TTI: 584XXA3010

TEXAS TRANSPORTATION INSTITUTE

Benefits of the Texas Traffic Light Synchronization (TLS) Grant Program III: Volume I. Executive Summary and Appendices A-C

Research Report 3010-2F

Cooperative Research Program

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

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Texas Department of Transportation

Technical Report Documentation Page

1. Report No. TX-96/3010-2F, Volume I	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle BENEFITS OF THE TEXAS TRAFFIC LIGHT SYNCHRONIZATION (TLS) GRANT PROGRAM III: VOLUME I. EXECUTIVE SUMMARY AND APPENDICES A - C		5. Report Date November 1995 6. Performing Organization Code
7. Author(s) Daniel B. Fambro, David A. Noyce, Carlos A. Lopez, Xiao-qin Zhang, and Ronald T. Barnes		8. Performing Organization Report No. Report 3010-2F, Volume I
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Contract No. 584XXA3010
12. Sponsoring Agency Name and Address Texas Department of Transportation Division of Maintenance and Operations 125 East 11th Street, File D-18 Austin, Texas 78701-2483		13. Type of Report and Period Covered Final: August 1994 - September 1995 14. Sponsoring Agency Code

15. Supplementary Notes
This program was conducted in cooperation with the Texas Governor's Energy Office, Texas Department of Transportation, and the U.S. Department of Energy.
Program Title: Texas Traffic Light Synchronization (TLS) Grant Program III

16. Abstract

The Texas Department of Transportation (TxDOT) was the administering agency for the Texas Traffic Light Synchronization (TLS) Grant Program III which was funded with Oil Overcharge funds made available by the Governor's Energy Office. The TLS Program was approved by the United States Department of Energy as part of a package of transportation-related programs with the objective of reducing energy consumption. TLS III resulted in a total expenditure of $1.7 million in program funds and local matches for the optimization of traffic signal timing plans and the replacement of outdated signal controller equipment across the state. As stated previously, the program's objective was to reduce traffic congestion and facilitate the flow of traffic, with the goal of achieving more efficient use of energy resources.

With 26 completed projects, the TLS III Program has resulted in benefits that will pay for the cost of the program many times over. These benefits were estimated from the required before and after studies that were submitted by the cities. These studies document the major goals of the TLS III Program -- reductions in fuel consumption and unnecessary delay and stops. All projects were evaluated using the same unit costs. The TLS III Program resulted in 258 intersections in 19 cities being improved; the expenditure of $1.7 million of program funds and local matches; and annual reductions of 13.3 percent in fuel consumption (5.5 million gallons), 19.4 percent in delay (5.7 million hours), and 8.8 percent in stops (139 million stops). The total savings to the public in the form of reduced fuel, delay, and stops will be approximately $64 million in the next year alone. In regard to fuel savings, Texas motorists are realizing $3.28 in savings for every dollar spent, and if stops and delay are included, Texas motorists are realizing $38.13 in savings for every dollar spent. These savings will continue for the next few years without additional expenditures; therefore, the benefits to the public will be even greater.

This report is the first of two volumes. The other volume is:
Benefits of Texas Traffic Light Synchronization (TLS) Grant Program III: Volume II. Appendices D - F

17. Key Words Traffic Signal Improvements, Fuel Consumption, Traffic Signal Retiming, PASSER II, PASSER III, TRANSYT	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 62	22. Price

Form DOT F 1700.7 (8-72)

BENEFITS OF THE TEXAS TRAFFIC LIGHT SYNCHRONIZATION (TLS) GRANT PROGRAM III

VOLUME I. EXECUTIVE SUMMARY AND APPENDICES A - C

by

Daniel B. Fambro, P.E.
Associate Research Engineer, Texas Transportation Institute
Associate Professor, Civil Engineering Department

David A. Noyce, P.E.
Graduate Research Assistant
Texas Transportation Institute

Carlos A. Lopez, P.E.
Engineer of Traffic
Texas Department of Transportation

Xiao-qin Zhang
Graduate Research Assistant
Texas Transportation Institute

and

Ronald T. Barnes
Program Manager
Texas Department of Transportation

Report 3010-2F, Volume I
Program Title: Texas Traffic Light Synchronization (TLS)
Grant Program III

Sponsored by the
Texas Department of Transportation
and
The Texas Governor's Energy Office

November 1995

TEXAS TRANSPORTATION INSTITUTE
Texas A&M University System
College Station, Texas 77843-3135

IMPLEMENTATION STATEMENT

This report documents results of a special grant program, "Texas Traffic Light Synchronization (TLS) Grant Program III" rather than the results of a research study. Thus, there are no findings, recommended procedures for implementation, or additional work needed to achieve implementation.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT), Governor's Energy Office, or U.S. Department of Energy. This report does not constitute a standard, specification, or regulation and is NOT INTENDED FOR CONSTRUCTION, BIDDING, OR PERMIT PURPOSES. The engineers in charge of preparing this report were Daniel B. Fambro, P.E. No. 47535 (Texas) and David A. Noyce, P.E. No. 25726 (Wisconsin).

This report provides a summary of the "before" and "after" reports, completed by other agencies using English units, and prepared specifically for the 26 projects in the TLS III program. English units have been maintained in this report to provide consistency with reported data and to allow comparison with the previously completed TLS I and TLS II programs.

ACKNOWLEDGMENT

The results reported herein were accomplished as a result of a program entitled "Texas Traffic Light Synchronization (TLS) Grant Program III." The Texas Department of Transportation (TxDOT) administered the program which was sponsored by the Governor's Energy Office in cooperation with the U.S. Department of Energy. Training and technical assistance for the program were provided by the Texas Transportation Institute and Texas Engineering Extension Service at Texas A&M University and the McTrans Center at the University of Florida. Program managers/supervisors were Robert L. Otto, P.E., with the Governor's Energy Office; Carlos A. Lopez, P.E., and Ronald T. Barnes with the Texas Department of Transportation; and Daniel B. Fambro, P.E., with the Texas Transportation Institute. The authors wish to acknowledge the contributions of the many people who helped make this program a success.

The Texas Department of Transportation secured the funding, prepared the grant manual, and was responsible for all contractual and administrative matters. TxDOT staff members making significant contributions to the TLS III Program include

Nader Ayoub	James Kratz	Brenda Nilsson
Mike Chacon	Adrian Madison	Manny Sehgal
Rick Collins	Michael J. McAndrew	Jim Taylor
John Everett	Darren McDaniel	Gary K. Trietsch
Phil Fredricks	Wilbur Mehaffey	Henry Wickes
Terry Jones	Cindy Nelson	Chris Willrich
Charles Koonce	Tom Newburn	David Valdez

The training manuals, related materials, and documentation of benefits were prepared by the Texas Transportation Institute and Texas Engineering Extension Service at Texas A&M University, and the McTrans Center at the University of Florida. Staff members from these organizations who made significant contributions to the TLS III Program include

James A. Bonneson	Christopher M. Hoff	Joan M. Stapp
Edmond C.P. Chang	Carroll J. Messer	Srinivasa R. Sunkari
Kenneth G. Courage	Dana S. Mixson	Steven P. Venglar
A. Nelson Evans	Dongjoo Park	Charles E. Wallace

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

The Texas Department of Transportation (TxDOT) was the administering agency for the Texas Traffic Light Synchronization III (TLS III) Program, which was funded with Oil Overcharge funds made available through the Governor's Energy Office. The United States Department of Energy approved the TLS III Program as part of a package of transportation-related programs with the objective of reducing energy consumption. TLS III resulted in a total expenditure of $1.7 million in program funds and local matches for the optimization of traffic signal timing plans and the replacement of outdated signal controller equipment across the state. As stated previously, the program's objective was to reduce traffic congestion and facilitate the flow of traffic, with the goal of achieving more efficient use of energy resources.

With 26 completed projects, the TLS III Program has resulted in benefits that will pay for the cost of the program many times over. These benefits were estimated from the required "before" and "after" studies that were submitted by the cities. These studies document the major goals of the TLS III Program -- reductions in fuel consumption and unnecessary delay and stops. All projects were evaluated using the same unit costs. The TLS III Program resulted in the improvement of 258 intersections in 19 cities; the expenditure of $1.7 million in program funds and local matches; and annual reductions of 13.3 percent in fuel consumption (5.5 million gallons), 19.4 percent in delay (5.6 million hours), and 8.8 percent in stops (139 million stops). The total savings to the public in the form of reduced fuel, delay, and stops will be approximately $64 million in the next year alone. In regard to fuel savings, Texas motorists are realizing $3.28 in savings for every dollar spent. These savings will continue for the next few years without additional expenditures; therefore, the benefits to the public will be even greater.

Besides the intuitive benefits of reducing unnecessary vehicle stops, delays, fuel consumption and emissions, the TLS III Program brought together the diverse transportation community of city staffs, consultants, TxDOT personnel, and researchers to improve traffic operations at the state's signalized intersections. The program also has increased the expertise of transportation professionals in Texas and created a traffic database that can be used for additional transportation projects. Most importantly, the TLS III Program has enhanced the image of the transportation profession by improving the quality of traffic flow on signalized streets in Texas.

CHAPTER ONE

INTRODUCTION

It has been estimated that motor vehicles use approximately one-fifth of the total daily U.S. oil consumption while traveling through signalized intersections in urban areas. A significant portion of this fuel consumption is wasted due to poor signal timing. In street networks with poorly timed traffic signals, the fuel consumed by vehicles stopping and idling at traffic signals accounts for approximately 40 percent of network-wide vehicular fuel consumption. Improving traffic signal timing improves the quality of traffic flow 24 hours per day, 7 days per week with no sacrifice required on the part of the individual driver. Driving is made faster and easier for all cars, trucks, and buses using the street system (1).

Today, there are more than 300,000 traffic signals in North America as two-thirds of all miles driven each year occur on roadways controlled by traffic signals (2). It also has been estimated that 30,000 of these signalized intersections are in need of signal timing optimization, while another 148,000 need signal timing optimization and upgrading of outdated equipment (3). Much of the delay experienced by motorists during the day occurs at signalized intersections, as they wait for the light to turn green. Optimizing the timing of the signals reduces this delay. Traffic signal improvements also rank as one of the most cost-effective energy strategies in urban areas as fuel consumption and exhaust emissions are reduced (2).

Signal timing optimization projects generally provide noticeable improvements in traffic flow on arterial streets for relatively small costs (3). For example, past retiming projects have generally reported benefit/cost ratios between 20 to 1 and 40 to 1 (1, 2). More significantly, however, an average of 10 gallons of fuel was saved for each dollar that was spent on signal retiming projects, i.e., about 10 cents in project costs for each gallon saved (4). Signal timing optimization projects are extraordinarily cost effective providing an estimated 20 to 40 dollars in benefits for each project dollar invested. Several other important benefits have also been noted (5):

- Basic traffic signal improvements can result in a 12 percent improvement in vehicle speed or travel time.
- More advanced improvements can increase speeds by 25 percent.
- Retimed traffic signals, with no changes in hardware, can generally save 12 percent in travel time. In some cases, the time savings can reach 22 percent.
- Improved traffic signal operations mean less stop-and-go traffic, which in turn means fewer rear-end accidents.

Reducing the total vehicle hours of travel by reducing the delay to motorists, by as little as 10 percent, can result in a 3.5 percent savings in area wide vehicle fuel consumption. That amounts to almost 12 million gallons of fuel saved annually in an urban area with a population of 1 million people (6).

In recognition of these potential savings, and as a result of the Oil Overcharge Restitutionary Act, the Texas Department of Transportation (TxDOT) in conjunction with the Governor's Energy Office, secured funding and developed the Texas Traffic Light Synchronization (TLS) Grant Program for retiming traffic signals and replacing outdated equipment on city streets. The objective of this program was to reduce traffic congestion and facilitate the flow of traffic, with the goal of achieving more efficient use of energy resources. This objective was accomplished by:

1. Selecting projects and administering grants;
2. Training local staff/consultants in the use of computer technology for timing traffic signals;
3. Providing technical assistance in the use of computer models;
4. Providing technical assistance in collecting data and retiming signals; and
5. Providing for the replacement of outdated equipment.

This report documents the benefits resulting from the third phase of this program, TLS III. TLS I and II were completed in 1992 and 1995, respectively (7, 8). A similar program, the Texas Traffic Management (TM) Grant Program, was completed in 1993 (9). The following sections describe the Texas TLS Program in greater detail.

Program Description

The Texas Department of Transportation (TxDOT) was the administering agency for the Traffic Light Synchronization (TLS) Program, which was funded with Oil Overcharge funds made available by the Governor's Energy Office. The United States Department of Energy (DOE) approved the TLS Program as part of a package of transportation-related programs with the objective of reducing energy consumption. TLS III resulted in a total of $1.7 million in program funds and local matches being spent for the optimization of traffic signal timing plans and the replacement of outdated signal controller equipment across the state. As stated previously, the program's objective was to reduce traffic congestion and facilitate the flow of traffic, with the goal of achieving more efficient use of energy resources.

Besides the intuitive benefits of reducing unnecessary vehicle stops, delays, fuel consumption and emissions, the TLS program brought together the diverse transportation community of city staffs, consultants, TxDOT personnel and researchers to improve traffic operations at the state's signalized intersections. The program also has increased the signal timing expertise of transportation professionals in Texas and created a traffic database that can be used for additional transportation projects. Most importantly, perhaps, the TLS Program has enhanced the image of the transportation profession by improving the quality of traffic flow on signalized streets.

Funding Distribution

TLS funds were expended through contracts administered by TxDOT on signal retiming projects proposed by local city governments. There were three categories: large cities (cities with populations over 200,000), medium-sized cities (cities with populations ranging between 50,000 and 200,000), and small cities (cities with populations under 50,000). Table 1 shows the approved program of work, totaling 19 cities, 26 arterial and network signal system projects, and 258 of the state's approximately 13,000 traffic signals.

Four percent of available funds were expended in large cities with only one Texas city, presently over 200,000 population, receiving funds. Ten medium and eight small cities received seventy percent and twenty-six percent, respectively, of available funds. This distribution of funds helped to achieve one of the goals of the TLS program -- a widespread, geographic distribution of funds which allowed indirect restitution to a large segment of the population that was overcharged by the oil companies.

Table 1. Traffic Light Synchronization (TLS III) Program of Work

Funding Category	Cities	Systems	Signals
Large Cities	1	2	47
Medium Cities	10	15	151
Small Cities	8	9	60
Totals	19	26	258

Selection Criteria

Projects were recommended for funding using the following criteria developed by an advisory panel composed of local government officials and TxDOT personnel:

1. **Operational Characteristics of the Traffic Signal System** - operational characteristics such as delay, average travel speed, average daily traffic, etc., were used to estimate the benefits that improved signal timing could produce. This criteria was used to identify projects with the greatest needs and maximum potential benefits.

2. **Availability of Local Staff to Implement Timing Plans** - having local staff available allows the knowledge gained through the required technical training to be retained and facilitates future retiming efforts by local city governments.

3. **Average Signal Spacing** - the greater the concentration of signals, the more important synchronization and optimal signal timing become. A signal must be no further than one mile from an adjacent signal for it to be considered part of a signal system.

4. **Other Criteria such as Recent Growth in the Project Area, Date of Last Retiming Effort, Level of Expansion Over Current Effort, and Certification that TLS Funds will supplement and not Supplant Existing Funds** - this criteria aided in determining where the need for TLS funds was greatest and where maximum benefit could be achieved.

Reimbursement Guidelines and Eligibility

Up to 75 percent of project costs were eligible for reimbursement. If a project was funded, the local government or TxDOT paid a minimum of 25 percent of the total direct costs of the project in matching funds and/or in-kind services. TxDOT provided a local match when a project contained traffic signals that were maintained and operated by TxDOT, unless the local government and TxDOT agreed otherwise.

Costs eligible for reimbursement under the program included training local staff and/or consultants in the use of computer technology for retiming traffic signals; providing technical assistance in the use of the computer models; providing technical assistance in collecting data and retiming signals; and replacing outdated signal controller equipment. TLS Program funds could not be used to supplant or replace existing funds earmarked for specific signal retiming projects. That is, if existing funds were authorized for signal retiming expenditures, those funds could not be released and then replaced by TLS funds.

The TLS Program targeted traffic control systems (four signals minimum) currently coordinated and/or controlled in a manner that permitted implementation of multiple coordinated timing plans, i.e., timing plans that match traffic needs at different times of day. By focusing on traffic signal systems that currently have coordination capabilities, maximum energy savings could be realized with the available funds.

Signal systems included in the program ranged from those with sophisticated computer-controlled units to fixed-time electromechanical dial units. Many projects provided for the implementation of signal coordination which included signals that were not presently a part of a coordinated system. Coordination is being supplied to previously isolated intersections by time-based (as opposed to hard-wire interconnect) methods. Signal controller equipment purchased through a TLS project was, in general, either providing for coordination of a previously uncoordinated group of signals, adding signals to a currently coordinated system, or providing optimum signal timing capabilities.

Training and Technical Assistance

One of the program's major objectives was to train local staff in the use of the PASSER II, PASSER III, and TRANSYT-7F signal timing models to facilitate ongoing maintenance of efficient timing plans. Local governments awarded a grant were required to have local project staff and/or their consultant attend specialized training workshops that were offered at the onset of the program. TxDOT secured the services of the Texas Transportation Institute (TTI) to provide signal timing training and technical assistance to the cities during project development. The McTrans Center at the University of Florida and the Texas Engineering Extension Service (TEEX) at Texas A&M University assisted TTI in the training phase of the program. TTI also provided in-depth analysis of "before" and "after" studies submitted by cities and prepared the Final Report for submission to the Governor's Energy Office documenting reductions in fuel consumption, stops, and delay as a result of the TLS III Program.

Two training courses (PASSER II and PASSER III; TRANSYT-7F) were offered as part of the TLS III Program. Through these courses, 32 transportation professionals were trained (listing shown in Appendix A). Also, each of the participating cities was furnished copies of the PASSER II, PASSER III and TRANSYT-7F computer software. This training of city, consultant, and TxDOT personnel helped achieve another TLS goal - providing statewide expertise in signal retiming techniques so that these efforts can continue long after the last TLS dollar is spent.

TLS III General Facts

The following general facts relate to the TLS Program:

- Program Cost: $1,683,188.30;
- Date Started: July 1994 - Request for Proposals (RFPs) issued;
- Number of Cities Participating: 19 (1 large, 10 medium, 8 small - listing and funding amounts shown in Appendix B);
- Number of Signal Systems: 26;
- Number of Signals Retimed: 258; this total represents approximately 2 percent of all the signals in the state; and
- Date Completed: November 1995 - Final Report submitted to TxDOT and the Governor's Office.

CHAPTER TWO

RESULTS

As mentioned in Chapter One, previous traffic signal retiming projects have reported benefit/cost ratios of 20 to 1 to 40 to 1 and an average fuel savings of approximately 10 gallons per dollar spent (1, 2). Note that ultraconservative values for time were used in computing these benefits, and if more realistic values had been used, the resultant benefit/cost ratios would have been much greater. The two signal retiming programs cited most often in the literature are the Federal Highway Administration's (FHWA's) National Signal Timing Optimization Project (1) and California's FETSIM (Fuel Efficient Traffic Signal Management) Program (4). In both programs, TRANSYT-7F was used to estimate motorist benefits as the hourly difference in fuel consumption and delay between the before and after retiming conditions. These differences were converted to annual differences and then multiplied by unit costs for fuel consumption and vehicular delay to obtain an estimate of annual benefits. The estimated improvements were validated with arterial travel time data from field studies during the before and after conditions. The TLS Program followed the same procedure for estimating benefits.

The benefits from the FETSIM Program (4) through 1988 were substantial with an average first year reduction of 14 percent in stops and delay, 7.5 percent in travel time, and 8.1 percent in fuel use. Reductions in fuel usage in the first year were four times the program cost, and the first year benefit-to-cost ratio was 16 to 1. The state cost per signal, including retiming, training, and technical assistance was approximately $1,500 per intersection. Similar to the TLS Program, expenditures were allowed for all aspects of signal timing: data collection, data processing, timing plan development, implementation, and field evaluation. Unlike the TLS Program, however, expenditures were not allowed for replacing outdated equipment. Thus, the state cost per signal in the TLS Program will probably be slightly higher than in the FETSIM Program.

The preceding discussion demonstrates the range of benefits that have been obtained from other signal retiming projects, and can serve as a basis for comparison of the TLS Program. The following sections describe the results of the TLS Program in more detail and compare those results to other signal retiming programs.

Program Results

With 26 projects completed, the TLS III Program has seen results that will pay for the cost of the program many times over. These results were estimated from the required before and after studies that were submitted by the cities. These studies document the major goal of the TLS program -- reductions in fuel consumption and unnecessary delay and stops. All projects were evaluated using the same unit costs. The cost for fuel was based on approximate current prices ($1.00 per gallon), and costs for delay and stops were based on values suggested by the American Association of State Highway and Transportation Officials (AASHTO) ($10 per vehicle-hour of delay and 1.4 cents per stop). A summary of the results follows:

- 26 projects completed;
- 258 signals in 19 cities retimed;
- Approximately $1.7 million of program funds and local matches expended (several cities expended more than the required local match);
- 5.5 million gallons of fuel saved within the next year alone;
- Texas motorists are realizing $3.28 in fuel savings for every program dollar spent;
- Reductions in fuel consumption, delay, and stops of 13.3, 19.4, and 8.8 percent, respectively;
- The total savings to the public in the form of reduced fuel, delay, and stops will be approximately $64 million within the next year alone; and
- The TLS III Program benefit-to-cost (b/c) ratio is 38 to 1; in other words, Texas motorists are realizing $38 in savings for every program dollar spent.

Table 2 summarizes the expected benefits during the first year after implementation of the signal timing improvements. As expected, the largest benefits occurred in the large cities where population and traffic volumes are highest. Note, however, that substantial benefits also occurred in the medium and small cities, and that the average benefit-to-cost ratio for projects in small cities was 11 to 1.

Table 2. Traffic Light Synchronization (TLS III) Program Annual Benefits

	Stops (veh)	Delay (veh-hrs)	Fuel (gals)	Savings ($)	Cost ($)
Large Cities	71,374,150	3,313,297	2,337,341	36,469,544	66,535
Medium Cities	61,321,575	1,945,733	2,812,404	23,128,138	1,186,920
Small Cities	6,322,320	412,497	363,350	4,576,847	492,733
Total	139,018,045	5,671,527	5,513,095	64,174,529	1,683,188

Annual Benefits

The annual benefits estimated for each project were calculated on the basis of a 300-day year and a 10 to 15-hour day, depending on local traffic conditions. These conservative hour per day values were used in order **not** to claim benefits when traffic volumes were low; i.e, retiming probably will not benefit weekend or late night traffic. In other words, an intentional effort was made to **not** overestimate benefits. Furthermore, field data from the required before and after arterial travel time runs were used to verify the benefits that were being estimated. These travel time improvements were comparable to the percentage reductions in fuel, delay, and stops.

Table 3 and 4 illustrate annual benefits and changes in measures of effectiveness for each of the 19 cities in the program. Note that the majority of the benefits were in the large city category; however, significant benefits also occurred in the medium and small city categories. Given that higher traffic volumes are generally found in the larger cities, this result was expected. When interpreting these tables, one should try not to compare between cities, as the number of retimed signals and the types of projects varied greatly. Generally, the more intersections that were retimed, the larger the improvements; however, this was not always the case as cities with the same number of signals experienced completely different traffic conditions.

Type of signal retiming project also had an impact on the estimated benefits. Generally, coordinating a previously uncoordinated system resulted in large improvements. Also, projects that involved the purchase of new hardware or arterial streets with relatively low traffic volumes resulted in low benefit-to-cost ratios. Finally, note that there were eight projects in eight different cities with projects that resulted in increases in either fuel consumption, delay, stops, or a combination of the three MOE's. These increases were generally a result of increases in side street delay in order to provide better flow along the arterials.

In Laredo, the increase in fuel consumption and delay was a result of a significant change in traffic volumes as volumes increased between 20 to 24 percent during the analysis period. The large majority of this traffic volume increase took place on the cross streets, thus signal timing improvements made to improve traffic flow and progression along the frontage roads were at the expense of the cross streets. This change in cross street traffic contributed to an increase in the overall project fuel consumption, as well as delay and total stops. Other factors such as changes in lane assignments and new traffic control devices during the analysis period reduced the capacity of the roadway system in the study area and also contributed to the negative results.

The increase in fuel consumption in Abilene was attributed to the modeling process as different fuel consumption models and intersection characteristics were applied to the "before" and "after" reports. The reported increase in fuel consumption was offset by decreases in stops and total delay on the arterial streets, with the net effect being a positive benefit-to-cost ratio.

The city of Childress also experienced an increase in fuel consumption which was compounded by an increase in total stops. This fuel consumption increase was attributed to a 10 percent increase in traffic volume on US 287 during the analysis period. An improvement in overall delay in Childress allowed the net effect to result in a positive benefit-to-cost ratio.

Table 3. Annual Benefits By City

Cities	Number of Intersections	Stops	Percent	Delay (hrs)	Percent	Fuel Cons. (Gal)	Percent	Range of B/C Ratio
Large Cities								
Arlington	47	71,374,150	33.5	3,313,297	63.7	2,337,341	33.5	472-653
Total	47	71,374,150	33.5	3,313,297	63.7	2,337,341	33.5	472-653
Medium Cities								
Abilene	13	5,417,175	9.6	20,918	9.6	141,338	9.8	1-3
Brownsville	9	2,079,000	5.3	46,620	15.4	45,600	5.8	11
Bryan	33	6,399,000	3.3	308,100	18.9	333,540	8.7	44
Carrollton	9	-2,427,000	-6.5	250,842	21	633,948	41.6	23
Denton	9	1,774,800	7.5	-1,980	-1.7	17,580	6.7	0-1.5
Killeen	5	14,727,000	44.6	136,635	49.3	273,406	43.8	92
Laredo	7	1,461,900	8.2	-72,705	-8.1	-44,940	-4.2	0
Longview	12	492,000	3.3	-1,200	-1.5	2,700	1.2	0
Mesquite	17	4,204,200	9.7	179,004	33.7	417,918	35.3	8-43
Midland	33	22,222,800	23.3	202,899	34.8	275,214	15.5	5-22
Tyler	4	4,970,700	15.0	876,600	68.9	716,100	37.8	129
Total	151	61,321,575	10.4	1,945,733	20.9	2,812,404	15.5	0-129
Small Cities								
Childress	5	-1,249,200	-9.7	10,836	32.4	-26,028	-9.2	0.7
Hurst	11	1,310,745	8.8	90,425	35.1	71,945	21.9	5-181
North Richland Hills	12	1,599,975	2.3	51,375	10.4	54,897	3.2	10-15
Pharr	18	-344,400	-0.7	17,100	5.4	8,940	0.8	1.5
Round Rock	7	1,309,200	9.6	176,520	63.5	139,200	28.8	123.5
San Benito	3	-156,600	-1.0	4,980	8.6	43,869	19.4	1.5
Vernon	4	3,852,600	27.5	61,263	40.6	70,527	31.5	10.5
Total	60	6,322,320	4.0	412,499	23.4	363,350	10.6	0.7-181
Grand Total	258	139,018,045	8.8	5,671,529	19.4	5,513,095	13.3	0-653

Table 4. Annual Changes in Measures of Effectiveness

Cities	Number of Inter-sections	Overall Stops Before	Overall Stops After	Overall Delay (hrs) Before	Overall Delay (hrs) After	Overall Fuel Cons. (Gal) Before	Overall Fuel Cons. (Gal) After	Range of B/C Ratio
Large Cities								
Arlington	47	213,112,000	141,737,850	5,449,575	2,136,279	6,303,783	3,966,443	472-653
Total	47	213,112,000	141,737,850	5,449,575	2,136,279	6,303,783	3,966,443	472-653
Medium Cities								
Abilene	13	56,446,125	51,028,875	209,910	189,000	1,142,204	1,000,866	1-3
Brownsville	9	39,585,000	37,506,000	301,800	255,180	783,600	738,000	11
Bryan	33	192,588,600	186,189,600	1,632,180	1,324,080	3,829,380	3,495,840	44
Carrollton	9	37,529,400	39,956,400	1,196,388	945,546	1,524,054	890,106	23
Denton	9	23,262,000	21,487,200	89,880	91,860	271,440	253,860	0-1.5
Killeen	5	31,621,800	16,895,400	276,954	140,322	624,678	351,276	92
Laredo	7	17,823,000	16,361,100	901,524	974,229	1,066,059	1,110,999	0
Longview	12	14,945,400	14,453,400	79,800	81,000	221,700	219,000	0
Mesquite	17	40,087,200	35,883,000	501,492	322,488	1,237,158	819,240	8-43
Midland	33	82,413,975	60,191,250	538,896	335,999	1,646,314	1,371,101	5-22
Tyler	4	33,112,200	28,141,500	1,271,400	394,800	1,895,100	1,179,000	129
Total	151	569,414,700	508,093,725	7,000,224	5,054,504	14,241,687	11,429,288	0-129
Small Cities								
Childress	5	12,931,200	14,180,400	33,480	22,644	284,040	310,068	0.7
Hurst	11	39,798,165	38,487,570	381,651	291,227	663,468	591,524	5-181
North Richland Hills	12	51,379,200	49,779,225	567,159	515,784	1,619,453	1,564,556	10-15
Pharr	18	49,818,000	50,162,400	317,760	300,660	1,067,700	1,058,760	1.5
Round Rock	7	13,648,200	12,339,000	278,040	101,520	483,000	343,800	123.5
San Benito	3	15,466,500	15,623,100	58,110	53,130	226,653	182,784	1.5
Vernon	4	14,027,400	10,174,800	150,900	89,637	224,217	153,690	10.5
Total	60	197,068,665	190,746,495	1,787,100	1,374,602	4,568,531	4,205,182	0.7-181
Grand Total	258	979,595,365	840,578,070	14,236,899	8,565,385	25,114,001	19,600,913	0-653

The Welch Street system in the city of Denton experienced an increase in both fuel consumption and delay. The city of Longview experienced an increase in total delay while the cities of Carrollton, Pharr, and San Benito experienced increases in total stops. Similarly, each of these increases are attributed to a combination of slight traffic volume changes during the analysis period and changes in side street effects due to optimization of the primary routes.

Laredo, Longview, and the Welch Street system in Denton resulted in negative benefit-to-cost ratios associated with the increases in the associated Measures of Effectiveness (MOEs). Although some results of the signal retiming proved to be negative, these results would likely have been much worse without the TLS program improvements.

The cost side of the benefit-to-cost ratios reflect not only the time spent by local staff in developing and implementing timing plans but also the total equipment costs. Even though the equipment installed under a TLS project will likely last several years, the total equipment costs (not an amortized value) were used in the calculation of the b/c ratios. Furthermore, the benefits were assumed to last only one year, when in reality, some measure of the benefits will be realized over several years. Thus, the true benefits to Texas drivers are probably two to three times greater than the values reported in this report.

Travel Times

Travel times "before" and "after" the TLS improvements were measured using various forms of the test car technique. No travel times were computed for the Welch Street system in the city of Denton, the city of Tyler, US 277/South 14th Street in the city of Abilene, and the Airport Freeway Frontage Roads in the city of Hurst due to construction on part of the system during the "after" analysis, change in project limits, unreported data, and the objectives of the project, respectively. Reported travel times decreased by an average of 19.5 percent due to the TLS III improvements. The travel time improvements ranged from 0.3 percent on Rufe Snow Drive in the city of North Richland Hills to 44 percent for the Central Business District System I in the city of Denton. This average and range of travel time improvement, however, did not include the results produced by the city of Laredo and the Oak/Hickory System in the city of Denton.

Both the city of Laredo and the Oak/Hickory System in the city of Denton experienced travel time increases at all system locations. In Laredo, this increase in total travel time was due to the traffic changes in the project area previously described. The travel time increase associated with the Oak/Hickory System in Denton was attributed to the travel time evaluation. The "before" and "after" travel times were determined using different travel patterns; thus, the reported increase in travel times may not reflect actual conditions. Outside of small link travel time increases within various systems, the overall system travel time improved on twenty-four of the twenty-six projects. The fact that many of the cities who experienced increases in MOEs reported decreases in travel times supports the idea that increases in MOEs were generally a result of additional side street delay.

Benefits Per Intersection

Tables 5 and 6 illustrate annual benefits and changes in measures of effectiveness per intersection for each of the 19 cities in the program. Note that on the average, the program resulted in savings of more than 21,705 gallons of gasoline (13.3 percent), 22,329 hours of delay (19.4 percent), and 558,766 stops (8.8 percent) per intersection. The values reported in these tables are somewhat easier to compare between cities and could be used to estimate a range of potential benefits from retiming a certain number of signalized intersections; however, the discrepancy between different traffic volumes and types of projects in each of the participating cities still exists.

Note that the average benefits per intersection generally decreases from the large city to the medium and small city categories. This is primarily a result of different traffic volumes in each location. There is also a range of benefits per intersection observed within each city size category. The range of benefits within each city size is primarily a result of variability in project types. For example, coordinating a series of isolated intersections generally produced greater benefits than retiming an existing system. In other words, how bad or good the "before" condition was had a great deal to do with the benefits that could be obtained. Appendix C presents benefits for twelve different types of signal retiming projects.

Comparison With Other Programs

The estimated benefits from the Texas TLS III Program are consistent with those reported by other statewide signal retiming programs. TLS III reduced fuel, delay, and stops by 13.3, 19.4, and 8.8 percent, respectively. This can be compared to TLS II which reduced fuel, delay, and stops by 13.5, 29.6, and 11.5 percent, respectively. California's FETSIM Program reduced fuel consumption by 8.1 percent and stops and delay by 14 percent. Texas motorists realized $3.28 in fuel savings for every program dollar spent, whereas California motorists realized $4.00 in fuel savings for every program dollar spent. It should be noted, however, that FETSIM used a slightly higher cost per gallon for fuel in their analysis. In terms of average annual fuel savings per intersection, TLS III and North Carolina's Traffic Signal Timing Optimization Program (10) estimated savings per intersection of 21,705 gallons and 13,900 gallons, respectively.

First year benefit-to-cost ratios were 38 to 1 for TLS III. The results of TLS III can be compared to TLS II, TLS I, TM, and FETSIM which had benefit-to-cost ratios of 32, 62, 16, and 16 to 1, respectively. The FETSIM results must be interpreted carefully, however, since different delay costs were used by the FETSIM program. Thus, the reported benefit-to-cost ratios are not easily comparable. Because the benefits of the five programs in terms of percent reductions in fuel, delay, and stops were similar and the costs were higher for TLS III because of equipment purchases, the comparable benefit-to-cost ratios for TLS III were probably slightly lower than they were for the other programs.

Table 5. Annual Benefits Per Intersection By City

Cities	Number of Intersections	Stops	Percent	Delay (hrs)	Percent	Fuel Cons. (Gal)	Percent	Range of B/C Ratio
Large Cities								
Arlington	47	1,518,599	33.5	70,496	63.7	49,731	33.5	472-653
Average	47	1,518,599	33.5	70,496	63.7	49,731	33.5	
Medium Cities								
Abilene	13	416,706	9.6	1,609	9.6	10,872	9.8	1-3
Brownsville	9	231,000	5.3	5,180	15.4	5,067	5.8	11
Bryan	33	193,909	3.3	9,336	18.9	10,107	8.7	44
Carrollton	9	-269,667	-6.5	27,871	21.0	70,439	41.6	23
Denton	9	197,200	7.5	-220	-1.7	1,953	6.7	0-1.5
Killeen	5	2,945,400	44.6	27,327	49.3	54,681	43.8	92
Laredo	7	208,843	8.2	-10,386	-8.1	-6,420	-4.2	0
Longview	12	41,000	3.3	-100	-1.5	225	1.2	0
Mesquite	17	247,306	9.7	10,530	33.7	24,583	35.3	8-43
Midland	33	673,418	23.3	6,148	34.8	8,340	15.5	5-22
Tyler	4	1,242,675	15.0	219,150	68.9	179,025	37.8	129
Average	151	406,103	10.4	12,886	20.9	18,625	15.5	
Small Cities								
Childress	5	-249,840	-9.7	2,167	32.4	-5,206	-9.2	0.7
Hurst	11	119,159	8.8	8,220	35.1	6,540	21.9	3-8
North Richland Hills	12	133,331	2.3	4,281	10.4	4,575	3.2	5-7
Pharr	18	-19,133	-0.7	950	5.4	497	0.8	1.5
Round Rock	7	187,029	9.6	25,217	63.5	19,886	28.8	123.5
San Benito	3	-52,200	1.0	1,660	8.6	14,623	19.4	1.5
Vernon	4	963,150	27.5	15,316	40.6	17,632	31.5	10.5
Average	60	105,372	4.0	6,875	23.4	6,056	10.6	
Overall Mean	258	538,830	8.8	21,983	19.4	21,369	13.3	

Table 6. Annual Changes in Measures of Effectiveness Per Intersection By City

Cities	Number of Intersections	Overall Stops Before	Overall Stops After	Overall Delay (hrs) Before	Overall Delay (hrs) After	Overall Fuel Cons. (Gal) Before	Overall Fuel Cons. (Gal) After	Range of B/C Ratio
Large Cities								
Arlington	47	4,534,298	3,015,699	115,948	45,453	134,123	84,392	472-653
Average	47	4,534,298	3,015,699	115,948	45,453	134,123	84,392	
Medium Cities								
Abilene	13	4,342,010	3,925,298	16,147	14,538	87,862	76,990	1-3
Brownsville	9	4,398,333	4,167,333	33,533	28,353	87,067	82,000	11
Bryan	33	5,836,018	5,642,109	49,460	40,124	116,042	105,935	44
Carrollton	9	4,169,933	4,439,600	132,932	105,061	169,339	98,901	23
Denton	9	2,584,667	2,387,467	9,987	10,207	30,160	28,207	0-1.5
Killeen	5	6,324,360	3,379,080	55,391	28,064	124,936	70,255	92
Laredo	7	2,546,143	2,337,300	128,789	139,176	152,294	158,714	0
Longview	12	1,245,450	1,204,450	6,650	6,750	18,475	18,250	0
Mesquite	17	2,358,071	2,110,765	29,500	18,970	72,774	48,191	8-43
Midland	33	2,497,393	1,823,977	16,330	10,182	49,888	41,549	5-22
Tyler	4	8,278,050	7,035,375	317,850	98,700	473,775	294,750	129
Average	151	3,770,958	3,364,859	46,359	33,474	94,316	75,691	
Small Cities								
Childress	5	2,586,240	2,836,080	6,696	4,529	56,808	62,014	0.7
Hurst	11	3,618,015	3,498,870	34,696	26,475	60,315	53,775	5-181
North Richland Hills	12	4,281,600	4,148,269	47,263	42,982	134,954	130,380	10-15
Pharr	18	2,767,667	2,786,800	17,653	16,703	59,317	58,820	1.5
Round Rock	7	1,949,743	1,762,714	39,720	14,503	69,000	49,114	123.5
San Benito	3	5,155,500	5,207,700	19,370	17,710	75,551	60,928	1.5
Vernon	4	3,506,850	2,543,700	37,725	22,409	56,054	38,423	10.5
Average	60	3,284,478	3,179,108	29,785	22,910	76,142	70,086	
Overall Mean	258	3,796,881	3,258,055	55,182	33,199	97,341	75,973	

CHAPTER THREE

CONCLUSIONS

The TxDOT experience in administering the TLS Program has been very positive. The working relationship between TxDOT and city transportation professionals has been enhanced, and Texas motorists have benefited from improved operation on many arterials. These benefits will extend well beyond the life of the TLS Program. Several cities have received positive press coverage as a result of improvements made through the TLS Program. Partial program results of the TLS I Program were presented at meetings of the Texas Section of the Institute of Transportation Engineers. Final program results are being shared with all of the participating cities.

With 26 projects completed, the TLS III Program has seen results that will pay for the cost of the program many times over. These results were estimated from the required before and after studies that were submitted by the cities. These studies document the major goal of the TLS Program -- reductions in fuel consumption and unnecessary delay and stops. All projects were evaluated using the same unit costs. The TLS Program resulted in 258 signals in 19 cities (26 separate projects) being retimed; the expenditure of $1.7 million in program funds and local matches; and annual reductions in fuel consumption, delay, and stops of 13.3 percent (5.5 million gallons), 19.4 percent (5.6 million hours), and 8.8 percent (139 million stops), respectively. Appendices D, E, and F present individual project summaries.

The total savings to the public in the form of reduced fuel, delay, and stops will be approximately $64 million in the next year alone. In regard to fuel savings, Texas motorists are realizing $3.28 in savings for every dollar spent, and if stops and delay are included, Texas motorists are realizing $38.13 in savings for every dollar spent. These savings will continue for the next few years without additional expenditures; therefore, the benefits to the public will be even greater.

Benefits besides those that can be given a dollar value have been realized through the TLS Program. The bringing together of the entire transportation community (local, state, consultant, and academic) to try to reach a common goal has been rewarding. In the area of traffic signal retiming, the technical expertise of more than 32 transportation professionals has been enhanced. The driver perspective of the "stop" light or the "red" light is starting to change to that of the "green" light.

Overall, the TLS Program has been developed, funded, and implemented on a multi-jurisdictional basis (local city governments and state agencies). The program has had a significant visible and positive effect on actual operation on a large part of the transportation system, as well as on the citizens' perception of the system. The direct savings in fuel consumption and delay represent significant increased efficiency, resulting in a more economical transportation system.

REFERENCES

1. "National Signal Timing Optimization Project: Summary Evaluation Report," Federal Highway Administration, Office of Traffic Operations, and University of Florida, Transportation Research Center (May 1982) 43 pp. [An Executive Summary of this report can be found in ITE Journal Vol. 52, No. 10 (October 1982) pp. 12-14.]

2. "Improving Traffic Signal Operations - A Primer," Institute of Transportation Engineers, Washington, D.C. (1995).

3. "A Toolbox for Alleviating Traffic Congestion," Institute of Transportation Engineers, Washington, D.C. (1989).

4. Deakin, E.A., A. Skabardonis, and A.D. May, "Traffic Signal Timing as a Transportation Management Measure: The California Experience," in *Transportation Research Record 1081: Urban Traffic Management*, Transportation Research Board, National Research Council, Washington, D.C. (1986) pp. 59-65.

5. Urban and Suburban Traffic Congestion: Working Paper No. 10, Federal Highway Administration, U.S. Department of Transportation, Washington D.C. (1987).

6. Wagner, F.A., "Energy Impacts of Urban Transportation Improvements," Institute of Transportation Engineers, Washington D.C. (1980).

7. Fambro, Daniel B., Carlos A. Lopez, and Srinivasa R. Sunkari, "Benefits of the Texas Traffic Light Synchronization (TLS) Grant Program I: Volume I. Executive Summary and Appendices F - G," Texas Transportation Institute, Report No. 0258-3, College Station, Texas (1992).

8. Fambro, Daniel B., Srinivas M. Sangineni, Carlos A. Lopez, Srinivasa R. Sunkari, and Ronald T. Barnes, "Benefits of the Texas Traffic Light Synchronization (TLS) Grant Program II: Volume 1. Executive Summary and Appendices A - C," Texas Transportation Institute, Report No. 3010-1F, College Station, Texas (1994).

9. Fambro, Daniel B., Srinivas M. Sangineni, Carlos A. Lopez, Srinivasa R. Sunkari, and Ronald T. Barnes, "Benefits of the Texas Traffic Management (TM) Grant Program: Volume 1. Executive Summary and Appendices A - B," Texas Transportation Institute, Report No. 8820-1, College Station, Texas (1993).

10. North Carolina Department of Transportation and the Institute for Transportation Research and Education, "North Carolina's Traffic Signal Management Program for Energy Conservation," *ITE Journal*, (December 1987) pp. 35-38.

APPENDIX A

PROGRAM PARTICIPANTS

TLS Participants Trained in PASSER II and/or TRANSYT-7F

Jon Krieg
City Traffic Engineer
P.O. Box 60
Abilene, Texas 79604

Steve Oliver
Signal Engineer
P.O. Box 231
Arlington, Texas 76004

Lynn Jordan
Graduate Traffic Engineer
P.O. Box 231
Arlington, Texas 76004

Lee Robinson
Traffic System Manager
City of College Station
College Station, Texas 77840

Danny Halden
Engineer III
2008 Enterprise
Round Rock, Texas 78664

Doris Brock
Traffic Analyst
P.O. Box 850137
Mesquite, Texas 75185

Mark D. Barnes
Traffic Engineering Tech. II
P.O. Box 1152
Midland, Texas 79702

Kathy Hornaday
Engineering Assoc. II
2717 Rio Grande St.
Austin, Texas 78705

Bill Martin
Traffic Control Sup.
1505 Precinct Line Rd.
Hurst, Texas 76054

James Ward
Traffic Signal Manager
P.O. Box 6868
Fort Worth, Texas 76115

Romeo Rosales
Traffic Signal Tech.
202 E. Clark
Pharr, Texas 78577

Roy Garcia
Traffic Signal Tech.
202 E. Clark
Pharr, Texas 78577

Edward Schroeder
Traffic Signal Supervisor
7901 N. IH 35
Austin, Texas 78753

Miguel Gonzalez
Traffic Safety Foreman
202 E. Clark
Pharr, Texas 78577

Dannie B. Tiffin
Signal Repair Tech. IV
Box 900
Childress, Texas 79201

Robert L. Mills
Dist. Maint. Supt. (Traf.)
Box 900
Childress, Texas 79201

TLS Participants Trained in PASSER II and/or TRANSYT-7F Continued

Robert L. Otto
Director of Programs
125 E. 11th Street
Austin, Texas 78701

Jackie White
Traffic Safety Specialist
P.O. Box 6868
Fort Worth, Texas 76115

Jim Sparks
Tech. Services Engr.
1505 Precinct Line Road
Hurst, Texas 76054

Donnie Wright
Signal Maint. Tech.
1101 E. Main
Mesquite, Texas 75149

Jerry J. Hernandez, Sr.
Traffic Foreman
1111 Waco St.
Bryan, Texas 77803

Mike Towns
Engineer Assistant
8323 S W Freeway, Ste 200
Houston, Texas 77074

Erwin Burden
Design Engineer
2 North Main St.
Temple, Texas 76501

John Pena
Traffic Supt.
P.O. Box 1329
Killeen, Texas 76540

Cecil D. Goff
Traffic Surveyor
Box 900
Childress, Texas 79201

Favian J. Perez
Traffic Signal Tech.
P.O. Box 1793
Denton, Texas 76202

Jeff Gann
Traffic Signal Tech.
901A Texas St.
Denton, Texas 76201

Greg Van Winkle
Traffic Signal Tech.
4915 Rolling Vista
Mesquite, Texas 75150

Victor Iracheta
Associate
8323 S W Freeway, Ste. 200
Houston, Texas 77074

John Urubek
Traffic Signal Tech.
2 North Main St.
Temple, Texas 76501

Dale Levsen
Traffic Signal Supv.
404 E. Washington
Brownsville, Texas 78520

Andy Osborn
Project Manager
P.O. Box 1329
Killeen, Texas 76540

APPENDIX B

PROGRAM OF WORK

Table B-1. Traffic Light Synchronization III (TLS III) Program of Work

City	Project	City Match $	State Match $	Oil Overcharge Funds $	Total Project Cost $	Number of Signals Retimed
LARGE CITIES						
Arlington	Ballpark Area	7,165.77	0.00	20,772.62	27,938.39	19
	Pioneer Parkway and Arkansas Lane	8,352.46	0.00	30,244.43	38,596.89	28
Arlington Totals		15,518.23	0.00	51,017.05	66,535.28	47
LARGE CITY TOTALS		15,518.23	0.00	51,017.05	66,535.28	47
MEDIUM CITIES						
Abilene	Ambler Avenue	14,966.36	0.00	46,325.26	61,291.62	5
	US 277/South 14th Street	39,485.57	0.00	79,770.74	119,256.31	8
Abilene Totals		54,451.93	0.00	126,096.00	180,547.93	13
Brownsville	Boca Chica Boulevard and FM 802	14,438.36	0.00	35,069.11	49,507.47	9
Brownsville Totals		14,438.36	0.00	35,069.11	49,507.47	9
Bryan	Seven Arterial Signal System	19,880.83	0.00	59,642.49	79,523.32	33
Bryan Totals		19,880.83	0.00	59,642.49	79,523.32	33
Carrollton	Carrollton Signal System	34,250.00	0.00	99,999.31	134,253.31	9
Carrollton Totals		34,250.00	0.00	99,999.31	134,253.31	9
Denton	Oak/ Hickory System	14,789.54	0.00	42,278.09	57,067.63	5
Denton Totals	Welch Avenue System	15,041.07	0.00	39,264.73	54,305.80	4
		29,830.61	0.00	81,542.82	111,373.43	9

Table B-1. Traffic Light Synchronization III (TLS III) Program of Work

City	Project	City Match $	State Match $	Oil Overcharge Funds $	Total Project Cost $	Number of Signals Retimed
MEDIUM CITIES						
Killeen	Hood Road	5,000.06	0.00	15,002.17	20,002.23	5
Killeen Totals		5,000.06	0.00	15,002.17	20,002.23	5
Laredo	IH 35 Frontage Road	86,209.00	0.00	29,645.00	115,854.00	7
Laredo Totals		86,209.00	0.00	29,645.00	115,854.00	7
Longview	Central Business District System	24,246.85	0.00	72,740.66	96,987.41	12
Longview Totals		24,246.85	0.00	72,740.66	96,987.41	12
Mesquite	Bryan-Belt Line Road/Galloway Avenue	32,312.43	0.00	70,390.12	102,602.55	9
	Galloway Avenue	8,608.53	0.00	25,600.46	34,208.99	8
Mesquite Totals		40,920.96	0.00	95,990.58	136,811.54	17
Midland	Central Business District I	25,215.44	0.00	75,646.33	100,861.77	18
	Central Business District II	21,757.73	0.00	65,273.18	87,030.91	15
Midland Totals		46,973.17	0.00	140,919.51	187,892.68	33
Tyler	Subsystem 6	39,167.14	0.00	35,000.00	74,167.14	4
Tyler		39,167.14	0.00	35,000.00	74,167.14	4
MEDIUM CITY TOTALS		395,368.91	0.00	791,647.65	1,186,920.46	151
SMALL CITIES						
Childress	US 287	0.00	40,374.12	69,834.90	96,114.84	5
Childress Totals		0.00	40,374.12	69,834.90	96,114.84	5

Table B-1. Traffic Light Synchronization III (TLS III) Program of Work

City	Project	City Match $	State Match $	Oil Overcharge Funds $	Total Project Cost $	Number of Signals Retimed
SMALL CITIES						
Hurst	Airport (SH 1221) Freeway Frontage Road	4,729.78	580.07	15,929.55	21,239.40	3
	North East Mall Area	1,197.82	112.42	3,593.59	4,903.83	8
Hurst Totals		5,927.60	692.49	19,523.14	26,143.23	11
North Richland Hills	Holiday Lane	2,229.84	1,223.31	10,064.78	13,517.93	5
	Rufe Snow Drive	7,590.43	0.00	23,071.30	30,761.73	7
North Richland Hills Totals		9,820.27	1,223.31	33,136.08	44,279.66	12
Pharr	US Business 83 and Cage Boulevard	29,201.79	0.00	87,605.37	116,807.16	18
Pharr Totals		29,201.79	0.00	87,605.37	116,807.16	18
Round Rock	US 79 Arterial Systems	462.84	4,486.41	10,614.00	15,563.25	7
Round Rock Totals		462.84	4,486.41	10,614.00	15,563.25	7
San Benito	SH 345	14,934.69	0.00	44,804.05	59,738.74	3
San Benito Totals		14,934.69	0.00	44,804.05	59,738.74	3
Vernon	US 183/283	0.00	26,970.53	44,115.15	71,085.68	4
Vernon Totals		0.00	26,970.53	44,115.15	71,085.68	4
SMALL CITY TOTALS		60,347.19	73,746.86	309,632.69	429,732.56	60
GRAND TOTAL		471,234.33	73,746.86	1,152,297.39	1,683,188.30	258

APPENDIX C

BENEFITS BY TYPE OF TRAFFIC SIGNAL TIMING IMPROVEMENT

Table C-1. Annual Benefits when Optimizing Uncoordinated Arterial with Existing Equipment

Cities	Projects	Number of Intersections	Stops	Percent	Delay(hrs)	Percent	Fuel Cons.(gal)	Percent	B/C Ratio
Medium Cities									
Killeen	Ford Hood Street	5	14,727,000	44.6	136,635	49.3	273,406	43.8	92
Total		5	14,727,000	44.6	136,635	49.3	273,406	43.8	92

Table C-2. Annual Changes in MOEs when Optimizing Uncoordinated Arterial with Existing Equipment

Cities	Projects	Number of Intersections	Overall Stops		Overall Delays (hrs)		Overall Fuel Consumption (gals)		B/C Ratio
			Before	After	Before	After	Before	After	
Medium Cities									
Killeen	Ford Hood Street	5	31,621,800	16,895,400	276,954	140,322	624,678	351,276	92
Total		5	31,621,800	16,895,400	276,954	140,322	624,678	351,276	92

Table C-3. Annual Benefits when Optimizing Coordinated Arterial with Existing Equipment

Cities	Projects	Number of Intersections	Stops	Percent	Delay(hrs)	Percent	Fuel Cons.(gal)	Percent	B/C Ratio
Large Cities									
Arlington	Pioneer Parkway and Arkansas Lane	28	33,266,100	33.5	1,648,377	70.6	1,280,705	39.9	472
Total		28	33,266,100	33.5	1,648,377	70.6	1,280,705	39.9	472

Table C-4. Annual Changes in MOEs when Optimizing Coordinated Arterial with Existing Equipment

Cities	Projects	Number of Intersections	Overall Stops		Overall Delays (hrs)		Overall Fuel Consumption (gals)		B/C Ratio
			Before	After	Before	After	Before	After	
Large Cities									
Arlington	Pioneer Parkway and Arkansas Lane	28	99,368,700	66,102,600	2,334,855	686,479	3,208,140	1,927,436	472
Total		28	99,368,700	66,102,600	2,334,855	686,479	3,208,140	1,927,436	472

Table C-5. Annual Benefits when Optimizing Uncoordinated Arterial with New Equipment

Cities	Projects	Number of Intersections	Stops	Percent	Delay(hrs)	Percent	Fuel Cons.(gal)	Percent	B/C Ratio
Medium Cities									
Abilene	Ambler Avenue	5	1,887,600	9.7	4,568	7.4	-6,761	2.3	1
	US 277/South 14th St.	8	3,529,575	9.6	16,350	11.0	148,098	17.3	3
Mesquite	Galloway Avenue	8	3,240,000	14.6	130,884	38.8	120,498	18.8	43
Tyler	Subsystem 6	4	4,970,700	15.0	876,600	68.9	716,100	37.8	129
Small Cities									
Childress	US 287	5	-1,249,200	-9.7	10,836	32.4	-26,028	-9.2	0.7
North Richland Hills	Holiday Lane	5	-24,300	-0.2	12,488	13.4	7,767	2.8	10
San Benito	Sam Houston Ave. (SH345)	3	-156,600	-1.0	4,980	8.6	43,869	19.4	1.5
Vernon	US 183/283	4	3,852,600	27.5	61,263	40.6	70,527	31.5	10.5
Total		42	16,050,375	8.6	1,117,969	26.9	1,074,070	14.4	0.7-129

Table C-6. Annual Changes in MOEs when Optimizing Uncoordinated Arterial with New Equipment

Cities	Projects	Number of Intersections	Overall Stops Before	Overall Stops After	Overall Delays (hrs) Before	Overall Delays (hrs) After	Overall Fuel Consumption (gals) Before	Overall Fuel Consumption (gals) After	B/C Ratio
Medium Cities									
Abilene	Ambler Avenue	5	19,564,125	17,676,450	61,838	57,270	288,563	295,323	1
	US 277/South 14th St.	8	36,882,000	33,352,425	148,072	131,730	853,641	705,543	3
Mesquite	Galloway Avenue	8	22,227,000	18,987,000	336,906	206,022	642,558	522,060	43
Tyler	Subsystem 6	4	33,112,200	28,141,500	1,271,400	394,800	1,895,100	1,179,000	129
Small Cities									
Childress	US 287	5	12,931,200	14,180,400	33,480	22,644	284,040	310,068	0.7
North Richland Hills	Holiday Lane	5	12,158,550	12,182,850	93,249	80,762	274,995	267,228	10
San Benito	Sam Houston Ave. (SH 345)	3	15,466,500	15,623,100	58,110	53,130	226,653	182,784	1.5
Vernon	US 183/283	4	14,027,400	10,174,800	150,900	89,637	224,217	153,690	10.5
Total		42	166,368,975	150,318,525	2,153,955	1,035,995	4,689,767	3,615,696	0.7-129

Table C-7. Annual Benefits when Optimizing Partially Coordinated Arterial with New Equipment

Cities	Projects	Number of Intersections	Stops	Percent	Delay(hrs)	Percent	Fuel Cons.(gal)	Percent	B/C Ratio
Medium Cities									
Brownsville	Boca Chica Boulevard and FM 802	9	2,079,000	5.3	46,620	15.4	45,600	5.8	11
Carrollton	Carrollton Signal System	9	-2,427,000	-6.5	250,842	21.0	633,948	41.6	23
Total		18	-348,000	-0.6	297,462	18.2	679,548	23.7	11-23

Table C-8. Annual Changes in MOEs when Optimizing Partially Coordinated Arterial with New Equipment

		Number of	Overall Stops		Overall Delays (hrs)		Overall Fuel Consumption (gals)		
Cities	Projects	Intersections	Before	After	Before	After	Before	After	B/C Ratio
Medium Cities									
Brownsville	Boca Chica Boulevard and FM 802	9	39,585,000	37,506,000	301,800	255,180	783,600	738,000	11
Carrollton	Carrollton Signal System	9	37,529,400	39,956,400	1,196,388	945,546	1,524,054	890,106	23
Total		18	77,114,400	77,462,400	1,498,188	1,200,726	2,307,654	1,628,106	11-23

Table C-9. Annual Benefits when Optimizing Coordinated Arterial with New Equipment

Cities	Projects	Number of Intersections	Stops	Percent	Delay(hrs)	Percent	Fuel Cons.(gal)	Percent	B/C Ratio
Medium Cities									
Denton	Oak/Hickory System	5	3,228,000	24.8	1,140	2.5	23,340	15.8	1.5
	Welch Ave. System	4	-1,453,200	-14.2	-3,120	-7.0	-5,760	-4.6	0
Small Cities									
North Richland Hills	Rufe Snow Drive	7	1,624,275	4.1	38,888	8.2	47,130	3.5	15
Total		16	3,399,075	6.0	36,908	2.6	64,710	5.3	0-15

Table C-10. Annual Changes in MOEs when Optimizing Coordinated Arterial with New Equipment

Cities	Projects	Number of Intersections	Overall Stops Before	Overall Stops After	Overall Delays (hrs) Before	Overall Delays (hrs) After	Overall Fuel Consumption (gals) Before	Overall Fuel Consumption (gals) After	B/C Ratio
Medium Cities									
Denton	Oak/Hickory System	5	13,011,600	9,783,600	45,360	44,220	147,360	124,020	1.5
	Welch Ave. System	4	10,250,400	11,703,600	44,520	47,640	124,080	129,840	0
Small Cities									
North Richland Hills	Rufe Snow Drive	7	39,220,650	37,596,375	473,910	435,023	1,344,458	1,297,328	15
Total		16	62,482,650	59,083,575	563,790	526,883	1,615,898	1,551,188	0-15

Table C-11. Annual Benefits when Optimizing Partially Coordinated Network with Existing Equipment

Cities	Projects	Number of Intersections	Stops	Percent	Delay(hrs)	Percent	Fuel Cons.(gal)	Percent	B/C Ratio
Large Cities									
Arlington	Ballpark Area	19	38,108,050	33.5	1,664,920	53.5	1,056,636	24.1	653
Small Cities									
Round Rock	US 79 Arterial Systems	7	1,309,200	9.6	176,520	63.5	139,200	28.8	123.5
Total		26	39,417,250	27.1	1,841,440	56.2	1,195,836	25.4	123.5-653

Table C-12. Annual Changes in MOEs when Optimizing Partially Coordinated Network with Existing Equipment

Cities	Projects	Number of Intersections	Overall Stops		Overall Delays (hrs)		Overall Fuel Consumption (gals)		B/C Ratio
			Before	After	Before	After	Before	After	
Large Cities									
Arlington	Ballpark Area	19	113,743,300	75,635,250	3,114,720	1,449,800	3,095,643	2,039,007	653
Small Cities									
Round Rock	US 79 Arterial Systems	7	13,648,200	12,339,000	278,040	101,520	483,000	343,800	123.5
Total		26	127,391,500	87,974,250	3,392,760	1,551,320	3,578,643	2,382,807	123.5-653

Table C-13. Annual Benefits when Optimizing Coordinated Network with Existing Equipment

Cities	Projects	Number of Intersections	Stops	Percent	Delay(hrs)	Percent	Fuel Cons.(gal)	Percent	B/C Ratio
Small Cities									
Hurst	North East Mall Area	8	1,179,450	3.0	80,655	21.9	65,750	10.1	181
Total		8	1,179,450	3.0	80,655	21.9	65,750	10.1	181

Table C-14. Annual Changes in MOEs when Optimizing Coordinated Network with Existing Equipment

		Number of	Overall Stops		Overall Delays (hrs)		Overall Fuel Consumption (gals)		
Cities	Projects	Intersections	Before	After	Before	After	Before	After	B/C Ratio
Small Cities									
Hurst	North East Mall Area	8	39,225,600	38,076,150	367,710	287,055	651,821	586,071	181
Total		8	39,225,600	38,076,150	367,710	287,055	651,821	586,071	181

Table C-15. Annual Benefits when Optimizing Uncoordinated Network with New Equipment

Cities	Projects	Number of Intersections	Stops	Percent	Delay(hrs)	Percent	Fuel Cons.(gal)	Percent	B/C Ratio
Medium Cities									
Mesquite	Bryan-Belt Line Road/Galloway Ave.	9	964,200	5.4	48,120	29.2	297,420	50.0	8
Small Cities									
Pharr	US Business 83 and Cage Boulevard	18	-344,400	-0.7	17,100	5.4	8,940	0.8	1.5
Total		27	619,800	1.2	65,220	12.7	306,360	15.9	1.5-8

Table C-16. Annual Changes in MOEs when Optimizing Uncoordinated Network with New Equipment

Cities	Projects	Number of Intersections	Overall Stops		Overall Delays (hrs)		Overall Fuel Consumption (gals)		B/C Ratio
			Before	After	Before	After	Before	After	
Medium Cities									
Mesquite	Bryan-Belt Line Road/Galloway Ave.	9	17,860,200	16,896,000	164,586	116,466	594,600	297,180	8
Small Cities									
Pharr	US Business 83 and Cage Boulevard	18	49,818,000	50,162,400	317,760	300,660	1,067,700	1,058,760	1.5
Total		27	67,678,200	67,058,400	482,346	417,126	1,662,300	1,355,940	1.5-8

Table C-17. Annual Benefits when Optimizing Partially Coordinated Network with New Equipment

Cities	Projects	Number of Intersections	Stops	Percent	Delay(hrs)	Percent	Fuel Cons.(gal)	Percent	B/C Ratio
Medium Cities									
Bryan	Seven Arterial Signal System	33	6,399,000	3.3	308,100	18.9	333,540	8.7	44
Midland	Central Business District I	18	19,497,000	30.9	168,800	40.5	225,390	18.3	22
	Central Business District II	15	2,725,725	14.1	34,098	28.0	49,824	12.1	5
Total		66	22,222,725	13.3	202,898	26.9	275,214	12.1	5-44

Table C-18. Annual Changes in MOEs when Optimizing Partially Coordinated Network with New Equipment

Cities	Projects	Number of Intersections	Overall Stops Before	Overall Stops After	Overall Delays (hrs) Before	Overall Delays (hrs) After	Overall Fuel Consumption (gals) Before	Overall Fuel Consumption (gals) After	B/C Ratio
Medium Cities									
Bryan	Seven Arterial Signal System	33	192,588,600	186,189,600	1,632,180	1,324,080	3,829,380	3,495,840	44
Midland	Central Business District I	18	63,042,300	43,545,300	416,963	248,163	1,232,729	1,007,340	22
	Central Business District II	15	19,371,675	16,645,950	121,934	87,836	413,585	363,761	5
Total		66	275,002,575	246,380,850	2,171,077	1,660,079	5,475,694	4,866,941	5-44

Table C-19. Annual Benefits when Optimizing Coordinated Network with New Equipment

Cities	Projects	Number of Intersections	Stops	Percent	Delay(hrs)	Percent	Fuel Cons.(gal)	Percent	B/C Ratio
Medium Cities									
Longview	Central Business District System	12	492,000	3.3	-1,200	-1.5	2,700	1.2	0
Total		12	492,000	3.3	-1,200	-1.5	2,700	1.2	0

Table C-20. Annual Changes in MOEs when Optimizing Coordinated Network with New Equipment

		Number of	Overall Stops		Overall Delays (hrs)		Overall Fuel Consumption (gals)		
Cities	Projects	Intersections	Before	After	Before	After	Before	After	B/C Ratio
Medium Cities									
Longview	Central Business District System	12	14,945,400	14,453,400	79,800	81,000	221,700	219,000	0
Total		12	14,945,400	14,453,400	79,800	81,000	221,700	219,000	0

Table C-21. Annual Benefits when Developing An Emergency Queue Discharge Timing Plan with New Equipment

Cities	Projects	Number of Intersections	Stops	Percent	Delay(hrs)	Percent	Fuel Cons.(gal)	Percent	B/C Ratio
Small Cities									
Hurst	Airport (SH 121) Freeway Frontage Road	3	131,145	24.2	9,770	70.1	6,195	53.2	5
Total		3	131,145	24.2	9,770	70.1	6,195	53.2	5

Table C-22. Annual Changes in MOEs when Developing An Emergency Queue Discharge Timing Plan with New Equipment

Cities	Projects	Number of Intersections	Overall Stops		Overall Delays (hrs)		Overall Fuel Consumption (gals)		B/C Ratio
			Before	After	Before	After	Before	After	
Small Cities									
Hurst	Airport (SH 121) Freeway Frontage Road	3	542,565	411,420	13,941	4,172	11,648	5,453	5
Total		3	542,565	411,420	13,941	4,172	11,648	5,453	5

Table C-23. Annual Benefits when Optimizing Uncoordinated Diamond Interchanges with New Equipment

Cities	Projects	Number of Intersections	Stops	Percent	Delay(hrs)	Percent	Fuel Cons.(gal)	Percent	B/C Ratio
Medium Cities									
Laredo	IH 35 Frontage Rd.	7	1,461,900	8.2	-72,705	-8.1	-44,940	-4.2	0
Total		7	1,461,900	8.2	-72,705	-8.1	-44,940	-4.2	0

Table C-24. Annual Changes in MOEs when Optimizing Uncoordinated Diamond Interchanges with New Equipment

		Number of	Overall Stops		Overall Delays (hrs)		Overall Fuel Consumption (gals)		
Cities	Projects	Intersections	Before	After	Before	After	Before	After	B/C Ratio
Medium Cities									
Laredo	IH 35 Frontage Rd.	7	17,823,000	16,361,100	901,524	974,229	1,066,059	1,110,999	0
Total		7	17,823,000	16,361,100	901,524	974,229	1,066,059	1,110,999	0

The following numbering system is used to identify the project type in the Travel Time Tables located in Appendices D-F:

Project Type	**Type of Traffic Signal Timing Improvement**
01	Optimizing Uncoordinated Arterial with Existing Equipment
02	Optimizing Partially Coordinated Arterial with Existing Equipment
03	Optimizing Coordinated Arterial with Existing Equipment
04	Optimizing Uncoordinated Arterial with New Equipment
05	Optimizing Partially Coordinated Arterial with New Equipment
06	Optimizing Coordinated Arterial with New Equipment
07	Optimizing Uncoordinated Network with Existing Equipment
08	Optimizing Partially Coordinated Network with Existing Equipment
09	Optimizing Coordinated Network with Existing Equipment
10	Optimizing Uncoordinated Network with New Equipment
11	Optimizing Partially Coordinated Network with New Equipment
12	Optimizing Coordinated Network with New Equipment
13	Developing an Emergency Queue Discharge Timing Plan with New Equipment
14	Optimizing Uncoordinated Diamond Interchange with New Equipment