed at Jones-Maltsberger. The average delay per delayed vehicle is estimated at 50 seconds for Airport Blvd. and 37 seconds for Jones-Maltsberger Road. Approximately 1300 vehicles were delayed at the two intersections each day for a total of 26 vehicle-hours.

It is estimated that an additional 1350 vehicles made this maneuver during the off-peak. Half of these off-peak vehicles were delayed at Airport Blvd., 60 percent at Jones-Maltsberger. Off-peak stopped delays were typically 35 seconds.

Table 3 summarizes the daily road user costs under the "before" conditions. Running and travel time costs can be reduced but not eliminated through this type of improvement. Delay and idling costs can be eliminated if no queues exist on the freeway.

Typical "After" Conditions

The analyses of operating conditions after the grade-separated ramps were opened assumed that demand remained constant. In actuality the demand increased considerably since this route provided improved access to others

Table 3. Daily Road User Costs Before Construction

	Peak Period (800 veh.)		Off-Peak (1350 veh.)		Total
Running Cost	$190		$320		$510
Travel Time Cost	130	(20 v-h)	220	(35 v-h)	350
Delay Cost					
Airport Blvd.	60	(6 v-h)	60	(7 v-h)	
Jones-Maltsberger Rd.	50	(5 v-h)	70	(8 v-h)	
Total Delay	110		130		240
TOTAL	$430		$670		$1,100

besides the target group. Benefits for the increased volume are not estimated since there is no indication in the historical data of what portion was latent demand and what was expected growth.

Table 4 summarizes the road user costs for the same categories as Table 3. The most obvious savings was in delay cost, since stopped delay was eliminated at the Airport and Jones-Maltsberger intersections. However, a significant improvement was also realized in running cost, due primarily to the elimination of speed changes at the two intersections.

Analysis of Improvement

Road User Benefits

The net savings in road user costs is $550 per working day. Excluding non-working day benefits, annual benefits equal $137,500. Since a major shopping mall is directly involved, it is reasonable to assume that 500 vehicles would use this facility (and thereby benefit) on Saturdays. This benefit would add approximately $6400 to the annual benefit.

The total construction cost was approximately $900,000. At an annual saving of $143,000 and an interest rate of 10 percent, the public expenditure on this project will be amortized by public benefit in just over 10 years. The benefit/cost ratio over the twenty year life of this project is approximately 1.6:1. This rate of return assumes no growth in traffic volumes, and is therefore a conservative estimate of benefits.

Recent counts throughout the area indicates that increases of 25 - 35% over the 1977 - 82 time interval are typical. However, exit ramp volumes have increased more than twofold (Figure 18) to about 5600 vehicles per day. Recently measured delays indicate that about 4000 vehicles would be delayed at the study area intersections for a total of 80 vehicle-hours daily. Combining

Table 4. Daily Road User Costs After Construction

	Peak Period (800 veh.)		Off-Peak (1350 veh.)		Total
Running Cost	$100		$170		$270
Travel Time Cost	110	(17 v-h)	170	(28 v-h)	280
Delay Cost	0		0		0
	$210		$340		$550

delay with the running and travel time costs, the annual road user savings with the grade-separated ramp is approximately \$340,000 (\$700,000 (without ramp) - \$360,000 (with)). The benefit/cost ratio over the twenty-year project life is over 3:1, with amoritization of capital costs expected within 4 years.

Accident History

A second aspect of grade-separated ramps that merits consideration is the potential accident reduction that may accrue from the improved weaving conditions and/or reduced queues onto the main lanes. In the case under study, there were no critical weaving distances involved, since the exit ramp did not originally exist. However, because of the heavy demand using the westbound exit to Airport Blvd. (a large portion of which was bound for McCullough), exit ramp queues frequently extended onto the main lanes east of Airport. Reduction of those queues reduced accidents in that section of freeway and contributed to the overall benefit of the project.

Figure 19 shows the number of accidents occurring during the two years before and two years after construction of the grade-separated ramp. Accident frequency is shown rather than accident rate because traffic volumes throughout the study area are essentially constant, so that the frequency and rate distributions were almost identical. Each pair of columns represents before and after accidents that occurred in each 1/10 mile section of the study area.

There was a considerable amount of main lane construction underway during a large portion of the before time period. While there is no reason to assume that accidents occurring during active construction were construction related, it was decided that two separate analyses should be conducted.

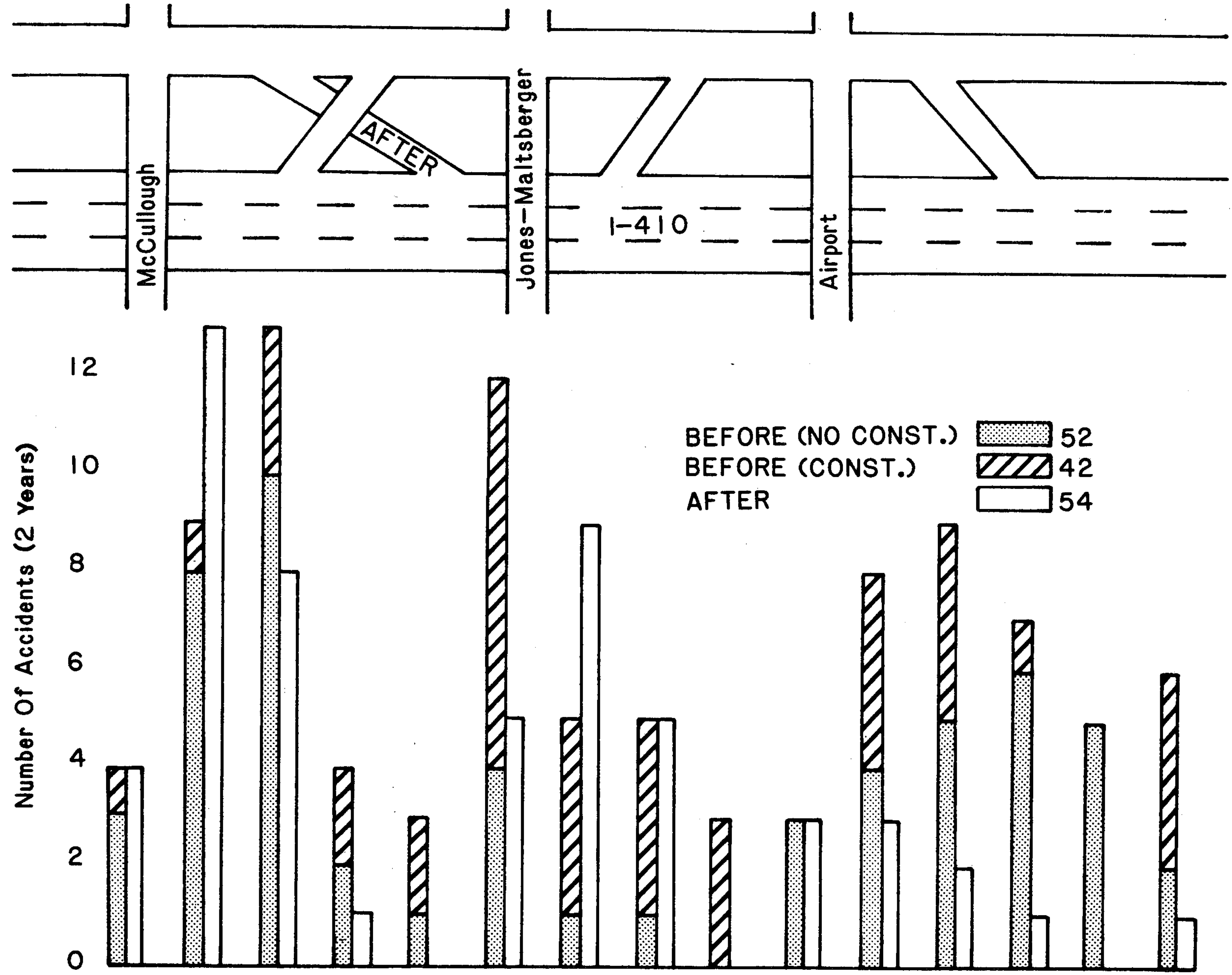


Figure 19. Accident History

Several statistical analyses were performed on the accident data, both by frequency and rate. Most analyses showed that there was no significant difference between before and after accident patterns. Those that produced different results included the following:

- A paired t-test of westbound accidents, including construction accidents indicated there was a significant reduction in the after period; however, the same analysis on data that excluded construction period accidents showed no significant difference.
- A chi-squared analysis of non-construction accidents showed that, where grouped by location, there was a significant reduction in accidents after ramp construction.
- When specific freeway sections were analyzed by the chi-squared technique, only the section east (upstream) of the Airport Blvd. exit showed a significant reduction.

The inconsistent results among the various tests appears to indicate an accident reduction that borders on significant. The reduction in accidents upstream of the Airport exit is where a reduction would be expected. Similarly, a slight increase in accidents (compared to non-construction) is observed between the Airport entrance and the new McCullough exit. This increase would also be expected since a new weaving section was added, as well as an additional group of vehicles.

It is difficult to conclude very much from these accident patterns. However, it appears reasonable to conclude that this type of project would be only weakly justified by accident reduction alone. Either a much greater reduction in accidents, or a combination of accident reductions and savings in road user costs (as in this case) are necessary to justify the level of funds required to construct grade-separated ramps.

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Appendix A

Medina Base Road Analysis

Table 5. Abbreviated Analysis - Running Cost Savings

Frontage Road Running Cost:

Cost at running speed (43 mph):

$0.11/veh.* X 5400 veh. = $594/day

Freeway Running Cost:

Cost at running speed (55 mph):

$0.10/veh.* X 5400 veh. = $540/day

Expected Savings:

Frontage Road Cost	-	Freeway Cost	=	Daily Savings
$594	-	$540	=	$54/day

Annual Savings:

$54/day X 250 working days = $13,500

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*Cost figures taken from Figure E-13 "Operations and Procedures Manual" - Appendix E.

Table 6. Abbreviated Analysis - Delay Cost Savings

Average daily delay before ramp construction: 21 sec./veh.

Value of time: $2.50/hour

Delay Cost:

$0.0375/veh.* X 3933 veh. = $148/day

$0.0240/veh.** X 1467 veh. = $35/day

After ramp construction: NO DELAY to ramp users.

Annual Savings:

Daily Savings X 250 Working Days

$183/day X 250 = $45,750

*Cost figures taken from Figure E-12 "Operations and Procedures Manual" - Appendix E for 43 mph with 21 seconds of standing delay.

**Cost figures taken from Figure E-12 "Operations and Procedures Manual" - Appendix E for 43 mph with no standing delay

Table 7. Average Delay by Approach and Condition

	Total Vehicles	Percent Vehicles Delayed	Average Delay in Seconds
A.M. Peak (6:45 - 8:00 a.m.)			
Southbound Frontage Road			
Before Signal Retimed	1565	90	130
After Signal Retimed	1610	65	35
After Ramp Additions	1345	50	25
Northbound Frontage Road			
Before Signal Retimed	975	75	50
After Signal Retimed	800	70	30
After Ramp Additions	570	60	25
Eastbound Valley Hi			
Before Signal Retimed	330	75	40
After Signal Retimed	320	80	45
After Ramp Additions	340	70	35
Westbound Valley Hi			
Before Signal Retimed	300	65	45
After Signal Retimed	280	55	20
After Ramp Additions	340	50	25
Total Intersection			
Before Signal Retimed	3170	80	95
After Signal Retimed	3010	70	32
After Ramp Additions	2595	55	22
P.M. Peak (3:45 - 5:00 p.m.)			
Southbound Frontage Road			
Before Signal Retimed	670	75	40
After Signal Retimed	650	65	35
After Ramp Additions	430	60	25
Northbound Frontage Road			
Before Signal Retimed	835	70	20
After Signal Retimed	815	70	25
After Ramp Additions	500	60	20
Eastbound Valley Hi			
Before Signal Retimed	220	75	30
After Signal Retimed	200	75	30
After Ramp Additions	200	75	30

Table 7 - Continued

	Total Vehicles	Percent Vehicles Delayed	Average Delay in Seconds
Westbound Valley Hi			
Before Signal Retimed	980	65	30
After Signal Retimed	1070	65	15
After Ramp Additions	1130	35	20
Total Intersection			
Before Signal Retimed	2705	70	30
After Signal Retimed	2735	65	25
After Ramp Additions	2260	60	20

Table 8. Expanded Running Cost Savings

Frontage Road Running Cost:

1) Cost at operating speed (45 mph):

$0.09/veh. X 5400 veh. = $486/day

2) Cost of slowing/stopping at Valley Hi intersection:

Final Speed	Cost/veh.	X	# Vehicle	=	Total
0 mph	6¢	X	3500*	=	$210
10 mph	5¢	X	1175**	=	59
20 mph	4¢	X	725**	=	29
					$298/day

3) Total running cost:

1) + 2) = $486 + $298 = $784/day

Freeway Running Cost:

Cost at operating speed (55 mph):

$0.0815/veh. X 5400 veh.*** = $440/day

Expected Savings:

Frontage Road Cost	-	Freeway Cost	=	Daily Savings
$784	-	$440	=	$344/day

Annual Savings:

$344/day X 250 working days = $86,000/year

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*Known volume of vehicles stopped from Delay Studies.
**Assumed volume
***Expected ramp volume used in analysis.

Table 9. Expanded Travel Time Cost Savings

Travel time before ramps	-	Travel time after ramps	=	Savings
65.6 sec.	-	50.3 sec.	=	15.3 sec.

Value of Time: \$6.30/hour

Value of Time Savings = 15.3 sec. X $\frac{6.30}{3600}$ = \$0.026/veh.

Daily Volume	X	Savings	=	Total
5400 veh	X	\$0.026/veh.	=	\$140/day

Annual Savings:

Daily Savings X 250 working days

\$140/day X 250 = \$35,000/year

Table 6. Expanded Delay Cost Savings

Average daily delay before ramp construction: 21 sec./veh.

Value of time in stopped vehicle: \$6.30/hour

Delay Cost: \$0.04/veh. X 3933 delayed veh. = \$157/day

After ramp construction: NO DELAY to ramp users.

Annual Savings:

Daily Savings X 250 working days

\$157/day X 250 = \$39,000/year

Table 10. Expanded Idling Cost Savings

Average daily idling time before ramp construction: 21 sec./veh.

Cost of idling vehicle: 37.5¢/hour

Idling cost: \$0.002/veh. X 3933 idling veh. = \$8/day

After ramp construction: NO IDLING for ramp users.

Annual Savings:

Daily Savings	X	250 working days		
\$8/day	X	250	=	\$2,000/year

Table 11. Delay Cost Savings - Valley Hi Intersection

Average delay before ramp construction: 29 sec./veh.*

Value of time in stopped vehicle: $6.30/hour

Delay Cost:

$0.05/veh. X 2738** = $137/day

Average delay after ramp construction: 21 sec./veh.*

Delay Cost:

$0.04/veh. X 2738*** = $111/day

Daily Savings	=	Before Cost	-	After Cost
	=	$137	-	$111
	=	$ 26		

Annual Savings:

Daily Savings	X	250 Working Days		
$26	X	250	=	$6,500/year

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*Delay for peak periods only. No significant change in intersection operation during off peak.

**Peak period volumes only minus through volume (potential ramp traffic)

***Peak period volumes only

Table 12. Idling Cost Savings - Valley Hi Intersection

Average idling time before ramp construction: 29 sec./veh.*

Cost of idling vehicle: 37.5¢/hour

Idling Cost:

$.003/veh. X 2738** = $8/day

Average idling time after ramp construction: 21 sec./veh.*

Idling Cost:

$.002/veh. X 2783*** = $6/day

Daily Savings	=	Before Cost	-	After Cost
	=	$8	-	$6
	=	$2/day		

Annual Savings:

Daily Savings X 250 Working Days

$2 X 250 = $500/year

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*Delay for peak periods only. No significant change in intersection operation during off-peak.
**Peak period volumes only minus through volume (potential ramp traffic)
***Peak period volumes only

Appendix B

Wurzbach at I-10 Analysis

Table 13. Running Cost Savings - Signal Upgrade

A. Average operating speed before signal upgrade: 40 mph

Running Cost: 6.9¢/veh. x 3775 veh. = $260/day

B. Average operating speed after signal upgrade: 50 mph

Running Cost: 4.2¢/veh. x 3775 veh. = $159/day

Daily Savings = A. - B.
= $260/day - $159/day
= $101/day

Annual Savings:

Daily Savings x 250 working days
$101/day x 250 = $25,250/year

Table 14. Travel Time Savings - Signal Upgrade

Value of time: $6.30/hour

Travel time before upgrade	-	Travel time after upgrade	=	Savings
30.7 sec.	-	23.2 sec.	=	7.5 sec.

Value of time savings = 7.5 sec. x $\frac{6.30}{36000}$ = $0.013/veh.

Daily Savings = Volume x Savings
= 3775 veh. x $0.013/veh.
= $49/day

Annual Savings:

Daily Savings x 250 working days
$49/day x 250 = $12,250/year

Table 15. Delay Cost Savings - Signal Upgrade

Value of Time: \$6.30/hour

A. Average delay before signal upgrade: 125 sec./veh.

Delay Cost: \$0.22/veh. x 3250 veh. = \$715/day

B. Average delay after signal upgrade: 62 sec./veh.

Delay cost: \$0.11/veh. x 3250 veh. = \$358/day

Daily Savings = A. - B.
= \$715/day - \$358/day
= \$357/day

Annual Savings:

Daily Savings x 250 working days
\$357 x 250 = \$89,250/year

Table 16. Idling Cost Savings - Signal Upgrade

Cost of Idling: 37.5¢/hour

A. Average idling time before signal upgrade: 125 sec./veh.

Idling Cost: 1.30¢/veh. x 3250 veh. = \$42/day

B. Average idling time after signal upgrade: 62 sec./veh.

Idling Cost: 0.65¢/veh. x 3250 veh. = \$21/day

Daily Savings = A. - B.
= \$42/day - \$21/day
= \$21/day

Annual Savings:

Daily Savings x 250 working days
\$21/day x 250 = \$5,250/year

Table 17. Running Cost Savings - Ramp Relocation

A. Average operating speed before ramp relocation: 50 mph

Running Cost: 4.2¢/veh. x 3775 veh. = \$159/day

B. Average operating speed after ramp relocation: 55 mph

Running Cost: 3.6¢/veh. x 3775 veh. = \$136/day

Daily Savings = A. - B.
= \$159/day - \$136/day
= \$23/day

Annual Savings:

Daily Savings x 250 working days
\$23/day x 250 working days = \$5,750/year

Table 18. Travel Time Savings - Ramp Relocation

Value of Time: \$6.30/hour

Travel time before relocation	-	Travel time after relocation	=	Savings
23.6 sec.	-	20.2 sec.	=	3.0 sec.

Value of time savings = 3.0 sec. x $\frac{6.30}{3600}$ = \$0.0053/veh

Daily Savings = Volume x Savings
= 3775 veh. x \$0.0053/veh.
= \$20/day

Annual Savings:

Daily Savings x 250 working days
\$20/day x 250 = \$5,000/year

Table 19. Delay Cost Savings - Ramp Relocation

Value of Time: $6.30/hour

A. Average delay before ramp relocation: 62 sec./veh.

Delay Cost: $0.11/veh. x 3250 veh. = $358/day

B. Average delay after ramp relocation: 39 sec./veh.

Delay cost: $0.07/veh. x 3250 veh. = $228/day

Daily Savings = A. - B.
= $358/day - $228/day
= $130/day

Annual Savings:

Daily Savings x 250 working days
$130 x 250 = $32,500/year

Table 20. Idling Cost Savings - Ramp Relocation

Cost of idling: 37.5¢/hour

A. Average idling time before ramp relocation: 62 sec./veh.

Idling cost: 0.65¢/veh. x 3250 veh. = $21/day

B. Average idling time after ramp relocation: 39 sec./veh.

Idling cost: 0.40¢/veh. x 3250 veh. = $13/day

Daily Savings = A. - B.
= $21/day - $13/day
= $8/day

Annual Savings:

Daily Savings x 250 working days
$8/day x 250 = $2,000/year