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16. Abstract

This report investigates the economic feasibility of implementing the Managed Transportation System (MTS) concept in Texas. As indicated in Report 1326-1, this research project has determined that the Texas Interstate highway network faces an imminent congestion problem. This report, the second report of this study, discusses several possible alternatives for alleviating this congestion problem. For each alternative, a full-cost evaluation is performed and results are compared. Our analysis suggests that the Managed Transportation System concept is the alternative that can potentially yield the greatest benefits.

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PRELIMINARY ECONOMIC EVALUATION OF ALTERNATIVES FOR REDUCING CONGESTION PROBLEMS IN TEXAS

by

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Research Report 1326-2

Research Project 0-1326:
Preliminary Economic Evaluation of the Super Corridor Concept

conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION
in cooperation with the
U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

May 1996

IMPLEMENTATION RECOMMENDATIONS

This report is the second of three reports evaluating the economic feasibility of implementing the Managed Transportation System (MTS) concept in Texas. In addition, it presents an economic analysis of several other possible alternatives presently being considered for reducing congestion problems in Texas. In terms of implementation, the findings reported herein could prove useful to state transportation planners and policymakers involved in crafting the Texas Transportation Plan. Additional recommendations are as follows:

1. In general, we recommend that the methodology developed in this report be applied to all major transportation corridors in Texas.
2. An important component of the MTS concept is dependent on the successful implementation of ITS technology and higher operating speeds. Therefore, it is essential that research continues in this area in order to enhance our understanding of the potential benefits, feasibility of implementation, and costs.
3. All user/social costs were based on available models that have some limitations. Hence, it is necessary to update these models or create new ones that reflect the special characteristics of motor vehicle transport.
4. A proposed solution should consider multiple modes of transportation, such as passenger rail, intermodal combinations of trucks and trains, and special lanes for automobiles and commercial vehicles. In addition, other transmission agencies, such as those associated with oil, gas, electricity, and fiber optics, could share the right of way and, thus, could further reduce costs.
5. A conservative approach was used in this evaluation, with the prediction of emissions, accidents, and meticulous workzone costs excluded. Insofar as the purpose of this analysis was to determine broad directions and magnitudes of investment, the inclusion of these other factors is strongly recommended in a more detailed corridor feasibility study.

Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

DISCLAIMER

B. F. McCullough, P.E. (Texas No. 19914)
Research Supervisor

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SUMMARY

This report investigates the economic feasibility of implementing the Managed Transportation System (MTS) concept in Texas. As indicated in Report 1326-1, this research project has determined that the Texas Interstate highway network faces an imminent congestion problem. This report, the second report of this study, discusses several possible alternatives for alleviating this congestion problem. For each alternative, a full-cost evaluation is performed and results are compared. Our analysis suggests that the Managed Transportation System concept is the alternative that can potentially yield the greatest benefits.

CHAPTER 1. INTRODUCTION

BACKGROUND

Increasingly, travelers on rural segments of major corridors in Texas are conceding that roadway congestion is eroding the once unrestrained personal mobility that for generations had characterized Texas highways. In addressing this growing problem, the Center for Transportation Research (CTR) of The University of Texas of Austin has proposed that the Texas Department of Transportation (TxDOT) examine the implementation of what CTR has dubbed a "Managed Transportation System" (MTS) on certain segments of rural IH-35, one of the most heavily traveled corridors in the state. This report, the second in a series of three for this project, uses the IH-35 traffic projections obtained in the first report to perform an evaluation of the full costs associated with developing and deploying such a managed transportation system to alleviate congestion problems. This new approach is compared with other possible alternatives so as to quantify the possible benefits that such a facility could yield.

REPORT OBJECTIVE

The objective of this report is to present a preliminary economic evaluation of a potential managed transportation facility that could alleviate the congestion that increasingly impedes mobility on major corridors within Texas. The study performs a full-cost evaluation of different alternatives to determine the feasibility of a managed transportation system.

ANALYSIS APPROACH

In focusing on the economic evaluation of an MTS for Texas, this report specifically:

- discusses the concepts and capacity requirements associated with alternative solutions—for example, adding lanes and retrofitting with an Intelligent Transportation System (ITS) and a Managed Transportation System;
- evaluates the full cost of alternatives (i.e., agency costs, external costs, and internal costs); and
- compares full costs among alternatives.

METHODOLOGY

The first step in this evaluation process is to identify possible solutions for alleviating congestion in Texas. As part of this discussion, the report describes the primary characteristics and advantages of the alternatives, including a conceptual highway cross section for each alternative. The next step is to determine the capacity requirements for each of the alternatives. This is performed using both the traffic projections presented in Report 1326-1 and the *Highway Capacity Manual* (HCM) as a guide.

The next task is to define each of the significant costs associated with the roadway. The agency cost is obtained through a comprehensive factorial pavement design exercise that includes various scenarios. The user/social costs, obtained for all levels of service, are presented in terms of $/km. The user/social costs include ownership, travel time, air pollution, and accident costs. Following this, we evaluate the agency costs and user/social costs for each alternative. To complete the analysis, we make a full-cost comparison among the proposed alternatives so as to obtain the least-cost strategy.

REPORT SCOPE

Because this project proceeded as a preliminary prefeasibility study, many details are necessarily omitted from this and subsequent reports. For example, such issues as how much ROW would be needed for interchanges/service facilities, or where the beginning and ending points of the MTS would be located are matters that would be addressed during detailed follow-up planning. Also note that, because the project was a preliminary review only, the analysis included herein is of a deterministic nature, as against a more precise probabilistic one. We recommend that any future studies approach the concept of a managed transportation system probabilistically. In this way, more precise costs could be identified.

ORGANIZATION OF REPORT

Chapter 2 calculates the capacity requirements for each alternative. In Chapter 3, the full-cost analysis framework used for this study is outlined based on earlier research. Chapter 4 discusses in detail the agency costs. A comprehensive factorial pavement design exercise is performed to obtain the agency costs for each of the alternatives.

Chapter 5 then examines each of the costs included in the user/social costs presented in Chapter 3. These costs are related to the speed for each of the levels of service, and are then presented in terms of $/km. Using this information, we calculate user/social costs for each alternative. In Chapter 6, we present a full-cost comparison among the alternatives using the information obtained in previous chapters. Finally, Chapter 7 provides conclusions and recommendations.

CHAPTER 2. ALTERNATIVES TO MEET DEMAND

Growing congestion on IH-35 is increasingly compromising the mobility of travelers on that major Texas corridor (Ref 1). At the same time, available solutions, particularly those involving new technologies, are typically both complex and expensive, and state departments of transportation (DOTs) are finding that they lack adequate resources to meet even current needs. More important, conventional approaches do not offer effective solutions to the crisis rapidly overwhelming links on the Interstate system.

A relatively new idea developed at the Center for Transportation Research (CTR) over the past few years is providing a new conception of how the capacity dilemma for intercity ground transport should be approached. Originally termed a "supercorridor," this concept blends a variety of approaches to congestion management that have proved effective in urban settings, primarily by capitalizing on the benefits of multimodality, as well as by providing financial mechanisms to sustain itself. Among its features are measures to curb adjacent development and a greater sensitivity to the environment. With the passing of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) (Ref 3), this concept has gained new momentum, particularly among public agencies; similar approaches are now being considered for implementation in other parts of the country as well (Ref 4). In addressing the alternatives available to meet demand, this chapter outlines the approaches that can be used to assess intercity travel demand requirements, and then elaborates on the capacity requirements of each, in preparation for a further economic comparison.

DISCUSSION OF CONCEPTS FOR ALTERNATIVE SOLUTIONS

There are various strategies that could be deployed to provide added capacity to our roadways. Concepts ranging from the simple addition of traffic lanes to existing facilities (or equivalent construction of parallel routes) to the more complex mechanisms inducing mode/link shifts to balance and optimize the existing transportation infrastructure are common both in the literature and in practice.

In addition, the financing of expenditures for maintenance of the current system and for the construction of new facilities has emerged as a new challenge to both government and the general public (tax payers). In particular, new attitudes toward the use of tolls for highway projects in Texas (Ref 5) have set the stage for a more equitable sharing of transportation costs. The idea that highway users should pay the full cost of highway use has gained currency, especially within the context of achieving better levels of service over increasingly congested links. Yet, as established recently (Ref 6), not all highway projects are compatible with toll implementation; moreover, most U.S. travelers and their public officials are unfamiliar with (and therefore would perhaps be unsupportive of) the implementation of tolls on existing non-tolled roadways. Thus, as an initial attempt to broadly encompass the reviewed concepts for improving highway capacity, three main alternatives have been devised for a preliminary evaluation of economic performance over an intercity highway corridor, namely, (1) adding lanes, (2) retrofitting with an intelligent transportation system (ITS), or (3) building a separate managed transportation system (MTS). In addition to these three main alternatives, which are discussed below, a "do nothing" alternative has been included as a control (or reference) element to form a comprehensive preliminary comparison scheme. For this analysis, IH-35 was selected as a representative high-traffic corridor.

Adding lanes

The addition of lanes is currently the approach most frequently used by state DOTs to increase highway capacity. Such expansion requires the use of any space available beyond the existing right-of-way (ROW), including medians and safety lateral clearances. Since most highways have been planned to include space for additional traffic lanes, this alternative initially proceeds as a favorable option. Yet continuous demand has stretched space reserves to the limit, requiring that DOTs now purchase additional land.

Depending on the space available for expansion, the need for workzones represents another potential disadvantage to this approach. Because they typically cause travel delays throughout the construction period, workzones can be a major and costly inconvenience to road users.

For IH-35, the lane-addition approach would require building by-pass routes along major cities to separate urban traffic from intercity traffic passing through. Such a strategy was considered less disruptive than building additional lanes within the traffic-intensive urban area. The facility would operate according to its conventional format: mixed traffic at 104 kph (65 mph) maximum legal speed or at 112 kph (70 mph), if otherwise authorized, with typical access control and frontage roads incorporated. Current land-use policies need not be modified over abutting areas. Figure 2.1 shows a conceptual cross-section layout of the "adding lanes" alternative.

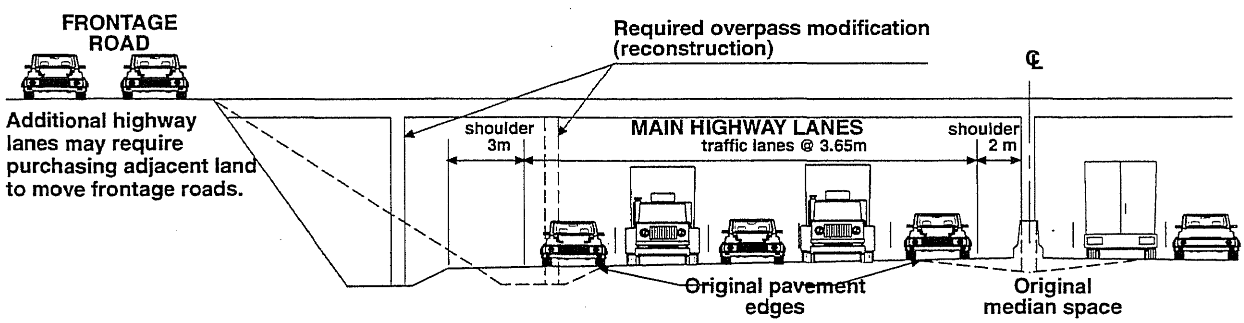


Figure 2.1. Conceptual cross-section of the "adding lanes" approach to capacity

Retrofit with ITS

The "retrofitting with ITS" alternative would require upgrading IH-35 to operate as a semi-supercorridor, mainly by providing separate traffic lanes for automobiles and heavy trucks, and by increasing the width of these lanes from the current 3.60 m (12 feet) to 4.60 m (15 feet). Such provisions would be required to safely accommodate heavier and larger trucks, and to permit a marginal speed increase for automobiles. As with the previous approach discussed, these modifications would create workzones along the IH-35 route. Figure 2.2 shows a conceptual layout of the cross-section for the "retrofit" alternative.

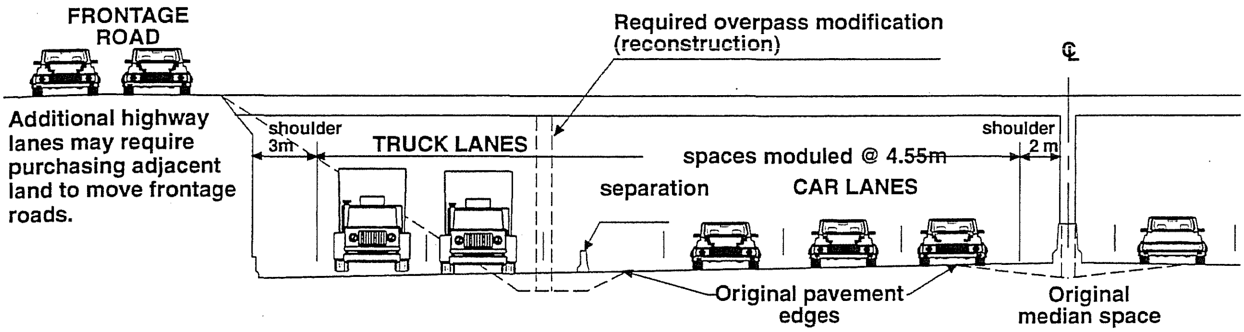


Figure 2.2. Conceptual cross-section of the "retrofit" approach to capacity

Owing to the geometric constraints of the current alignment, operational speeds would be increased to only 128 kph (80 mph) on most segments, and up to 144 kph [90 mph] on some straight segments. Additionally, to ensure safety, such speeds would be implemented only after the installation of vehicle-control technology and an ITS. Again, as with the previous approach, this alternative would require building by-pass alignments within major urban areas.

Restricting adjacent development would likely generate some public opposition, since neighboring landowners already have access to the system. Finally, current space restrictions make it improbable that multimodal capabilities could be incorporated without major capital investment. Thus for the present evaluation, this alternative does not provide for transportation modes other than the highway element.

A Managed Transportation System (MTS)

Formerly referred to as a supercorridor, the fully monitored and controlled *managed transportation system* (MTS) would complement IH-35 operations by providing a separate alignment running parallel to that highway. The MTS highway could also have separate and wider lanes for automobiles and heavy trucks; its geometric design could also incorporate provisions for travel speeds of up to 240 kph (150 mph), anticipating future advances in vehicle-control technology and ITS.

Specially designed limited-access points would be incorporated to control abutting land development and to ensure a continuous and fluid operation. Accordingly, no frontage roads would be provided. Moreover, sufficient right-of-way would be acquired to reserve additional space for a gradual incorporation of other high-capacity transportation modes within the alignment (including electricity, gas, and fiber optic transmission lines). For the present evaluation, though, only the highway element costs, including full right-of-way acquisition, are being considered. Also, since this facility is expected to complement IH-35 in accommodating future traffic demand, rehabilitation expenditures for IH-35 are being considered as part of the overall cost of this alternative. Figure 2.3 shows a conceptual cross-section of the MTS alternative.

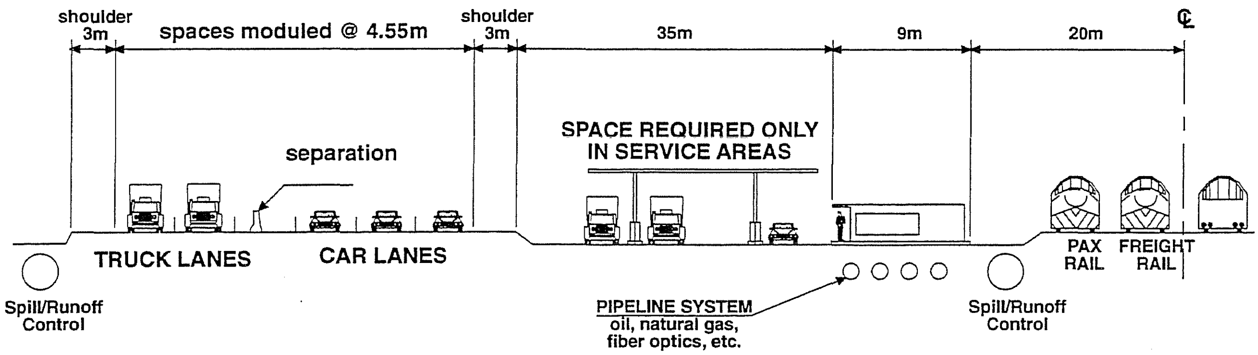


Figure 2.3. Conceptual cross-section of the MTS approach to capacity

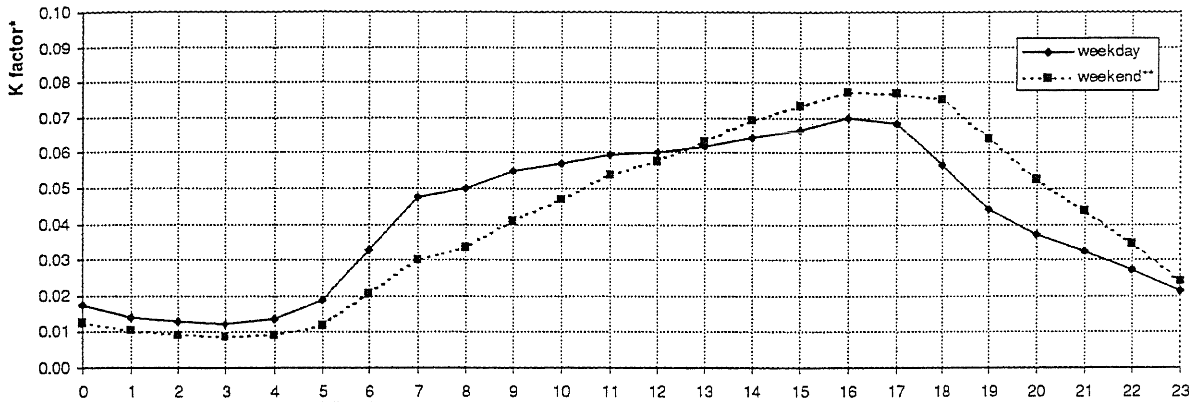
CAPACITY REQUIREMENTS

Our evaluation requires that we establish the capacity requirements for each of the alternatives under consideration. Since the current analysis concentrates specifically on highway operation, the capacity requirements are described in terms of the number of traffic lanes needed.

As a preliminary step, and following the procedures outlined in the 1994 *Highway Capacity Manual* (HCM-94) (Ref 7), we used three traffic composition conditions to obtain service flows (SF) of a minimum level of service (LOS) C over the design peak period. Using a maximum service flow MSF=1,550 passengers cars per hour per lane (pcphpl) for LOS C, the following are used:

Condition	Characterization	Service Flow (LOS C)
Automobiles only	0% heavy trucks (fhv=1.00)	Sfc=1,550vph per lane
Mixed traffic	20% heavy trucks (fhv=0.71)	Sfc=1,100vph per lane
Heavy trucks only	100% heavy trucks (fhv=0.33)	Sfc=510vph per lane

In reviewing the typical hourly traffic distribution scheme for IH-35 depicted in Figure 2.4, we observe that the travel patterns present a favorable hourly distribution in terms of optimal use of capacity. This pattern is the result of a fairly constant demand occurring over a 12-hour period (from about 7:00 a.m. to 7:00 p.m.), which thus allows for a somewhat constant level of service over much of the day. This is in contrast to the more typical urban roadway pattern where two or three high peaks take place over narrow periods, which in turn creates huge gaps of underutilized capacity.



* K factor is the ratio of hourly volume to daily volume.

** Weekend traffic is characterized by Friday and Sunday data (Source: TxDOT "Permanent Automatic Traffic Records", 1993 Annual Report).

Figure 2.4. Typical hourly distribution of traffic over rural IH-35

In addition, we observe that critical peaks (or design ADT) take place toward the weekends; thus, in any scheme seeking a minimum LOS C, the weekday LOS would probably not fall below LOS B.

Using the computed service flows, along with traffic growth forecasts generated in Report 1326-1 (Ref 1), we obtained lane requirements over the next 50 years for each of the alternative approaches. Since at the present time it is difficult to predict preference levels in the case of parallel alignments for IH-35 and the MTS, we adopted two demand scenarios to establish and compare broad magnitudes of investment: The first scenario assumes that 55 percent of the traffic would be redirected to the MTS, while the remaining 45 percent would continue using IH-35. A second scenario assumes that the traffic attracted to the MTS would grow to 70 percent of the total corridor traffic. Table 2.1 summarizes the lane requirements for each alternative solution and for the conditions described herein.

Our analysis of station traffic counts showed that Williamson County rural traffic achieved a median ADT of 34,000 vehicles in 1992. We used this figure as a representative rural value for the IH-35 corridor segment between Dallas/Ft. Worth and San Antonio.

DISCUSSION OF RESULTS

As noted in Table 2.1, both the lane-addition and retrofit approaches require the construction of a staggering number of lanes over the next 50 years. Depending on the growth scenario, a total of 10 to 18 lanes would be required for any of these two alternatives. It is important to note, however, that for the retrofit approach, conventional capacity standards were used to compute the required number of lanes (ITS technology notwithstanding) primarily because, given the highway's current state of commercial development, it would be difficult to accommodate major capacity improvements. Thus, in all fairness, the MTS approach, which also includes the use of ITS technology, was also forecast using conventional capacity standards. While it can be argued that ITS implementation can result in increased capacity to existing roadways, the fact remains that, by itself, this technology can only buy additional time before the highway again reaches congested conditions (Ref 8). The mere building of traffic lanes — without implementing other measures to modify travel behavior (including traffic demand and vehicle occupancy patterns) — has demonstrated only that more capacity begets more vehicles.

Table 2.1. Total lane requirements for different alternatives and scenarios (year 2045)

Alternative	Growth Scenario (%)	Traffic Condition	Forecast ADT (Year 2045)	Peak Flow (K=0.11)	Required Lanes
Add lanes to IH-35	4	Mixed traffic	106,080vpd	11,700vph	10
	8	Mixed traffic	178,160vpd	19,600vph	18
Retrofit IH-35	4	Autos only Trucks only	384,864vpd 21,216vpd	9,300vph 2,300vph	6 4
	8	Autos only Trucks only	142,528vpd 35,632vpd	15,700vph 3,900vph	10 8
MTS + IH-35 IH-35 attraction: 45% MTS attraction: 55%	4	IH-35: Mixed MTS: Autos MTS: Trucks	47,736vpd 46,675vpd 11,669vpd	5,300vph 5,100vph 1,300vph	4 4 min 4
	8	IH-35: Mixed MTS: Autos MTS: Trucks	80,172vpd 78,390vpd 19,598vpd	8,800vph 8,600vph 2,200vph	8 6 or 4 HOV* 4
MTS + IH-35 IH-35 attraction: 30% MTS attraction: 70%	4	IH-35: Mixed MTS: Autos MTS: Trucks	31,824vpd 59,405vpd 14,851vpd	3,500vph 6,500vph 1,600vph	4 4 4
	8	IH-35: Mixed MTS: Autos MTS: Trucks	53,448vpd 99,770vpd 24,942vpd	5,900vph 11,000vph 2,700vph	6 8 or 4 HOV 6 or 4LI**

*HOV lanes considered here for autos with at least two passengers.
**LI represents here a load increase of 20%.

The MTS approach would encourage changes in travel behavior. Since the MTS would represent a "managed" facility, new user fees or tolls could be introduced not only as a mechanism for obtaining the necessary resources, but also as a control device. Through the use of pricing schemes, for example, travel behavior could be modified in a way that would take full advantage of the capacity properties at hand.

From this perspective, and balancing the lane requirements under the conventional capacity estimation procedure, the MTS could conceivably operate with a maximum of 10 lanes under the critical 8-percent growth scenario over the next 50 years. Four lanes (two in each direction) could be allocated for exclusive heavy truck use if a 20-percent load increase is allowed; the other six lanes could be designated for automobile use, with two of these lanes available for later implementation of bus-HOV lanes (one in each direction). The built-in multimodal capabilities and the expected improvements in vehicle occupancy patterns can further increase the service life of the MTS far beyond the 50-year threshold without any additional lane investment.

At the same time, under this alternative solution, rural IH-35 should not increase its total number of lanes over six for the 8-percent growth scenario — thus requiring only the addition of two lanes from Austin to Dallas-Ft. Worth in a worst-case scenario. This is the approach that must be followed if an MTS is to be implemented. Otherwise, the strategy could potentially be regarded as doing more of the same thing: just adding extra lanes. Table 2.2 summarizes the optimal lane allocation used for the cost evaluation of the alternative solutions.

Table 2.2. Optimal lane allocation to be used for cost comparison

Alternative	Growth Scenario (%)	Traffic Condition	Allocated Lanes
Add lanes to IH-35	4	Mixed traffic	10
	8	Mixed traffic	18
Retrofit IH-35	4	Autos only Trucks only	6 4
	8	Autos only Trucks only	10 8
MTS + IH-35	4	IH-35: Mixed MTS: Autos MTS: Trucks	4 4 4
	8	IH-35: Mixed MTS: Autos MTS: Trucks	6 6 4

CHAPTER 3. GENERAL FULL-COST EVALUATION OF ALTERNATIVES

Traditional highway evaluation is based solely on agency costs, with vehicle operating costs, environmental damage, accidents, and traffic congestion costs excluded. However, that may now be changing in the U.S. Since the 1990s, transportation planning and investment strategies have moved toward providing a more economically efficient and environmental friendly transportation system. One of the objectives of the 1991 ISTEA legislation (Ref 3) was to begin regarding transportation planning as a system in which each mode (highway, transit, and rail) interacts with other modes. This means that each mode must be fully evaluated and compared with other modes in order to select the most appropriate mode or combination of modes. Because it estimates the real costs of transportation — including user and social costs (Refs 9, 10) — full-cost evaluation allows policymakers to make more cost-effective decisions by allowing them to determine what portion of the total cost of transportation is actually paid by the users (travelers, vehicle owners, carriers).

Recent research efforts have examined different ways of including external and internal costs in the full-cost analysis of transportation. The elements of full-cost evaluation that have been studied widely include facility costs, maintenance, operating costs, and fuel costs. On the other hand, strategies designed to incorporate such other costs as congestion, accidents, and pollution are in the early stages of development and, thus, somewhat questionable and extremely variable. In the section below, we review several full-cost frameworks used in previous studies. Following this, we present a full-cost framework for evaluating transportation corridors in Texas.

RELATED WORKS

Full-cost transportation analysis is not new. The basic concepts behind this approach were outlined by Walters, Vickrey, and others in the late 1950s and early 1960s. More recent work has been published by Litman (Ref 11); MacKenzie, Dower, and Chen (Ref 12); Miller and Moffet (Ref 13); and Apogee Research (Ref 14). All of these research efforts point to a more comprehensive cost analysis approach to transportation alternatives.

Directions: The Final Report of the Royal Commission on National Passenger Transportation

In October 1989, the government of Canada began a three-year project to "inquire into and report upon a national integrated intercity passenger transportation system to meet the need of Canada and Canadians in the 21st century" (Ref 15). The Royal Commission recognized the need to assess in an accurate manner the real cost of each mode of transportation available in Canada in order to determine its share in the total cost of transportation: "Travelers would not be paying for a passenger transportation system that is wasteful because it has too much or too little capacity, or capacity of the wrong type and in the wrong place" (Ref 15). The Canadian report is a comprehensive study that provides an effective framework for full-cost analysis.

The cost components identified in the Canadian study include: (1) infrastructure, (2) environmental, (3) accident, (4) special transportation taxes and fees, and (5) vehicle or carrier operating costs. (The fourth category, special transportation taxes and fees, is not actually a cost group but a cost recovery category that is used to offset the other transportation costs.) Cost estimates were derived for each of the major transportation modes in Canada. The results of the study are summarized in Table 3.1.

Table 3.1. Systemwide annual costs of intercity domestic travel in Canada in 1991 (Canadian cents per passenger-kilometer)

	Car			Bus		
Type of Cost	**User**	**Others**	**Total**	**User**	**Others**	**Total**
Infrastructure	0.0	2.1	2.1	0.0	0.3	0.3
Environment	0.0	0.6	0.6	0.0	0.2	0.2
Accident	3.7	0.1	3.8	0.4	0	0.4
Special Tax/Fee	1.2	-1.2	0.0	0.3	-0.3	0.0
Vehicle/Carrier	10.9	0	10.9	8.4	0.2	8.6
Total	**15.8**	**1.6**	**17.4**	**9.1**	**0.4**	**9.5**
	Airplane			**Train**		
Type of Cost	**User**	**Others**	**Total**	**User**	**Others**	**Total**
Infrastructure	2.2	3.4	5.6	2.9	0	2.9
Environment	0.0	1	1.0	0.0	0.6	0.6
Accident	0.1	0	0.1	0.2	0	0.2
Special Tax/Fee	0.6	-0.6	0.0	0.4	-0.4	0.0
Vehicle/Carrier	14.4	0.1	14.4	7.4	32.8	40.2
Total	**17.3**	**3.9**	**21.1**	**10.9**	**33.0**	**43.9**
	Ferry			**All intercity Travel**		
Type of Cost	**User**	**Others**	**Total**	**User**	**Others**	**Total**
Infrastructure	0.0	4.7	4.7	0.2	2.2	2.4
Environment	0.0	2	2.0	0.0	0.6	0.6
Accident	0.1	0	0.1	3.3	0.2	3.4
Special Tax/Fee	0.9	-0.9	0.0	1.1	-1.1	0.0
Vehicle/Carrier	24.1	11.6	35.7	11.2	0.2	11.4
Total	**25.1**	**17.4**	**42.5**	**15.8**	**2.1**	**17.8**

Users refers to travelers, vehicle owners, and carriers.
"Other" refers to taxpayers and the general public.
Source: Ref 15

Among the recommendations that grew out of this national study, the following are most pertinent to our research efforts:

1. Each traveler should pay the full cost of his or her travel, and travelers, in total, should pay the full cost of the passenger transportation system, including those costs related to protecting the environment.
2. Competition and market forces should be the prime agents in providing viable and efficient carrier services.
3. Where regulations are required, they should be designed to ensure fair pricing and prudent investment decisions.

Implementation of these recommendations could result in additional costs to transportation users. However, because of the improvements in efficiency, total costs to society (i.e., all taxpayers) would decline at a more significant rate. And while the recommendations are interesting, the most important element of the study is its methodology: It is this component that is most relevant to the study of transportation corridors in Texas.

Truck versus Rail Freight System Cost Comparison: Conrail and I-80 Pennsylvania Corridors

The importance of using a full-cost analysis approach for a transportation corridor was underscored in a recent report published by the Texas Research and Development Foundation (TRDF) (Ref 16). On behalf of CONRAIL, Inc., TRDF studied the line-haul motor vehicle freight costs along the Pennsylvania IH-80 corridor (500 km, or 311 miles) and the line-haul rail freight costs along a comparable route. The purpose of the study was to identify the most cost-effective mode of transportation for line-haul freight, in order to develop warrants for the use of highway funds to improve truck capacity within the freight corridor.

Similar to the Canadian full-cost framework, costs for the two modes in the TRDF analysis were categorized into facility (infrastructure) costs, operating costs, and external costs. External costs included costs related to safety (i.e., property damage, injuries, fatalities, law enforcement, cleanup, delay costs, and additional fuel costs). Facility costs for trucks were further distinguished by those supported by truck user fees (primarily through motor fuel taxes and registration fees) and subsidies. The cost results for the truck mode and rail mode are shown in Tables 3.2 and 3.3, respectively.

Because they do not pay their full transportation costs, trucking companies enjoy a competitive advantage over rail freight transportation. The impact of this subsidy was reported in a subsequent study (Ref 17). Based on the Association of American Railroads' (AAR) cross-elasticity model (CEM), between 4.5 billion metric ton-km (3.1 billion ton-miles) and 8.5 billion metric ton-km (5.8 billion ton-miles) are diverted from the rail network to the road network each year along the I-80 Pennsylvania corridor. This translates into $112 million to $204 million in lost revenues annually. The TRDF study found inefficiencies in the passenger transportation system comparable to those reported in the earlier Canadian study. Both studies highlight the need to analyze transportation investment alternatives from a full-cost perspective.

Table 3.2. IH-80 truck costs, 5 axle semi-trailer, 1990 (in dollars)

	$/mile	$/km	$/ton-mile	$/met. ton-km
Truck Paid Facility Costs	0.125	0.078	0.010	0.007
Truck Operating Costs	0.931	0.579	0.071	0.048
Subtotal	1.057	0.657	0.081	0.055
Society Facility Costs	0.177	0.110	0.012	0.008
Society External Costs	0.067	0.042	0.005	0.003
Subtotal	0.244	0.152	0.017	0.012
TOTAL	1.301	0.809	0.098	0.067

Source: Ref 16

Table 3.3. IH-80 rail freight system costs, 1990

	$/ton-mile	$/met. ton-km
Rail Paid Facility Costs	0.008	0.005
Rail Paid Operating Costs	0.013	0.008
Subtotal	0.021	0.013
Society External Costs	0.000	0.000
TOTAL	0.021	0.013

Source: Ref 16

A Framework for Evaluating Multimodal Transportation in Texas

As noted in the introduction to this section, ISTEA has served as a catalyst in the promotion of a multimodal transportation system. Because of the potential efficiency gains in an interconnected multimodal transportation system, TxDOT commissioned Project 1282 to study the mobility and economic development issues associated with a multimodal transportation system. The final report of that study, "A Framework for Evaluating Multimodal Transportation Investment in Texas" (Ref 9), presents a comprehensive overview of multimodal transportation planning, as well as a framework for analyzing transportation investment alternatives. While the study clearly identifies the need for more research to evaluate the marginal costs of transportation, at the same time it establishes a point of departure for analyzing more efficient transportation alternatives. The basic framework for multimodal transportation investment decision-making is outlined in Figure 3.1.

An efficient transportation system requires a coordinated transfer of people and goods from one mode to another. In the past, neither the planning process nor the environment for supporting analysis of the total transportation system has been viewed from a multimodal, full-cost perspective. Changes in federal and state policies have created a new contextual environment for transportation. Based on these changes, the private sector is rapidly embracing the advantages of an intermodal system. In order to efficiently support this new direction, a total system or full-cost analysis of transportation alternatives must be pursued. The framework presented in Figure 3.1 outlines such an approach. Various studies have demonstrated that inclusion of all transportation costs in analyzing alternatives will yield a more efficient transportation system and can result in the lowest costs to society.

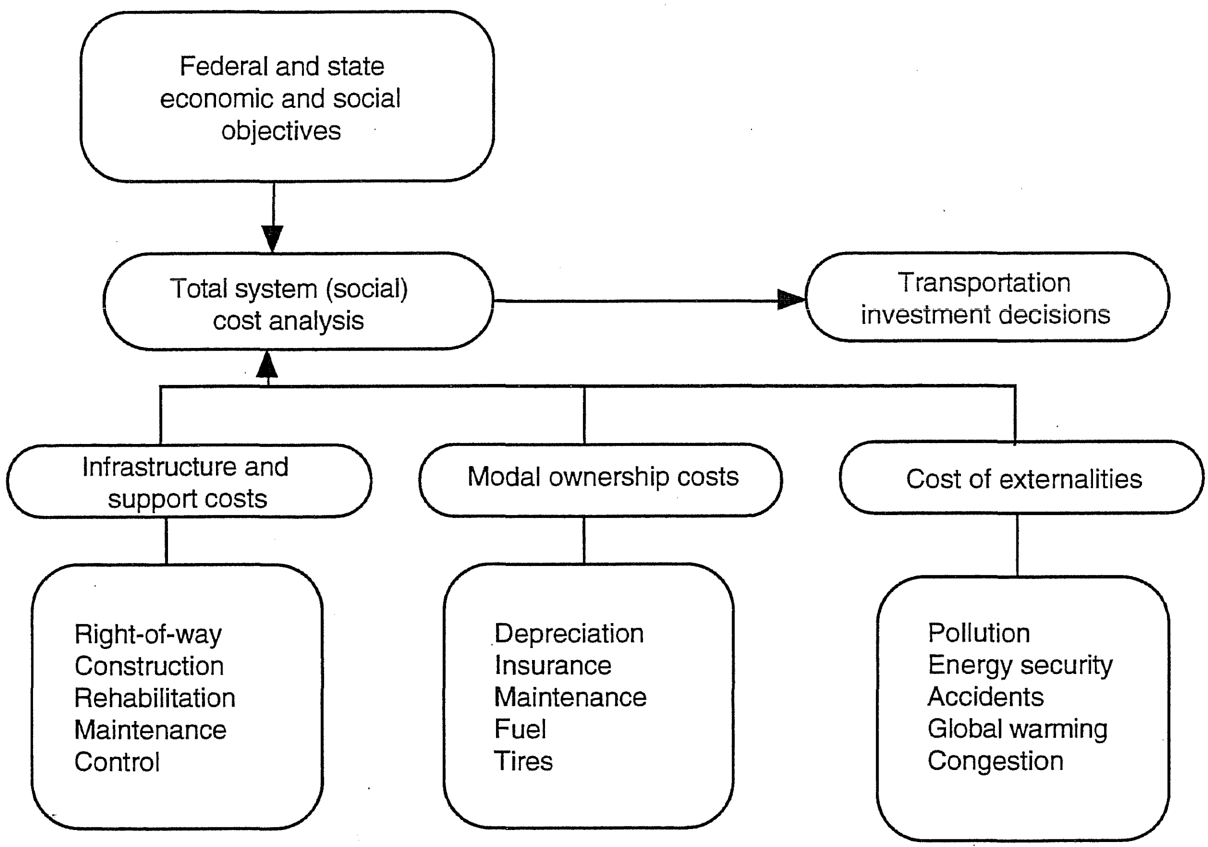


Figure 3.1. Multimodal transportation decision model (Ref 9)

Evaluating Full Costs of Urban Passenger Transportation

The multimodal transportation investment framework established in Project 1282 has become operational in TxDOT Project 1356. In this research effort, again undertaken by CTR, a full-cost transportation model, dubbed MODECOST, has been developed. MODECOST is a microcomputer model that examines the full costs of a transportation corridor on a life-cycle cost basis. The model is being used to examine transportation alternatives along the IH-10 corridor and

U.S. 59 corridors in Houston, the IH-410 loop in San Antonio, a light-rail corridor in the northeast Dallas area, the Houston-Harte freeway in San Angelo, and for transportation control measures in El Paso.

MODECOST identifies the full costs of different passenger transportation options, including lane additions, high occupancy vehicle (HOV) lanes, light rail transportation, and the transportation control measures deployed along a transportation corridor. The cost components for MODECOST are divided into agency costs, user costs, and external costs (Ref 10).

ELEMENTS OF A FULL-COST EVALUATION IN TRANSPORTATION

Using the findings of the previously reviewed studies, we developed the full-cost framework illustrated in Figure 3.2, which is a modified version of the MODECOST model (Ref 10) described above and adapted to reflect intercity travel. The full cost of a roadway is divided into agency costs and internal/external costs, with agency costs then further divided into capital costs and non-capital costs. Capital costs include land acquisition, construction, and rehabilitation. Non-capital costs refer to routine maintenance, administration and safety, and debt service.

Internal/external costs (or user/social costs) are divided into five major groups: ownership costs, operating costs, travel time costs, air pollution costs, and accident costs. The next two chapters analyze each of these cost components. Chapter 4 reports on the agency cost, while Chapter 5 looks at external/internal costs (also termed in this study *user/social costs).*

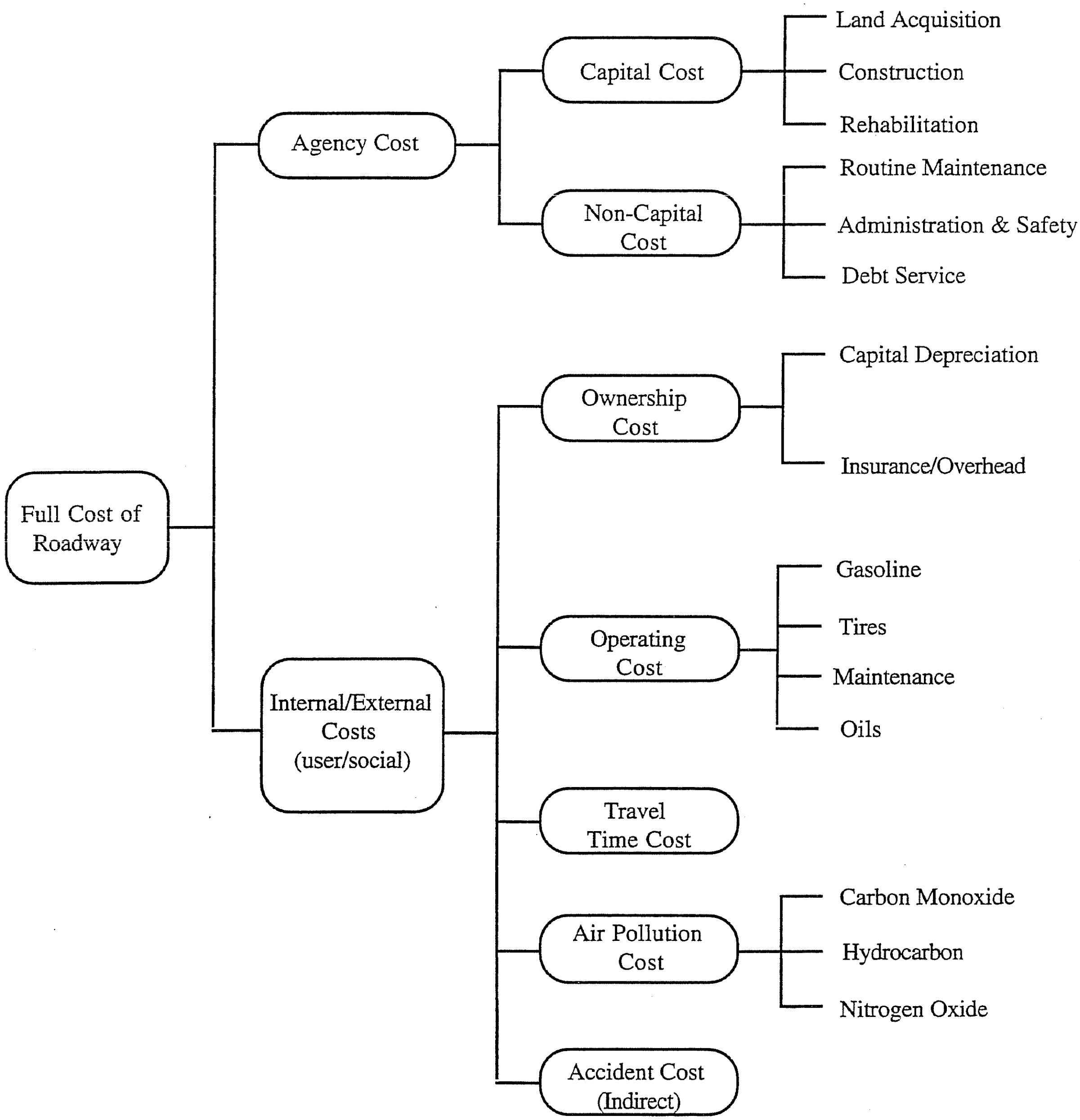


Figure 3.2. Elements of the full cost of roadways (modified version of the MODECOST model)

CHAPTER 4. AGENCY COST EVALUATION

As part of an overall feasibility evaluation, it is necessary to determine the total investment costs associated with each of the options available for meeting future traffic demand over the IH-35 corridor. In this regard, given that pavement construction, rehabilitation, and maintenance account for a substantial portion of total highway costs, the first section of this chapter examines specifically the pavement cost variations as a function of the attracted traffic.

For this purpose, different conditions observed over the IH-35 corridor — and relevant to pavement performance — were introduced in a factorial design analysis to obtain a set of pavement solutions and associated costs. Because they were to include designs for both new construction and major rehabilitation of existing pavement, these pavement solutions accord with the previously discussed alternatives for meeting future traffic demand.

Having then defined the set of pavement solutions and associated costs, the second section of this chapter estimates the agency costs for each of the IH-35 alternatives.

PAVEMENT REQUIREMENTS

As mentioned previously, we performed in this study a factorial design analysis of pavement solutions and associated costs, taking into account the life-cycle cost (construction costs, maintenance costs, and rehabilitation costs) of the pavements. The three major factors related to the procedure used for the factorial design analysis are described in this section.

Elements of the Factorial Design

A large number of variables affect the performance of pavement in the field, among them traffic and loading, materials characteristics, and the environment. In addition, an economic evaluation requires that we consider the cost of different items and a discount rate. For the present exercise, the analysis was divided into two construction procedures:

1) new construction of a pavement structure, and
2) overlay (O/L) of an existing pavement structure.

Factors for New Construction

Under this procedure, pavement designs for new construction were generated using computer software based on AASHTO specifications (Ref 18) to yield the lowest net present cost (in dollars per square meter of pavement), including construction and maintenance, for a maximum period of 50 years.

Two types of pavement were considered for the new construction procedure; if required, both pavement types could be rehabilitated with an asphalt overlay.

a) Flexible pavement design variables

	Layer coeff.	Layer drain. coeff.	Mod. of Elasticity kg/cm^2 (psi)	High Bid \$/m^3 (\$/CY)	Low Bid \$/m^3 (\$/CY)
Hot mix asphalt concrete (AC)	0.44	1.00	31,700 (450,000)	94.63 (72.30)	86.13 (65.80)
Asphalt stabilized base	0.14	1.20	2,100 (30,000)	72.91 (55.70)	66.36 (50.70)
Granular subbase	0.10	1.20	1,050 (15,000)	18.93 (14.46)	17.23 (13.16)

As a conservative assumption, no salvage value was considered after 50 years.
Maintenance costs: \$0.036/m^3/year (\$0.03/SY/year) (beginning in year 3 after construction).
Cost bids were obtained from two sources: Means Heavy Construction Cost Data, 1994 (Ref 19) and Cost Estimation Reports (Ref 20). The high bid cost is the national average cost and the low bid cost is the Texas average cost.

b) Rigid pavement design variables

Portland Cement Concrete (PCC) slab:
Type: Continuous Reinforced Concrete Pavement (CRCP)
High Bid: \$/CY=135.90-2.06(D)
Low Bid: \$/CY=123.70-1.87(D) (D: depth of slab)
Elastic Modulus: 31,700 kg/cm^2 (4,500,000 psi)
Modulus of rupture: 56 kg/cm^2 (800 psi)

Subbase:
Type: 15 cm (6") granular asphalt stabilized
High Bid: \$72.91/m^3 (\$55.70/CY)
Low Bid: \$ 66.36/m^3 (\$50.70/CY)
Elastic Modulus: 2,100 kg/cm^2 (30,000 psi)

Other structural characteristics:
Load transfer coefficient: 2.60
Drainage coefficient: 1.05
Loss of support factor: 0.50

As a conservative assumption, no salvage value was assigned after 50 years.
Maintenance costs: \$0.036/m^3/year (\$0.03/SY/year) (beginning in year 7 after construction).
Cost bids obtained from Refs 19 and 20.

For the two pavement types, the following conditions were considered:
Overall reliability (analysis period): 95 percent
Standard deviation: 0.40
Frost heave and roadbed swelling: None

Serviceability index: 4.5 (initial) and 2.5 (final)
Resilient Modulus (weak soil) M_R=420 kg/cm^2 (6,000 psi)
Resilient Modulus (strong soil) M_R=1400 kg/cm^2 (20,000 psi)
Discount rates: 4 percent and 8 percent

Factors for major rehabilitation of an existing pavement (AC O/L): Because the rehabilitation procedure most commonly used by TxDOT on IH-35 is asphalt concrete overlay, we therefore adopted this procedure for this study. Under this procedure, the asphalt concrete overlays designed for IH-35 would allow it to sustain an expected number of load applications over the full analysis period. According to the existing characteristics of this highway in rural areas, two specific pavement structures were selected as representative.

a) Existing pavement structure "X"

Existing pavement structure "X" (which is the typical rigid pavement structure used throughout IH-35) is comprised of a 25-cm (10 in.) PCC pavement with a 5.7-cm (2.25 in.) AC overlay. In essence, the required design of the overlay was for a composite pavement. Thus, the procedure outlined in the 1993 AASHTO Guide, Part III, Section 5.6, for overlay design of a composite pavement (AC overlay on PCC pavement) was utilized with the following characteristics:

k-eff= 17 kg/cm^2 (240 psi) (for weak soil M_R = 420 kg/cm^2 (6,000 psi))
k-eff= 35 kg/cm^2 (500 psi) (for strong soil M_R = 1400 kg/cm^2 (20,000 psi))

J=3.0	Initial Serviceability index: 4.0
Cd=0.90	Fjc=0.95
S'c=50 kg/cm^2 (700 psi)	Fdur=0.90
Ec=31700 kg/cm^2 (4,500,000 psi)	Fac=0.96

b) Existing pavement structure "Y"

The existing pavement structure "Y" (which is the typical flexible pavement structure used throughout IH-35) consists of a 5-cm (2 in.) AC layer over a 12.5-cm (5 in.) thick asphalt stabilized base over a 55-cm (22 in.) granular subbase. The required design is an AC overlay on an AC pavement. Thus, the procedure outlined in the 1993 AASHTO Guide, Part III, Section 5.4, for overlay design of an AC pavement was utilized with the following characteristics:

	a	m	D
Hot mix AC	0.40	---	5.0 cm (2 in.)
Asphalt stabilized base	0.10	1.00	12.5 cm (5 in.)
Granular subbase	0.10	1.00	25.0 cm (10 in.)

a= Layer coefficient O/L: a=0.44
Initial Serviceability index: 3.5

For the two pavement types, the following conditions were considered:
Overall reliability (analysis period): 95 percent
Standard deviation: 0.40
Frost heave and roadbed swelling: No
Final Serviceability index: 2.5
Resilient Modulus (weak soil) M_R=420 kg/cm^2 (6,000 psi)
Resilient Modulus (strong soil) M_R=1400 kg/cm^2 (20,000 psi)
Asphalt O/L cost: High Bid: \$94.63/m^3 (\$72.30/CY)
Low Bid: \$86.13/m^3 (\$65.80/CY)
Discount rates: 4 percent and 8 percent
Maintenance costs: \$0.036/m^3/year (\$0.03/SY/year)(beginning in year 3 after construction).
Cost bids obtained from Ref. 19 and 20.

Traffic factor: Two different ESAL* growth rates (compounded yearly), based on previous observations over rural highways in Texas (Ref 21), were applied to the current IH-35 traffic volume of 4,800,000 kips. In addition, for the design of the critical traffic lane a Directional Distribution factor (Dd) was kept constant at 0.50, and for the Design Lane factor, values of 0.90 and 0.70 were used. Finally, attraction rates of 100 percent, 45 percent, and 10 percent were used to characterize scenarios of user preference for parallel alignments within the IH-35 corridor.

After combining these traffic factors, we obtained a wide range of ESAL applications over the maximum 50 year period with the associated pavement designs and costs, going from a minimum of 10 million ESALs to a maximum of 300 million ESALs.

Discussion of Results

The use of the previously described factors results in the determination of pavement layer thicknesses for the new construction procedure, or AC overlay thicknesses for the rehabilitation procedure. In turn, these thicknesses yield a unit cost, expressed in dollars per square meter. In an iterative process, the several thicknesses are varied until they produce a minimum cost for a given set of factorial conditions.

Using the results of the described procedure, Figures 4.1 to 4.8 summarize the behavior of pavement costs for the design lane, obtained as a function of the number of ESAL applications under the prevailing physical conditions over the IH-35 corridor.

The dispersion or noise observed in these figures is due mainly to the level of precision used in the iteration processes. Therefore, curves were fitted for the different data arrays.

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* To measure the effects of mixed traffic loading (and to reduce these effects to a single value), equivalent single axle load (ESAL) formulas are used. Conceived by the AASHO Road Test in the late 1950s, the standard single axle load was determined to be 8.2 Mg (18 kip).

Main observations on "new construction" results: After carefully analyzing the "new construction" results, we observed the following:

1) Caution with AASHTO computer software (DNPS86)
The AASHTO computer program for pavement design should be revised to incorporate performance time limits, or at least be set up to warn the user against impractically long performance periods in lieu of the experienced criterion. Performance periods over 20 years were obtained (up to 23 years for initial performance, and even longer ones for overlays), but they were left unchanged for input control purposes. The major flaw responsible for this outcome is the restricted number of overlays allowed by the program (just one for rigid pavements and two for flexible pavements). This aspect should be revised and corrected as soon as possible, especially if longer analysis periods are to be used, as suggested in the AASHTO Guide.

2) Effect of subgrade strength (M_R)
The M_R value has a major impact on pavement structure thicknesses and, thus, on its overall cost. As expected, this impact is more conspicuous with respect to flexible pavements, where shifts from a strong soil to a weak soil support could increase costs by up to 18 percent. In fact, as suggested by the results, most of the flexible pavements over strong soils (M_R=1400 kg/cm^2) did not require a subbase layer. In general, pavements constructed over weak soils (M_R=420 kg/cm^2) are about 15 percent more expensive than pavements constructed over strong soils (M_R=1400 kg/cm^2), considering both rigid and flexible pavements.

3) Effect of discount rate
In this exercise, the lower discount rate (4 percent) always yielded a higher overall net present value. But the major impact was in the designation of performance periods: lower discount rates always yielded longer performance periods.

4) Overall cost
As expected, the cost of materials influenced neither the performance period nor the pavement characteristics (given the same soil support type). Of course, only the pavement cost was impacted.

As depicted in the summary graphs, pavement costs increase in a logarithmic form as the number of applications increases, with rigid pavements typically more costly than flexible pavements (20 percent approximately). In this regard, we noted that maintenance costs and overlay costs did not include the user costs associated with delays. Even though this is a difficult parameter to assess (among other things because it is traffic-volume dependent), it is very important that it be considered, given that the fewer maintenance operations required by rigid pavements tend to enhance their feasibility. Obviously, this expected behavior is not reflected in the graphs developed in this exercise.

Finally, from the observed smooth slopes (after 50 million ESALs) in both rigid and flexible pavements, it is suggested that designing for higher analysis periods should yield more cost-effective solutions: that is, increasing by 10 times the number of 18K-ESALs only increases the cost by 25 percent. Figures 4.1 to 4.4 summarize the results of the new construction procedure, with the costs provided in terms of net present value (NPV).

Main observations on "major rehabilitation (AC O/L)" results: After carefully analyzing the "major rehabilitation (AC O/L)" results, we observed the following:

1) Effect of subgrade strength
As with new construction, increasing values of M_R require decreasing overlay thicknesses. Moreover, for the studied structures, the strong soils would have a remaining life 30 percent higher than that for weak soils.

2) Effect of discount rate
In this exercise, the lower discount rate (4 percent) always yielded a higher overall pavement cost. Unfortunately, owing to the limitations of the data, performance periods could not be determined for these examples, underscoring the importance of nondestructive testing (NDT).

3) Overall costs
As depicted in the summary graphs, the cost of the pavement increases in a logarithmic fashion as the number of load applications increases (again, as with new construction).

4) Also, from the observed smooth slopes on both rigid and flexible pavements (after 100 million ESALs), we suggest that designing for higher analysis periods should yield more cost-effective solutions: that is, increasing by 2 times the number of 18K-ESALs increases the cost by only 30 percent.

Figures 4.5 to 4.8 summarize the results of the major rehabilitation procedures for existing pavement. The costs provided are in terms of net present value (NPV).*

* It should be understood that when projecting the cost of future rehabilitation work on ACP, an overlay alone may not be sufficient, and that many times more extensive basework and rework must be undertaken to bring the pavement up to specifications — all of which is more expensive than overlay work. As indicated in the first chapter of this report, the calculations are preliminary and are not meant to represent precise figures (which would be the objective of a detailed planning-stage study). Thus, the calculations included in this and other chapters do not include such things as milling to reduce crown height. This and other technical issues were simply not a part of this study. In future work, we recommend that these technical issues be identified and used as probabilistic values. Indeed, we recommend the entire life-cycle cost analysis be probabilistic (rather than deterministic) in nature, utilizing recent software programs to facilitate such analysis.

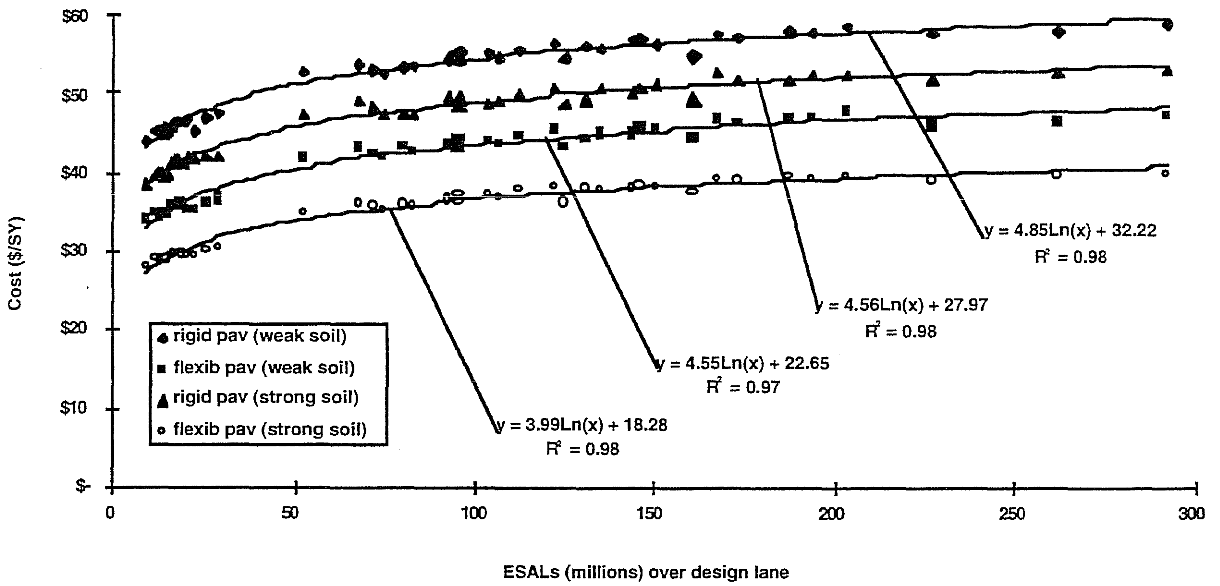

Figure 4.1. ESAL vs. cost graph (new construction) using low cost bids and an 8-percent discount rate

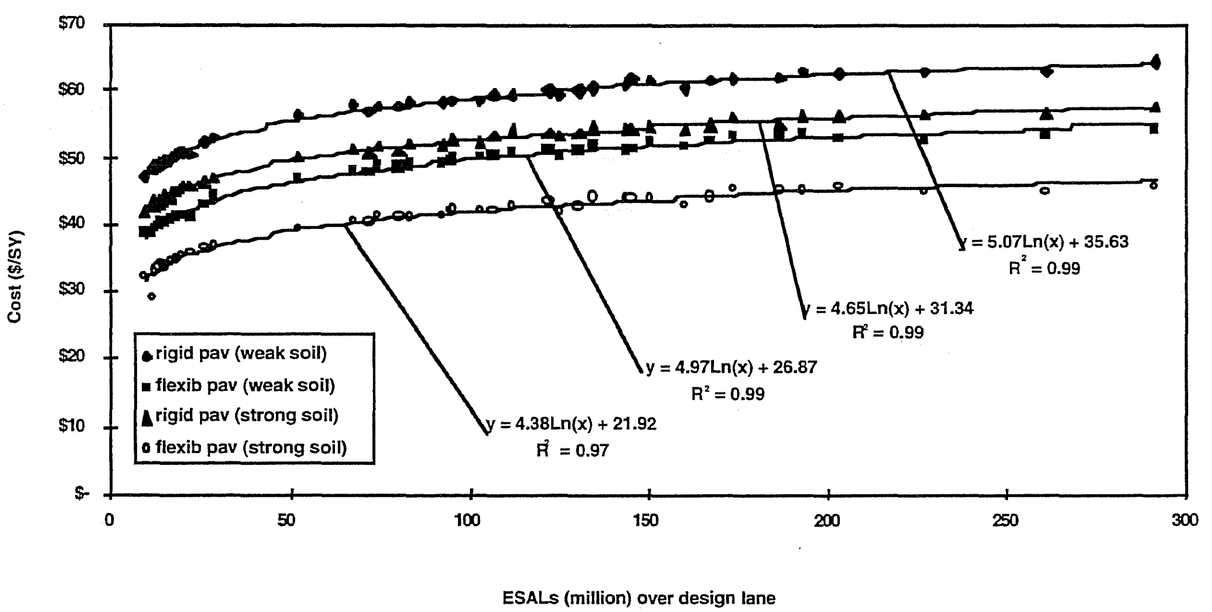

Figure 4.2. ESAL vs. cost graph (new construction) using low cost bids and a 4-percent discount rate

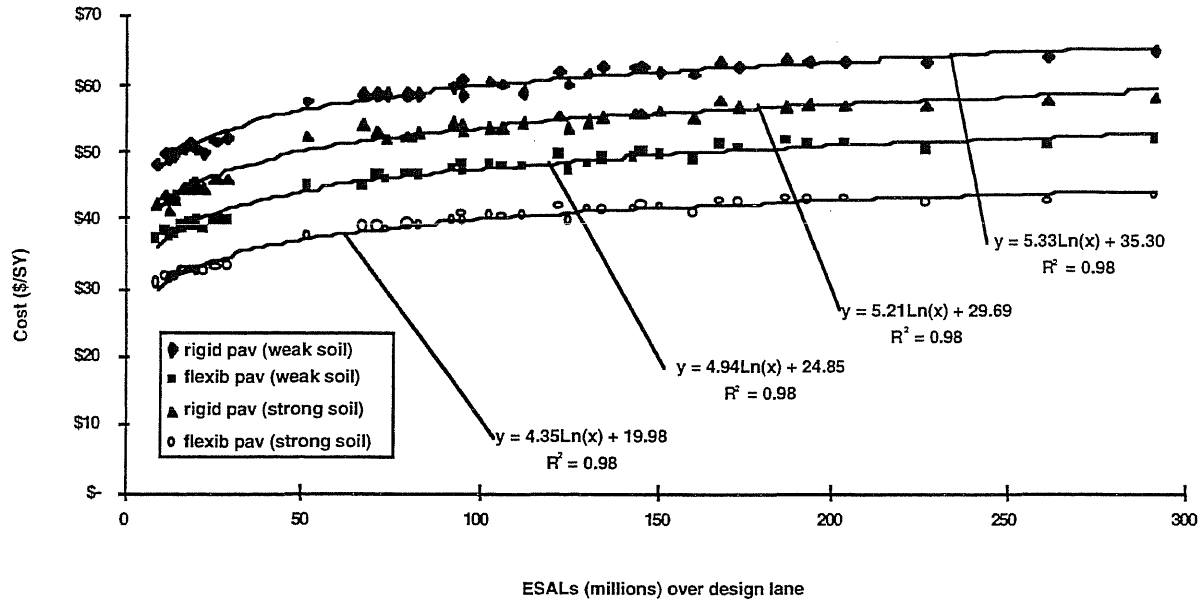

Figure 4.3. ESAL vs. cost graph (new construction) using high cost bids and an 8-percent discount rate

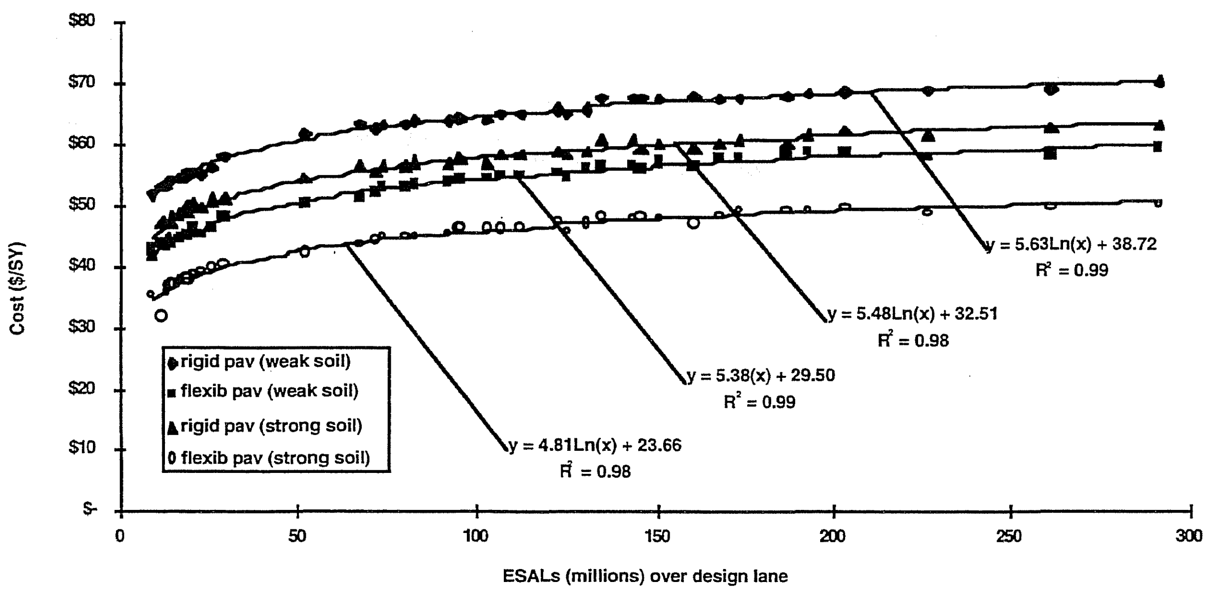

Figure 4.4. ESAL vs. cost graph (new construction) using high cost bids and a 4-percent discount rate

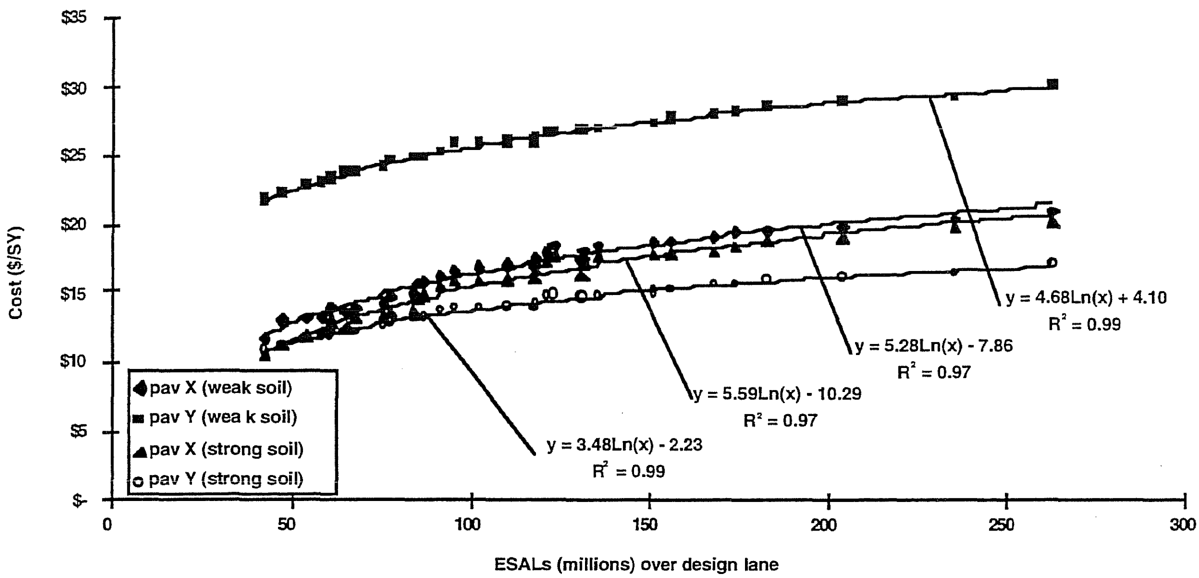

Figure 4.5. ESAL vs. cost graph (AC O/L) using low cost bids and an 8-percent discount rate

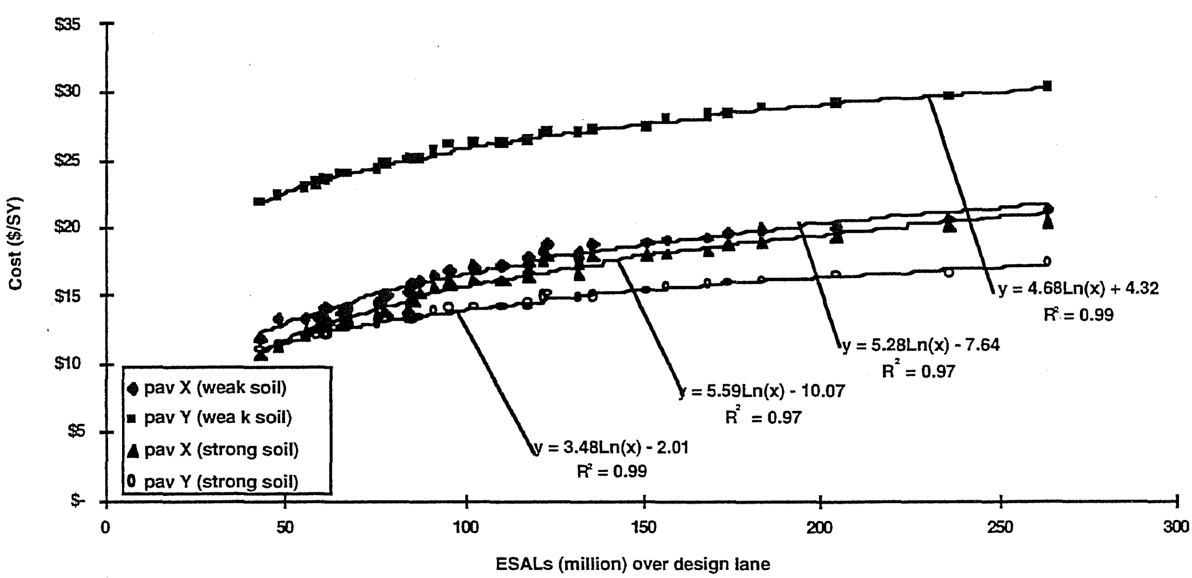

Figure 4.6. ESAL vs. cost graph (AC O/L) using low cost bids and a 4-percent discount rate

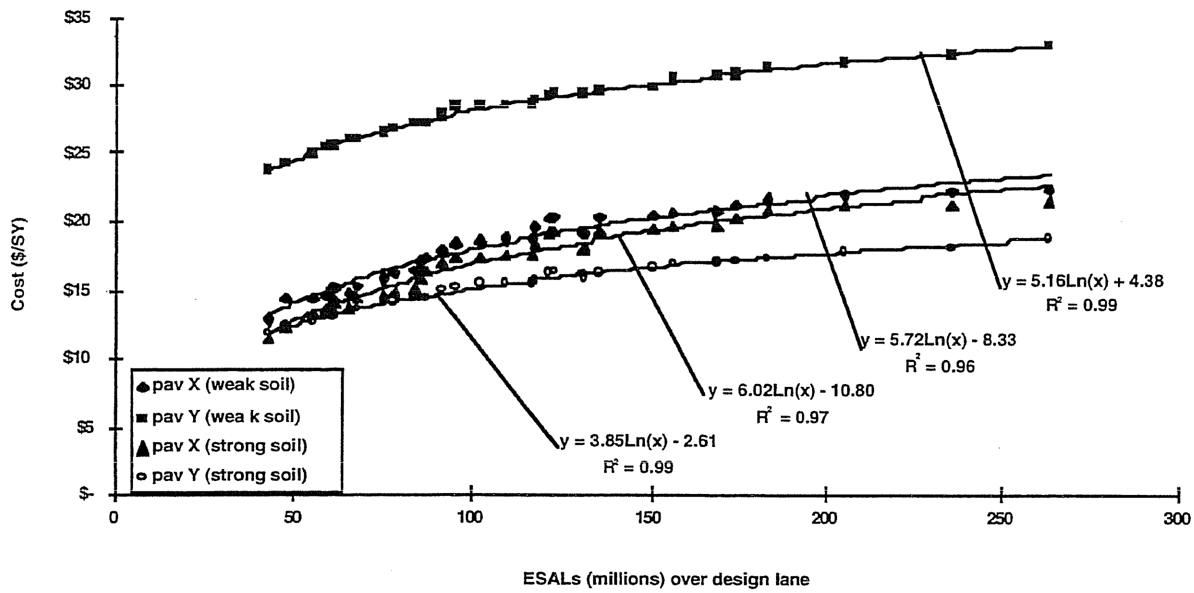

Figure 4.7. ESAL vs. cost graph (AC O/L) using high cost bids and an 8-percent discount rate

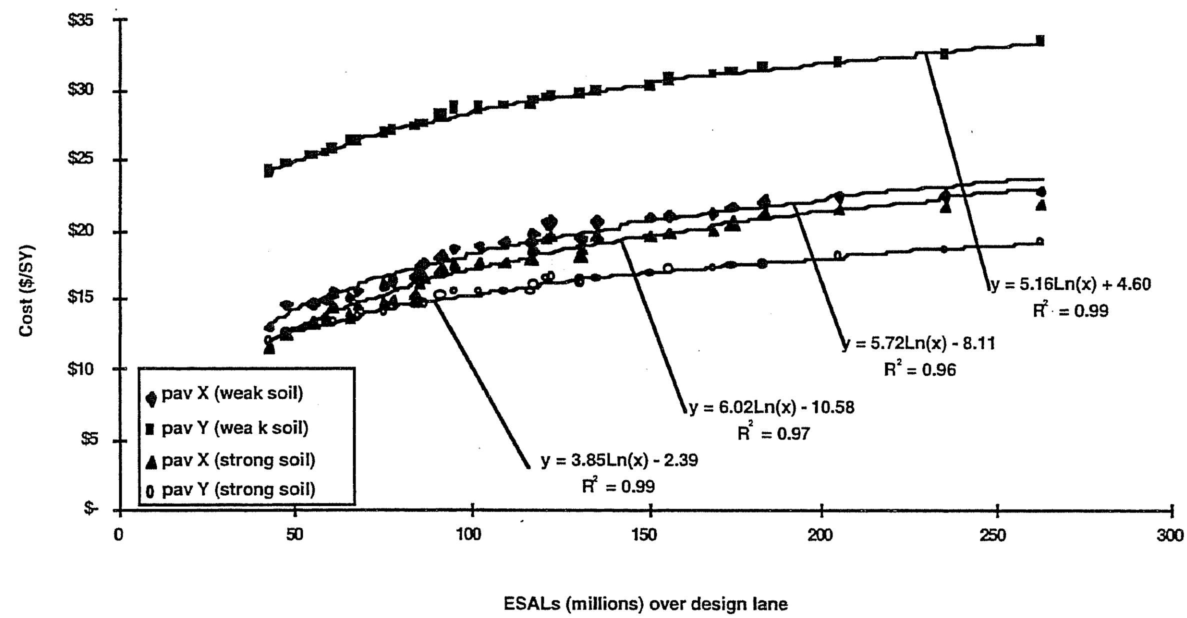

Figure 4.8. ESAL vs. cost graph (AC O/L) using high cost bids and a 4-percent discount rate

ESTIMATED AGENCY COST OF ALTERNATIVES

Having defined in the previous section the set of pavement solutions and associated costs, this second part analyzes the first element of the full-cost evaluation, namely, the agency cost. This section summarizes the agency cost estimates for each of the previously discussed alternatives for the IH-35 corridor (Chapter 2). These costs were computed for a 50-year life cycle of the facilities, which is the analysis period established under the current study. In addition, maintenance and rehabilitation costs for the rural segments of the existing roadway were determined as well, as part of the "no build" approach, to serve as a base reference. Figure 4.9 shows the current alignment configuration for IH-35 from San Antonio to Dallas-Fort Worth.

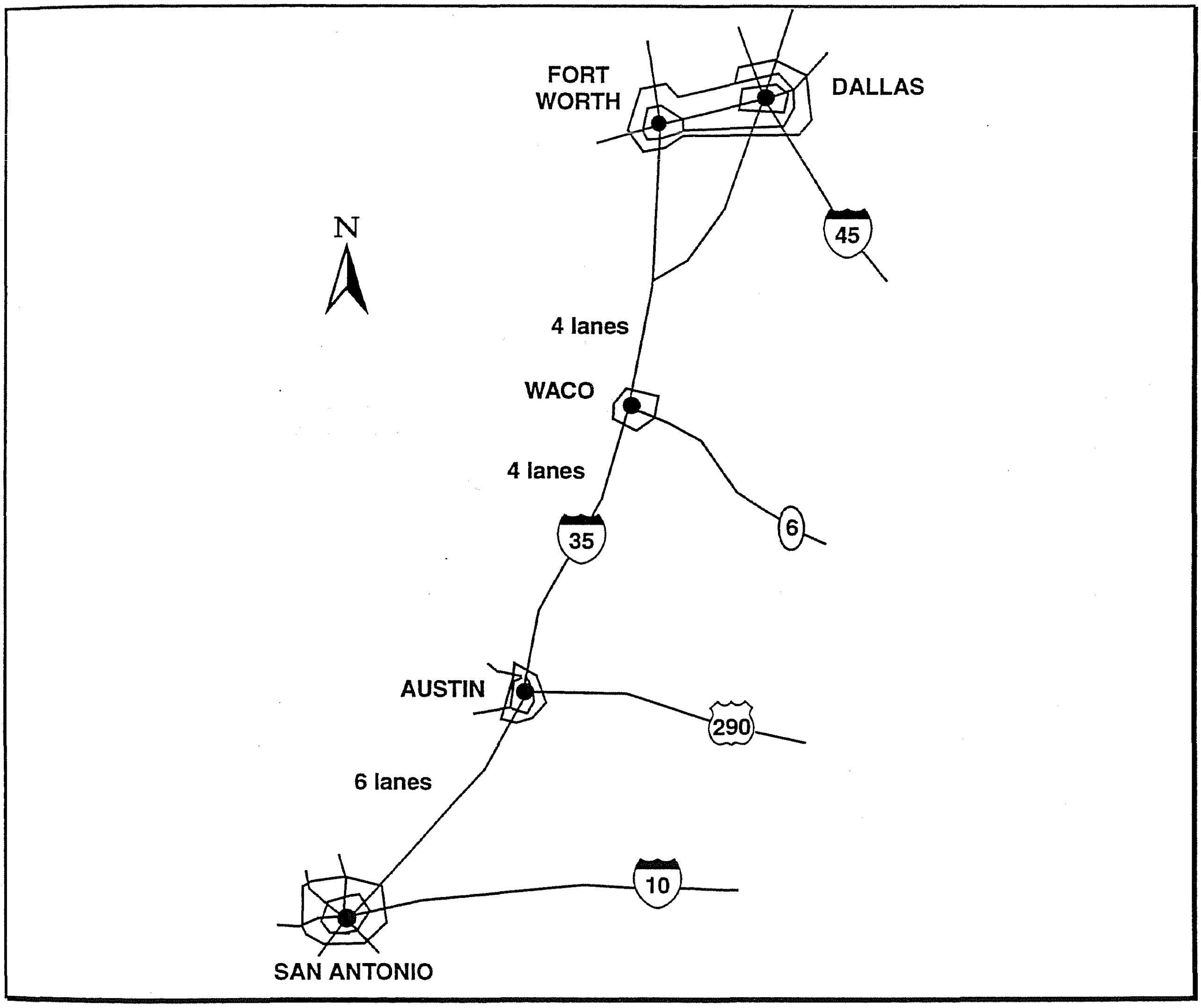

Figure 4.9. Layout of the current IH-35 configuration between San Antonio and Dallas/Ft. Worth

General Considerations

Before estimating the agency costs of alternatives, it is necessary first to establish the construction schedule to determine the present worth value and to define the criteria followed for pavement selection and cost estimation.

Construction stages: In order to properly determine the present worth of each of the alternatives, it has been necessary to establish an approximate implementation schedule. Based on recent IH-35 construction experience, an overall construction program was established, one composed of three major periods of 5 years each. These periods were allocated for the construction of three equally long roadway segments: (1) Austin to Waco, (2) Waco to DFW, and (3) San Antonio to Austin. This order was selected based on priorities for congestion relief. Currently, the segment having the highest traffic volume is the San Antonio-Austin section; but, as depicted in Figure 4.9, the recent construction of two additional lanes to this segment should reduce its congestion somewhat. Figure 4.10 shows the general construction stages, which apply to all the alternatives considered.

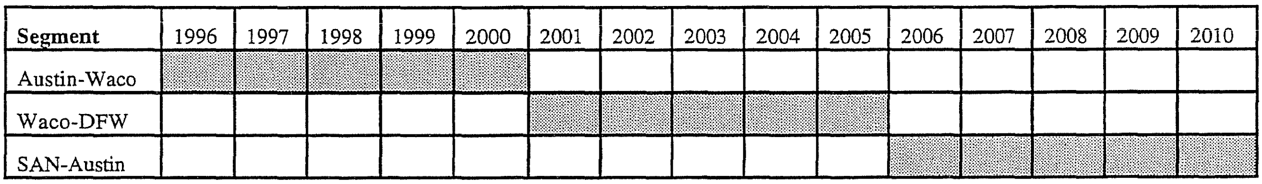

Figure 4.10. General construction schedule for solutions to the IH-35 corridor

Agency cost components: Agency costs in general include capital investments for construction, rehabilitation, maintenance, and operation of the facility (life-cycle costs). As previously indicated, the evaluation has been performed for a 50-year analysis period. Based on prevailing economic conditions, a 4-percent real rate of return was used to obtain the present worth (PW) of the cost items in terms of constant dollars. The real rate of return (also known as "real MARR," or minimum attractive rate of return) represents only the time value of capital (i.e., it does not account for inflation).

A substantial portion of agency costs relates to the construction and maintenance of pavement structures. In this regard, the relationship of pavement expenses as a function of ESALs, developed in the previous section, was used as the basis for its design; this relationship was also used to itemize this cost for each of the alternatives evaluated. After performing an inventory of pavement types and soil support conditions along IH-35, several pavement solutions reflecting these conditions were generated in the first section of this chapter. Then, the pavement costs were calculated using this broad characterization of the corridor conditions. Appendix B shows how these were computed. In addition, we followed the criteria listed below in selecting pavements and in estimating costs:

1) For any new construction procedure (i.e., MTS or by-passes), a rigid pavement (CRCP) was considered (in order to reduce maintenance operations).

2) When adding lanes to an existing pavement, a similar structure should be provided; thus, for the IH-35 case, a flexible pavement was considered.
3) Construction costs in Texas for public works (Ref 22) fall in the category of "low bids" developed for the pavement-cost vs. ESAL relationships.

Therefore, Figures 4.2 and 4.6 from the previous section were used to obtain pavement costs for new construction and asphalt overlay procedures. In order to include other agency cost items for new construction, such as right-of-way, grading, drainage, bridge structures, etc., the present evaluation built on a previous estimation of infrastructure requirements for a roadway that would parallel IH-35 (Ref 23). Finally, the unit cost for lane additions to IH-35 was obtained from TxDOT (Ref 24).

Agency Costs of Alternatives

Using the information previously obtained, it is now possible to estimate the agency cost for each of the alternatives.

No Build: This is the equivalent of a "do nothing" approach, which serves as a control element or performance reference to the alternative solutions. Only future costs for maintenance and rehabilitation of the existing pavements were obtained for this case, and only for the rural sections of IH-35. The detailed procedure and computations are presented in Appendix B. Tables 4.1 and 4.2 summarize the major items and corresponding costs for this approach, under 4-percent and 8-percent traffic growth projections, respectively.

*Table 4.1. Agency cost summary for the "no build" alternative (4-percent growth)**

Cost Item	Roadway Segment	Cost (millions)	n (years)	PWF	PW (millions)
Overlay traffic lanes	Austin-Waco	$77	0	1.00	$77
	Waco-DFW	$93	5	0.82	$76
Overlay traffic lanes	SAN-Austin	$83	10	0.68	$56
		Total present worth (millions)			$210

Table 4.2. Agency cost summary for the "no build" alternative (8-percent growth)

Cost Item	Roadway Segment	Cost (millions)	n (years)	PWF	PW (millions)
Overlay traffic lanes	Austin-Waco	$84	0	1.00	$84
	Waco-DFW	$102	5	0.82	$84
Overlay traffic lanes	SAN-Austin	$90	10	0.68	$61
		Total present worth (millions)			$229

*In using the 50-year design life, 4 and 8 percent traffic growth rates were used, with total ESAL lives of 150 million and 227 million, respectively. Overlay designs to meet these total ESAL estimates resulted in three cost items for the three main legs of the project. For the purposes of the preliminary analysis, it was assumed that the overlays would be undertaken in years 0, 5, 10. Actually these may occur in different years, but these are the kinds of assumptions required in early modeling.

Adding lanes: Figure 4.11 presents the general configuration generated for this alternative. As previously established, by-passes should be constructed around major urban areas to separate urban traffic from through intercity traffic. This condition was considered less disruptive (and thus less costly) than building the additional lanes within the traffic-intense urban area.

The detailed procedure and computations to determine the agency costs are presented in Appendix B. Tables 4.3 and 4.4 summarize the major items and corresponding costs for this approach, under 4-percent and 8-percent traffic growth scenarios, respectively. It should be noted that a "bridge overpass reconstruction" item has been included, which considers modifications to transverse overpass crossings due to the additional space requirements.

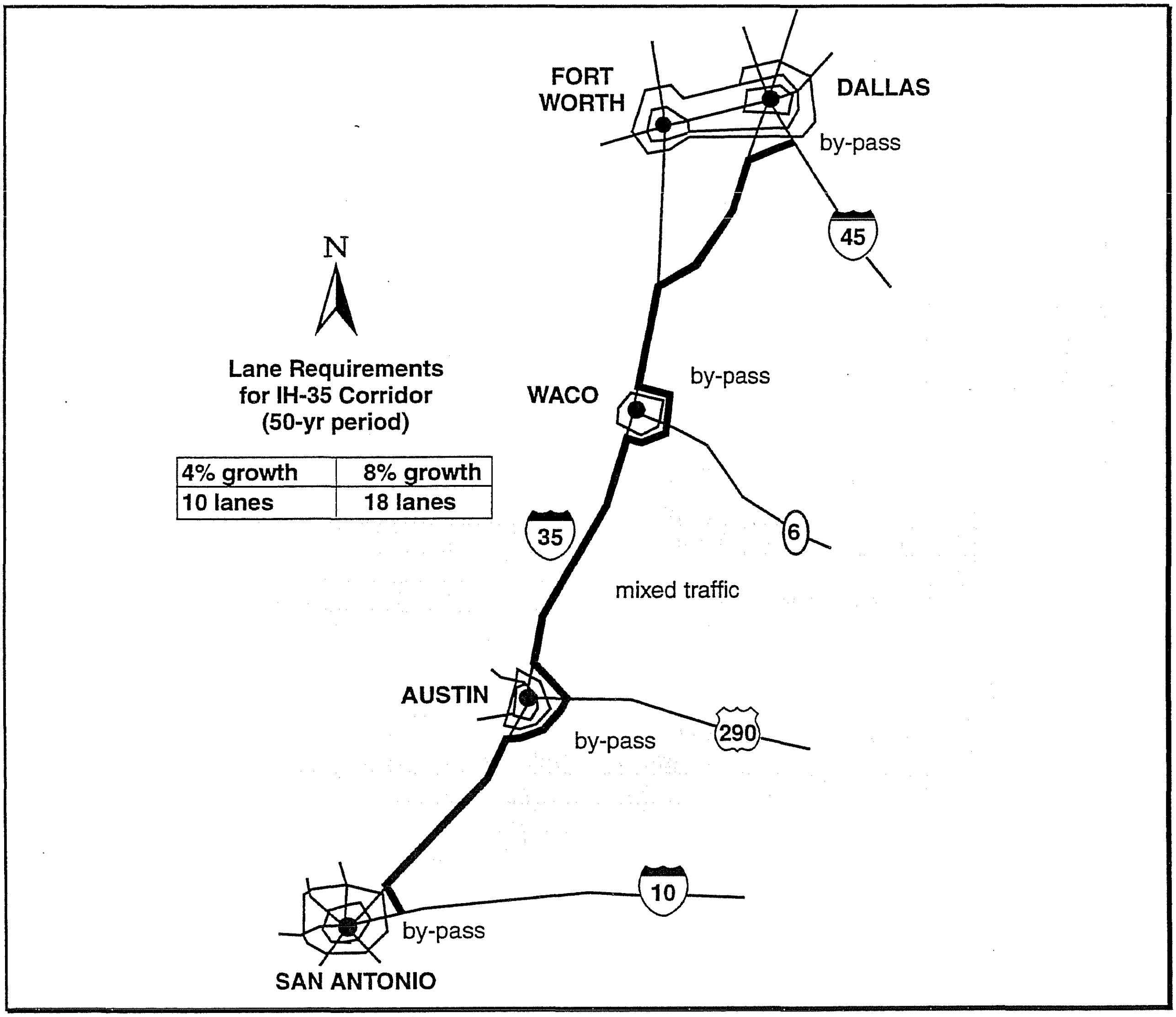

Figure 4.11. "Adding lanes" configuration between San Antonio and Dallas/Ft. Worth

Table 4.3. Agency cost summary for the "adding lanes" alternative (4-percent growth)

Cost Item	Roadway Segment	Cost (millions)	n (years)	PWF	PW (millions)
275 km (170 mi) upgrade from 4 to 10 lanes	Austin-Waco	$496	0	1.00	$496
105 km (65 mi) upgrade from 6 to 10 lanes	Waco-DFW	$606	5	0.82	$497
	SAN-Austin	$281	10	0.68	$191
Overlay traffic lanes	Austin-Waco	$137	0	1.00	$137
	Waco-DFW	$170	5	0.82	$139
	SAN-Austin	$120	10	0.68	$82
By-pass construction	Austin-Waco	$432	0	1.00	$432
	Waco-DFW	$648	5	0.82	$531
	SAN-Austin	$216	10	0.68	$147
Bridge overpass reconstruction	Austin-Waco	$16	0	1.00	$16
	Waco-DFW	$20	5	0.82	$16
	SAN-Austin	$14	10	0.68	$10
			Total present worth (millions)		$2,694

Table 4.4. Agency cost summary for the "adding lanes" alternative (8-percent growth)

Cost Item	Roadway Segment	Cost (millions)	n (years)	PWF	PW (millions)
275 km (170 mi) upgrade from 4 to 10 lanes	Austin-Waco	$1,157	0	1.00	$1,157
105 km (65 mi) upgrade from 6 to 10 lanes	Waco-DFW	$1,413	5	0.82	$1,159
	SAN-Austin	$842	10	0.68	$573
Additional ROW	Austin-Waco	$4	0	1.00	$4
	Waco-DFW	$5	5	0.82	$4
	SAN-Austin	$3	10	0.68	$2
Overlay traffic lanes	Austin-Waco	$239	0	1.00	$239
	Waco-DFW	$298	5	0.82	$244
	SAN-Austin	$209	10	0.68	$142
By-pass construction	Austin-Waco	$649	0	1.00	$649
	Waco-DFW	$984	5	0.82	$807
	SAN-Austin	$335	10	0.68	$228
Bridge overpass reconstruction	Austin-Waco	$22	0	1.00	$22
	Waco-DFW	$28	5	0.82	$23
	SAN-Austin	$20	10	0.68	$14
			Total present worth (millions)		$5,266

Retrofit with ITS: Figure 4.12 shows the general configuration established for this alternative. Again, by-passes should be constructed around major urban areas. In addition, 4.6-m (15-foot) traffic lanes were considered for pavement costs, bridge structures, and right-of-way requirements. Finally, ITS implementation costs were considered under the "operational controls" item in Appendix B. Tables 4.5 and 4.6 summarize the major items and corresponding costs for this approach, under 4-percent and 8-percent traffic growth scenarios, respectively. It should be noted, again, that a "bridge overpass reconstruction" item has been included, which considers modifications to transverse overpass crossings due to the additional space requirements on IH-35.

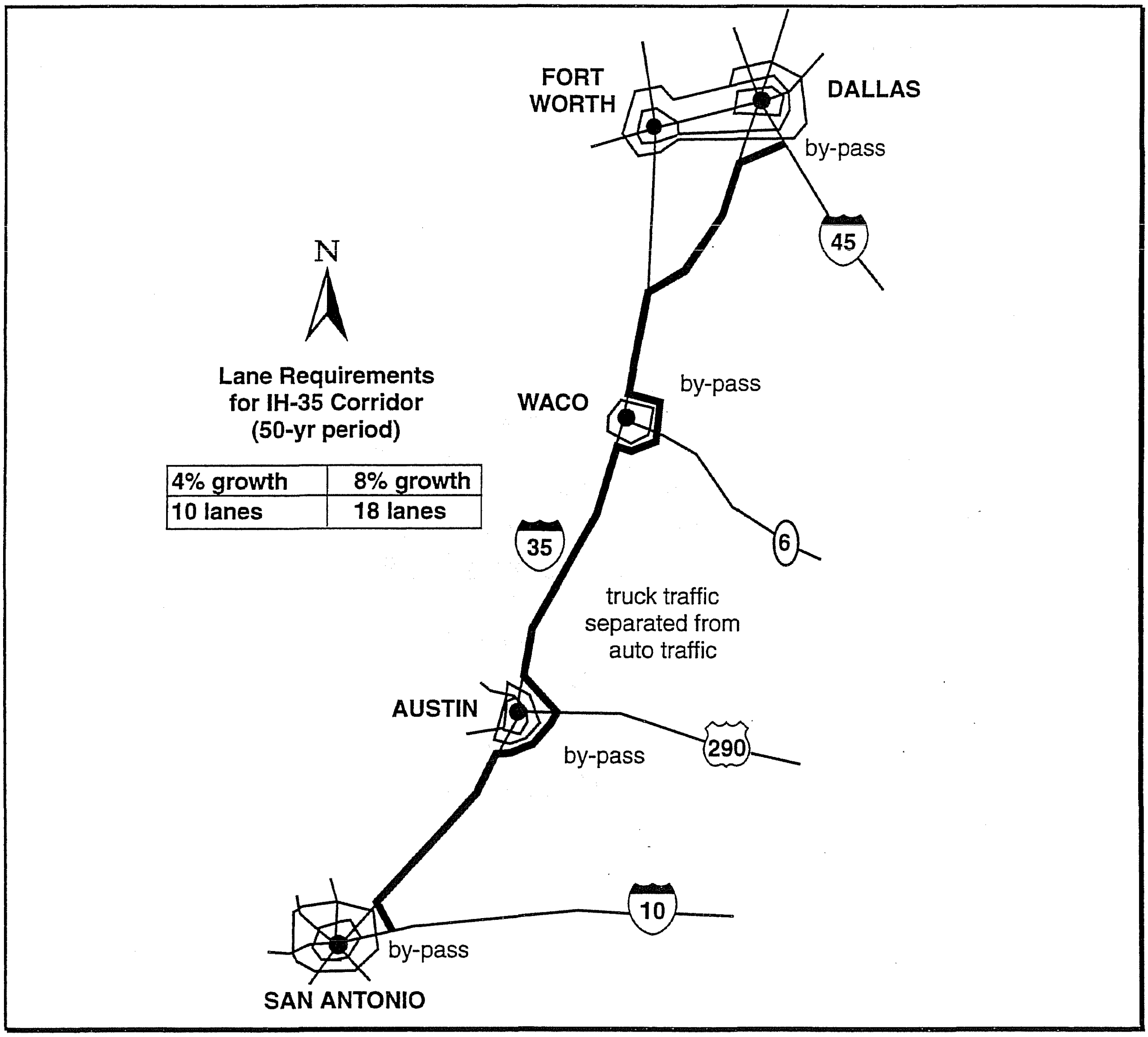

Figure 4.12. "Retrofit with ITS" configuration between San Antonio and Dallas/Ft. Worth

Table 4.5. Agency cost summary for the "retrofit with ITS" alternative (4-percent growth)

Cost Item	Roadway Segment	Cost (millions)	n (years)	PWF	PW (millions)
275 km (170 mi) upgrade from 4 to 10 lanes	Austin-Waco	$620	0	1.00	$620
105 km (65 mi) upgrade from 6 to 10 lanes	Waco-DFW	$757	5	0.82	$621
	SAN-Austin	$351	10	0.68	$239
Overlay car lanes	Austin-Waco	$59	0	1.00	$59
	Waco-DFW	$74	5	0.82	$61
	SAN-Austin	$52	10	0.68	$35
Overlay truck lanes	Austin-Waco	$74	0	1.00	$74
	Waco-DFW	$93	5	0.82	$76
	SAN-Austin	$65	10	0.68	$44
By-pass construction	Austin-Waco	$523	0	1.00	$523
	Waco-DFW	$792	5	0.82	$649
	SAN-Austin	$269	10	0.68	$183
Service/Access stations	Austin-Waco	$20	0	1.00	$20
	Waco-DFW	$10	5	0.82	$8
	SAN-Austin	$10	10	0.68	$7
Bridge overpass reconstruction	Austin-Waco	$19	0	1.00	$19
	Waco-DFW	$24	5	0.82	$20
	SAN-Austin	$17	10	0.68	$12
			Total present worth (millions)		$3,270

Table 4.6. Agency cost summary for the "retrofit with ITS" alternative (8-percent growth)

Cost Item	Roadway Segment	Cost (millions)	n (years)	PWF	PW (millions)
275 km (170 mi) upgrade from 4 to 10 lanes	Austin-Waco	$1,446	0	1.00	$1,446
105 km (65 mi) upgrade from 6 to 10 lanes	Waco-DFW	$1,767	5	0.82	$1,449
	SAN-Austin	$1,053	10	0.68	$716
Additional ROW	Austin-Waco	$5	0	1.00	$5
	Waco-DFW	$7	5	0.82	$6
	SAN-Austin	$5	10	0.68	$3
Overlay car lanes	Austin-Waco	$104	0	1.00	$104
	Waco-DFW	$130	5	0.82	$107
	SAN-Austin	$90	10	0.68	$61
Overlay truck lanes	Austin-Waco	$135	0	1.00	$135
	Waco-DFW	$169	5	0.82	$139
	SAN-Austin	$119	10	0.68	$81
By-pass construction	Austin-Waco	$792	0	1.00	$792
	Waco-DFW	$1,200	5	0.82	$984
	SAN-Austin	$408	10	0.68	$277
Service/Access stations	Austin-Waco	$20	0	1.00	$20
	Waco-DFW	$10	5	0.82	$8
	SAN-Austin	$10	10	0.68	$7
Bridge overpass reconstruction	Austin-Waco	$27	0	1.00	$27
	Waco-DFW	$34	5	0.82	$28
	SAN-Austin	$24	10	0.68	$16
			Total present worth (millions)		$6,411

Managed Transportation System: Figure 4.13 shows the general configuration established for this alternative. In addition to the agency costs of the MTS, maintenance costs for IH-35 were included under the overall evaluation of this alternative. Moreover, for the 8-percent growth scenario, the agency cost of upgrading IH-35 from 4 to 6 lanes (from Austin to DFW) was included as well. In this regard, Figure 4.14 shows a modified version of the construction schedule, which includes the IH-35 lane addition.

For pavement design, a preliminary traffic attraction split of 55 percent and 45 percent was considered for the MTS and IH-35, respectively. The detailed procedure and computations to determine the agency costs are presented in Appendix B. Tables 4.7 and 4.8 summarize the major items and corresponding costs for this approach, under 4-percent and 8-percent traffic growth scenarios, respectively.

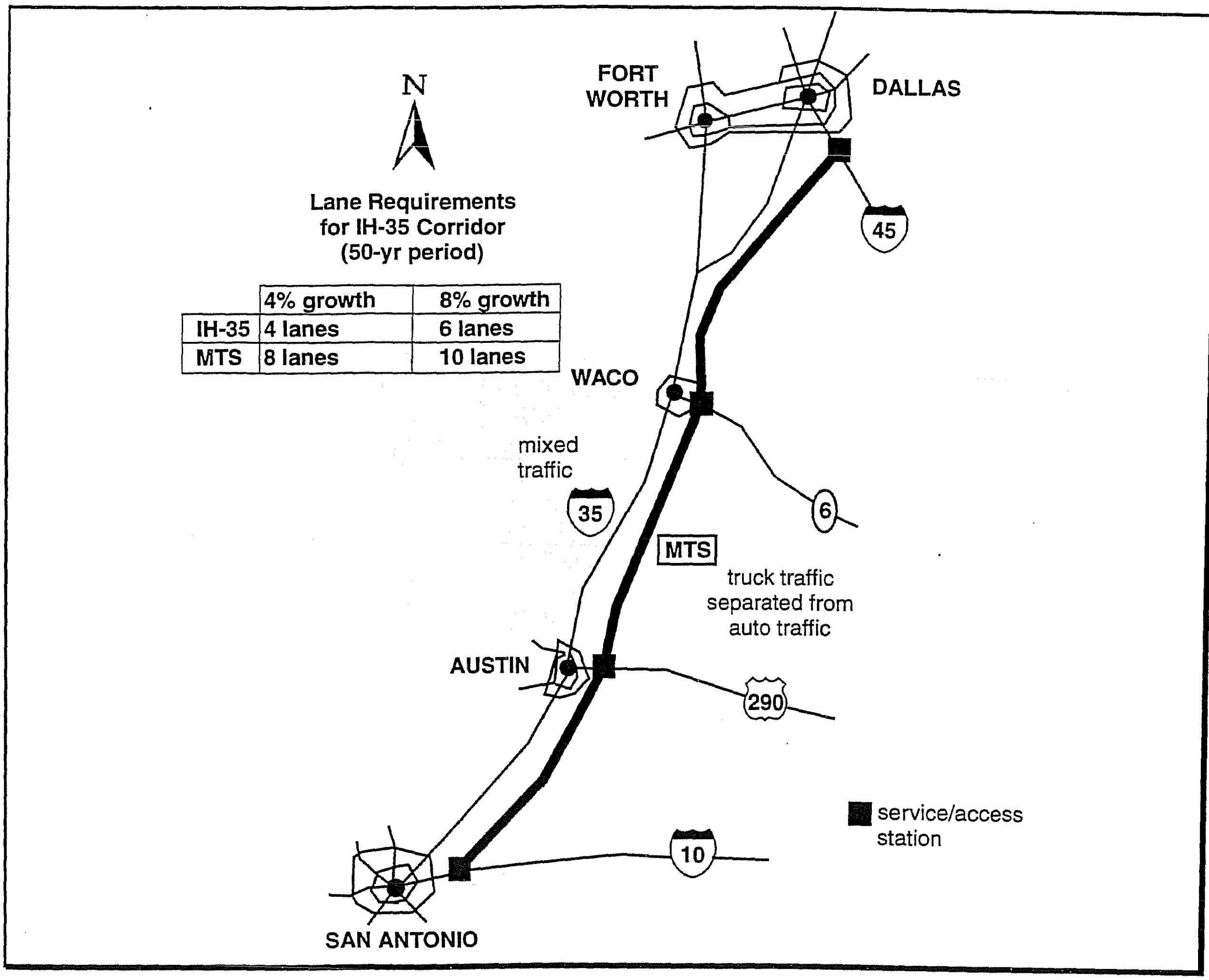

Figure 4.13. MTS configuration between San Antonio and Dallas/Ft. Worth

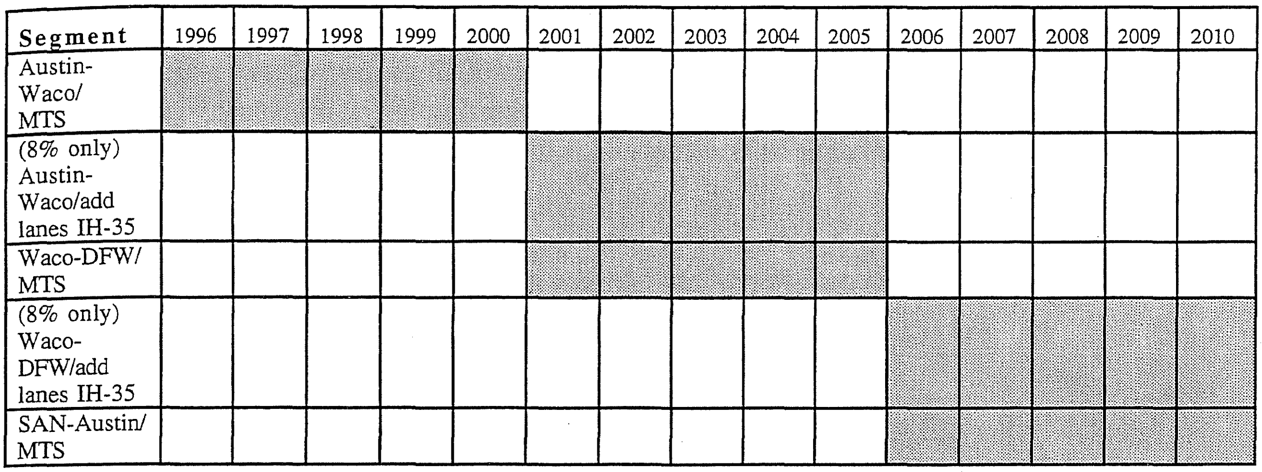

Figure 4.14. Construction schedule including lane addition for IH-35

Table 4.7. Agency cost summary for the "MTS" alternative (4-percent growth)

Cost Item	**Roadway Segment**	**Cost (millions)**	**n (years)**	**PWF**	**PW (millions)**
IH-35 overlay	Austin-Waco	$57	0	1.00	$57
	Waco-DFW	$70	5	0.82	$57
	SAN-Austin	$142	10	0.68	$97
MTS	Austin-Waco	$1,011	0	1.00	$1,011
	Waco-DFW	$1,263	5	0.82	$1,036
	SAN-Austin	$884	10	0.68	$601
				Total present worth (millions)	$2,859

Table 4.8. Agency cost summary for the "MTS" alternative (8-percent growth)

Cost Item	**Roadway Segment**	**Cost (millions)**	**n (years)**	**PWF**	**PW (millions)**
309 km (192 mi) upgrade from 4 to 10 lanes	Austin-Waco	$187	5	0.82	$153
	Waco-DFW	$228	10	0.68	$155
		$142			
IH-35 overlay	Austin-Waco	$82	0	1.00	$82
	Waco-DFW	$101	5	0.82	$83
	SAN-Austin	$154	10	0.68	$105
MTS	Austin-Waco	$1,162	0	1.00	$1,162
	Waco-DFW	$1,452	5	0.82	$1,191
	SAN-Austin	$1,017	10	0.68	$692
				Total present worth (millions)	$3,622

SUMMARY OF RESULTS

Table 4.9 summarizes the estimated present worth of the agency costs for each of the alternatives, under 4-percent and 8-percent growth scenarios, and for the 50-year analysis period. As expected, the "no build" option yielded the least cost of all the approaches under consideration; however, it is an option that doesn't provide congestion relief measures (as do the other alternatives). The corresponding costs associated with this approach are for maintaining the facility only.

Table 4.9. Agency cost comparison between alternatives (50-year analysis period)

Alternative	**Agency cost (millions)**	
	4% growth	**8% growth**
No build	$210	$229
Adding lanes	$2,694	$5,266
Retrofit with ITS	$3,270	$6,411
MTS	$2,859	$3,622

Of all the alternative solutions, the "adding lanes" approach shows the lowest agency cost under the 4-percent growth scenario. However, for the 8-percent growth scenario, the MTS alternative shows the lowest agency cost. Overall, even though the MTS is a new facility, reconstruction requirements and the need for by-passes for both the "add lanes" and "retrofit" approaches make all options comparable with respect to infrastructure costs. Still, for a complete economic evaluation, user and external costs would need to be incorporated.

CHAPTER 5. USER/SOCIAL COST EVALUATION

The main objective of this chapter is to, first, determine the costs associated with roadway use and then to relate such costs to speed reductions. Obtaining cost as a function of speed was chosen for two reasons. The first is that the internal and external costs (also termed user/social costs) can be determined as a function of speed; the second is that all levels of service (LOS) have an associated speed, and that it is therefore possible to associate user/social costs as a function of LOS. In the next sections, all the user/social costs (also termed internal and external costs) shown in Figure 3.1 are examined in detail and presented in terms of $/km, in order to apply them to the full-cost evaluation of the alternatives. It is important to note that the approach used to obtain the user/social costs related to LOS is not exclusive to IH-35: it could also be used in similar studies of other highways.

These costs were obtained for the two primary users of the highway system, namely, passenger vehicles and heavy trucks. In order to simplify the analysis, two types of average vehicles were selected (except in the case of accident costs) as representative of each group to obtain the costs: A medium-sized passenger car and a five-axle, semi-trailer (18-wheeler). The cost presented herein for the depreciation, fuel consumption, tire wear, and maintenance and repair were based on an average 0 percent grade on the vertical alignment.

OWNERSHIP COSTS

Ownership cost, the first element of the user/social costs, includes depreciation and insurance/overhead. This section describes these costs.

Depreciation Cost

Depreciation expense is one of the most difficult of all non-fuel running costs to estimate accurately. The major question concerning depreciation expense is: What portion of the expense should be assigned to operations on the road? We used two reports published by the Texas Research and Development Foundation (Refs 16, 25) to calculate depreciation. A detailed explanation of the depreciation costs is included in Appendix C. Table 5.1 shows the depreciation costs for each LOS for car and for trucks.

Table 5.1. Depreciation costs

		Level of Service					
		LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Car:	$/km	0.058	0.059	0.061	0.061	0.064	0.079
	$/mile	0.094	0.095	0.099	0.099	0.104	0.127
Truck:	$/km	0.079	0.079	0.089	0.089	0.104	0.140
	$/mile	0.128	0.128	0.144	0.144	0.167	0.225

Insurance/Overhead Costs

For cars, the FHWA estimates the insurance cost to average $0.044 per km ($0.07 per mile) (Ref 11). Insurance cost is determined by vehicle type, the amount and type of coverage selected, the user's driving record and age, and the region in which the vehicle is used. It is well known that as traffic speed decreases, the accident rate increases. Insurance companies account for this effect by adjusting upward the insurance premiums paid by motorists operating vehicles in large urbanized areas. A Texas Transportation Institute (TTI) study (Ref 26) shows for automobiles a correlation between insurance cost and congestion index in urban areas. The congestion index is a value that indicates the level of congestion in a specific area, where a value of 1.0 or greater indicates an undesirable areawide congestion level. Table 5.2 shows the relation between insurance premium and congestion index.

Unfortunately, the scope of the TTI study was limited to urban areas. The insurance companies do not consider this premium in rural areas because there is little or no congestion in rural highways; but if the LOS continues to drop, we can expect a similar factor applied to motorists in those rural areas where congestion has appreciably increased.

For trucks, the overhead is the estimate of all other indirect costs, including insurance, administration, and regulations. For configurations that normally are used in door-to-door service, these costs were estimated to average $0.14 per km ($0.22 per mile) (Ref 27).

The costs given above for insurance/overhead costs were assumed for a speed of 89 kph (55 mph) (LOS C); the costs for the other levels of service were assumed as speed-proportional to LOS C. Table 5.3 shows these values.

Table 5.2. Insurance rates for Texas — 1988

Urbanized Area	Car Insurance Rates ($/year)	Annual Insurance Difference ($/year)	Congestion Index
Austin	470	40	0.96
Corpus Christi	470	40	0.70
Dallas	580	150	1.02
El Paso	510	80	0.74
Forth Worth	540	110	0.87
Houston	630	200	1.15
San Antonio	540	110	0.86
Statewide Average (1)	430	0	-

(1) The statewide area rate is an average of small urbanized area rates, excluding the above large urbanized areas (Ref 26).

Table 5.3. Insurance/overhead costs

		Level of Service					
		LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Car:	$/km	0.037	0.041	0.044	0.046	0.064	0.135
	$/mile	0.060	0.066	0.070	0.074	0.103	0.218
Truck:	$/km	0.118	0.130	0.137	0.144	0.201	0.425
	$/mile	0.190	0.209	0.220	0.232	0.324	0.684

OPERATING COSTS

Following the order established in Figure 3.1, the next costs to define are the operating costs. These costs include fuel cost, tire wear cost, maintenance and repair cost, and oil cost, all of which are described in this section.*

Fuel Cost

The cost of the fuel used by trucks and cars is defined by the equation:

$$\text{Fuel Cost } (\$ / \text{mile}) = \frac{\text{Fuel Price } (\$ / \text{gal})}{\text{Fuel Consumption } (\text{miles} / \text{gal})}$$

The selected fuel price for trucks was $0.15 per liter ($0.55 per gallon) of diesel and for cars, $.20 per liter ($0.76 per gallon) of gasoline (Ref 28). These prices do not include the state and federal taxes on motor fuels. The fuel cost and fuel consumption for each LOS are shown in Table 5.4. A more detailed explanation of the fuel consumption computations is included in Appendix C.

Table 5.4. Fuel cost and consumption

		Level of Service											
		LOS A		LOS B		LOS C		LOS D		LOS E		LOS F	
		Car	Truck	Car	Truck	Car	Truck	Car	Truck	Car	Truck	Car	Truck
Fuel Consumption (mpg)		23.1	5.03	26.3	5.53	27.0	5.85	29.4	6.14	19.5	3.04	13.8	2.01
Fuel Cost	($/km)	0.020	0.068	0.018	0.062	0.017	0.058	0.016	0.056	0.024	0.112	0.034	0.170
	($/mile)	0.033	0.109	0.029	0.100	0.028	0.094	0.026	0.090	0.039	0.181	0.055	0.273

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* Please note that taxes are not included as part of the fuel costs to users. This is following customary economics practice, in which economic evaluations are always performed *net of taxes and transfers*. These are not included because they reside within the national accounts, and are thus not true resource costs.

Tire Wear Cost

The Forest Service Developed the slip-energy theory for computing tire wear based on the forces required for a given operating situation. This theory was used by Zaniewski to estimate the tire wear differentials between different speeds and speed change cycles (Ref 25). The costs for tire wear for each LOS are shown in Table 5.5.

The tire wear predicted using Zaniewski values for trucks was checked against the tire wear estimates measured by Jack Faucett Associates (JFA) (Ref 27). This study estimates a tire cost for a five-axle configuration to be \$0.022 per km (\$0.035 per mile) for an operating speed of 89 kph (55 mph). This figure is similar to the one obtained using Zaniewski values for the same speed. A detailed explanation of the tire wear costs is included in Appendix C.

Table 5.5. Tire wear cost

		Level of Service					
		LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Car:	\$/km	0.001	0.001	0.001	0.001	0.005	0.009
	\$/mile	0.002	0.002	0.001	0.001	0.008	0.014
Truck:	\$/km	0.026	0.023	0.019	0.018	0.162	0.323
	\$/mile	0.041	0.036	0.031	0.029	0.260	0.519

Maintenance and Repair Cost

Maintenance and repair expenditures, which represent a major portion of total vehicle operating costs, are difficult to measure accurately. For an individual vehicle, the exact maintenance and repair expense incurred will depend on how well it has been maintained and on the specific conditions under which the vehicle operates (Refs 11, 25). Using an average cost for repair and maintenance, and the values suggested by Zaniewski for different speeds, we calculated the maintenance and repair costs to be those presented in Table 5.6. A detailed explanation of these costs is included in Appendix C.

Table 5.6. Maintenance and repair cost

		Level of Service					
		LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Car:	\$/km	0.022	0.021	0.020	0.019	0.019	0.017
	\$/mile	0.035	0.033	0.032	0.031	0.031	0.027
Truck:	\$/km	0.137	0.128	0.120	0.115	0.111	0.091
	\$/mile	0.221	0.207	0.192	0.185	0.179	0.147

Oil Cost

The cost of oil is a relatively insignificant component of total vehicle operating cost. According to Zaniewski (Ref 25), the oil cost represents only between 3 and 4 percent of the fuel cost; consequently, it was ignored in this study.

TRAVEL TIME COST

Travel time has the greatest impact on the total cost of operating a vehicle. It accounts for approximately 30 percent of the total operating cost for trucks and 50 percent of the total operating cost for cars. To obtain the travel time, a constant speed was assumed (even in the cases of LOS E and F, where there is a speed-change cycle). The calculations used to obtain these particular average speeds are included in Appendix C.

$$\text{Total Travel Time (hr)} = \frac{\text{Distance (miles)}}{\text{Average Speed (mph)}}$$

$$\text{Travel Time Cost (\$)} = \text{Total Travel Time (hr)} * \text{Cost of Travel Time (\$/hr)}$$

Travel Time Cost for Cars

User travel-time values vary considerably, depending on who is traveling, for what purpose, and under what conditions. The California Energy Commission calculated the value of congestion delay reduction at $10.6 per hour in its personal vehicle model (Ref 11). The AASHTO *Manual* values average travel time savings at $10.44 per vehicle hour in 1985 dollars, which represents a mix of private and commercial vehicles (Ref 11). Finally, the Texas Transportation Institute calculated an average cost of time for cars at $10.0 per person-hour in 1990 dollars, and an average vehicle occupancy of 1.25 persons per vehicle. Using the Consumer Price Index (Ref 29), this gives a total cost of $14.38 per vehicle-hour in 1995 dollars. This cost seems to be the most adequate for our analysis, since it takes into account only passenger cars and the vehicle occupancy used. Using the value of $14.38 per vehicle per hour and the average speeds for each LOS, we then calculated the travel time costs shown in Table 5.7.

Table 5.7. Travel time costs for cars

	Level of Service					
	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Average Speed (kph)	104	94	90	85	61	29
Travel Time Cost ($/km)	0.137	0.151	0.160	0.169	0.235	0.497
($/mile)	0.221	0.244	0.257	0.271	0.378	0.799

Travel Time Cost for Trucks

This cost refers to the salary paid to the truck driver. A Texas Research and Development Foundation study (Ref 29) shows that the driver wage per year (including benefits) for a company-owned truck is $33,583 per year, or $16.14 per hour. Also, a study by JFA (Ref 27) estimates the driver cost for a non-refrigerated, single-trailer combination to be 19 cents per km (30 cents per mile). Assuming an average speed of 89 kph (55 mph), this value is equivalent to $16.5 per hour, which is similar to the first cost. In this study, we selected a driver cost of $16.5 per hour. The results of the calculation are shown in Table 5.8.

Table 5.8. Driver cost

		Level of Service					
		LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Average Speed	(kph)	104	94	90	85	61	29
Driver Cost	($/km)	0.158	0.174	0.183	0.193	0.270	0.570
	($/mile)	0.254	0.280	0.295	0.311	0.434	0.917

AIR POLLUTION

Air pollution is generated by either natural processes (e.g., volcanic eruptions and forest fires) or by anthropogenic events (caused by man). While both types of pollution are significant to the planet, anthropogenic pollution in particular continues to be viewed as a serious problem.

Air pollution is the contamination of the ambient air by chemical compounds or by solid particulates in a concentration that adversely affects living organisms. In this study, we focused on the pollution produced by vehicles.

As has been frequently noted, traffic congestion, along with its concomitant pollution, can have severe negative impacts on society: Pollution can impair health and can increase environmental clean-up costs. The main air pollutants produced by vehicles, along with their characteristics, are listed below (Ref 30).

Carbon Monoxide (CO): As the air/fuel ratio increases, the concentration of CO decreases rapidly (leaner mixes provide more complete combustion of the fuel). This implies that while idling and decelerating, the CO concentration is very high. It decreases during acceleration and high-speed cruising. Diesel engine CO emissions are very low for all modes of operation.

Hydrocarbons (HC): Vehicular HC emission is high during idling and deceleration, as opposed to those levels associated with cruising and acceleration. Cruising at high speeds results in a further reduction in HC emissions.

Nitrogen Oxides (NOx): NOx emissions are the major contributors to photochemical smog. NOx absorbs ultraviolet portions of the solar spectrum, an action that generates high oxidant concentrations. High levels of NOx are produced during vehicle acceleration and high-speed cruising; lower concentrations exist during vehicle deceleration and idling, suggesting that these emissions are dependent on the temperature of combustion. Diesel engine NOx emissions are high for all modes of operation.

Air Pollution Modeling

To obtain the relation between emissions and speed, we used both the Federal Test Procedure (FTP) driving cycle testing program and the MOBILE4.1 model developed for testing emissions prediction (Ref 30). The FTP provides an irregular sequence of accelerations, decelerations, idle, and cruise modes. Table 5.9 shows the periods of idle, acceleration, cruise, and deceleration associated with a driving cycle.

For each one of the modes, the MOBILE4.1 model provides equations for each pollutant that predicts the emissions according to the speed. This cycle is valid for urban-congestion scenarios, but not for rural congestion, where speed is fairly constant (cruise mode) and where idle, acceleration, and deceleration cycles are infrequent. Hence, for this study for LOS E and F, the FTP cycle was used, and for LOS A, B, C, and D, only the cruise mode was used in 100 percent of the travel time. The equations used for the emissions prediction are included in Appendix D.

Table 5.10 shows the emissions for each LOS, while Figures 5.1, 5.2, and 5.3 depict the emissions for CO, HC, and NOx, respectively. The truck emission rates differ from those of cars, insofar as trucks typically generate much more NOx and less CO and HC.

Table 5.9. FTP driving cycle conditions

	FTP start mode		FTP stable mode		Total FTP test	
Driving Mode	seconds	percent	seconds	percent	seconds	percent
Idle	94	18.6	150	17.3	488	17.8
Acceleration	122	24.2	238	27.5	720	26.2
Cruise	190	37.6	313	36.1	1006	36.7
Deceleration	99	19.6	166	19.1	530	19.3
Total	505	100.0	867	100.0	2744	100.0

Source: Sculley, R. D. "Vehicle Emission Rate Analysis for Carbon Monoxide Hot Spot Modeling," *Journal of Air Pollution Control Association,* v. 39, 1989.

Cruise mode defined as either a non-zero speed unchanged from the previous second or as an absolute speed change of less than 1 mph from that of the previous second, while the cumulative 4-second sum of speed changes totals less than 2 mph.

Table 5.10. CO, HC, and NOx emissions, gm/km (gm/mile)

	Level of Service											
	LOS A		LOS B		LOS C		LOS D		LOS E		LOS F	
Emission	Car	Truck	Car	Truck	Car	Truck	Car	Truck	Car	Truck	Car	Truck
CO	4.37	3.37	4.26	3.28	4.21	3.24	4.17	3.21	6.14	1.83	8.48	2.23
	(7.03)	(5.42)	(6.85)	(5.27)	(6.77)	(5.22)	(6.71)	(5.17)	(9.88)	(2.94)	(13.6)	(3.59)
HC	0.23	0.17	0.25	0.18	0.27	0.19	0.29	0.21	0.28	0.19	0.41	0.28
	(0.37)	(0.27)	(0.41)	(0.29)	(0.43)	(0.31)	(0.46)	(0.33)	(0.45)	(0.30)	(0.66)	(0.45)
NOx	0.02	0.21	0.03	0.24	0.03	0.25	0.03	0.26	0.04	0.26	0.04	0.34
	(0.04)	(0.34)	(0.05)	(0.38)	(0.05)	(0.40)	(0.05)	(0.42)	(0.06)	(0.42)	(0.07)	(0.55)

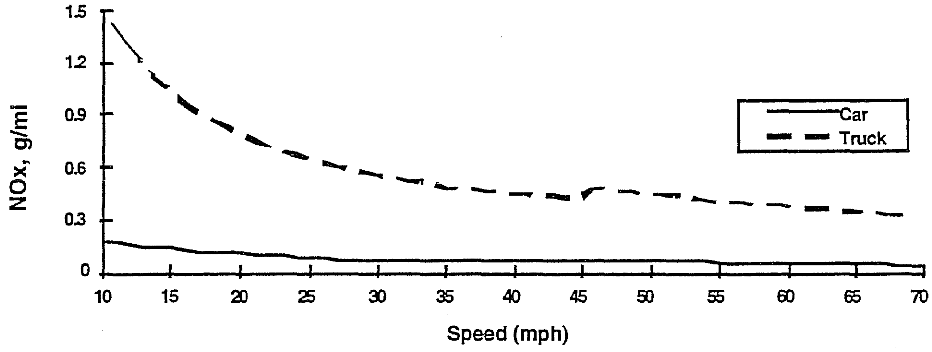

Figure 5.1. NOx emissions

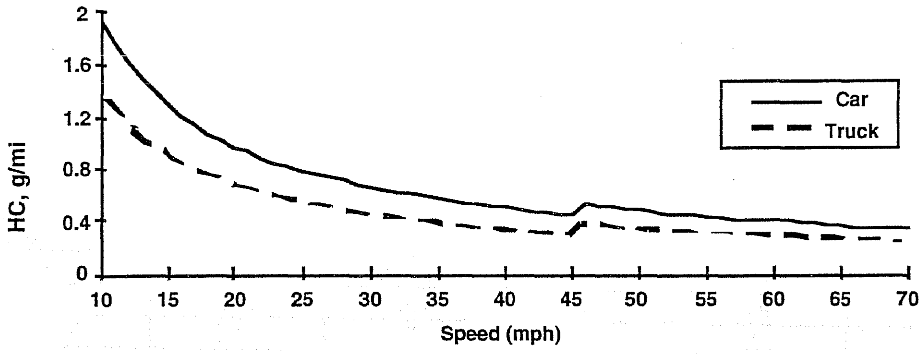

Figure 5.2. HC emissions

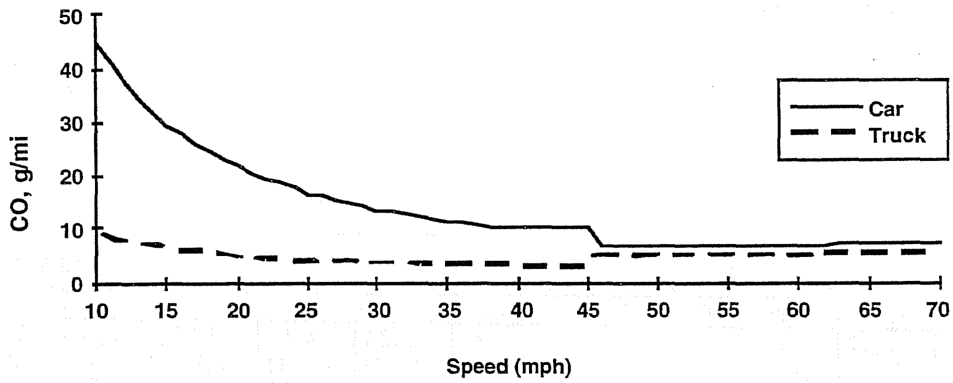

Figure 5.3. CO emissions

Pollution Cost

Estimating the cost of air pollution requires an understanding of the relationships between driving, emissions, atmospheric distribution, and impacts (Ref 11). Associating a cost to air pollution effects is a difficult task, one that requires placing dollar values on human mortality, loss of recreation, discomfort, and aesthetic damage. Because air pollution is also harmful to crops, wildlife, and materials, these also must be priced to determine the full cost of emissions. While most studies focus on human health impacts, new research indicates that other air pollution costs may also be significant, including those associated with global warming and aesthetic damage. Basically there are two approaches to calculating air emission unit costs: (1) according to damage cost or (2) according to control cost. The damage cost attempts to quantify in monetary terms the environmental damage caused by emissions. The control cost, on the other hand, is based either on the cost of emission control equipment or on the price needed to reduce emissions to specific levels, such as by charging an emission tax. Table 5.11 summarizes the emissions costs obtained through previous research.

Table 5.11. Air pollution costs ($/ton)

Source	Pollutant		
	CO	HC	NOx
Values from 37 regulatory and research sources (1990)			
Minimum			
Maximum	500	340	42
Average	1000	21175	40000
	842	5986	8212
Miller and J. Moffet			
Urban	12000	7200	600-8400
Rural	0	3600	60
Chernick and Caverhill (1993)	1000	2200	8800
EPRI rural (1987)	-	-	150
CA Energy Commission, in state (1993)	-	4140	14560

Sources: Refs 11 and 13

The pollution cost for vehicles varies tremendously, depending on the source that we select. But in order to obtain an approximate idea, we selected the following conservative values in an attempt to avoid overestimation of the total cost resulting from pollution:

$1000/ton for CO, $5986/ton for HC, and $8212/ton for NOx.

Because of a lack of available data, these costs do not include the global warming, ozone depletion, and acid rain costs. For example, MacKenzie (Ref 11) estimates that greenhouse gases (global warming) incur a \$0.007 per km (\$0.012 per mile) cost.

Using these costs for the three main pollutants and their respective emissions for each LOS (shown in Table 5.10), we calculated the pollution costs per km shown in Table 5.12. The fact that these costs are incidental compared with travel time and operating costs can be explained in part by observing that this study is considering primarily rural areas, where the damage is minimal in comparison with that occurring in urban areas. In addition, it is difficult to predict the future impact of new emission control technology; thus, as a conservative measure this item will be excluded from the total social/user cost estimation.

Table 5.12. Cost of CO, HC, and NOx emissions

		Level of Service					
		LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Car:	\$/km	0.0060	0.0060	0.0061	0.0062	0.0081	0.0113
	\$/mile	0.0096	0.0097	0.0098	0.0099	0.0131	0.0182
Truck:	\$/km	0.0061	0.0063	0.0064	0.0066	0.0051	0.0067
	\$/mile	0.0098	0.0101	0.0104	0.0106	0.0082	0.0108

ACCIDENTS

While accidents have always been an unfortunate aspect of transportation, for the different alternatives presented in Chapter 2 it is difficult to predict the associated accident rates so as to compare the benefits (and costs, which admittedly can be enormous) for each case. Such estimations require a separate study — one that could create specific models for evaluating each case.

The approach used in this study was to evaluate the reduction in accidents that resulted from the use of separate traffic lanes for passenger vehicles (cars, motorcycle, pickups, and light trucks) and medium/heavy trucks (trucks with gross vehicle weight ratings over 4,530 kg, or 10,000 pounds). Although trucks comprise only 3 percent of the nation's motor fleet (Ref 31), medium and heavy trucks recorded 240 billion km (150 billion miles) of travel in 1990, 7 percent of the total 3.4 trillion km (2.1 trillion miles) driven by all vehicles for that year.

Although a total of 5,254 people lost their lives in truck-related accidents in 1990, only 13 percent of these fatalities were truck occupants; and of the 130,000 injured in truck accidents, only 26 percent were truck occupants. These figures reflect the fact that the large mass of the truck, while instrumental in preventing serious injury to the truck occupants, can result in serious injury to the occupants of the other vehicles involved. In fact, 83 percent of the 5,254 fatalities resulting from truck accidents occurred in multi-vehicle collisions, and only 5 percent were truck occupants. Hence, there can be an important reduction in accidents if passenger cars and medium/heavy trucks are separated by exclusive lanes. Tables 5.13 and 5.14 show specific traffic accident data for 1990.

Table 5.13. Motor vehicle fatal traffic accidents for all types of roads — 1990

Accidents Involving	Fatal Accidents		Fatalities		Fatal Accidents only in Passenger Cars		Fatalities only in Passenger Cars	
	number	rate A	number	rate A	number B	rate A	number	rate A
All Vehicles	39779	1.85	44529	2.07	-	-	-	-
Trucks	4504	3.00	5254	3.50	3477	2.31	4057	2.70

Table 5.14. Motor vehicle injury traffic accidents for all types of roads — 1990

Accidents Involving	Injury Accidents		Persons Injured		Injury Accidents only in Passenger Cars		Persons Injured only in Passenger Cars	
	number	rate A	number	rate A	number C	rate A	number	rate A
All Vehicles	2,501,167	116.5	3,600,307	167.7	-	-	-	-
Trucks	86,500	57.7	130,000	86.7	63,211	42.1	95,000	63.3

Sources: Transportation Statistics 1994, Highway Statistics 1990, Fars 90

Sources: Transportation Statistics 1994, Highway Statistics 1990, Fars 90

A. Per 161 million vehicle km (per 100 million vehicle-miles) of travel.

B. This value was obtained assuming that the relation between fatalities only in passenger cars/fatalities was proportional to fatal accidents only in passenger cars/fatal accidents.

C. Same procedure as in B but using injury data.

The purpose of this section was to obtain the accident rates for passenger vehicles caused by trucks in mixed traffic. The numbers and rates in the above tables are for all types of roads; to obtain the rates for our case study (i.e., Interstate rural highway), we used the following:

$$\frac{\text{FR for all types of roads (all vehicles)}}{\text{FR for rural Interstate highway (all vehicles)}} = \frac{\text{FR only in passenger cars for all types of roads (trucks)}}{\text{FR only in passenger cars for rural Interstate highway (trucks)}}$$

where:

FR = Fatality rate per 100 million vehicle-miles of travel.
Parentheses indicate the type of vehicles involved.

DATA:

Fatality Rate for Rural Interstate Highway (all vehicles) = 1.4
Fatal Accidents Rate for Rural Interstate Highway (all vehicles) = 1.1
Injury Accidents Rate for Rural Interstate Highway (all vehicles) = 22

FR only in passenger cars for rural Interstate highway (trucks) = (2.7 * 1.4)/2.07 = 1.83

Using the same assumption and corresponding data, the following values were calculated:

Fatal accident rate in passenger cars for rural Interstate highway (trucks) = 1.38
Injury accident rate in passenger cars for rural Interstate highway (trucks) = 8.0

In a previous conclusion, this section found that in the case of separate lanes for cars and trucks, the fatalities would be 25 percent fewer than those occurring on a mixed-traffic facility. Thus, a simple separation of traffic could significantly improve highway safety.

Accidents in Workzones

Given that reconstruction usually takes place in areas where demand for mobility is high, and given also that most accidents result from the inability of drivers to react in time to merging vehicles, decelerating vehicles, stopped vehicles, or other obstructions in the roadway, the potential for accidents increases substantially within construction or reconstruction areas (workzones). Consequently, and without a doubt, there is an associated cost related to workzones and accidents, though it is difficult to determine (1) how many accidents are caused exclusively by the reconstruction activity and (2) what their exact costs are.

This adverse effect can to some degree be attenuated by implementing during construction an incident management system, one whose quick response to accidents could reduce associated delays. Deploying active traffic control devices (flagging, arrow and changeable message boards, concrete barriers, and law enforcement) can also decrease the number of traffic accidents.

Accident Costs

Accident costs include injuries, deaths, congestion, pain, grief, lost productivity and resources, disabilities, material damage, and accident prevention measures. Given this range of contingencies, it is difficult to estimate accident costs.*

Accident costs depend on the type, severity, and frequency of the accidents. The coverage provided by insurance companies tends to undervalue the cost of major losses, especially fatalities. There are several approaches to estimating appropriate values for loss of life. The first approach estimates the value of fatalities as the discounted present value of the victim's expected future income. It does not reflect how individuals value their own lives or the lives of others. The second approach — which relies on the trade-off between wealth and safety (Ref 32) — is problematic in that it relies heavily on labor markets. The better approach is to measure society's aggregated willingness to pay for safety. This approach has been adopted by some European countries and by the U.S. (as appropriate).

Miller (Ref 32) has developed a measure of accident cost based on per-victim and per-vehicle base. Rollins (Ref 32) later converted the data into a per-accident base by using the numbers of fatalities and injuries per-accident in five states. Table 5.15 shows the conclusions of

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* Again, we acknowledge that these costs can be enormous. However, their precise estimation was simply not a part of this prefeasibility study, though it should be included in any future study.

the study, which we converted from 1980 dollars to 1992 dollars using the Consumer Price Index (Ref 29).

A precise calculation of accident cost related to speed — the element of the user/social cost most difficult to evaluate — would require a special study. Moreover, it would be extremely difficult to assess the impact of new vehicles and technologies, higher speeds, and new highway designs on accidents. For these reasons, accident cost was also excluded from the total user/social cost evaluation.

Table 5.15. Cost of accidents in 1992 dollars ($/Accident)

	Rural	Urban
Fatal Accident	1,503,691	1,407,863
Non-Fatal Accident	18,123	14,890

SUMMARY

Tables 5.16 and 5.17 show the sum of travel time or driver's time cost, depreciation, fuel, tire wear, maintenance and repair, and insurance or overhead costs for cars and trucks. As indicated above, the cost of accidents is not included, owing to the wide range of contingencies that could affect such calculations; however, research has shown that separating cars and trucks can decrease traffic fatalities by 25 percent. Because pollution costs are insignificant (they vary from $0.006 to $0.011 per km) compared with travel time and operating costs, these costs were excluded from the total user/social cost evaluation.

According to these costs, it is 164 percent (cars) and 188 percent (trucks) more expensive to travel in stop-and-go situations (LOS F) than in more favorable traffic situations (LOS B). Figure 5.4 shows the dramatic increases in costs from one LOS to another.

Table 5.16. Summary of user/social costs for cars, $/km ($/mile)

Item	Level of Service					
	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Speed — km/h and (mph)	104 (65)	94.(59)	90 (56)	85 (53)	72 (45)	48 (30)
Travel Time	0.137 (0.221)	0.152 (0.244)	0.160 (0.257)	0.168 (0.271)	0.235 (0.378)	0.497 (0.799)
Depreciation	0.058 (0.094)	0.059 (0.095)	0.062 (0.099)	0.062 (0.099)	0.065 (0.104)	0.079 (0.127)
Fuel	0.021 (0.033)	0.018 (0.029)	0.017 (0.028)	0.016 (0.026)	0.024 (0.039)	0.034 (0.055)
Tire Wear	0.001 (0.002)	0.001 (0.002)	0.001 (0.001)	0.001 (0.001)	0.005 (0.008)	0.009 (0.014)
Maintenance & Repair	0.022 (0.035)	0.021 (0.033)	0.020 (0.032)	0.019 (0.031)	0.019 (0.031)	0.017 (0.027)
Insurance	0.037 (0.060)	0.041 (0.066)	0.044 (0.070)	0.046 (0.074)	0.064 (0.103)	0.135 (0.218)
Total Cost	0.277 (0.445)	0.291 (0.469)	0.303 (0.486)	0.312 (0.502)	0.412 (0.662)	0.771 (1.240)

Table 5.17. Summary of user/social costs for trucks, $/km ($/mile)

Item	Level of Service					
	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Speed— km/h and (mph)	104 (65)	94.(59)	90 (56)	85 (53)	72 (45)	48 (30)
Driver	0.158 (0.254)	0.174 (0.280)	0.183 (0.295)	0.193 (0.311)	0.270 (0.434)	0.570 (0.917)
Depreciation	0.080 (0.128)	0.080 (0.128)	0.089 (0.144)	0.089 (0.144)	0.104 (0.167)	0.140 (0.225)
Fuel	0.068 (0.109)	0.062 (0.100)	0.058 (0.094)	0.056 (0.090)	0.112 (0.181)	0.170 (0.273)
Tire Wear	0.025 (0.041)	0.022 (0.036)	0.019 (0.031)	0.018 (0.029)	0.162 (0.260)	0.323 (0.519)
Maintenance & Repair	0.137 (0.221)	0.129 (0.207)	0.119 (0.192)	0.115 (0.185)	0.111 (0.179)	0.091 (0.147)
Overhead	0.118 (0.190)	0.130 (0.209)	0.137 (0.220)	0.144 (0.232)	0.201 (0.324)	0.425 (0.684)
Total Cost	0.586 (0.943)	0.597 (0.959)	0.607 (0.976)	0.616 (0.992)	0.960 (1.545)	1.718 (2.765)

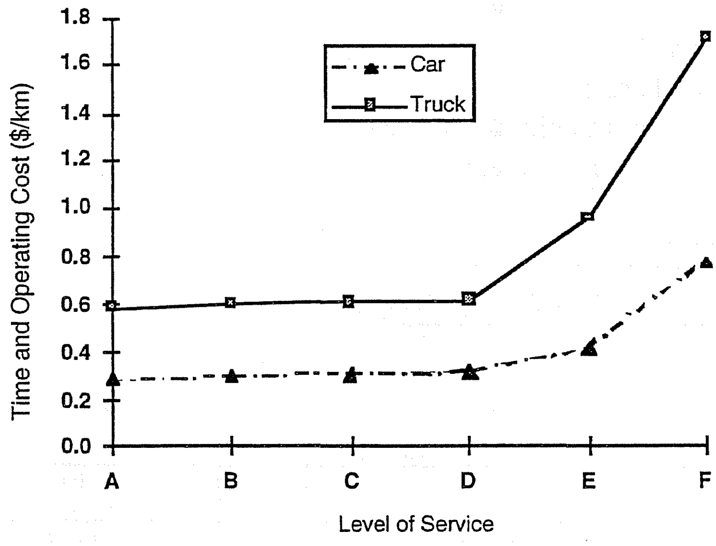

Figure 5.4. Time and operating costs comparison

CHAPTER 6. FULL-COST COMPARISON BETWEEN ALTERNATIVES

In order to estimate the total user/social costs generated under each of the respective alternatives, the projected traffic volumes for the IH-35 corridor (using both the 4- and 8-percent growth scenarios) were analyzed to forecast operating levels of service. For the 50-year analysis period, we completed this task using the procedures outlined by the 1994 HCM (Ref 7). The costs summarized in Tables 5.16 and 5.17 were then assigned to the projected traffic, according to the yielded level of service. Finally, the differential user and social costs obtained for the analysis period were added to the agency costs.

BASIC ASSUMPTIONS

To establish congestion conditions for the different alternatives, we sought, on the one hand, to model the disruption effects from workzones and, on the other hand, to determine the typical hourly volumes; such information allowed us to obtain a corresponding level of service.

Lane Narrowing Strategy

The capacity requirements previously established in Chapter 2 were in some instances modified as a result of lane width reductions over workzones. According to the 1994 HCM, a lane reduction from 3.6 to 3.0 m (12 to 10 feet), together with shoulders reduced to less than 1.8 m (6 feet), decreases by 25 percent the original capacity. These considerations were introduced into the "adding lanes" and "retrofit" alternatives during construction periods, as depicted by the schedules established in Chapter 4. The modified capacity can then be expressed as the effective number of traffic lanes, resulting from multiplying the original number by the reduction factor (in this case fw=0.75). While this strategy can account for only a small fraction of the disruption effects created by workzones, the general scope of the present study requires this simplification. The calculations for lane narrowing are presented in Appendix E.

Modeling the K-factor

The K-factor refers to that fraction of daily vehicles traveling during the peak hour. For the present study, a single average daily traffic (ADT) figure is being used as representative for a given year, in order to characterize the variation in hourly volumes (including the peak period). The real K-factors obtained from the representative ADT hourly volumes are represented with a continuous line in Figures 6.1 and 6.2. The hourly factors have been backcalculated from hourly flows, using the ADT of the base year. These so-called "surrogate K-factors" model hourly traffic flow in two-step periods during average weekdays (K=5 percent and 3.33 percent), and four-step periods during weekends (K=9 percent, 7.5 percent, 5.5 percent, and 1.0 percent). Appendix E shows how the surrogate K-factors were applied for each period. Figures 6.1 and 6.2 depict the real K factor and the surrogate K factor for weekdays and weekends.

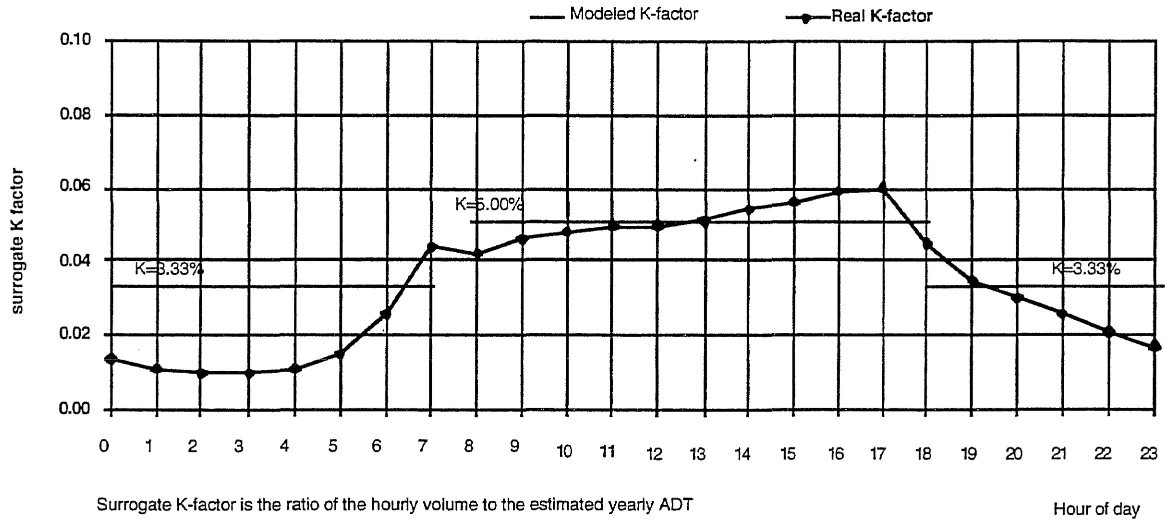

Figure 6.1. Typical surrogate K factor for daily behavior during weekdays

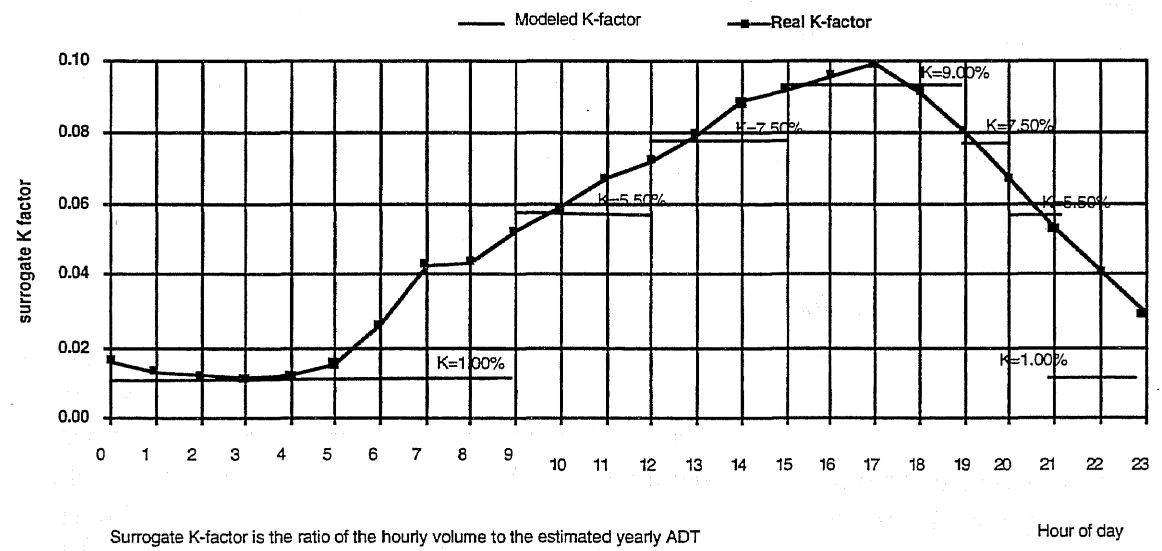

Figure 6.2. Typical surrogate K factor for daily behavior during weekends

Traffic Mix

To obtain the user/social costs in those cases where mixed traffic is present, we calculated weighted user/social costs from Tables 5.16 and 5.17. These costs were obtained assuming the same 20-percent-trucks-in-the-traffic-stream configuration previously used in this study. Table 6.1 shows the cost/km for each level of service for the three traffic compositions.

Table 6.1 Total user/social costs for different traffic compositions ($/km)

LOS	Traffic Composition		
	100% cars - 0% Trucks	0% cars - 100% Trucks	80% cars - 20% Trucks
A	0.277	0.586	0.339
B	0.291	0.596	0.352
C	0.302	0.607	0.363
D	0.312	0.617	0.373
E	0.411	0.960	0.521
F	0.771	1.718	0.960

SUMMARY OF RESULTS

Table 6.2 shows the total user and social costs for each of the alternatives considered. The computations of user/social costs for one county for each alternative and growth rate are shown in Appendix E. As depicted, the MTS shows the least costs, a result mainly of the fact that levels of service drop only to a minimum of C. In contrast, the "adding lanes" and "retrofit" alternatives drop in some instances to D and even to E levels as a consequence of workzone disruption during construction periods; these consequently show notably higher user and social costs. Since the "no-build" alternative does not provide any type of congestion relief measure, levels of service drop considerably, as expected, yielding the highest user and social costs of all the options.

Thus, considering the MTS as the only alternative free of congestion effects, the second column of each growth scenario in Table 6.2 shows the congestion/disruption cost of the alternatives computed as the algebraic difference between the user/social costs of the MTS and the other alternatives.

Table 6.2. Total user/social costs under each alternative (billions)

	8% Growth		4% Growth	
Alternative	Total user+social cost	Congestion/ disruption cost	Total user+social cost	Congestion/ disruption cost
No-build	$205.1	$78.2	$105.2	$21.2
Adding lanes	$132.5	$5.5	$88.6	$4.5
Retrofit with ITS	$132.5	$5.5	$88.5	$4.4
MTS	$127.0	$0.0	$84.0	$0.0

Finally, Table 6.3 summarizes the full cost of each of the alternatives, including the agency costs previously estimated.

Table 6.3. 50-Year full cost summary (billions)

	8% Growth			4% Growth		
Alternative	Agency cost	Congestion/ disruption cost	Total cost	Agency cost	Congestion/ disruption cost	Total cost
No-build	$0.3	$78.2	$78.5	$0.3	$21.2	$21.5
Adding lanes	$5.3	$5.5	$10.8	$2.7	$4.5	$7.2
Retrofit with ITS	$6.4	$5.5	$11.9	$3.3	$4.4	$7.7
MTS	$3.6	$0.0*	$3.6	$2.9	$0.0	$2.9

*Clearly there would be congestion/disruptions costs as structures are constructed for the MTS. However, such calculations were not a part of this prefeasibility study, though they should obviously be part of a detailed, planning-stage study.

From this last table, we note the proportion between the full cost of the MTS and the other alternatives.

DISCUSSION OF RESULTS

In this chapter, we calculated and compared the full cost for each of the alternatives. As a method of comparison among the alternatives, the congestion/disruption cost was obtained using the MTS as the alternative, with a congestion/disruption cost equal to zero. The results presented in Table 6.3 show that agency cost is not the only cost that should be considered by decision-makers. What we find is that the magnitude of the congestion/disruption cost raises the user/social costs to a very significant portion of the full cost of transportation. The MTS is the alternative that yields the highest benefits: For the 8-percent and 4-percent growth rates, the savings, as compared with the "no-build" alternative, are approximately $75 billion and $18 billion, respectively, for the 50-year analysis period. These figures demonstrate how the full-cost evaluation concept allows planners to determine the real costs of transportation, the result being more cost-effective decisions.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Based on the results documented in this report, conclusions are offered from both a general (or statewide) view point, as well as from the specific application to a major corridor in Texas.

General

The present study developed a methodology for evaluating alternatives for reducing congestion on intercity highways. The report clearly demonstrates that conventional solutions do not offer effective strategies for addressing the growing mobility demands associated with intercity travel. Several alternative solutions were explored and compared, with the comparison based on a full-cost analysis concept using agency costs, user costs, and social costs. The full-cost concept is an effective decision-making tool that can be used for planning and designing a more efficient transportation system.

From the alternatives analyzed, the MTS concept, viewed as a facility running parallel to existing high-traffic links, presents a viable investment alternative, one that would provide efficient ground transportation in the future. Traffic demand management, environmental issues, and the potential to be self-financed and self-sustained are also addressed through this concept. When implemented parallel to a high-traffic, non-tolled link, the MTS will be the facility of choice for those users in Texas willing to pay a premium for higher levels of service.

Specific Observations

Given the application of this methodology to the Interstate 35 corridor connecting Dallas and San Antonio (around 450 kilometers), and assuming a conservative range of 4- to 8-percent annual traffic growth rate, we found the following:

1. The need for by-passes along major cities, the reconstruction of transverse overpasses along IH-35, as well as the need to buy additional and more expensive right-of-way make the "adding lanes" and "retrofit" alternatives comparable (with respect to agency costs) to the MTS.
2. The user/social costs for automobiles and commercial vehicles will increase 164 percent and 188 percent, respectively, within the next 10 years if no additional capacity is provided.
3. While not examined in detail, preliminary calculations suggest that separating automobile traffic from commercial vehicle traffic on an MTS will reduce traffic accident fatalities by 25 percent.
4. The MTS is the alternative that yields the highest benefit: For the 8-percent and 4-percent growth rates, the savings, as compared with the "no-build" alternative, are approximately \$75 billion and \$18 billion, respectively, for the 50-year analysis period. Moreover, the MTS is the alternative that will yield the least disruption/congestion costs to the user and society during implementation.

RECOMMENDATIONS

1. In general, we recommend that the methodology developed in this report be applied to all major transportation corridors in Texas.
2. An important component of the MTS concept is dependent on the successful implementation of ITS technology and higher operating speeds. Therefore, it is essential that research continues in this area in order to enhance our understanding of the potential benefits, feasibility of implementation, and costs.
3. All user/social costs were based on available models that have some limitations. Hence, it is necessary to update these models or create new ones that reflect the special characteristics of motor vehicle transport.
4. A proposed solution should consider multiple modes of transportation, such as passenger rail, intermodal combinations of trucks and trains, and special lanes for automobiles and commercial vehicles. In addition, other transmission agencies, such as those associated with oil, gas, electricity, and fiber optics, could share the right of way and, thus, could further reduce costs.
5. A conservative approach was used in this evaluation, with the prediction of emissions, accidents, and meticulous workzone costs excluded. Insofar as the purpose of this analysis was to determine broad directions and magnitudes of investment, the inclusion of these other factors is strongly recommended in a more detailed corridor feasibility study.

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APPENDIX A.
ABBREVIATIONS

ABBREVIATIONS

a	Layer Coefficient
AC	Asphalt Concrete
ADT	Average Daily Traffic
Cd	Subdrainage Coefficient
CO	Carbon Monoxide
CRCP	Continuos Reinforced Concrete Pavement
CTR	Center for Transportation Research
D	Thickness of Pavement Slab
Dd	Directional Distribution Factor
E	Modulus of Elasticity
Ec	Modulus of Elasticity for Portland Cement Concrete
ESAL	Equivalent Single Axle Load
Fac	AC Quality Adjustment Factor
Fdur	Durability Adjustment Factor
fhv	Factor Hourly Volume
Fjc	Joints and Cracks Adjustment Factor
FR	Fatality Rate
FTP	Federal Test Procedure
fw	Lane Reduction Factor
HC	Hydrocarbons
HOV	High Occupancy Vehicle
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITS	Intelligent Transportation Systems
J	Load Transfer Coefficient
K	Ratio of Hourly Volume to Daily Volume
K	kip
k-eff	Effective k Value
kph	kilometers per hour
LI	Load Increase
LOS	Level of Service
m	meter
m	Layer Drainage Coefficient
Mr	Resilient Modulus
MSF	Maximum Service Flow
MTS	Managed Transportation System
n	Number of Years
NDT	Non-destructive Testing

NOx	Nitrogen Oxides
NPV	Net Present Value
O/L	Overlay
PCC	Portland Cement Concrete
pcphpl	Passenger Cars per Hour per Lane
PW	Pavement Worth Value
PWF	Pavement Worth Factor
ROW	Right of Way
S'c	Modulus of Rupture for Portland Cement Concrete
SF	Service Flows
Sfc	Service Flow Capacity
vph	Vehicles per Hour

APPENDIX B.
CAPACITY COST EVALUATION FOR ALTERNATIVES

NO BUILD alternative

Cost estimation for a 4% traffic growth rate over 50 years

18k-ESALs over design lane* (mixed traffic) N=150 million

Concepts	cost (current value)
Unit O/L cost for pav X (strong soil) = 5.59Ln(N)-10.07 = $17.93/SY Unit O/L cost for pav Y (strong soil) = 3.48Ln(N)-2.01 = $15.43/SY Unit O/L cost for pav Y (weak soil) = 4.68Ln(N)+4.32 = $27.77/SY Weighted unit O/L cost = $17.93(50/235)+$15.43(120/235)+$27.77(65/235) = $19.38/SY	
Total pavement width: (4 lanes x 12ft)+(4 shoulders x 10ft) = 88ft O/L cost from DFW to Austin = [88ft(1/3)(1760)]x170mi x$19.38/SY =	$ 170 million
Total pavement width: (6 lanes x 12ft)+(4 shoulders x 10ft) = 112ft O/L cost from DFW to Austin = [112ft(1/3)(1760)]x65mi x$19.38/SY =	$ 83 million

*Reference: Dossey, T., A. Weissmann, CTR Report 472-6 (November 1989)

Design considerations:

Dd=0.5, DL=0.7

20% heavy trucks

Cost estimation for an 8% traffic growth rate over 50 years

18k-ESALs over design lane* (mixed traffic) N=227 million

Concepts	cost (current value)
Unit O/L cost for pav X (strong soil) = 5.59Ln(N)-10.07 = $20.26/SY Unit O/L cost for pav Y (strong soil) = 3.48Ln(N)-2.01 = $16.87/SY Unit O/L cost for pav Y (weak soil) = 4.68Ln(N)+4.32 = $29.71/SY Weighted unit O/L cost = $20.26(50/235)+$16.87(120/235)+$29.71(65/235) = $21.14/SY	
Total pavement width: (4 lanes x 12ft)+(4 shoulders x 10ft) = 88ft O/L cost from DFW to Austin = [88ft(1/3)(1760)]x170mi x$21.14/SY =	$ 186 million
Total pavement width: (6 lanes x 12ft)+(4 shoulders x 10ft) = 112ft O/L cost from DFW to Austin = [112ft(1/3)(1760)]x65mi x$21.14/SY =	$ 90 million

*Reference: Dossey, T., A. Weissmann, CTR Report 472-6 (November 1989)

Design considerations:

Dd=0.5, DL=0.7

20% heavy trucks

ADDING LANES alternative

Cost estimation for a 4% traffic growth rate over 50 years

18k-ESALs over design lane* (mixed traffic) N=150 million

Concepts	cost (current value)
170 mile upgrade from 4 to 10 lanes = ($1.08 million**/ln/mi)(6ln)(170mi) =	$ 1,102 million
65 mile upgrade from 6 to 10 lanes = ($1.08 million**/ln/mi)(4ln)(65mi) =	$ 281 million
Unit O/L cost for pav X (strong soil) = 5.59Ln(N)-10.07 = $17.93/SY Unit O/L cost for pav Y (strong soil) = 3.48Ln(N)-2.01 = $15.43/SY Unit O/L cost for pav Y (weak soil) = 4.68Ln(N)+4.32 = $27.77/SY Weighted unit O/L cost = $17.93(50/235)+$15.43(120/235)+$27.77(65/235) = $19.38/SY Total pavement width: (10 lanes x 12ft)+(4 shoulders x 10ft) = 160ft O/L cost = [160ft(1/3)(1760)]x235mi x$19.38/SY =	$ 427 million
By-passes for major cities = (120mi)($10.8 million***/mi) =	$ 1,296 million
Bridge overpass reconstruction = (50 bridges)($1 million/bridge) =	$ 50 million

*Reference: Dossey, T., A. Weissmann, CTR Report 472-6 (November 1989)

Design considerations:

Dd=0.5, DL=0.7

20% heavy trucks

**Source: TxDOT/San Antonio District (1995)

***Source: Table B1

Cost estimation for an 8% traffic growth rate over 50 years

18k-ESALs over design lane* (mixed traffic) N=227 million

Concepts	cost (current value)
170 mile upgrade from 4 to 18 lanes = ($1.08 million**/ln/mi)(14ln)(170mi) =	$ 2,570 million
65 mile upgrade from 6 to 18 lanes = ($1.08 million**/ln/mi)(12ln)(65mi) =	$ 842 million
Additional right-of-way = (100ft)(5280ft/mi)($0.10/sf)(235mi) =	$ 12 million
Unit O/L cost for pav X (strong soil) = 5.59Ln(N)-10.07 = $20.26/SY Unit O/L cost for pav Y (strong soil) = 3.48Ln(N)-2.01 = $16.87/SY Unit O/L cost for pav Y (weak soil) = 4.68Ln(N)+4.32 = $29.71/SY Weighted unit O/L cost = $20.26(50/235)+$16.87(120/235)+$29.71(65/235) = $21.14/SY Total pavement width: (18 lanes x 12ft)+(4 shoulders x 10ft) = 256ft O/L cost = [256ft(1/3)(1760)]x235mi x$21.14/SY =	$ 746 million
By-passes for major cities = (120mi)($16.4 million***/mi) =	$ 1,968 million
Bridge overpass reconstruction = (50 bridges)($1.4 million/bridge) =	$ 70 million

*Reference: Dossey, T., A. Weissmann, CTR Report 472-6 (November 1989)

Design considerations:

Dd=0.5, DL=0.7

20% heavy trucks

**Source: TxDOT/San Antonio District (1995)

***Source: Table B2

RETROFIT WITH ITS alternative

Cost estimation for a 4% traffic growth rate over 50 years

18k-ESALs over design lane* (mixed traffic) (car traffic) Nc=22 million
(truck traffic) Nt=128 million

Concepts	cost (current value)
170 mile upgrade from 4 to 10 (15-ft) lanes = ($1.35 million**/ln/mi)(6ln)(170mi) =	$ 1,377 million
65 mile upgrade from 6 to 10 (15-ft) lanes = ($1.35 million**/ln/mi)(4ln)(65mi) =	$ 351 million
Unit O/L cost for pav X (strong soil) for car lanes = 5.59Ln(Nc)-10.07 = $7.21/SY Unit O/L cost for pav Y (strong soil) for car lanes = 3.48Ln(Nc)-2.01 = $8.75/SY Unit O/L cost for pav Y (weak soil) for car lanes = 4.68Ln(Nc)+4.32 = $18.79/SY Weighted unit O/L cost (cars) = $7.21(50/235)+$8.75(120/235)+$18.79(65/235) = $11.20/SY Total pavement width: (6 lanes x 15ft)+(30ft of shoulders) = 120ft O/L cost for car lanes = [120ft(1/3)(1760)]x235mi x$11.20/SY =	$ 185 million
Unit O/L cost for pav X (strong soil) for truck lanes = 5.59Ln(Nt)-10.07 = $17.05/SY Unit O/L cost for pav Y (strong soil) for truck lanes = 3.48Ln(Nt)-2.01 = $14.88/SY Unit O/L cost for pav Y (weak soil) for truck lanes = 4.68Ln(Nt)+4.32 = $27.03/SY Weighted unit O/L cost (trks) = $17.05(50/235)+$14.88(120/235)+$27.03(65/235) = $18.70/SY Total pavement width: (4 lanes x 15ft)+(30ft of shoulders) = 90ft O/L cost for truck lanes = [90ft(1/3)(1760)]x235mi x$18.70/SY =	$ 232 million
By-passes for major cities = (120mi)($13.2 million***/mi) =	$ 1,584 million
Service/access stations = (4 stations)($10 million each) =	$ 40 million
Bridge overpass reconstruction = (50 bridges)($1.2 million/bridge) =	$ 60 million

*Reference: Dossey, T., A. Weissmann, CTR Report 472-6 (November 1989)
Design considerations:
Dd=0.5, DL=0.7
20% heavy trucks
**Source: TxDOT/San Antonio District (1995)
***Source: Table B3

Cost estimation for an 8% traffic growth rate over 50 years

18k-ESALs over design lane* (mixed traffic) (car traffic) Nc=34 million
(truck traffic) Nt=193 million

Concepts	cost (current value)
170 mile upgrade from 4 to 18 (15-ft) lanes = ($1.35 million**/ln/mi)(14ln)(170mi) =	$ 3,213 million
65 mile upgrade from 6 to 18 (15-ft) lanes = ($1.35 million**/ln/mi)(12ln)(65mi) =	$ 1,053 million
Additional right-of-way = (140ft)(5280ft/mi)($0.10/sf)(235mi) =	$ 17 million
Unit O/L cost for pav X (strong soil) for car lanes = 5.59Ln(Nc)-10.07 = $9.64/SY Unit O/L cost for pav Y (strong soil) for car lanes = 3.48Ln(Nc)-2.01 = $10.26/SY Unit O/L cost for pav Y (weak soil) for car lanes = 4.68Ln(Nc)+4.32 = $20.82/SY Weighted unit O/L cost (cars) = $9.64(50/235)+$10.26(120/235)+$20.82(65/235) = $13.05/SY Total pavement width: (10 lanes x 15ft)+(30ft of shoulders) = 180ft O/L cost for car lanes = [180ft(1/3)(1760)]x235mi x$13.05/SY =	$ 324 million
Unit O/L cost for pav X (strong soil) for truck lanes = 5.59Ln(Nt)-10.07 = $19.35/SY Unit O/L cost for pav Y (strong soil) for truck lanes = 3.48Ln(Nt)-2.01 = $16.30/SY Unit O/L cost for pav Y (weak soil) for truck lanes = 4.68Ln(Nt)+4.32 = $28.95/SY Weighted unit O/L cost (trks) = $19.35(50/235)+$16.30(120/235)+$28.95(65/235) = $20.45/SY Total pavement width: (8 lanes x 15ft)+(30ft of shoulders) = 150ft O/L cost for truck lanes = [150ft(1/3)(1760)]x235mi x$20.45/SY =	$ 423 million
By-passes for major cities = (120mi)($20 million***/mi) =	$ 2,400 million
Service/access stations = (4 stations)($10 million each) =	$ 40 million
Bridge overpass reconstruction = (50 bridges)($1.7 million/bridge) =	$ 85 million

*Reference: Dossey, T., A. Weissmann, CTR Report 472-6 (November 1989)
Design considerations:
Dd=0.5, DL=0.7
20% heavy trucks
**Source: TxDOT/San Antonio District (1995)
***Source: Table B4

MTS alternative

Cost estimation for a 4% traffic growth rate over 50 years

18k-ESALs over design lane* (mixed traffic)

(IH35 traffic) Nm=67 million
(MTS cars) Nc=12 million
(MTS trucks) Nt= 71 million

Concepts	cost (current value)
IH-35 (Austin to DFW): Unit O/L cost for pav X (strong soil) = 5.59Ln(Nm)-10.07 = $13.43/SY Unit O/L cost for pav Y (strong soil) = 3.48Ln(Nm)-2.01 = $12.62/SY Weighted unit O/L cost = $13.43(50/192)+$12.62(142/192) = $12.83/SY Total pavement width: (4 lanes x 12ft)+(4 shoulders x 10ft) = 88ft O/L cost = [88ft(1/3)(1760)]x192mi x$12.83/SY =	$ 127 million
IH-35 (San Antonio to Austin): Unit O/L cost for pav Y (weak soil) = 4.68Ln(Nm)+4.32 = $24.00/SY Total pavement width: (6 lanes x 12ft)+(4 shoulders x 10ft) = 112ft O/L cost = [112ft(1/3)(1760)]x90mi x$24.00/SY =	$ 142 million
MTS total cost (from Table B5).	$ 3,158 million

*Reference: Dossey, T., A. Weissmann, CTR Report 472-6 (November 1989)

Design considerations:

Dd=0.5, DL=0.7

20% heavy trucks

Cost estimation for an 8% traffic growth rate over 50 years

18k-ESALs over design lane* (mixed traffic)

(IH35 traffic) Nm=102 million
(MTS cars) Nc=19 million
(MTS trucks) Nt= 106 million

Concepts	cost (current value)
IH-35 (Austin to DFW): 192mile upgrade from 4 to 6 lanes = ($1.08 million**/ln/mi)(2ln)(192mi) =	$ 415 million
IH-35 (Austin to DFW): Unit O/L cost for pav X (strong soil) = 5.59Ln(Nm)-10.07 = $15.78/SY Unit O/L cost for pav Y (strong soil) = 3.48Ln(Nm)-2.01 = $14.08/SY Weighted unit O/L cost = $15.78(50/192)+$14.08(142/192) = $14.52/SY Total pavement width: (6 lanes x 12ft)+(4 shoulders x 10ft) = 112ft O/L cost = [112ft(1/3)(1760)]x192mi x$14.52/SY =	$ 183 million
IH-35 (San Antonio to Austin): Unit O/L cost for pav Y (weak soil) = 4.68Ln(Nm)+4.32 = $25.96/SY Total pavement width: (6 lanes x 12ft)+(4 shoulders x 10ft) = 112ft O/L cost = [112ft(1/3)(1760)]x90mi x$25.96/SY =	$ 154 million
MTS total cost (from Table B6).	$ 3,631 million

*Reference: Dossey, T., A. Weissmann, CTR Report 472-6 (November 1989)

Design considerations:

Dd=0.5, DL=0.7

20% heavy trucks

**Source: TxDOT/San Antonio District (1995)

TABLE B1. Procedure to estimate conventional by-pass cost per mile

10-lane rural alignment from San Antonio to DFW (parallel to IH-35). No frontage roads considered.

Attracted traffic*: 100% (4% annual growth) Length: 235 miles rural

Item	unit	No.units	unit cost	cost
ROW acquisition (200' ROW)	ac	5697	$ 3,000	$17,091,000
Grading	mi	235.0	$ 596,000	$140,060,000
Drainage	mi	235.0	$ 256,000	$60,160,000
10 Ln Pavement str (mixed tr)**	mi	235.0	$ 5,294,844	$1,244,288,279
Landscaping	mi	235.0	$ 176,000	$41,360,000
Delineation marking	mi	235.0	$ 636,000	$149,460,000
(STR) Grade Sep 220ft	ea	15	$ 1,971,200	$29,568,000
(STR) Grade Sep 100ft	ea	198	$ 864,000	$171,072,000
(STR) Bridge 250ft	ea	13	$ 2,240,000	$29,120,000
(STR) Bridge 130ft	ea	74	$ 1,123,200	$83,116,800
(STR) Bridge 50ft	ea	125	$ 432,000	$54,000,000
				$2,019,296,079
MAINTENANCE & MANAGEMENT FACILITIES*** (1%)				$ 20,192,961
ENGINEERING AND CONTINGENCIES (15%)				$ 302,894,412
MOBILIZATION (10%)				$ 201,929,608
TOTAL COST/SECTION				$ 2,544,313,059
Avg cost/mile:				**$ 10,826,864**

* 100% traffic attracted at 4% growth is equivalent to 150 million ESALs in 50 years over design lane.

** Pavement cost=(4.65*LN(150)+31.34)*170/235+(5.07*LN(150)+35.63)*65/235

*** Maintenance & management reduced to 1% since cost of pavement includes rehabilitation.

No "Operational controls" included, since this is a conventional highway.

Source: Ref 23

TABLE B2. Procedure to estimate conventional by-pass cost per mile

18-lane rural alignment from San Antonio to DFW (parallel to IH-35). No frontage roads considered.

Attracted traffic*: 100% (8% annual growth) Length: 235 miles rural

Item	unit	No.units	unit cost	cost
ROW acquisition (300' ROW)	ac	8545	$ 3,000	$ 25,635,000
Grading	mi	235.0	$ 596,000	$ 140,060,000
Drainage	mi	235.0	$ 256,000	$ 60,160,000
18 Ln Pavement str (mixed tr)**	mi	235.0	$ 8,768,323	$ 2,060,555,850
Landscaping	mi	235.0	$ 176,000	$ 41,360,000
Delineation marking	mi	235.0	$ 636,000	$ 149,460,000
(STR) Grade Sep 220ft	ea	15	$ 3,153,920	$ 47,308,800
(STR) Grade Sep 100ft	ea	198	$ 1,382,400	$ 273,715,200
(STR) Bridge 250ft	ea	13	$ 3,584,000	$ 46,592,000
(STR) Bridge 130ft	ea	74	$ 1,797,120	$ 132,986,880
(STR) Bridge 50ft	ea	125	$ 691,200	$ 86,400,000
				$ 3,064,233,730
MAINTENANCE & MANAGEMENT FACILITIES*** (1%)				$ 30,642,337
ENGINEERING AND CONTINGENCIES (15%)				$ 459,635,060
MOBILIZATION (10%)				$ 306,423,373
TOTAL COST/SECTION				$ 3,860,934,500
Avg cost/mile:				**$ 16,429,509**

* 100% traffic attracted at 8% growth is equivalent to 227 million ESALs in 50 years over design lane.

** Pavement cost=(4.65*LN(227)+31.34)*170/235+(5.07*LN(227)+35.63)*65/235

*** Maintenance & management reduced to 1% since cost of pavement includes rehabilitation.

No "Operational controls" included, since this is a conventional highway.

Source: Ref 23

TABLE B3. Procedure to estimate Retrofit type by-pass cost per mile

10-lane rural alignment from San Antonio to DFW (parallel to IH-35). No frontage roads considered.

Attracted traffic*: 100% (4% annual growth) Length: 235 miles rural

Item	unit	No units	unit cost	cost
ROW acquisition (250' ROW)	ac	7121	$ 3,000	$21,363,000
Grading	mi	235.0	$ 596,000	$140,060,000
Drainage	mi	235.0	$ 256,000	$60,160,000
6 Ln Pavement str (car)**	mi	235.0	$ 3,327,036	$781,853,396
4 Ln Pavement str (truck)***	mi	235.0	$ 2,938,436	$690,532,471
Landscaping	mi	235.0	$ 176,000	$41,360,000
Delineation marking	mi	235.0	$ 636,000	$149,460,000
(STR) Grade Sep 220ft	ea	15	$ 2,587,200	$38,808,000
(STR) Grade Sep 100ft	ea	198	$ 1,134,000	$224,532,000
(STR) Bridge 250ft	ea	13	$ 2,940,000	$38,220,000
(STR) Bridge 130ft	ea	74	$ 1,474,200	$109,090,800
(STR) Bridge 50ft	ea	125	$ 567,000	$70,875,000
				$2,366,314,667
MAINTENANCE & MANAGEMENT FACILITIES**** (1%)				$ 23,663,147
OPERATIONAL CONTROLS (5%)				$ 118,315,733
ENGINEERING AND CONTINGENCIES (15%)				$ 354,947,200
MOBILIZATION (10%)				$ 236,631,467
TOTAL COST/SECTION				$ 3,099,872,214
Avg cost/mile:				**$ 13,190,946**

* 100% traffic attracted at 4% growth is equivalent to 150 million ESALs in 50 years over design lane.

** Pavement cost=(4.65*LN(22)+31.34)*170/235+(5.07*LN(22)+35.63)*65/235

*** Pavement cost=(4.65*LN(128)+31.34)*170/235+(5.07*LN(128)+35.63)*65/235

**** Maintenance & management reduced to 1% since cost of pavement includes rehabilitation.

Source: Ref 23

TABLE B4. Procedure to estimate Retrofit type by-pass cost per mile

18-lane rural alignment from San Antonio to DFW (parallel to IH-35). No frontage roads considered.

Attracted traffic*: 100% (8% annual growth) Length: 235 miles rural

Item	unit	No units	unit cost	cost
ROW acquisition (370' ROW)	ac	10540	$ 3,000	$ 31,620,000
Grading	mi	235.0	$ 596,000	$ 140,060,000
Drainage	mi	235.0	$ 256,000	$ 60,160,000
10 Ln Pavement str (car)**	mi	235.0	$ 5,209,652	$ 1,224,268,331
8 Ln Pavement str (truck)***	mi	235.0	$ 5,069,634	$ 1,191,363,901
Landscaping	mi	235.0	$ 176,000	$ 41,360,000
Delineation marking	mi	235.0	$ 636,000	$ 149,460,000
(STR) Grade Sep 220ft	ea	15	$ 4,065,600	$ 60,984,000
(STR) Grade Sep 100ft	ea	198	$ 1,782,000	$ 352,836,000
(STR) Bridge 250ft	ea	13	$ 4,620,000	$ 60,060,000
(STR) Bridge 130ft	ea	74	$ 2,316,600	$ 171,428,400
(STR) Bridge 50ft	ea	125	$ 891,000	$ 111,375,000
				$ 3,594,975,632
MAINTENANCE & MANAGEMENT FACILITIES**** (1%)				$ 35,949,756
OPERATIONAL CONTROLS (5%)				$ 179,748,782
ENGINEERING AND CONTINGENCIES (15%)				$ 539,246,345
MOBILIZATION (10%)				$ 359,497,563
TOTAL COST/SECTION				$ 4,709,418,078
Avg cost/mile:				**$ 20,040,077**

* 100% traffic attracted at 8% growth is equivalent to 227 million ESALs in 50 years over design lane.

** Pavement cost =(4.65*LN(34)+31.34)*170/235+(5.07*LN(34)+35.63)*65/235

*** Pavement cost=(4.65*LN(193)+31.34)*170/235+(5.07*LN(193)+35.63)*65/235

**** Maintenance & management reduced to 1% since cost of pavement includes rehabilitation.

Source: Ref 23

TABLE B5. Procedure to estimate MTS cost

8-lane rural alignment from San Antonio to DFW (parallel to IH-35).

Attracted traffic*: 55% (4% annual growth) Length: 282 miles rural

Item	unit	No.units	unit cost	cost
ROW acquisition (400' ROW)	ac	13673	$ 3,000	$41,019,000
Grading	mi	282.0	$ 596,000	$168,072,000
Drainage	mi	282.0	$ 256,000	$72,192,000
4 Ln Pavement str (car)**	mi	282.0	$ 2,342,740	$660,652,800
4 Ln Pavement str (truck)***	mi	282.0	$ 2,790,124	$786,814,909
Landscaping	mi	282.0	$ 176,000	$49,632,000
Delineation marking	mi	282.0	$ 636,000	$179,352,000
Service/access stations	ea	4.0	$ 10,000,000	$40,000,000
(STR) Grade Sep 220ft	ea	15	$ 2,217,600	$33,264,000
(STR) Grade Sep 100ft	ea	198	$ 972,000	$192,456,000
(STR) Bridge 250ft	ea	13	$ 2,520,000	$32,760,000
(STR) Bridge 130ft	ea	74	$ 1,263,600	$93,506,400
(STR) Bridge 50ft	ea	125	$ 486,000	$60,750,000
				$2,410,471,109
MAINTENANCE & MANAGEMENT FACILITIES**** (1%)				$ 24,104,711
OPERATIONAL CONTROLS (5%)				$ 120,523,555
ENGINEERING AND CONTINGENCIES (15%)				$ 361,570,666
MOBILIZATION (10%)				$ 241,047,111
TOTAL COST/SECTION				**$ 3,157,717,152**
Avg cost/mile:				$ 11,197,579

* 55% traffic attracted at 4% growth is equivalent to 83 million ESALs in 50 years over design lane.
The rest 45% (67 million ESALs) channelized through IH-35.

** Pavement cost=(4.65*LN(12)+31.34)*170/235+(5.07*LN(12)+35.63)*65/235

*** Pavement cost=(4.65*LN(71)+31.34)*170/235+(5.07*LN(71)+35.63)*65/235

**** Maintenance & management reduced to 1% since cost of pavement includes rehabilitation.

Source: Ref 23

TABLE B6. Procedure to estimate MTS cost

10-lane rural alignment from San Antonio to DFW (parallel to IH-35).

Attracted traffic*: 55% (8% annual growth) Length: 282 miles rural

Item	unit	No.units	unit cost	cost
ROW acquisition (400' ROW)	ac	13673	$ 3,000	$ 41,019,000
Grading	mi	282.0	$ 596,000	$ 168,072,000
Drainage	mi	282.0	$ 256,000	$ 72,192,000
6 Ln Pavement str (car)**	mi	282.0	$ 3,277,845	$ 924,352,187
4 Ln Pavement str (truck)***	mi	282.0	$ 2,890,976	$ 815,255,335
Landscaping	mi	282.0	$ 176,000	$ 49,632,000
Delineation marking	mi	282.0	$ 636,000	$ 179,352,000
Service/access stations	ea	4.0	$ 10,000,000	$40,000,000
(STR) Grade Sep 220ft	ea	15	$ 2,587,200	$ 38,808,000
(STR) Grade Sep 100ft	ea	198	$ 1,134,000	$ 224,532,000
(STR) Bridge 250ft	ea	13	$ 2,940,000	$ 38,220,000
(STR) Bridge 130ft	ea	74	$ 1,474,200	$ 109,090,800
(STR) Bridge 50ft	ea	125	$ 567,000	$ 70,875,000
				$ 2,771,400,322
MAINTENANCE & MANAGEMENT FACILITIES**** (1%)				$ 27,714,003
OPERATIONAL CONTROLS (5%)				$ 138,570,016
ENGINEERING AND CONTINGENCIES (15%)				$ 415,710,048
MOBILIZATION (10%)				$ 277,140,032
TOTAL COST/SECTION				**$ 3,630,534,422**
Avg cost/mile:				$ 12,874,236

* 55% traffic attracted at 8% growth is equivalent to 125 million ESALs in 50 years over design lane.
The rest 45% (102 million ESALs) channelized through IH-35.

** Pavement cost=(4.65*LN(19)+31.34)*170/235+(5.07*LN(19)+35.63)*65/235

*** Pavement cost=(4.65*LN(106)+31.34)*170/235+(5.07*LN(106)+35.63)*65/235

**** Maintenance & management reduced to 1% since cost of pavement includes rehabilitation.

Source: Ref 23

APPENDIX C.
CALCULATIONS OF OPERATING COSTS

CALCULATIONS OF OPERATING COSTS

C.1 ACCELERATION AND DECELERATION MODELS

A non-uniform acceleration model was used for the speed-change computations presented in this study. For deceleration, a uniform deceleration model was used. Both models were developed by Zaniewski, with the original work referring to Drew (Refs 25, 33). In the non-uniform acceleration model, acceleration varies as a linear function of speed; that is:

$$ACCEL = A - B(V)$$

where:

ACCEL = acceleration at velocity V (ft/sec^2),

A, B = constants, and

V = speed (ft/sec).

Using this formulation the time to change from speed Vo to V1 is:

$$t = (\ln(A - B(V1)) - \ln(A - B(Vo)))/-B$$

where:

t = time (sec)

The distance traveled over the time interval t from initial speed Vo can be expressed as:

$$x = (A/B)t - (A/B^2)(1 - e^{-Bt}) + (Vo/B)(1 - e^{-Bt})$$

where:

x = distance (ft)

Thus, to quantify this model, only the two coefficients A and B need to be determined. Owing to the formulation of this model, A represents the maximum acceleration, while A/B is the maximum speed attainable. The values of A and B selected as representative of the two vehicles used in this study were:

A(car) = 8.6

B(car) = 0.076

A(truck) = 1.8

B(truck) = 0.016

A uniform deceleration model was chosen for braking for two primary reasons. First, sliding friction is theoretically independent of the relative speed of the surface in contact. Second, it is difficult to quantify a typical braking pattern for the population of vehicles on the road. Much of the existing research in the area has quantified braking performance according to levels of constant deceleration. The time to change from speed Vo to V1 using the constant deceleration model may be expressed as:

$$t = (Vo - V1)/D$$

where:

t = time (sec),
Vo = initial speed (ft/sec),
$V1$ = final speed (ft/sec), and
D = deceleration rate (ft/sec^2).

The distance traveled in changing from speed Vo to V1 is:

$$x = Vot - .5(Dt^2)$$

In the above formulations, the deceleration has been expressed as a positive quantity. For decelerations at initial speeds below 30 mph, a 7.33 ft/sec^2 rate was used. For initial speeds greater than 30 mph, a rate of 4.84 rate ft/sec^2 was used. These rates were used for both vehicles.

C.2 MODELING SPEED-CHANGE CYCLE FOR LOS E AND F

For the LOS A through D, a constant speed was assumed for this study. For LOS E and F, a different approach was used. AASHTO (Ref 34) defines the traffic on LOS F as "forced flow," where the speeds range from near 30 mph to stop-and-go operation. This speed-change cycle profoundly influences the operating cost of a vehicle; accordingly, to reflect this condition we used a cycle of acceleration-deceleration. For LOS E this study assumes a similar cycle. Three situations where modeled: The first assumes that the speed of the vehicle varies from 45 mph to 30 mph; the second assumes the speed varies from 30 mph to 5 mph; the third assumes the speed varies from 15 mph to 0 mph. Using the above formulas, we calculated the values shown in Table C-1.

The average speeds for the first, second, and third cycles are approximately 38 mph, 18 mph, and 7.6 mph, respectively. The third average speed is too slow to be considered, even though it is realistic for LOS F; but in order to maintain the conservative criteria adopted in this study, the first average speed was selected for LOS E and the second for LOS F.

Table C-1. Average speed and total distance per acceleration-deceleration cycle

	Cycle 45 to 30 mph		Cycle 30 to 5 mph		Cycle 15 to 0 mph	
	Car	Truck	Car	Truck	Car	Truck
t in acceleration mode (sec)	5.0	24.2	5.6	26.8	2.8	13.6
x in acceleration mode (ft)	280.6	1348.8	150.9	722.8	32.4	155.0
t in deceleration mode (sec)	4.6	4.6	5.0	5.0	3.0	3.0
x in deceleration mode (ft)	250.0	250.0	128.3	128.3	33.0	33.0
Total time/cycle (sec)	9.6	28.8	10.6	31.8	5.9	16.6
Total x/cycle (ft)	530.6	1598.8	279.3	851.1	65.4	188.0
Average cycle speed (mph)	37.8	37.9	18.0	18.3	7.63	7.72
Number of cycle per mile	10.0	3.3	18.9	6.2	80.7	28.1

C.3 OPERATING COST OF SPEED-CHANGE CYCLE

The excesses in operating cost resulting from the speed-change cycle are based on Zaniewski's results. These results are presented in cycles per 1000 vehicle miles for cars and trucks. This unit is compatible with the data obtained in Table C-1. These excesses in operating costs are added to the costs obtained for LOS E and F using a constant speed of 45 and 30 mph, respectively. The excesses in operating cost values obtained for the speed-change cycle of 45 mph to 30 mph and 30 mph to 15 mph are shown in Table C-2.

According to Table C-1, the number of cycles per mile differs between cars and trucks but in the scenarios of mixed traffic, the trucks and cars share the same lanes; this means that the trucks are limiting the greater acceleration capacity of the cars and, thus, trucks govern the acceleration-deceleration cycle. Accordingly, a value of 3.3 (LOS E) and 6.2 (LOS F) cycles per mile were selected for both vehicles, the result being a lower operating cost for cars. In the case of separate traffic, each one must obey its own acceleration-deceleration cycle; but in these scenarios there are no LOS E and F for the analysis period analyzed in this study.

Table C-2. Excess in operating cost for speed-change cycle

Item	LOS F		LOS E	
	Car	Truck	Car	Truck
Excess fuel consumption (gal/1000 cycles)	6.08	55.5	5.81	57.00
Excess depreciation (% new price/1000 cycles)	.003	.003	.005	.005
Excess tire wear (% worn/1000 cycles)	0.78	0.83	0.87	0.94
Excess maint. and repair cost (% avg. cost/1000 cycles)	1.53	1.72	1.27	1.13

C.4 FUEL CONSUMPTION

Several studies have sought to predict fuel consumption as a function of vehicle speed. A report by the Texas Research and Development Foundation (Ref 25) published in 1982 contains the most up-to-date vehicle-operating cost data set for several representative U.S. vehicles. Based on this work, another study was conducted in 1994 (Ref 35) to update the previous findings using a program obtained from the ARBB (Australian Road Research Board) named ARFCOM (ARBB Road Fuel Consumption Model).

The results of this study are summarized in Figure C-1, which shows the fuel consumption for cars and trucks for different constant speeds (not including a speed-change cycle). The numerical results from the computer program ARFCOM for the fuel consumption are shown in Table C-3.

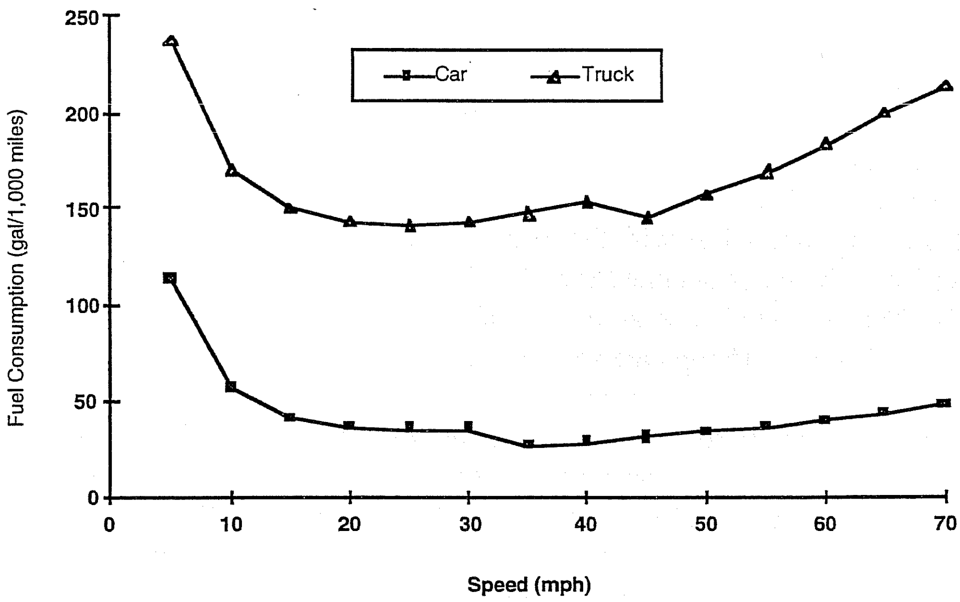

Figure C-1. Fuel consumption for constant speed

C.5 DEPRECIATION

To obtain the depreciation cost for cars and trucks, two different approaches were used, both of which use the values proposed by Zaniewski (Ref 25). Figure C-2 shows the percentage of depreciation for the car and truck used in this study.

C.5.1 Car Depreciation

To obtain the car depreciation cost, we used:

$$\text{Dep} = \% \text{ Dep} * \text{Cost}$$

where:

Dep = Cost of depreciation ($/mile),

%Dep = Percent of depreciable value per mile, and

Cost = Average car price ($).

An average car price of $16,700 (Ref 36) and the respective values of %Dep for each LOS shown in Table C-3 were used to calculate Dep.

C.5.2 Truck Depreciation

For truck tractors and trailers, Zaniewski suggests (Ref 16) a depreciation cost of $0.128 per mile (1991 dollars) for an operating speed at 60 mph. This cost was obtained using a depreciable value for the tractor of $83,640. The depreciable value was calculated as retail price minus tire costs and a 10 percent salvaged value. For the trailer dry van type, we used: purchase price = $19,813, salvage value = $1,981, annual mileage = 100,000 miles, and 6 years' life. Given a value of 0.08 for %Dep at 60 mph and using it to obtain the relation with %Dep for other speeds, the depreciation cost was obtained using the following equation:

$$\text{Dep} = \frac{\%\text{Dep}}{0.08} * \$0.1276 / \text{mile}$$

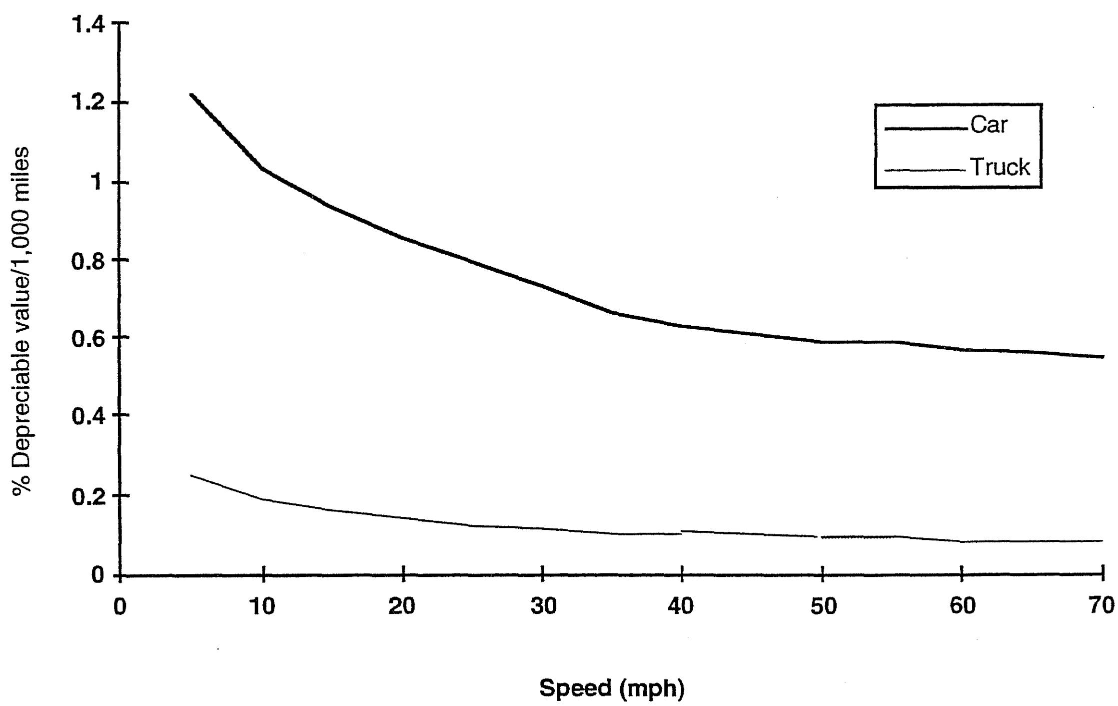

Figure C-2. Vehicle depreciation for constant speed

C.6 TIRE WEAR

The values developed by Zaniewski for tire wear are expressed in percent worn per 1,000 miles. Figure C-3 and Table C-3 show these values. Using a tire cost of $65 per car tire (including balance) and $480 per truck tire (Ref 16), the tire wear cost was calculated using the equation:

Tire = %worn * tire price

where:

Tire = Cost of tire wear ($/mile),

%worn = Percent worn per mile, and

tire price = Price of tires, 4 tires for car and 18 for truck.

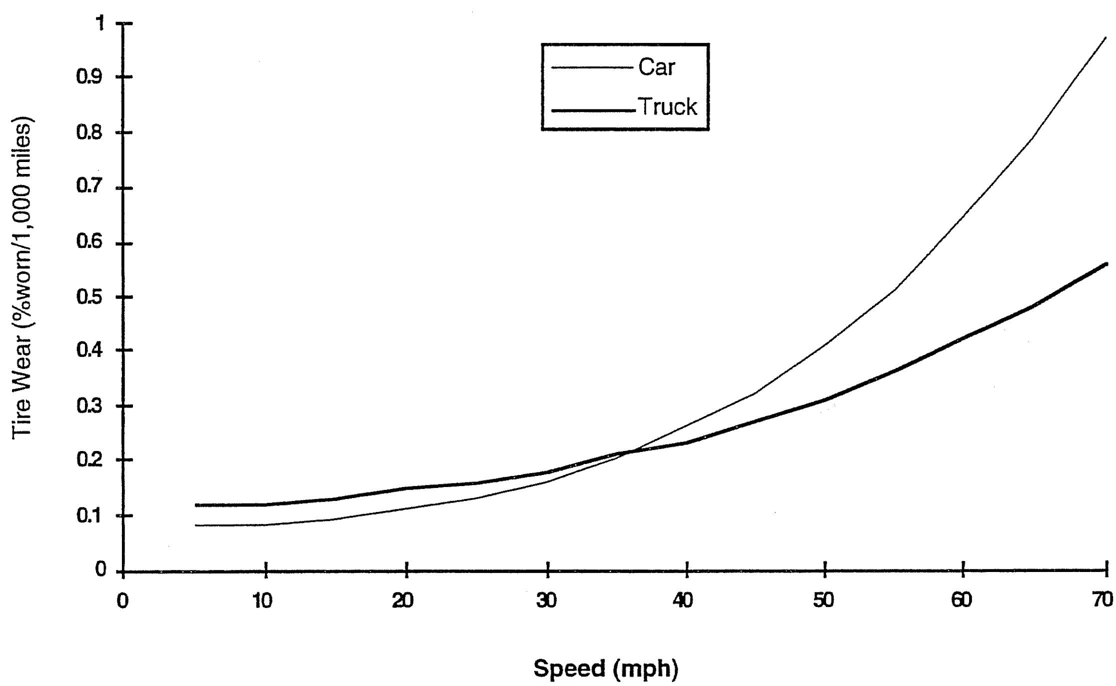

Figure C-3. Tire wear for constant speed

C.7 MAINTENANCE AND REPAIR

There are several categories in which maintenance and repair were divided to obtain the average cost; these categories are:

1. General (body, chassis, and electrical)
2. Brakes
3. Drive train (engine and power train)

The maintenance and repair (M&R) cost for each LOS is obtained as a percentage of an M&R average cost:

M&R cost ($/mile) = % of M&R cost * M&R avg. cost ($/mile)

The values obtained for % of maintenance and repair average cost as a function of speed (Ref 25) are shown in Figure C-4 and Table C-3. The Federal Highway Administration suggests an average maintenance and repair cost for cars of $0.042 per mile and, for trucks, $0.237 per mile (Refs 11, 16).

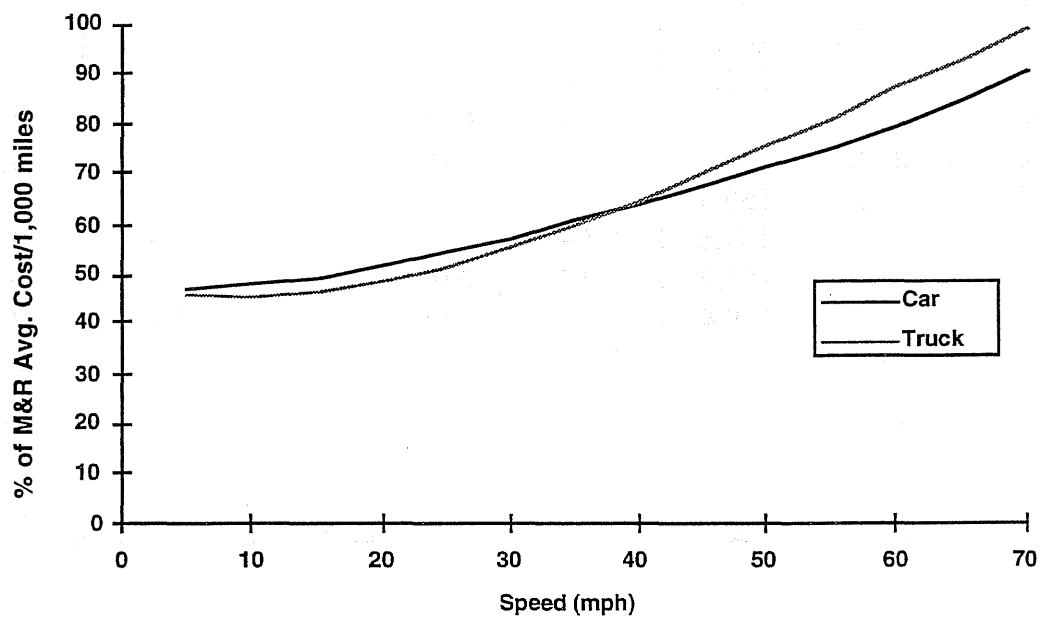

Figure C-4. Maintenance and repair for constant speed

C.8 COMPONENT CONSUMPTION TABLE

In this section, consumption values for various speeds and cost components are presented. Table C-3 is divided into two categories: The first category corresponds to constant speed (range from 5 to 70 mph), using values obtained by Zaniewski (Ref 25). The second category is for the speed-change cycles used for LOS E and F in this study. All the values were based on a 0 percent grade.

Table C-3. Component Consumption Table

Constant Speed (mph)	Fuel Consumption (gal/1,000 mi)		Depreciation (%dep. value/1,000 mi)		Tire Wear (% worn/1,000 mi)		Maint. and Repair (%avg. cost/1,000mi)	
	Car	Truck	Car	Truck	Car	Truck	Car	Truck
5	112.7	237.2	1.22	0.25	0.08	0.12	46.9	45.9
10	56.1	170.5	1.03	0.19	0.08	0.12	47.8	45.5
15	40.4	150.5	0.93	0.16	0.09	0.13	49.4	46.4
20	36.6	143.3	0.85	0.14	0.11	0.15	51.6	48.4
25	35.7	141.6	0.79	0.12	0.13	0.16	54.4	51.4
30	35.7	143.3	0.73	0.11	0.16	0.18	57.4	55.1
35	26.4	147.5	0.66	0.10	0.20	0.21	60.6	59.6
40	28.1	153.9	0.63	0.10	0.26	0.23	64.0	64.5
45	30.6	145.8	0.61	0.09	0.32	0.27	67.6	69.8
50	33.2	156.9	0.59	0.09	0.41	0.31	71.3	75.4
55	36.1	169.6	0.59	0.09	0.51	0.36	75.2	81.2
60	39.5	183.7	0.57	0.08	0.64	0.42	79.4	87.2
65	43.4	199.4	0.56	0.08	0.79	0.48	84.3	93.1
70	47.6	213.4	0.55	0.08	0.97	0.56	90.2	99.3
45*	20.0	183.0	0.01	0.01	2.57	2.74	5.0	5.7
30*	36.0	353.0	0.03	0.03	5.40	5.80	7.9	7.0

*This speed is for the speed-change cycle.

APPENDIX D.
EMISSION RATE EQUATIONS

EMISSION RATE EQUATIONS

The following formulas were published by Seshadri et al. The original work refers to the computer models MOBILE4.1, CALINE4, and MICRO2 (Ref 32).

CARS

Carbon Monoxide

$$m_{COi} = 293.1$$

$$m_{COd} = 439.65$$

$$m_{COc} = 155.33 + 0.0714\,\xi v^2$$

$$m_{COa} = 1011.4 - 9.0\,\xi v + 0.804\,\xi v^2 - 0.04903\,\xi v^3 + 0.000729\,\xi v^4$$

Hydrocarbons

$$m_{HCi} = 24.27$$

$$m_{HCd} = 24.27$$

$$m_{HCc} = 24.27$$

$$m_{HCa} = 5.8127 - 0.14173\,\xi v + 0.014535\,\xi v^2 - 0.00034403\,\xi v^3 + 0.0000028941\,\xi v^4$$

Nitrogen Oxides

$$m_{NOxi} = 2.9$$

$$m_{NOxd} = -0.0081618 + 0.030774\,\xi v - 0.00048009\,\xi v^2 - 0.0000013859\,\xi v^3 + 0.00000013574\,\xi v^4$$

$$m_{NOxc} = 2.9$$

$$m_{NOxa} = -0.20963 + 0.15404\,\xi v - 0.0045707\,\xi v^2 + 0.000060109\,\xi v^3$$

TRUCKS

Carbon Monoxide

$$m_{COi} = 51.18$$

$$m_{COd} = 76.77$$

$$m_{COc} = 119.64 + 0.0550\,\xi v^2$$

$$m_{COa} = 20.125 + 8.5098\,\xi v - 0.37135\,\xi v^2 + 0.0061456\,\xi v^3 - 0.000029472\,\xi v^4$$

Hydrocarbons

$$m_{HCi} = 17.37$$

$$m_{HCd} = 17.37$$

$$m_{HCc} = 17.37$$

$$m_{HCa} = 0.16072 + 0.21664\,\xi v - 0.0077947\,\xi v^2 + 0.0001216\,\xi v^3 - 0.00000064191\,\xi v^4$$

Nitrogen Oxides

$$m_{NOxi} = 22.32$$

$$m_{NOxd} = -0.20101 + 0.31205\,\xi v - 0.0101\,\xi v^2 + 0.00014347\,\xi v^3$$

$$m_{NOxc} = 22.32$$

$$m_{NOxa} = -0.69458 + 1.046\,\xi v - 0.033855\,\xi v^2 + 0.00048059\,\xi v^3$$

where:

v = speed, in mph,

m_{pi} = emission rate of pollutant p (CO, HC, or NO_X) emitted under idle condition (gm/hr),

m_{pd} = emission rate of pollutant p (CO, HC, or NO_X) emitted under deceleration (gm/hr),

m_{pc} = emission rate of pollutant p (CO, HC, or NO_X) emitted under cruising (gm/hr), and

m_{pa} = emission rate of pollutant p (CO, HC, or NO_X) emitted under acceleration (gm/hr).

After applying the typical FTP driving cycle from Table 5.9 to all vehicles, converting the unit from g/hr to g/mile by dividing by the speed, and combining the above equations, the following equations for pollutant CO, HC, and NO_X for LOS E and F were derived:

CARS

$$m_{CO} = \frac{459.02}{v} - 2.358 + 0.2368\xi v - 0.01285\xi v^2 + 0.000191\xi v^3$$

$$m_{HC} = \frac{19.4342}{v} - 0.03713 + 0.00381\xi v - 0.000090136\xi v^2 + 0.000000758\xi v^3$$

$$m_{NOx} = \frac{1.524}{v} + 0.0463 - 0.00129\xi v + 0.000015481\xi v^2 + 0.0000000262\xi v^3$$

TRUCKS

$$m_{CO} = \frac{73.113}{v} + 2.23 - 0.07712\xi v + 0.00161\xi v^2 - 0.000007722\xi v^3$$

$$m_{HC} = \frac{12.86}{v} + 0.05676 - 0.00204\xi v + 0.0000319\xi v^2 - 0.000000168\xi v^3$$

$$m_{NOx} = \frac{11.9436}{v} + 0.3343 - 0.01082\xi v + 0.0001536\xi v^2$$

To quantify the emissions for LOS A, B, C, and D only the cruise equations were used:

CARS

$$m_{COc} = \frac{155.33}{v} + 0.0714\xi v$$

$$m_{HCc} = \frac{24.27}{v}$$

$$m_{NOxc} = \frac{2.9}{v}$$

TRUCKS

$$m_{COc} = \frac{119.64}{v} + 0.0550\,\xi v$$

$$m_{HCc} = \frac{17.37}{v}$$

$$m_{NOxc} = \frac{22.32}{v}$$

where:

v = speed, in mph,

m_{pi} = emission rate of pollutant p (CO, HC, or NO_x) emitted under idle condition (gm/mi),

m_{pd} = emission rate of pollutant p (CO, HC, or NO_x) emitted under deceleration (gm/mi),

m_{pc} = emission rate of pollutant p (CO, HC, or NO_x) emitted under cruising (gm/mi), and

m_{pa} = emission rate of pollutant p (CO, HC, or NO_x) emitted under acceleration (gm/mi).

APPENDIX E.
USER/SOCIAL COSTS COMPUTATIONS FOR McCLENNAN COUNTY

Table E-1. User/Social Costs Calculation for "No-Build" alternative.

D: 56% surrog K: 5.00% 3.33% 9.00% 7.50% 5.50% 1.00%

McClennan segment miles: 42 "No-Build" alternative

8% growth rate			WEEKDAY MONDAY-THURSDAY				WEEKEND FRIDAY-SUNDAY								TOTAL	Present Worth 4% real MARR
		dir	PERIOD 1 (12hr)		PERIOD 2 (12hr)		PERIOD 1 (4hr)		PERIOD 2 (4hr)		PERIOD 3 (4hr)		PERIOD 4 (12hr)		user$/yr	user$/yr
YEAR	ADT	ln	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	[$million]	[$million]
1983	28,000		784		523		1,411		1,176		862		157			
1984	28,000		784		523		1,411		1,176		862		157			
1985	29,000		812		541		1,462		1,218		893		162			
1986	31,000		868		579		1,562		1,302		955		174			
1987	32,530		911		607		1,640		1,366		1,002		182			
1988	32,500		910		607		1,638		1,365		1,001		182			
1989	34,670		971		647		1,747		1,456		1,068		194			
1990	36,130		1,012		674		1,821		1,517		1,113		202			
1991	38,180		1,069		713		1,924		1,604		1,176		214			
1992	39,910		1,117		745		2,011		1,676		1,229		223			
1993	43,103		1,207		805		2,172		1,810		1,328		241			
1994	46,296		1,296		864		2,333		1,944		1,426		259			
1995	49,488		1,386		924		2,494		2,079		1,524		277			
1996	52,681	2	1,475	$ 0.567	983	$ 0.545	2,655	$ 0.839	2,213	$ 0.600	1,623	$ 0.584	295	$ 0.545	$ 467	$ 449
1997	55,874	2	1,564	$ 0.584	1,043	$ 0.567	2,816	$ 0.839	2,347	$ 0.600	1,721	$ 0.584	313	$ 0.545	$ 505	$ 467
1998	59,067	2	1,654	$ 0.584	1,103	$ 0.567	2,977	$ 1.545	2,481	$ 0.600	1,819	$ 0.584	331	$ 0.545	$ 579	$ 515
1999	62,260	2	1,743	$ 0.584	1,162	$ 0.567	3,138	$ 1.545	2,615	$ 0.600	1,918	$ 0.584	349	$ 0.545	$ 610	$ 522
2000	65,452	2	1,833	$ 0.584	1,222	$ 0.567	3,299	$ 1.545	2,749	$ 0.839	2,016	$ 0.584	367	$ 0.545	$ 658	$ 541
2001	68,645	2	1,922	$ 0.584	1,281	$ 0.567	3,460	$ 1.545	2,883	$ 1.545	2,114	$ 0.584	384	$ 0.545	$ 742	$ 587
2002	71,838	2	2,011	$ 0.584	1,341	$ 0.567	3,621	$ 1.545	3,017	$ 1.545	2,213	$ 0.600	402	$ 0.545	$ 778	$ 591
2003	75,031	2	2,101	$ 0.584	1,401	$ 0.567	3,782	$ 1.545	3,151	$ 1.545	2,311	$ 0.600	420	$ 0.545	$ 813	$ 594
2004	78,224	2	2,190	$ 0.584	1,460	$ 0.567	3,942	$ 1.545	3,285	$ 1.545	2,409	$ 0.600	438	$ 0.545	$ 847	$ 595
2005	81,416	2	2,280	$ 0.600	1,520	$ 0.567	4,103	$ 1.545	3,419	$ 1.545	2,508	$ 0.600	456	$ 0.545	$ 888	$ 600
2006	84,609	2	2,369	$ 0.600	1,579	$ 0.584	4,264	$ 1.545	3,554	$ 1.545	2,606	$ 0.600	474	$ 0.545	$ 929	$ 603
2007	87,802	2	2,458	$ 0.600	1,639	$ 0.584	4,425	$ 1.545	3,688	$ 1.545	2,704	$ 0.839	492	$ 0.545	$ 986	$ 616
2008	90,995	2	2,548	$ 0.600	1,699	$ 0.584	4,586	$ 1.545	3,822	$ 1.545	2,803	$ 0.839	510	$ 0.545	$ 1,022	$ 614
2009	94,188	2	2,637	$ 0.839	1,758	$ 0.584	4,747	$ 1.545	3,956	$ 1.545	2,901	$ 1.545	527	$ 0.545	$ 1,230	$ 710
2010	97,380	2	2,727	$ 0.839	1,818	$ 0.584	4,908	$ 1.545	4,090	$ 1.545	2,999	$ 1.545	545	$ 0.545	$ 1,271	$ 706
2011	100,573	2	2,816	$ 0.839	1,877	$ 0.584	5,069	$ 1.545	4,224	$ 1.545	3,098	$ 1.545	563	$ 0.545	$ 1,313	$ 701
2012	103,766	2	2,905	$ 1.545	1,937	$ 0.584	5,230	$ 1.545	4,358	$ 1.545	3,196	$ 1.545	581	$ 0.545	$ 1,680	$ 863
2013	106,959	2	2,995	$ 1.545	1,997	$ 0.584	5,391	$ 1.545	4,492	$ 1.545	3,294	$ 1.545	599	$ 0.545	$ 1,732	$ 855
2014	110,152	2	3,084	$ 1.545	2,056	$ 0.584	5,552	$ 1.545	4,626	$ 1.545	3,393	$ 1.545	617	$ 0.545	$ 1,784	$ 847
2015	113,344	2	3,174	$ 1.545	2,116	$ 0.584	5,713	$ 1.545	4,760	$ 1.545	3,491	$ 1.545	635	$ 0.545	$ 1,835	$ 838
2016	116,537	2	3,263	$ 1.545	2,175	$ 0.584	5,873	$ 1.545	4,895	$ 1.545	3,589	$ 1.545	653	$ 0.545	$ 1,887	$ 828
2017	119,730	2	3,352	$ 1.545	2,235	$ 0.600	6,034	$ 1.545	5,029	$ 1.545	3,688	$ 1.545	670	$ 0.545	$ 1,947	$ 822
2018	122,923	2	3,442	$ 1.545	2,295	$ 0.600	6,195	$ 1.545	5,163	$ 1.545	3,786	$ 1.545	688	$ 0.545	$ 1,999	$ 811
2019	126,116	2	3,531	$ 1.545	2,354	$ 0.600	6,356	$ 1.545	5,297	$ 1.545	3,884	$ 1.545	706	$ 0.545	$ 2,051	$ 800
2020	129,308	2	3,621	$ 1.545	2,414	$ 0.600	6,517	$ 1.545	5,431	$ 1.545	3,983	$ 1.545	724	$ 0.545	$ 2,103	$ 789
2021	132,501	2	3,710	$ 1.545	2,473	$ 0.600	6,678	$ 1.545	5,565	$ 1.545	4,081	$ 1.545	742	$ 0.545	$ 2,155	$ 777
2022	135,694	2	3,799	$ 1.545	2,533	$ 0.600	6,839	$ 1.545	5,699	$ 1.545	4,179	$ 1.545	760	$ 0.545	$ 2,207	$ 765
2023	138,887	2	3,889	$ 1.545	2,593	$ 0.600	7,000	$ 1.545	5,833	$ 1.545	4,278	$ 1.545	778	$ 0.545	$ 2,259	$ 753
2024	142,080	2	3,978	$ 1.545	2,652	$ 0.839	7,161	$ 1.545	5,967	$ 1.545	4,376	$ 1.545	796	$ 0.545	$ 2,462	$ 789
2025	145,272	2	4,068	$ 1.545	2,712	$ 0.839	7,322	$ 1.545	6,101	$ 1.545	4,474	$ 1.545	814	$ 0.545	$ 2,517	$ 776
2026	148,465	2	4,157	$ 1.545	2,771	$ 0.839	7,483	$ 1.545	6,236	$ 1.545	4,573	$ 1.545	831	$ 0.545	$ 2,572	$ 763
2027	151,658	2	4,246	$ 1.545	2,831	$ 0.839	7,644	$ 1.545	6,370	$ 1.545	4,671	$ 1.545	849	$ 0.545	$ 2,628	$ 749
2028	154,851	2	4,336	$ 1.545	2,891	$ 1.545	7,804	$ 1.545	6,504	$ 1.545	4,769	$ 1.545	867	$ 0.545	$ 3,169	$ 869
2029	158,044	2	4,425	$ 1.545	2,950	$ 1.545	7,965	$ 1.545	6,638	$ 1.545	4,868	$ 1.545	885	$ 0.545	$ 3,234	$ 852
2030	161,236	2	4,515	$ 1.545	3,010	$ 1.545	8,126	$ 1.545	6,772	$ 1.545	4,966	$ 1.545	903	$ 0.545	$ 3,300	$ 836
2031	164,429	2	4,604	$ 1.545	3,069	$ 1.545	8,287	$ 1.545	6,906	$ 1.545	5,064	$ 1.545	921	$ 0.545	$ 3,365	$ 820
2032	167,622	2	4,693	$ 1.545	3,129	$ 1.545	8,448	$ 1.545	7,040	$ 1.545	5,163	$ 1.545	939	$ 0.545	$ 3,430	$ 804
2033	170,815	2	4,783	$ 1.545	3,189	$ 1.545	8,609	$ 1.545	7,174	$ 1.545	5,261	$ 1.545	957	$ 0.545	$ 3,496	$ 788
2034	174,008	2	4,872	$ 1.545	3,248	$ 1.545	8,770	$ 1.545	7,308	$ 1.545	5,359	$ 1.545	974	$ 0.545	$ 3,561	$ 771
2035	177,200	2	4,962	$ 1.545	3,308	$ 1.545	8,931	$ 1.545	7,442	$ 1.545	5,458	$ 1.545	992	$ 0.545	$ 3,627	$ 755
2036	180,393	2	5,051	$ 1.545	3,367	$ 1.545	9,092	$ 1.545	7,577	$ 1.545	5,556	$ 1.545	1,010	$ 0.567	$ 3,705	$ 742
2037	183,586	2	5,140	$ 1.545	3,427	$ 1.545	9,253	$ 1.545	7,711	$ 1.545	5,654	$ 1.545	1,028	$ 0.567	$ 3,770	$ 726
2038	186,779	2	5,230	$ 1.545	3,487	$ 1.545	9,414	$ 1.545	7,845	$ 1.545	5,753	$ 1.545	1,046	$ 0.567	$ 3,836	$ 710
2039	189,972	2	5,319	$ 1.545	3,546	$ 1.545	9,575	$ 1.545	7,979	$ 1.545	5,851	$ 1.545	1,064	$ 0.567	$ 3,901	$ 695
2040	193,164	2	5,409	$ 1.545	3,606	$ 1.545	9,735	$ 1.545	8,113	$ 1.545	5,949	$ 1.545	1,082	$ 0.567	$ 3,967	$ 679
2041	196,357	2	5,498	$ 1.545	3,665	$ 1.545	9,896	$ 1.545	8,247	$ 1.545	6,048	$ 1.545	1,100	$ 0.567	$ 4,032	$ 664
2042	199,550	2	5,587	$ 1.545	3,725	$ 1.545	10,057	$ 1.545	8,381	$ 1.545	6,146	$ 1.545	1,117	$ 0.567	$ 4,098	$ 649
2043	202,743	2	5,677	$ 1.545	3,785	$ 1.545	10,218	$ 1.545	8,515	$ 1.545	6,244	$ 1.545	1,135	$ 0.567	$ 4,164	$ 634
2044	205,936	2	5,766	$ 1.545	3,844	$ 1.545	10,379	$ 1.545	8,649	$ 1.545	6,343	$ 1.545	1,153	$ 0.567	$ 4,229	$ 619
2045	209,128	2	5,856	$ 1.545	3,904	$ 1.545	10,540	$ 1.545	8,783	$ 1.545	6,441	$ 1.545	1,171	$ 0.567	$ 4,295	$ 604

Cum TOTAL ($million): $ 35,452

Table E-2. User/Social Costs Calculation for "Adding lanes" alternative.

D: 56% surrog K: 5.00% 3.33% 9.00% 7.50% 5.50% 1.00%

McClennan segment miles: 42 "Adding lanes" alternative

			WEEKDAY				WEEKEND									Present Worth
8% growth rate			MONDAY-THURSDAY				FRIDAY-SUNDAY								TOTAL	4% real MARR
		dir	PERIOD 1 (12hr)		PERIOD 2 (12hr)		PERIOD 1 (4hr)		PERIOD 2 (4hr)		PERIOD 3 (4hr)		PERIOD 4 (12hr)		userS/yr	userS/yr
YEAR	ADT	ln	vph/dir	usrS/vh/mi	vph/dir	usrS/vh/mi	vph/dir	usrS/vh/mi	vph/dir	usrS/vh/mi	vph/dir	usrS/vh/mi	vph/dir	usrS/vh/mi	[Smillion]	[Smillion]
1983	28,000		784		523		1,411		1,176		862		157			
1984	28,000		784		523		1,411		1,176		862		157			
1985	29,000		812		541		1,462		1,218		893		162			
1986	31,000		868		579		1,562		1,302		955		174			
1987	32,530		911		607		1,640		1,366		1,002		182			
1988	32,500		910		607		1,638		1,365		1,001		182			
1989	34,670		971		647		1,747		1,456		1,068		194			
1990	36,130		1,012		674		1,821		1,517		1,113		202			
1991	38,180		1,069		713		1,924		1,604		1,176		214			
1992	39,910		1,117		745		2,011		1,676		1,229		223			
1993	43,103		1,207		805		2,172		1,810		1,328		241			
1994	46,296		1,296		864		2,333		1,944		1,426		259			
1995	49,488		1,386		924		2,494		2,079		1,524		277			
1996	52,681	2	1,475	S 0.567	983	S 0.545	2,655	S 0.839	2,213	S 0.600	1,623	S 0.584	295	S 0.545	S 467	S 449
1997	55,874	2	1,564	S 0.584	1,043	S 0.567	2,816	S 0.839	2,347	S 0.600	1,721	S 0.584	313	S 0.545	S 505	S 467
1998	59,067	2	1,654	S 0.584	1,103	S 0.567	2,977	S 1.545	2,481	S 0.600	1,819	S 0.584	331	S 0.545	S 579	S 515
1999	62,260	2	1,743	S 0.584	1,162	S 0.567	3,138	S 1.545	2,615	S 0.600	1,918	S 0.584	349	S 0.545	S 610	S 522
2000	65,452	2	1,833	S 0.584	1,222	S 0.567	3,299	S 1.545	2,749	S 0.839	2,016	S 0.584	367	S 0.545	S 658	S 541
2001	68,645	1.5	1,922	S 0.600	1,281	S 0.584	3,460	S 1.545	2,883	S 1.545	2,114	S 0.839	384	S 0.545	S 771	S 609
2002	71,838	1.5	2,011	S 0.839	1,341	S 0.584	3,621	S 1.545	3,017	S 1.545	2,213	S 1.545	402	S 0.545	S 938	S 713
2003	75,031	1.5	2,101	S 0.839	1,401	S 0.584	3,782	S 1.545	3,151	S 1.545	2,311	S 1.545	420	S 0.545	S 979	S 716
2004	78,224	1.5	2,190	S 1.545	1,460	S 0.584	3,942	S 1.545	3,285	S 1.545	2,409	S 1.545	438	S 0.545	S 1,267	S 890
2005	81,416	1.5	2,280	S 1.545	1,520	S 0.584	4,103	S 1.545	3,419	S 1.545	2,508	S 1.545	456	S 0.545	S 1,318	S 891
2006	84,609	9	2,369	S 0.545	1,579	S 0.545	4,264	S 0.545	3,554	S 0.545	2,606	S 0.545	474	S 0.545	S 707	S 459
2007	87,802	9	2,458	S 0.545	1,639	S 0.545	4,425	S 0.545	3,688	S 0.545	2,704	S 0.545	492	S 0.545	S 734	S 458
2008	90,995	9	2,548	S 0.545	1,699	S 0.545	4,586	S 0.567	3,822	S 0.545	2,803	S 0.545	510	S 0.545	S 762	S 458
2009	94,188	9	2,637	S 0.545	1,758	S 0.545	4,747	S 0.567	3,956	S 0.545	2,901	S 0.545	527	S 0.545	S 789	S 456
2010	97,380	9	2,727	S 0.545	1,818	S 0.545	4,908	S 0.567	4,090	S 0.545	2,999	S 0.545	545	S 0.545	S 816	S 453
2011	100,573	9	2,816	S 0.545	1,877	S 0.545	5,069	S 0.567	4,224	S 0.545	3,098	S 0.545	563	S 0.545	S 843	S 450
2012	103,766	9	2,905	S 0.545	1,937	S 0.545	5,230	S 0.567	4,358	S 0.545	3,196	S 0.545	581	S 0.545	S 869	S 446
2013	106,959	9	2,995	S 0.545	1,997	S 0.545	5,391	S 0.567	4,492	S 0.567	3,294	S 0.545	599	S 0.545	S 899	S 444
2014	110,152	9	3,084	S 0.545	2,056	S 0.545	5,552	S 0.567	4,626	S 0.567	3,393	S 0.545	617	S 0.545	S 926	S 439
2015	113,344	9	3,174	S 0.545	2,116	S 0.545	5,713	S 0.567	4,760	S 0.567	3,491	S 0.545	635	S 0.545	S 952	S 435
2016	116,537	9	3,263	S 0.545	2,175	S 0.545	5,873	S 0.567	4,895	S 0.567	3,589	S 0.545	653	S 0.545	S 979	S 430
2017	119,730	9	3,352	S 0.545	2,235	S 0.545	6,034	S 0.567	5,029	S 0.567	3,688	S 0.545	670	S 0.545	S 1,006	S 424
2018	122,923	9	3,442	S 0.545	2,295	S 0.545	6,195	S 0.567	5,163	S 0.567	3,786	S 0.545	688	S 0.545	S 1,033	S 419
2019	126,116	9	3,531	S 0.545	2,354	S 0.545	6,356	S 0.567	5,297	S 0.567	3,884	S 0.545	706	S 0.545	S 1,060	S 413
2020	129,308	9	3,621	S 0.545	2,414	S 0.545	6,517	S 0.567	5,431	S 0.567	3,983	S 0.545	724	S 0.545	S 1,086	S 408
2021	132,501	9	3,710	S 0.545	2,473	S 0.545	6,678	S 0.567	5,565	S 0.567	4,081	S 0.545	742	S 0.545	S 1,113	S 402
2022	135,694	9	3,799	S 0.545	2,533	S 0.545	6,839	S 0.567	5,699	S 0.567	4,179	S 0.545	760	S 0.545	S 1,140	S 395
2023	138,887	9	3,889	S 0.545	2,593	S 0.545	7,000	S 0.567	5,833	S 0.567	4,278	S 0.545	778	S 0.545	S 1,167	S 389
2024	142,080	9	3,978	S 0.545	2,652	S 0.545	7,161	S 0.584	5,967	S 0.567	4,376	S 0.545	796	S 0.545	S 1,196	S 384
2025	145,272	9	4,068	S 0.545	2,712	S 0.545	7,322	S 0.584	6,101	S 0.567	4,474	S 0.567	814	S 0.545	S 1,227	S 378
2026	148,465	9	4,157	S 0.545	2,771	S 0.545	7,483	S 0.584	6,236	S 0.567	4,573	S 0.567	831	S 0.545	S 1,254	S 372
2027	151,658	9	4,246	S 0.545	2,831	S 0.545	7,644	S 0.584	6,370	S 0.567	4,671	S 0.567	849	S 0.545	S 1,281	S 365
2028	154,851	9	4,336	S 0.545	2,891	S 0.545	7,804	S 0.584	6,504	S 0.567	4,769	S 0.567	867	S 0.545	S 1,308	S 358
2029	158,044	9	4,425	S 0.545	2,950	S 0.545	7,965	S 0.584	6,638	S 0.567	4,868	S 0.567	885	S 0.545	S 1,335	S 352
2030	161,236	9	4,515	S 0.567	3,010	S 0.545	8,126	S 0.584	6,772	S 0.567	4,966	S 0.567	903	S 0.545	S 1,377	S 349
2031	164,429	9	4,604	S 0.567	3,069	S 0.545	8,287	S 0.584	6,906	S 0.567	5,064	S 0.567	921	S 0.545	S 1,405	S 342
2032	167,622	9	4,693	S 0.567	3,129	S 0.545	8,448	S 0.584	7,040	S 0.584	5,163	S 0.567	939	S 0.545	S 1,435	S 336
2033	170,815	9	4,783	S 0.567	3,189	S 0.545	8,609	S 0.584	7,174	S 0.584	5,261	S 0.567	957	S 0.545	S 1,462	S 329
2034	174,008	9	4,872	S 0.567	3,248	S 0.545	8,770	S 0.584	7,308	S 0.584	5,359	S 0.567	974	S 0.545	S 1,489	S 323
2035	177,200	9	4,962	S 0.567	3,308	S 0.545	8,931	S 0.584	7,442	S 0.584	5,458	S 0.567	992	S 0.545	S 1,517	S 316
2036	180,393	9	5,051	S 0.567	3,367	S 0.545	9,092	S 0.584	7,577	S 0.584	5,556	S 0.567	1,010	S 0.545	S 1,544	S 309
2037	183,586	9	5,140	S 0.567	3,427	S 0.545	9,253	S 0.584	7,711	S 0.584	5,654	S 0.567	1,028	S 0.545	S 1,571	S 303
2038	186,779	9	5,230	S 0.567	3,487	S 0.545	9,414	S 0.584	7,845	S 0.584	5,753	S 0.567	1,046	S 0.545	S 1,599	S 296
2039	189,972	9	5,319	S 0.567	3,546	S 0.545	9,575	S 0.584	7,979	S 0.584	5,851	S 0.567	1,064	S 0.545	S 1,626	S 290
2040	193,164	9	5,409	S 0.567	3,606	S 0.545	9,735	S 0.584	8,113	S 0.584	5,949	S 0.567	1,082	S 0.545	S 1,653	S 283
2041	196,357	9	5,498	S 0.567	3,665	S 0.545	9,896	S 0.584	8,247	S 0.584	6,048	S 0.567	1,100	S 0.545	S 1,681	S 277
2042	199,550	9	5,587	S 0.567	3,725	S 0.545	10,057	S 0.600	8,381	S 0.584	6,146	S 0.567	1,117	S 0.545	S 1,712	S 271
2043	202,743	9	5,677	S 0.567	3,785	S 0.545	10,218	S 0.600	8,515	S 0.584	6,244	S 0.567	1,135	S 0.545	S 1,739	S 265
2044	205,936	9	5,766	S 0.567	3,844	S 0.545	10,379	S 0.600	8,649	S 0.584	6,343	S 0.567	1,153	S 0.545	S 1,766	S 258
2045	209,128	9	5,856	S 0.567	3,904	S 0.545	10,540	S 0.600	8,783	S 0.584	6,441	S 0.567	1,171	S 0.545	S 1,794	S 252

Cum TOTAL (Smillion): S 21,098

Table E-3. User/Social Costs Calculation for "Retrofit with ITS" (cars) alternative.

D: 56% surrog K: 5.00% 3.33% 9.00% 7.50% 5.50% 1.00%

McClennan segment miles: 42 "Retrofit with ITS" (cars)

			WEEKDAY				WEEKEND								TOTAL	Present Worth
8% growth rate			MONDAY-THURSDAY				FRIDAY-SUNDAY									4% real MARR
		dir	PERIOD 1 (12hr)		PERIOD 2 (12hr)		PERIOD 1 (4hr)		PERIOD 2 (4hr)		PERIOD 3 (4hr)		PERIOD 4 (12hr)		user$/yr	user$/yr
YEAR	ADT	ln	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	[$million]	[$million]
1983	28,000		784		523		1,411		1,176		862		157			
1984	28,000		784		523		1,411		1,176		862		157			
1985	29,000		812		541		1,462		1,218		893		162			
1986	31,000		868		579		1,562		1,302		955		174			
1987	32,530		911		607		1,640		1,366		1,002		182			
1988	32,500		910		607		1,638		1,365		1,001		182			
1989	34,670		971		647		1,747		1,456		1,068		194			
1990	36,130		1,012		674		1,821		1,517		1,113		202			
1991	38,180		1,069		713		1,924		1,604		1,176		214			
1992	39,910		1,117		745		2,011		1,676		1,229		223			
1993	43,103		1,207		805		2,172		1,810		1,328		241			
1994	46,296		1,296		864		2,333		1,944		1,426		259			
1995	49,488		1,386		924		2,494		2,079		1,524		277			
1996	52,681	2	1,475	$ 0.567	983	$ 0.545	2,655	$ 0.839	2,213	$ 0.600	1,623	$ 0.584	295	$ 0.545	$ 467	$ 449
1997	55,874	2	1,564	$ 0.584	1,043	$ 0.567	2,816	$ 0.839	2,347	$ 0.600	1,721	$ 0.584	313	$ 0.545	$ 505	$ 467
1998	59,067	2	1,654	$ 0.584	1,103	$ 0.567	2,977	$ 1.545	2,481	$ 0.600	1,819	$ 0.584	331	$ 0.545	$ 579	$ 515
1999	62,260	2	1,743	$ 0.584	1,162	$ 0.567	3,138	$ 1.545	2,615	$ 0.600	1,918	$ 0.584	349	$ 0.545	$ 610	$ 522
2000	65,452	2	1,833	$ 0.584	1,222	$ 0.567	3,299	$ 1.545	2,749	$ 0.839	2,016	$ 0.584	367	$ 0.545	$ 658	$ 541
2001	68,645	1.5	1,922	$ 0.600	1,281	$ 0.584	3,460	$ 1.545	2,883	$ 1.545	2,114	$ 0.839	384	$ 0.545	$ 771	$ 609
2002	71,838	1.5	2,011	$ 0.839	1,341	$ 0.584	3,621	$ 1.545	3,017	$ 1.545	2,213	$ 1.545	402	$ 0.545	$ 938	$ 713
2003	75,031	1.5	2,101	$ 0.839	1,401	$ 0.584	3,782	$ 1.545	3,151	$ 1.545	2,311	$ 1.545	420	$ 0.545	$ 979	$ 716
2004	78,224	1.5	2,190	$ 1.545	1,460	$ 0.584	3,942	$ 1.545	3,285	$ 1.545	2,409	$ 1.545	438	$ 0.545	$ 1,267	$ 890
2005	81,416	1.5	2,280	$ 1.545	1,520	$ 0.584	4,103	$ 1.545	3,419	$ 1.545	2,508	$ 1.545	456	$ 0.545	$ 1,318	$ 891
2006c	67,687	5	1,895	$ 0.445	1,263	$ 0.445	3,411	$ 0.445	2,843	$ 0.445	2,085	$ 0.445	379	$ 0.445	$ 462	$ 300
2007c	70,242	5	1,967	$ 0.445	1,311	$ 0.445	3,540	$ 0.469	2,950	$ 0.445	2,163	$ 0.445	393	$ 0.445	$ 481	$ 300
2008c	72,796	5	2,038	$ 0.445	1,359	$ 0.445	3,669	$ 0.469	3,057	$ 0.445	2,242	$ 0.445	408	$ 0.445	$ 498	$ 299
2009c	75,350	5	2,110	$ 0.445	1,407	$ 0.445	3,798	$ 0.469	3,165	$ 0.445	2,321	$ 0.445	422	$ 0.445	$ 516	$ 298
2010c	77,904	5	2,181	$ 0.445	1,454	$ 0.445	3,926	$ 0.469	3,272	$ 0.445	2,399	$ 0.445	436	$ 0.445	$ 533	$ 296
2011c	80,459	5	2,253	$ 0.445	1,502	$ 0.445	4,055	$ 0.469	3,379	$ 0.445	2,478	$ 0.445	451	$ 0.445	$ 551	$ 294
2012c	83,013	5	2,324	$ 0.445	1,550	$ 0.445	4,184	$ 0.469	3,487	$ 0.445	2,557	$ 0.445	465	$ 0.445	$ 568	$ 292
2013c	85,567	5	2,396	$ 0.445	1,597	$ 0.445	4,313	$ 0.469	3,594	$ 0.469	2,635	$ 0.445	479	$ 0.445	$ 588	$ 290
2014c	88,121	5	2,467	$ 0.445	1,645	$ 0.445	4,441	$ 0.469	3,701	$ 0.469	2,714	$ 0.445	493	$ 0.445	$ 606	$ 287
2015c	90,676	5	2,539	$ 0.445	1,693	$ 0.445	4,570	$ 0.469	3,808	$ 0.469	2,793	$ 0.445	508	$ 0.445	$ 623	$ 284
2016c	93,230	5	2,610	$ 0.445	1,740	$ 0.445	4,699	$ 0.469	3,916	$ 0.469	2,871	$ 0.445	522	$ 0.445	$ 641	$ 281
2017c	95,784	5	2,682	$ 0.445	1,788	$ 0.445	4,828	$ 0.469	4,023	$ 0.469	2,950	$ 0.445	536	$ 0.445	$ 658	$ 278
2018c	98,338	5	2,753	$ 0.445	1,836	$ 0.445	4,956	$ 0.469	4,130	$ 0.469	3,029	$ 0.445	551	$ 0.445	$ 676	$ 274
2019c	100,892	5	2,825	$ 0.445	1,883	$ 0.445	5,085	$ 0.469	4,237	$ 0.469	3,107	$ 0.445	565	$ 0.445	$ 693	$ 271
2020c	103,447	5	2,897	$ 0.445	1,931	$ 0.445	5,214	$ 0.469	4,345	$ 0.469	3,186	$ 0.445	579	$ 0.445	$ 711	$ 267
2021c	106,001	5	2,968	$ 0.445	1,979	$ 0.445	5,342	$ 0.469	4,452	$ 0.469	3,265	$ 0.445	594	$ 0.445	$ 729	$ 263
2022c	108,555	5	3,040	$ 0.445	2,026	$ 0.445	5,471	$ 0.469	4,559	$ 0.469	3,344	$ 0.445	608	$ 0.445	$ 746	$ 259
2023c	111,109	5	3,111	$ 0.445	2,074	$ 0.445	5,600	$ 0.486	4,667	$ 0.469	3,422	$ 0.445	622	$ 0.445	$ 766	$ 255
2024c	113,664	5	3,183	$ 0.445	2,122	$ 0.445	5,729	$ 0.486	4,774	$ 0.469	3,501	$ 0.469	637	$ 0.445	$ 786	$ 252
2025c	116,218	5	3,254	$ 0.445	2,169	$ 0.445	5,857	$ 0.486	4,881	$ 0.469	3,580	$ 0.469	651	$ 0.445	$ 804	$ 248
2026c	118,772	5	3,326	$ 0.445	2,217	$ 0.445	5,986	$ 0.486	4,988	$ 0.469	3,658	$ 0.469	665	$ 0.445	$ 822	$ 244
2027c	121,326	5	3,397	$ 0.445	2,265	$ 0.445	6,115	$ 0.486	5,096	$ 0.469	3,737	$ 0.469	679	$ 0.445	$ 839	$ 239
2028c	123,881	5	3,469	$ 0.445	2,312	$ 0.445	6,244	$ 0.486	5,203	$ 0.469	3,816	$ 0.469	694	$ 0.445	$ 857	$ 235
2029c	126,435	5	3,540	$ 0.469	2,360	$ 0.445	6,372	$ 0.486	5,310	$ 0.469	3,894	$ 0.469	708	$ 0.445	$ 888	$ 234
2030c	128,989	5	3,612	$ 0.469	2,408	$ 0.445	6,501	$ 0.486	5,418	$ 0.469	3,973	$ 0.469	722	$ 0.445	$ 906	$ 230
2031c	131,543	5	3,683	$ 0.469	2,455	$ 0.445	6,630	$ 0.486	5,525	$ 0.486	4,052	$ 0.469	737	$ 0.445	$ 926	$ 226
2032c	134,098	5	3,755	$ 0.469	2,503	$ 0.445	6,759	$ 0.486	5,632	$ 0.486	4,130	$ 0.469	751	$ 0.445	$ 944	$ 221
2033c	136,652	5	3,826	$ 0.469	2,551	$ 0.445	6,887	$ 0.486	5,739	$ 0.486	4,209	$ 0.469	765	$ 0.445	$ 962	$ 217
2034c	139,206	5	3,898	$ 0.469	2,599	$ 0.445	7,016	$ 0.486	5,847	$ 0.486	4,288	$ 0.469	780	$ 0.445	$ 980	$ 212
2035c	141,760	5	3,969	$ 0.469	2,646	$ 0.445	7,145	$ 0.486	5,954	$ 0.486	4,366	$ 0.469	794	$ 0.445	$ 998	$ 208
2036c	144,315	5	4,041	$ 0.469	2,694	$ 0.445	7,273	$ 0.486	6,061	$ 0.486	4,445	$ 0.469	808	$ 0.445	$ 1,016	$ 204
2037c	146,869	5	4,112	$ 0.469	2,742	$ 0.445	7,402	$ 0.486	6,168	$ 0.486	4,524	$ 0.469	822	$ 0.445	$ 1,034	$ 199
2038c	149,423	5	4,184	$ 0.469	2,789	$ 0.445	7,531	$ 0.486	6,276	$ 0.486	4,602	$ 0.469	837	$ 0.445	$ 1,052	$ 195
2039c	151,977	5	4,255	$ 0.469	2,837	$ 0.445	7,660	$ 0.486	6,383	$ 0.486	4,681	$ 0.469	851	$ 0.445	$ 1,070	$ 191
2040c	154,532	5	4,327	$ 0.469	2,885	$ 0.445	7,788	$ 0.502	6,490	$ 0.486	4,760	$ 0.469	865	$ 0.445	$ 1,091	$ 187
2041c	157,086	5	4,398	$ 0.469	2,932	$ 0.445	7,917	$ 0.502	6,598	$ 0.486	4,838	$ 0.469	880	$ 0.445	$ 1,109	$ 183
2042c	159,640	5	4,470	$ 0.469	2,980	$ 0.445	8,046	$ 0.502	6,705	$ 0.486	4,917	$ 0.469	894	$ 0.445	$ 1,127	$ 178
2043c	162,194	5	4,541	$ 0.469	3,028	$ 0.445	8,175	$ 0.502	6,812	$ 0.486	4,996	$ 0.469	908	$ 0.445	$ 1,145	$ 174
2044c	164,748	5	4,613	$ 0.469	3,075	$ 0.445	8,303	$ 0.502	6,919	$ 0.486	5,074	$ 0.469	923	$ 0.445	$ 1,163	$ 170
2045c	167,303	5	4,684	$ 0.469	3,123	$ 0.445	8,432	$ 0.502	7,027	$ 0.486	5,153	$ 0.469	937	$ 0.445	$ 1,181	$ 166

Cum TOTAL ($million): $ 16,013

Table E-4. User/Social Costs Calculation for "Retrofit with ITS" (trucks) alternative.

D: 56% surrog K: 5.00% 3.33% 9.00% 7.50% 5.50% 1.00%

McClennan segment miles: 42 "Retrofit with ITS" (trucks)

8% growth rate

			WEEKDAY MONDAY-THURSDAY				WEEKEND FRIDAY-SUNDAY								TOTAL	Present Worth 4% real MARR
		dir	PERIOD 1 (12hr)		PERIOD 2 (12hr)		PERIOD 1 (4hr)		PERIOD 2 (4hr)		PERIOD 3 (4hr)		PERIOD 4 (12hr)		usr$/yr	usr$/yr
YEAR	ADT	ln	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	[$million]	[$million]
1983	28,000															
1984	28,000															
1985	29,000															
1986	31,000															
1987	32,530															
1988	32,500															
1989	34,670															
1990	36,130															
1991	38,180															
1992	39,910															
1993	43,103															
1994	46,296															
1995	49,488															
1996	52,681	2													$ -	$ -
1997	55,874	2													$ -	$ -
1998	59,067	2													$ -	$ -
1999	62,260	2													$ -	$ -
2000	65,452	2													$ -	$ -
2001	68,645	1.5													$ -	$ -
2002	71,838	1.5													$ -	$ -
2003	75,031	1.5													$ -	$ -
2004	78,224	1.5													$ -	$ -
2005	81,416	1.5													$ -	$ -
2006t	16,922	4	474	$ 0.943	316	$ 0.943	853	$ 0.943	711	$ 0.943	521	$ 0.943	95	$ 0.943	$ 245	$ 159
2007t	17,560	4	492	$ 0.943	328	$ 0.943	885	$ 0.943	738	$ 0.943	541	$ 0.943	98	$ 0.943	$ 254	$ 159
2008t	18,199	4	510	$ 0.943	340	$ 0.943	917	$ 0.943	764	$ 0.943	561	$ 0.943	102	$ 0.943	$ 263	$ 158
2009t	18,838	4	527	$ 0.943	352	$ 0.943	949	$ 0.959	791	$ 0.943	580	$ 0.943	105	$ 0.943	$ 273	$ 157
2010t	19,476	4	545	$ 0.943	364	$ 0.943	982	$ 0.959	818	$ 0.943	600	$ 0.943	109	$ 0.943	$ 282	$ 157
2011t	20,115	4	563	$ 0.943	375	$ 0.943	1,014	$ 0.959	845	$ 0.943	620	$ 0.943	113	$ 0.943	$ 291	$ 155
2012t	20,753	4	581	$ 0.943	387	$ 0.943	1,046	$ 0.959	872	$ 0.943	639	$ 0.943	116	$ 0.943	$ 300	$ 154
2013t	21,392	4	599	$ 0.943	399	$ 0.943	1,078	$ 0.959	898	$ 0.943	659	$ 0.943	120	$ 0.943	$ 310	$ 153
2014t	22,030	4	617	$ 0.943	411	$ 0.943	1,110	$ 0.959	925	$ 0.959	679	$ 0.943	123	$ 0.943	$ 319	$ 152
2015t	22,669	4	635	$ 0.943	423	$ 0.943	1,143	$ 0.959	952	$ 0.959	698	$ 0.943	127	$ 0.943	$ 328	$ 150
2016t	23,307	4	653	$ 0.943	435	$ 0.943	1,175	$ 0.959	979	$ 0.959	718	$ 0.943	131	$ 0.943	$ 338	$ 148
2017t	23,946	4	670	$ 0.943	447	$ 0.943	1,207	$ 0.959	1,006	$ 0.959	738	$ 0.943	134	$ 0.943	$ 347	$ 146
2018t	24,585	4	688	$ 0.943	459	$ 0.943	1,239	$ 0.959	1,033	$ 0.959	757	$ 0.943	138	$ 0.943	$ 356	$ 145
2019t	25,223	4	706	$ 0.943	471	$ 0.943	1,271	$ 0.959	1,059	$ 0.959	777	$ 0.943	141	$ 0.943	$ 365	$ 143
2020t	25,862	4	724	$ 0.943	483	$ 0.943	1,303	$ 0.959	1,086	$ 0.959	797	$ 0.943	145	$ 0.943	$ 375	$ 141
2021t	26,500	4	742	$ 0.943	495	$ 0.943	1,336	$ 0.959	1,113	$ 0.959	816	$ 0.943	148	$ 0.943	$ 384	$ 139
2022t	27,139	4	760	$ 0.943	507	$ 0.943	1,368	$ 0.959	1,140	$ 0.959	836	$ 0.943	152	$ 0.943	$ 393	$ 136
2023t	27,777	4	778	$ 0.943	519	$ 0.943	1,400	$ 0.959	1,167	$ 0.959	856	$ 0.943	156	$ 0.943	$ 403	$ 134
2024t	28,416	4	796	$ 0.943	530	$ 0.943	1,432	$ 0.959	1,193	$ 0.959	875	$ 0.943	159	$ 0.943	$ 412	$ 132
2025t	29,054	4	814	$ 0.943	542	$ 0.943	1,464	$ 0.976	1,220	$ 0.959	895	$ 0.943	163	$ 0.943	$ 422	$ 130
2026t	29,693	4	831	$ 0.943	554	$ 0.943	1,497	$ 0.976	1,247	$ 0.959	915	$ 0.943	166	$ 0.943	$ 431	$ 128
2027t	30,332	4	849	$ 0.943	566	$ 0.943	1,529	$ 0.976	1,274	$ 0.959	934	$ 0.959	170	$ 0.943	$ 441	$ 126
2028t	30,970	4	867	$ 0.943	578	$ 0.943	1,561	$ 0.976	1,301	$ 0.959	954	$ 0.959	173	$ 0.943	$ 450	$ 123
2029t	31,609	4	885	$ 0.943	590	$ 0.943	1,593	$ 0.976	1,328	$ 0.959	974	$ 0.959	177	$ 0.943	$ 459	$ 121
2030t	32,247	4	903	$ 0.943	602	$ 0.943	1,625	$ 0.976	1,354	$ 0.959	993	$ 0.959	181	$ 0.943	$ 468	$ 119
2031t	32,886	4	921	$ 0.943	614	$ 0.943	1,657	$ 0.976	1,381	$ 0.959	1,013	$ 0.959	184	$ 0.943	$ 478	$ 116
2032t	33,524	4	939	$ 0.959	626	$ 0.943	1,690	$ 0.976	1,408	$ 0.959	1,033	$ 0.959	188	$ 0.943	$ 489	$ 115
2033t	34,163	4	957	$ 0.959	638	$ 0.943	1,722	$ 0.976	1,435	$ 0.959	1,052	$ 0.959	191	$ 0.943	$ 499	$ 112
2034t	34,802	4	974	$ 0.959	650	$ 0.943	1,754	$ 0.976	1,462	$ 0.976	1,072	$ 0.959	195	$ 0.943	$ 509	$ 110
2035t	35,440	4	992	$ 0.959	662	$ 0.943	1,786	$ 0.976	1,488	$ 0.976	1,092	$ 0.959	198	$ 0.943	$ 518	$ 108
2036t	36,079	4	1,010	$ 0.959	673	$ 0.943	1,818	$ 0.976	1,515	$ 0.976	1,111	$ 0.959	202	$ 0.943	$ 527	$ 106
2037t	36,717	4	1,028	$ 0.959	685	$ 0.943	1,851	$ 0.976	1,542	$ 0.976	1,131	$ 0.959	206	$ 0.943	$ 537	$ 103
2038t	37,356	4	1,046	$ 0.959	697	$ 0.943	1,883	$ 0.976	1,569	$ 0.976	1,151	$ 0.959	209	$ 0.943	$ 546	$ 101
2039t	37,994	4	1,064	$ 0.959	709	$ 0.943	1,915	$ 0.976	1,596	$ 0.976	1,170	$ 0.959	213	$ 0.943	$ 555	$ 99
2040t	38,633	4	1,082	$ 0.959	721	$ 0.943	1,947	$ 0.976	1,623	$ 0.976	1,190	$ 0.959	216	$ 0.943	$ 565	$ 97
2041t	39,271	4	1,100	$ 0.959	733	$ 0.943	1,979	$ 0.976	1,649	$ 0.976	1,210	$ 0.959	220	$ 0.943	$ 574	$ 94
2042t	39,910	4	1,117	$ 0.959	745	$ 0.943	2,011	$ 0.976	1,676	$ 0.976	1,229	$ 0.959	223	$ 0.943	$ 583	$ 92
2043t	40,549	4	1,135	$ 0.959	757	$ 0.943	2,044	$ 0.976	1,703	$ 0.976	1,249	$ 0.959	227	$ 0.943	$ 593	$ 90
2044t	41,187	4	1,153	$ 0.959	769	$ 0.943	2,076	$ 0.992	1,730	$ 0.976	1,269	$ 0.959	231	$ 0.943	$ 603	$ 88
2045t	41,826	4	1,171	$ 0.959	781	$ 0.943	2,108	$ 0.992	1,757	$ 0.976	1,288	$ 0.959	234	$ 0.943	$ 612	$ 86

Cum TOTAL ($million): $ 5,081

Table E-5. User/Social Costs Calculation for "MTS" (Cars) alternative.

D: 56% surrog K: 5.00% 3.33% 9.00% 7.50% 5.50% 1.00%

McClennan segment miles: 42 "MTS" (Cars)

			WEEKDAY				WEEKEND									Present Worth
8% growth rate			MONDAY-THURSDAY				FRIDAY-SUNDAY								TOTAL	4% real MARR
		dir	PERIOD 1 (12hr)		PERIOD 2 (12hr)		PERIOD 1 (4hr)		PERIOD 2 (4hr)		PERIOD 3 (4hr)		PERIOD 4 (12hr)		userS/yr	userS/yr
YEAR	ADT	ln	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	[Smillion]	[Smillion]
1983																
1984																
1985																
1986																
1987																
1988																
1989																
1990																
1991																
1992																
1993																
1994																
1995																
1996															$ -	$ -
1997															$ -	$ -
1998															$ -	$ -
1999															$ -	$ -
2000															$ -	$ -
2001															$ -	$ -
2002															$ -	$ -
2003															$ -	$ -
2004															$ -	$ -
2005															$ -	$ -
2006c	37,228	3	1,042	$ 0.445	695	$ 0.445	1,876	$ 0.445	1,564	$ 0.445	1,147	$ 0.445	208	$ 0.445	$ 254	$ 165
2007c	38,633	3	1,082	$ 0.445	721	$ 0.445	1,947	$ 0.445	1,623	$ 0.445	1,190	$ 0.445	216	$ 0.445	$ 264	$ 165
2008c	40,038	3	1,121	$ 0.445	747	$ 0.445	2,018	$ 0.445	1,682	$ 0.445	1,233	$ 0.445	224	$ 0.445	$ 273	$ 164
2009c	41,443	3	1,160	$ 0.445	774	$ 0.445	2,089	$ 0.445	1,741	$ 0.445	1,276	$ 0.445	232	$ 0.445	$ 283	$ 163
2010c	42,847	3	1,200	$ 0.445	800	$ 0.445	2,160	$ 0.469	1,800	$ 0.445	1,320	$ 0.445	240	$ 0.445	$ 293	$ 163
2011c	44,252	3	1,239	$ 0.445	826	$ 0.445	2,230	$ 0.469	1,859	$ 0.445	1,363	$ 0.445	248	$ 0.445	$ 303	$ 162
2012c	45,657	3	1,278	$ 0.445	852	$ 0.445	2,301	$ 0.469	1,918	$ 0.445	1,406	$ 0.445	256	$ 0.445	$ 313	$ 161
2013c	47,062	3	1,318	$ 0.445	878	$ 0.445	2,372	$ 0.469	1,977	$ 0.445	1,450	$ 0.445	264	$ 0.445	$ 322	$ 159
2014c	48,467	3	1,357	$ 0.445	905	$ 0.445	2,443	$ 0.469	2,036	$ 0.445	1,493	$ 0.445	271	$ 0.445	$ 332	$ 158
2015c	49,872	3	1,396	$ 0.445	931	$ 0.445	2,514	$ 0.469	2,095	$ 0.445	1,536	$ 0.445	279	$ 0.445	$ 342	$ 156
2016c	51,276	3	1,436	$ 0.445	957	$ 0.445	2,584	$ 0.469	2,154	$ 0.469	1,579	$ 0.445	287	$ 0.445	$ 352	$ 155
2017c	52,681	3	1,475	$ 0.445	983	$ 0.445	2,655	$ 0.469	2,213	$ 0.469	1,623	$ 0.445	295	$ 0.445	$ 362	$ 153
2018c	54,086	3	1,514	$ 0.445	1,010	$ 0.445	2,726	$ 0.469	2,272	$ 0.469	1,666	$ 0.445	303	$ 0.445	$ 372	$ 151
2019c	55,491	3	1,554	$ 0.445	1,036	$ 0.445	2,797	$ 0.469	2,331	$ 0.469	1,709	$ 0.445	311	$ 0.445	$ 381	$ 149
2020c	56,896	3	1,593	$ 0.445	1,062	$ 0.445	2,868	$ 0.469	2,390	$ 0.469	1,752	$ 0.445	319	$ 0.445	$ 391	$ 147
2021c	58,301	3	1,632	$ 0.445	1,088	$ 0.445	2,938	$ 0.469	2,449	$ 0.469	1,796	$ 0.445	326	$ 0.445	$ 401	$ 145
2022c	59,705	3	1,672	$ 0.445	1,114	$ 0.445	3,009	$ 0.469	2,508	$ 0.469	1,839	$ 0.445	334	$ 0.445	$ 410	$ 142
2023c	61,110	3	1,711	$ 0.445	1,141	$ 0.445	3,080	$ 0.469	2,567	$ 0.469	1,882	$ 0.445	342	$ 0.445	$ 420	$ 140
2024c	62,515	3	1,750	$ 0.445	1,167	$ 0.445	3,151	$ 0.469	2,626	$ 0.469	1,925	$ 0.445	350	$ 0.445	$ 430	$ 138
2025c	63,920	3	1,790	$ 0.445	1,193	$ 0.445	3,222	$ 0.469	2,685	$ 0.469	1,969	$ 0.445	358	$ 0.445	$ 439	$ 135
2026c	65,325	3	1,829	$ 0.445	1,219	$ 0.445	3,292	$ 0.469	2,744	$ 0.469	2,012	$ 0.445	366	$ 0.445	$ 449	$ 133
2027c	66,730	3	1,868	$ 0.445	1,246	$ 0.445	3,363	$ 0.486	2,803	$ 0.469	2,055	$ 0.445	374	$ 0.445	$ 460	$ 131
2028c	68,134	3	1,908	$ 0.445	1,272	$ 0.445	3,434	$ 0.486	2,862	$ 0.469	2,099	$ 0.445	382	$ 0.445	$ 470	$ 129
2029c	69,539	3	1,947	$ 0.445	1,298	$ 0.445	3,505	$ 0.486	2,921	$ 0.469	2,142	$ 0.469	389	$ 0.445	$ 481	$ 127
2030c	70,944	3	1,986	$ 0.445	1,324	$ 0.445	3,576	$ 0.486	2,980	$ 0.469	2,185	$ 0.469	397	$ 0.445	$ 491	$ 124
2031c	72,349	3	2,026	$ 0.445	1,351	$ 0.445	3,646	$ 0.486	3,039	$ 0.469	2,228	$ 0.469	405	$ 0.445	$ 500	$ 122
2032c	73,754	3	2,065	$ 0.445	1,377	$ 0.445	3,717	$ 0.486	3,098	$ 0.469	2,272	$ 0.469	413	$ 0.445	$ 510	$ 120
2033c	75,159	3	2,104	$ 0.469	1,403	$ 0.445	3,788	$ 0.486	3,157	$ 0.469	2,315	$ 0.469	421	$ 0.445	$ 528	$ 119
2034c	76,563	3	2,144	$ 0.469	1,429	$ 0.445	3,859	$ 0.486	3,216	$ 0.469	2,358	$ 0.469	429	$ 0.445	$ 538	$ 116
2035c	77,968	3	2,183	$ 0.469	1,455	$ 0.445	3,930	$ 0.486	3,275	$ 0.469	2,401	$ 0.469	437	$ 0.445	$ 548	$ 114
2036c	79,373	3	2,222	$ 0.469	1,482	$ 0.445	4,000	$ 0.486	3,334	$ 0.486	2,445	$ 0.469	444	$ 0.445	$ 559	$ 112
2037c	80,778	3	2,262	$ 0.469	1,508	$ 0.445	4,071	$ 0.486	3,393	$ 0.486	2,488	$ 0.469	452	$ 0.445	$ 569	$ 110
2038c	82,183	3	2,301	$ 0.469	1,534	$ 0.445	4,142	$ 0.486	3,452	$ 0.486	2,531	$ 0.469	460	$ 0.445	$ 579	$ 107
2039c	83,588	3	2,340	$ 0.469	1,560	$ 0.445	4,213	$ 0.486	3,511	$ 0.486	2,574	$ 0.469	468	$ 0.445	$ 589	$ 105
2040c	84,992	3	2,380	$ 0.469	1,587	$ 0.445	4,284	$ 0.486	3,570	$ 0.486	2,618	$ 0.469	476	$ 0.445	$ 599	$ 102
2041c	86,397	3	2,419	$ 0.469	1,613	$ 0.445	4,354	$ 0.486	3,629	$ 0.486	2,661	$ 0.469	484	$ 0.445	$ 608	$ 100
2042c	87,802	3	2,458	$ 0.469	1,639	$ 0.445	4,425	$ 0.486	3,688	$ 0.486	2,704	$ 0.469	492	$ 0.445	$ 618	$ 98
2043c	89,207	3	2,498	$ 0.469	1,665	$ 0.445	4,496	$ 0.486	3,747	$ 0.486	2,748	$ 0.469	500	$ 0.445	$ 628	$ 96
2044c	90,612	3	2,537	$ 0.469	1,691	$ 0.445	4,567	$ 0.486	3,806	$ 0.486	2,791	$ 0.469	507	$ 0.445	$ 638	$ 93
2045c	92,016	3	2,576	$ 0.469	1,718	$ 0.445	4,638	$ 0.486	3,865	$ 0.486	2,834	$ 0.469	515	$ 0.445	$ 648	$ 91

Cum TOTAL (Smillion): S 5,318

Table E-6. User/Social Costs Calculation for "MTS" (IH-35) alternative.

D: 56%		surrog K:	5.00%		3.33%		9.00%		7.50%		5.50%		1.00%			
			McClennan				segment miles: 42								"MTS" (IH-35)	
			WEEKDAY				WEEKEND									Present Worth
8% growth rate			MONDAY-THURSDAY				FRIDAY-SUNDAY								TOTAL	4% real MARR
		dir	PERIOD 1 (12hr)		PERIOD 2 (12hr)		PERIOD 1 (4hr)		PERIOD 2 (4hr)		PERIOD 3 (4hr)		PERIOD 4 (12hr)		usr$/yr	usr$/yr
YEAR	ADT	ln	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	[$million]	[$million]
1983	28,000		784		523		1,411		1,176		862		157			
1984	28,000		784		523		1,411		1,176		862		157			
1985	29,000		812		541		1,462		1,218		893		162			
1986	31,000		868		579		1,562		1,302		955		174			
1987	32,530		911		607		1,640		1,366		1,002		182			
1988	32,500		910		607		1,638		1,365		1,001		182			
1989	34,670		971		647		1,747		1,456		1,068		194			
1990	36,130		1,012		674		1,821		1,517		1,113		202			
1991	38,180		1,069		713		1,924		1,604		1,176		214			
1992	39,910		1,117		745		2,011		1,676		1,229		223			
1993	43,103		1,207		805		2,172		1,810		1,328		241			
1994	46,296		1,296		864		2,333		1,944		1,426		259			
1995	49,488		1,386		924		2,494		2,079		1,524		277			
1996	52,681	2	1,475	$ 0.567	983	$ 0.545	2,655	$ 0.839	2,213	$ 0.600	1,623	$ 0.584	295	$ 0.545	$ 467	$ 449
1997	55,874	2	1,564	$ 0.584	1,043	$ 0.567	2,816	$ 0.839	2,347	$ 0.600	1,721	$ 0.584	313	$ 0.545	$ 505	$ 467
1998	59,067	2	1,654	$ 0.584	1,103	$ 0.567	2,977	$ 1.545	2,481	$ 0.600	1,819	$ 0.584	331	$ 0.545	$ 579	$ 515
1999	62,260	2	1,743	$ 0.584	1,162	$ 0.567	3,138	$ 1.545	2,615	$ 0.600	1,918	$ 0.584	349	$ 0.545	$ 610	$ 522
2000	65,452	2	1,833	$ 0.584	1,222	$ 0.567	3,299	$ 1.545	2,749	$ 0.839	2,016	$ 0.584	367	$ 0.545	$ 658	$ 541
2001	68,645	2	1,922	$ 0.584	1,281	$ 0.567	3,460	$ 1.545	2,883	$ 1.545	2,114	$ 0.584	384	$ 0.545	$ 742	$ 587
2002	71,838	2	2,011	$ 0.584	1,341	$ 0.567	3,621	$ 1.545	3,017	$ 1.545	2,213	$ 0.600	402	$ 0.545	$ 778	$ 591
2003	75,031	2	2,101	$ 0.584	1,401	$ 0.567	3,782	$ 1.545	3,151	$ 1.545	2,311	$ 0.600	420	$ 0.545	$ 813	$ 594
2004	78,224	2	2,190	$ 0.584	1,460	$ 0.567	3,942	$ 1.545	3,285	$ 1.545	2,409	$ 0.600	438	$ 0.545	$ 847	$ 595
2005	81,416	2	2,280	$ 0.600	1,520	$ 0.567	4,103	$ 1.545	3,419	$ 1.545	2,508	$ 0.600	456	$ 0.545	$ 888	$ 600
2006*	38,074	1.5	1,066	$ 0.567	711	$ 0.545	1,919	$ 0.600	1,599	$ 0.584	1,173	$ 0.584	213	$ 0.545	$ 327	$ 213
2007*	39,511	1.5	1,106	$ 0.567	738	$ 0.545	1,991	$ 0.839	1,659	$ 0.600	1,217	$ 0.584	221	$ 0.545	$ 350	$ 219
2008*	40,948	1.5	1,147	$ 0.567	764	$ 0.567	2,064	$ 0.839	1,720	$ 0.600	1,261	$ 0.584	229	$ 0.545	$ 367	$ 221
2009*	42,384	1.5	1,187	$ 0.584	791	$ 0.567	2,136	$ 1.545	1,780	$ 0.600	1,305	$ 0.584	237	$ 0.545	$ 415	$ 240
2010*	43,821	1.5	1,227	$ 0.584	818	$ 0.567	2,209	$ 1.545	1,840	$ 0.600	1,350	$ 0.584	245	$ 0.545	$ 429	$ 238
2011*	45,258	4	1,267	$ 0.545	845	$ 0.545	2,281	$ 0.567	1,901	$ 0.545	1,394	$ 0.545	253	$ 0.545	$ 379	$ 202
2012*	46,695	4	1,307	$ 0.545	872	$ 0.545	2,353	$ 0.567	1,961	$ 0.545	1,438	$ 0.545	261	$ 0.545	$ 391	$ 201
2013*	48,131	4	1,348	$ 0.545	898	$ 0.545	2,426	$ 0.567	2,022	$ 0.567	1,482	$ 0.545	270	$ 0.545	$ 404	$ 200
2014*	49,568	4	1,388	$ 0.545	925	$ 0.545	2,498	$ 0.567	2,082	$ 0.567	1,527	$ 0.545	278	$ 0.545	$ 416	$ 198
2015*	51,005	4	1,428	$ 0.545	952	$ 0.545	2,571	$ 0.567	2,142	$ 0.567	1,571	$ 0.545	286	$ 0.545	$ 429	$ 196
2016*	52,442	4	1,468	$ 0.545	979	$ 0.545	2,643	$ 0.567	2,203	$ 0.567	1,615	$ 0.545	294	$ 0.545	$ 441	$ 193
2017*	53,879	4	1,509	$ 0.545	1,006	$ 0.545	2,715	$ 0.567	2,263	$ 0.567	1,659	$ 0.545	302	$ 0.545	$ 453	$ 191
2018*	55,315	4	1,549	$ 0.545	1,033	$ 0.545	2,788	$ 0.567	2,323	$ 0.567	1,704	$ 0.545	310	$ 0.545	$ 465	$ 189
2019*	56,752	4	1,589	$ 0.545	1,059	$ 0.545	2,860	$ 0.567	2,384	$ 0.567	1,748	$ 0.545	318	$ 0.545	$ 477	$ 186
2020*	58,189	4	1,629	$ 0.545	1,086	$ 0.545	2,933	$ 0.567	2,444	$ 0.567	1,792	$ 0.545	326	$ 0.545	$ 489	$ 183
2021*	59,626	4	1,670	$ 0.545	1,113	$ 0.545	3,005	$ 0.567	2,504	$ 0.567	1,836	$ 0.545	334	$ 0.545	$ 501	$ 181
2022*	61,062	4	1,710	$ 0.545	1,140	$ 0.545	3,078	$ 0.567	2,565	$ 0.567	1,881	$ 0.545	342	$ 0.545	$ 513	$ 178
2023*	62,499	4	1,750	$ 0.545	1,167	$ 0.545	3,150	$ 0.584	2,625	$ 0.567	1,925	$ 0.545	350	$ 0.545	$ 526	$ 175
2024*	63,936	4	1,790	$ 0.545	1,193	$ 0.545	3,222	$ 0.584	2,685	$ 0.567	1,969	$ 0.545	358	$ 0.545	$ 538	$ 173
2025*	65,373	4	1,830	$ 0.545	1,220	$ 0.545	3,295	$ 0.584	2,746	$ 0.567	2,013	$ 0.567	366	$ 0.545	$ 552	$ 170
2026*	66,809	4	1,871	$ 0.545	1,247	$ 0.545	3,367	$ 0.584	2,806	$ 0.567	2,058	$ 0.567	374	$ 0.545	$ 564	$ 167
2027*	68,246	4	1,911	$ 0.545	1,274	$ 0.545	3,440	$ 0.584	2,866	$ 0.567	2,102	$ 0.567	382	$ 0.545	$ 576	$ 164
2028*	69,683	4	1,951	$ 0.545	1,301	$ 0.545	3,512	$ 0.584	2,927	$ 0.567	2,146	$ 0.567	390	$ 0.545	$ 588	$ 161
2029*	71,120	4	1,991	$ 0.567	1,328	$ 0.545	3,584	$ 0.584	2,987	$ 0.567	2,190	$ 0.567	398	$ 0.545	$ 607	$ 160
2030*	72,556	4	2,032	$ 0.567	1,354	$ 0.545	3,657	$ 0.584	3,047	$ 0.567	2,235	$ 0.567	406	$ 0.545	$ 620	$ 157
2031*	73,993	4	2,072	$ 0.567	1,381	$ 0.545	3,729	$ 0.584	3,108	$ 0.567	2,279	$ 0.567	414	$ 0.545	$ 632	$ 154
2032*	75,430	4	2,112	$ 0.567	1,408	$ 0.545	3,802	$ 0.584	3,168	$ 0.584	2,323	$ 0.567	422	$ 0.545	$ 646	$ 151
2033*	76,867	4	2,152	$ 0.567	1,435	$ 0.545	3,874	$ 0.584	3,228	$ 0.584	2,367	$ 0.567	430	$ 0.545	$ 658	$ 148
2034*	78,303	4	2,192	$ 0.567	1,462	$ 0.545	3,946	$ 0.584	3,289	$ 0.584	2,412	$ 0.567	438	$ 0.545	$ 670	$ 145
2035*	79,740	4	2,233	$ 0.567	1,488	$ 0.545	4,019	$ 0.584	3,349	$ 0.584	2,456	$ 0.567	447	$ 0.545	$ 683	$ 142
2036*	81,177	4	2,273	$ 0.567	1,515	$ 0.545	4,091	$ 0.584	3,409	$ 0.584	2,500	$ 0.567	455	$ 0.545	$ 695	$ 139
2037*	82,614	4	2,313	$ 0.567	1,542	$ 0.545	4,164	$ 0.584	3,470	$ 0.584	2,545	$ 0.567	463	$ 0.545	$ 707	$ 136
2038*	84,050	4	2,353	$ 0.567	1,569	$ 0.545	4,236	$ 0.584	3,530	$ 0.584	2,589	$ 0.567	471	$ 0.545	$ 719	$ 133
2039*	85,487	4	2,394	$ 0.567	1,596	$ 0.545	4,309	$ 0.584	3,590	$ 0.584	2,633	$ 0.567	479	$ 0.545	$ 732	$ 130
2040*	86,924	4	2,434	$ 0.567	1,623	$ 0.545	4,381	$ 0.584	3,651	$ 0.584	2,677	$ 0.567	487	$ 0.545	$ 744	$ 127
2041*	88,361	4	2,474	$ 0.567	1,649	$ 0.545	4,453	$ 0.600	3,711	$ 0.584	2,722	$ 0.567	495	$ 0.545	$ 758	$ 125
2042*	89,797	4	2,514	$ 0.567	1,676	$ 0.545	4,526	$ 0.600	3,771	$ 0.584	2,766	$ 0.567	503	$ 0.545	$ 770	$ 122
2043*	91,234	4	2,555	$ 0.567	1,703	$ 0.545	4,598	$ 0.600	3,832	$ 0.584	2,810	$ 0.567	511	$ 0.545	$ 783	$ 119
2044*	92,671	4	2,595	$ 0.567	1,730	$ 0.545	4,671	$ 0.600	3,892	$ 0.584	2,854	$ 0.567	519	$ 0.545	$ 795	$ 116
2045*	94,108	4	2,635	$ 0.567	1,757	$ 0.545	4,743	$ 0.600	3,953	$ 0.584	2,899	$ 0.567	527	$ 0.545	$ 807	$ 114

Cum TOTAL ($million): $ 12,219

Table E-7. User/Social Costs Calculation for "MTS" (trucks) alternative.

D: 56% surrog K: 5.00% 3.33% 9.00% 7.50% 5.50% 1.00%

McClennan segment miles: 42 "MTS" (Trucks)

			WEEKDAY				WEEKEND									Present Worth
8% growth rate			MONDAY-THURSDAY				FRIDAY-SUNDAY								TOTAL	4% real MARR
		dir	PERIOD 1 (12hr)		PERIOD 2 (12hr)		PERIOD 1 (4hr)		PERIOD 2 (4hr)		PERIOD 3 (4hr)		PERIOD 4 (12hr)		user$/yr	user$/yr
YEAR	ADT	ln	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	vph/dir	usr$/vh/mi	[$million]	[$million]
1983																
1984																
1985																
1986																
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1996															$ -	$ -
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1998															$ -	$ -
1999															$ -	$ -
2000															$ -	$ -
2001															$ -	$ -
2002															$ -	$ -
2003															$ -	$ -
2004															$ -	$ -
2005															$ -	$ -
2006t	9,307	2	261	$ 0.943	174	$ 0.943	469	$ 0.959	391	$ 0.943	287	$ 0.943	52	$ 0.943	$ 135	$ 88
2007t	9,658	2	270	$ 0.943	180	$ 0.943	487	$ 0.959	406	$ 0.943	297	$ 0.943	54	$ 0.943	$ 140	$ 87
2008t	10,009	2	280	$ 0.943	187	$ 0.943	504	$ 0.959	420	$ 0.943	308	$ 0.943	56	$ 0.943	$ 145	$ 87
2009t	10,361	2	290	$ 0.943	193	$ 0.943	522	$ 0.959	435	$ 0.943	319	$ 0.943	58	$ 0.943	$ 150	$ 87
2010t	10,712	2	300	$ 0.943	200	$ 0.943	540	$ 0.959	450	$ 0.943	330	$ 0.943	60	$ 0.943	$ 155	$ 86
2011t	11,063	2	310	$ 0.943	207	$ 0.943	558	$ 0.959	465	$ 0.959	341	$ 0.943	62	$ 0.943	$ 160	$ 86
2012t	11,414	2	320	$ 0.943	213	$ 0.943	575	$ 0.959	479	$ 0.959	352	$ 0.943	64	$ 0.943	$ 165	$ 85
2013t	11,765	2	329	$ 0.943	220	$ 0.943	593	$ 0.959	494	$ 0.959	362	$ 0.943	66	$ 0.943	$ 170	$ 84
2014t	12,117	2	339	$ 0.943	226	$ 0.943	611	$ 0.959	509	$ 0.959	373	$ 0.943	68	$ 0.943	$ 176	$ 83
2015t	12,468	2	349	$ 0.943	233	$ 0.943	628	$ 0.959	524	$ 0.959	384	$ 0.943	70	$ 0.943	$ 181	$ 82
2016t	12,819	2	359	$ 0.943	239	$ 0.943	646	$ 0.959	538	$ 0.959	395	$ 0.943	72	$ 0.943	$ 186	$ 82
2017t	13,170	2	369	$ 0.943	246	$ 0.943	664	$ 0.959	553	$ 0.959	406	$ 0.943	74	$ 0.943	$ 191	$ 81
2018t	13,522	2	379	$ 0.943	252	$ 0.943	681	$ 0.959	568	$ 0.959	416	$ 0.943	76	$ 0.943	$ 196	$ 79
2019t	13,873	2	388	$ 0.943	259	$ 0.943	699	$ 0.959	583	$ 0.959	427	$ 0.943	78	$ 0.943	$ 201	$ 78
2020t	14,224	2	398	$ 0.943	266	$ 0.943	717	$ 0.959	597	$ 0.959	438	$ 0.943	80	$ 0.943	$ 206	$ 77
2021t	14,575	2	408	$ 0.943	272	$ 0.943	735	$ 0.976	612	$ 0.959	449	$ 0.943	82	$ 0.943	$ 211	$ 76
2022t	14,926	2	418	$ 0.943	279	$ 0.943	752	$ 0.976	627	$ 0.959	460	$ 0.943	84	$ 0.943	$ 217	$ 75
2023t	15,278	2	428	$ 0.943	285	$ 0.943	770	$ 0.976	642	$ 0.959	471	$ 0.959	86	$ 0.943	$ 222	$ 74
2024t	15,629	2	438	$ 0.943	292	$ 0.943	788	$ 0.976	656	$ 0.959	481	$ 0.959	88	$ 0.943	$ 227	$ 73
2025t	15,980	2	447	$ 0.943	298	$ 0.943	805	$ 0.976	671	$ 0.959	492	$ 0.959	89	$ 0.943	$ 232	$ 72
2026t	16,331	2	457	$ 0.943	305	$ 0.943	823	$ 0.976	686	$ 0.959	503	$ 0.959	91	$ 0.943	$ 237	$ 70
2027t	16,682	2	467	$ 0.959	311	$ 0.943	841	$ 0.976	701	$ 0.959	514	$ 0.959	93	$ 0.943	$ 244	$ 69
2028t	17,034	2	477	$ 0.959	318	$ 0.943	858	$ 0.976	715	$ 0.959	525	$ 0.959	95	$ 0.943	$ 249	$ 68
2029t	17,385	2	487	$ 0.959	325	$ 0.943	876	$ 0.976	730	$ 0.976	535	$ 0.959	97	$ 0.943	$ 254	$ 67
2030t	17,736	2	497	$ 0.959	331	$ 0.943	894	$ 0.976	745	$ 0.976	546	$ 0.959	99	$ 0.943	$ 259	$ 66
2031t	18,087	2	506	$ 0.959	338	$ 0.943	912	$ 0.976	760	$ 0.976	557	$ 0.959	101	$ 0.943	$ 264	$ 64
2032t	18,438	2	516	$ 0.959	344	$ 0.943	929	$ 0.976	774	$ 0.976	568	$ 0.959	103	$ 0.943	$ 269	$ 63
2033t	18,790	2	526	$ 0.959	351	$ 0.943	947	$ 0.976	789	$ 0.976	579	$ 0.959	105	$ 0.943	$ 275	$ 62
2034t	19,141	2	536	$ 0.959	357	$ 0.943	965	$ 0.976	804	$ 0.976	590	$ 0.959	107	$ 0.943	$ 280	$ 61
2035t	19,492	2	546	$ 0.959	364	$ 0.943	982	$ 0.976	819	$ 0.976	600	$ 0.959	109	$ 0.943	$ 285	$ 59
2036t	19,843	2	556	$ 0.959	370	$ 0.943	1,000	$ 0.976	833	$ 0.976	611	$ 0.959	111	$ 0.943	$ 290	$ 58
2037t	20,194	2	565	$ 0.959	377	$ 0.943	1,018	$ 0.976	848	$ 0.976	622	$ 0.959	113	$ 0.943	$ 295	$ 57
2038t	20,546	2	575	$ 0.959	384	$ 0.943	1,036	$ 0.992	863	$ 0.976	633	$ 0.959	115	$ 0.943	$ 301	$ 56
2039t	20,897	2	585	$ 0.959	390	$ 0.943	1,053	$ 0.992	878	$ 0.976	644	$ 0.959	117	$ 0.943	$ 306	$ 54
2040t	21,248	2	595	$ 0.959	397	$ 0.943	1,071	$ 0.992	892	$ 0.976	654	$ 0.959	119	$ 0.943	$ 311	$ 53
2041t	21,599	2	605	$ 0.959	403	$ 0.943	1,089	$ 0.992	907	$ 0.976	665	$ 0.959	121	$ 0.943	$ 316	$ 52
2042t	21,951	2	615	$ 0.959	410	$ 0.943	1,106	$ 0.992	922	$ 0.976	676	$ 0.959	123	$ 0.943	$ 321	$ 51
2043t	22,302	2	624	$ 0.959	416	$ 0.943	1,124	$ 0.992	937	$ 0.976	687	$ 0.959	125	$ 0.943	$ 326	$ 50
2044t	22,653	2	634	$ 0.959	423	$ 0.943	1,142	$ 0.992	951	$ 0.976	698	$ 0.959	127	$ 0.943	$ 331	$ 49
2045t	23,004	2	644	$ 0.959	429	$ 0.943	1,159	$ 0.992	966	$ 0.976	709	$ 0.959	129	$ 0.943	$ 337	$ 47

Cum TOTAL ($million): $ 2,799