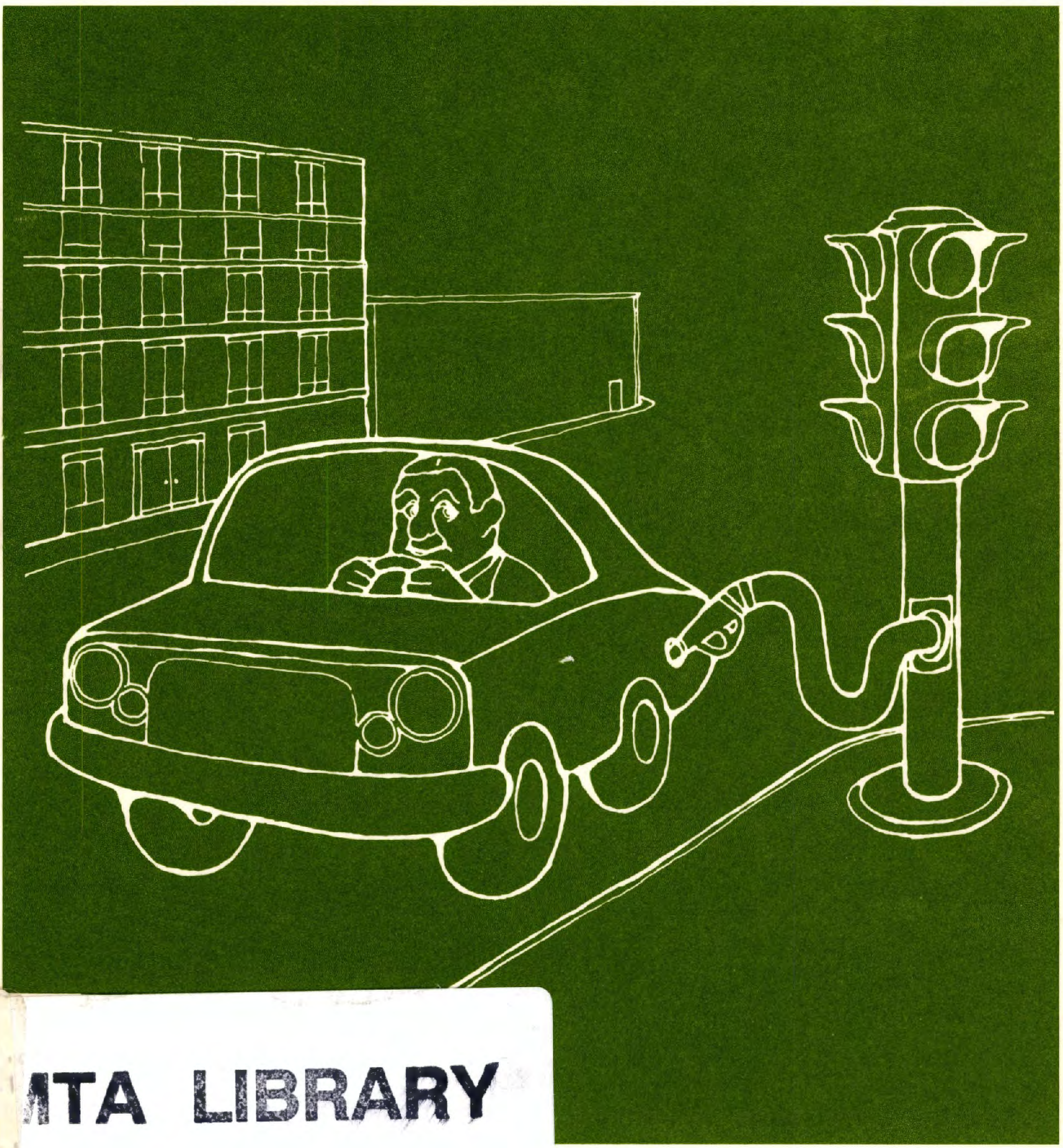
National Signal Timing Optimization Project:
Summary Evaluation Report

U.S. Department of Transportation
Federal Highway Administration

May 1982



MTA LIBRARY

National Signal Timing Optimization Project

Summary Evaluation Report

Prepared by

Federal Highway Administration, Office of Traffic Operations

and

University of Florida, Transportation Research Center

May 1982

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

EXECUTIVE SUMMARY

1.1 Background

The National Signal Timing Optimization Project was initiated by the Federal Highway Administration (FHWA) as a fuel conservation effort in response to the high cost of imported oil. An estimated 35 percent of the total United States daily oil consumption is still supplied by foreign sources at a cost of $65 billion in 1981. The Project is part of an overall effort on the part of FHWA to encourage States and municipalities to undertake traffic signal timing optimization projects to improve the quality of urban driving and thereby reduce fuel consumption.

It is estimated that approximately one-fifth of the total daily U.S. oil consumption is used by vehicles traveling in urban areas through signalized intersections. A significant portion of this is wasted due to poor traffic 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 will improve the quality of traffic flow 24 hours per day, 7 days per week with no sacrifice required on the part of the individual. Driving is made faster and easier for all cars, trucks, and buses using the street system.

If the signal operation at all of the estimated 240,000 signalized intersections nationwide were modernized and the signals were operated properly, an estimated 5 million gallons of gasoline per day could be conserved. Just optimizing the signal timing at the 130,000 intersections nationwide that are already part of coordinated signal systems and at most of the other non-coordinated signalized intersections would conserve about 2 million gallons of gasoline per day.

The FHWA's goal is for cities and States to develop optimal signal timing plans for all of the coordinated signals and most of the non-coordinated signals in the United States over the next 4 years. This will be just the beginning of an ongoing effort since traffic signal timing plans become inefficient due to constantly changing and/or growing traffic demands. The FHWA's role in this effort is to provide the tools and technical assistance that will enable cities and States to accomplish this.

The National Signal Timing Optimization Project, as an initial part of this overall effort, was intended to satisfy the following objectives:

1. To establish credible data on the effectiveness of signal timing optimization.

2. To make signal timing optimization projects easier to do.

3. To define the resources (cost, level of staff, computer, etc.) required to undertake a signal timing optimization project, such that traffic engineers and administrators can more effectively budget for this activity.

In order to accomplish these objectives the following activities were undertaken:

1. Development of the TRANSYT-7F signal timing optimization program and User's Manual, and provision of training in the use of the program.

2. Application of the program in 11 cities nationwide to evaluate the effectiveness of the optimized signal timing plans and to collect data on the needed resources.

1.2 Development of TRANSYT-7F

The acronym TRANSYT stands for TRAffic Network StudY Tool. TRANSYT is a tool for traffic engineers who desire to optimize their coordinated signal systems to reduce delay, stops, and fuel consumption. The TRANSYT program, which was developed in the United Kingdom, has been extensively and successfully used both in Europe and in the U.S. However, since the conventions and terminology used in TRANSYT are not the same as those used in the United States, FHWA secured the services of the University of Florida to develop a new version of the program which would be easier to use in this country. This version of the program is called TRANSYT-7F.

TRANSYT-7F is written in the FORTRAN IV programming language. The program has been executed successfully on the following 32 bit computer systems: IBM-360, 370, and 3033, Amdahl-470, CDC-7700, Digitial VAX-11/780, Burroughs-7700, and Honeywell-6220. It requires 288K bytes of CPU addressable memory in unoverlayed format or 172K bytes if the program is overlayed. The run time is approximately proportional to the number of intersections. On an IBM-3033 computer, networks of 4, 12, and 45 intersections required 5, 22, and 65 seconds of CPU time, respectively.

A comprehensive new User's Manual was developed to serve as an instructional and reference guide for traffic engineers who desire to use the TRANSYT-7F program. In addition, a number of presentations of a training course on how to use TRANSYT-7F to conduct a signal timing optimization project are being sponsored by the National Highway Institute of FHWA and presented in 1982 and 1983.

The Systems and Software Support Team (HTO-23), Office of Traffic Operations of FHWA will be providing technical support services to users of the TRANSYT-7F program. These service include: (1) distribution of the TRANSYT-7F program and User's Manual free of charge to all agencies that request it, (2) maintenance of the program and documentation, and (3) technical assistance to users of the program. Interested organizations should contact: Chief, Systems and Software Support Team, Office of Traffic Operations (HTO-23), FHWA, U.S. Department of Transportation, Washington, D.C. 20590

1.3 Summary of Eleven Cities' Projects

The 11 cities selected to participate in the National Signal Timing Optimization Project were: Charleston, SC; Denver, CO; Des Moines, IA; Fort Wayne, IN; Gainesville, FL; Milwaukee, WI; Nashville, TN; Portland, OR; Pawtucket, RI; San Francisco, CA; and Syracuse, NY. These cities contracted with FHWA to undertake a project to use TRANSYT-7F to optimize the signal timing in a portion of their street network, to evaluate the effectiveness of the optimized signal timing plans, and to determine the resources required to conduct the project.

Data collection activities were largely completed during the fall of 1980. Coding and computer runs were accomplished during the spring of 1981 (after attendance at one of four pilot TRANSYT-7F training courses) and the optimized signal timing plans were installed and evaluated during the summer of that year. The number of intersections to be retimed per city ranged from 23 to 81 with an average of 46.

All activities were accomplished by city personnel. The TRANSYT-7F program was implemented on local (city, county, or State) or approved commercial services computers. The cities kept records on the resources required for each project activity at a very detailed level. All eleven cities submitted final reports on the results of their projects.

1.4 Resources Requirements

Based on the results of the 11 projects, the cost to retime each signal averaged $456 per intersection. This included data collection, coding, running TRANSYT-7F, analyzing the output, installing the new timing, and fine tuning the new signal timing plans on the street, but did not include project evaluation and overhead. A breakdown of the personnel and cost requirements is shown in Table 1.1.

The labor required to retime each signal averaged approximately 40 hours per intersection. About one-half of this time was professional; the remainder was mainly technician time (engineering and maintenance).

For the purpose of summarizing the "first time" project level of effort and costs, the following hypothetical "average" project is assumed. Assumptions reflected in this hypothetical project are as follows:

TABLE 1.1

Personnel and Cost Requirements

Activity		Effort	Cost
Initial Start-Up		20.3(1)	$1,925 + travel + computer(3
Preparation of Data Collection Plans		7.8(1)	700(3)
Data Collection and Reduction		19.7(2)	166(4)
Data Coding		3.3(2)	36(4)
Running TRANSYT-7F:	Personnel	4.1(2)	44(4)
	Computer		27(4)
Installation and Fine-Tuning		3.9(2)	78(4)
Miscellaneous		7.5(1)	720(3)

Effort and Cost Units
(1) Person-days per project
(2) Person-hours per intersection
(3) Dollars per project
(4) Dollars per intersection

1. There are 46 intersections in the project network.

2. Travel to a training course is required.

3. The computer is publicly owned, but payment is required.

4. Field installation of timing plans is required.

The total number of person-hours for this project is 1,714 or about 214 person-days. Using the average costs reported by the project cities, the total project cost is $20,970 or $456 per intersection.

The first-time use of TRANSYT-7F to retime traffic signal systems requires a relatively extensive learning process. Subsequent projects should involve substantially less effort. For example, training in the use of the program will only be required for new personnel. Furthermore, data coding will go much more smoothly with repeated use.

For comparison with the "first-time" level of effort and cost values, the same hypothetical or "average" project having 46 intersections is assumed, but treated as if it were a subsequent project.

1. No initial start-up effort is required.

2. Preparation of data collection plans and data collection are reduced by 10 percent.

3. Coding data and running TRANSYT-7F are reduced by 30 percent.

4. Installation time is unchanged.

5. Personnel time in the miscellaneous category is reduced 40 percent.

6. Expenses are not reduced for efforts that remained part of the project. This is a conservative assumption.

The estimated total project level of effort and costs are reduced by 27 percent from $20,970 to $15,400. The average overall cost per intersection is reduced from $456 to $335. Two of the project cities have already carried out subsequent projects and confirm this estimate.

1.5 Benefits

According to the before and after TRANSYT-7F estimates, for the average intersection in the project, each year 15,470 vehicle-hours of delay were saved, 455,921 vehicle stops were eliminated, and 10,524 gallons of fuel were saved. Assuming that the cost of time delay saved is a conservative $0.50 per vehicle hour, non-fuel vehicle operating costs are reduced by $0.014 per vehicle stop eliminated, and gasoline costs $1.35 per gallon, the equivalent dollar total annual benefit averaged $28,695 per intersection. With an average cost of $456 per intersection, the benefit/cost ratio is an impressive 63 to 1. Considering fuel savings only, the benefit/cost ratio is still an impressive 31 to 1.

In some cases, the improvements predicted by TRANSYT-7F were overly optimistic, particularly when high degrees of saturation were eliminated by the signal timing optimization. When these high results are eliminated, lower, but still impressive benefit/cost ratios result. Considering fuel savings only, a benefit/cost ratio of 10 to 1 can be expected for first-time projects as a minimum, increasing to approximately 15 to 1 for subsequent projects when costs will be reduced. When the value of time saved and stops eliminated are considered, the benefit/cost ratio for first-time projects can be expected to be 20 to 1 as a minimum, increasing to 30 to 1 for subsequent projects.

Limited floating vehicle traveltime studies conducted by the cities confirmed that signal timing optimization did, indeed, significantly improve traffic performance. Measured traveltimes improved in every control period in every city with only two exceptions. Measured traveltime improvements ranged from less than 1 percent to 31 percent and averaged 8.5 percent.

1.6 Conclusions

The following conclusions can be drawn from the project:

1. Signal timing optimization can lead to significant reductions in vehicle delay, vehicle stops, and fuel consumption.

2. TRANSYT-7F is a very valuable tool for signal timing optimization projects.

3. Data collection is the major and key task in conducting a successful signal timing optimization project.

4. The provision of technical assistance is very helpful to those conducting projects.

5. Conducting a signal timing optimization project can lead to several side benefits such as the discovery of malfunctioning signal equipment.

6. Public reaction to signal timing improvements is favorable.

7. Energy conservation through optimization of signal timing plans is a valid national objective which can be realized through the actions of State and local governments.

CHAPTER 2

BACKGROUND

2.1 Reliance on Imported Oil

In 1981, it is estimated that foreign sources supplied 35 percent of the total U.S. daily oil consumption at a cost of $65 billion (1). Much of that imported oil came from nations in the Middle East where, in both 1973-74 and 1979, political events led to supply shortages in the U.S. Each time we purchase gasoline, we are reminded that the cost of imported oil has risen substantially since 1973. More must be done to reduce our reliance on imported oil, through both increased domestic supply and decreased consumption.

2.2 Transportation Oil Consumption

Approximately 38 percent of the total U.S. daily oil consumption is accounted for by fuel consumed on our Nation's highways and urban street systems (2). Therefore, through a series of planning and engineering actions designed to reduce fuel consumption on highways and urban streets, transportation professionals can directly affect the rate of use of a considerable portion of total U.S. petroleum demand. These actions fall into two categories: those designed to reduce the quantity of vehicle travel and those designed to improve the quality of that travel. Transportation professionals should ideally consider and recommend a combination of actions from both categories. A balanced approach is the most effective one. Even with a reduction in quantity, vehicle travel must still be made as efficient as possible.

2.3 The Importance of Traffic Signal Timing

Vehicles driving through or stopping for traffic signals in urban areas account for an estimated 20 percent of the oil consumed each day in the U.S. (3). Much of this fuel is wasted by vehicles unnecessarily stopped 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.

Driving in privately owned vehicles will continue to be the predominant method of travel in the U.S. in the foreseeable future. Optimized traffic signal timing can improve the quality of urban driving and thereby reduce fuel consumption 24 hours per day, 7 days a week with no sacrifice required on the part of the individual. Driving is made faster and easier for all cars, trucks, and buses using the street system.

The Federal Highway Administration (FHWA) estimates that modernizing traffic signal operation at all of the estimated 240,000 signalized intersections nationwide and operating the signals properly would conserve an estimated 5 million gallons of gasoline per day. Just optimizing the signal timing at the approximately 130,000 intersections that are already part of coordinated signal systems and at most of the other non-coordinated signalized intersections would conserve about 2 million gallons of gasoline per day (3).

2.4 The Role of FHWA

The FHWA is encouraging States and municipalities to give traffic signal improvement projects a high priority by promoting the utilization of modern traffic control and computer technology, making signal timing optimization computer programs easier to use, demonstrating the fuel conservation potential and cost-effectivenss of traffic signal timing optimization, and providing technical assistance to State and local agencies responsible for signal improvements.

The FHWA's goal is for States and municipalities to optimize the signal timing at all of the signalized intersections nationwide over the next 4 years and to maintain optimal signal timing thereafter. In order to continuously realize the fuel savings and traffic performance improvement benefits, signal timing must be updated to reflect changes in traffic demands and patterns. The FHWA's role in this effort is to provide the tools and technical assistance that will enable States and municipalities to accomplish this.

The National Signal Timing Optimization Project, as an initial part of this overall effort, was intended to satisfy the following objectives:

1. To establish credible data on the effectiveness of signal timing optimization.

2. To make signal timing optimization projects easier to do.

3. To define the resources (cost, level of staff, computer, etc.) required to undertake a signal timing optimization project, such that traffic engineers and administrators can more effectively budget for this activity.

In order to accomplish these objectives, the TRANSYT-7F signal timing optimization computer program and training course were developed and the program was applied in 11 cities nationwide to evaluate the effectiveness of the optimized signal timing plans and to collect data on the resources used. The following chapters, which are condensed from the project final evaluation report (4), summarize the results of the project.

CHAPTER 3

DEVELOPMENT OF TRANSYT-7F

3.1 Background

TRANSYT is an acronym for TRAffic Network StudY Tool. The program was developed at the Transport and Road Research Laboratory in the United Kingdom by Mr. Dennis Robertson and it has been extensively used both in the U.S. and throughout Europe. However, the program has several drawbacks which makes its use by U.S. traffic engineers somewhat awkward. Accordingly, as part of the National Signal Timing Optimization Project, FHWA secured the services of the University of Florida's Transportation Research Center to modify the latest freely distributed version of TRANSYT, TRANSYT-7, to make it easier to use in the U.S. The resulting version of the program is called TRANSYT-7F, where the "F" denotes that it is FHWA's version of the TRANSYT-7 program.

3.2 Operation of the TRANSYT Program

Over the years, the TRANSYT program has produced extremely reliable results when properly applied. Therefore, even though fairly extensive modifications were made to the program's input and output structures, it was not necessary to modify the way TRANSYT models traffic flow and develops an optimal signal timing plan.

The TRANSYT program contains a traffic flow simulation model which realistically models the dispersion of platoons of traffic between adjoining signalized intersections. The flow model produces estimates of the amount of traffic delay and the number of stops due to the traffic signal timing in the network. By systematically varying the offset and phase lengths at each signalized intersection and determining the effect on network-wide delay and stops, TRANSYT eventually produces a signal timing plan which minimizes a weighted linear combination of these two measures of effectiveness (MOE's).

The program requires input data typical of all signal timing calculation methods that explicitly consider vehicle delay and stops, although in probably more detail than most. Data is needed on traffic volumes, speeds, network geometry, and other parameters specific to TRANSYT. The outputs produced by the program include the optimal signal timing plan, a table containing various MOE's, flow profiles of traffic arriving at and departing from an intersection, and time-space diagrams.

3.3 Modifications Made to TRANSYT

In order to make TRANSYT easier to use for U.S. traffic engineers, a number of modifications were made to the program's input and output structures. A summary of these follows:

1. The user may now code inputs and receive outputs in either English (feet and mph) or metric (meters and km/hr) units.

2. Signal timing inputs now conform to U.S. conventions, namely intervals, phases, and offset or yield point. Signal timing inputs may be expressed in either seconds or percent of cycle. Signal timing outputs are always given in both seconds and percent of cycle.

3. The input structure was reorganized to group all input data pertaining to a single intersection in a contiguous group of cards within the input data deck.

4. An estimate of fuel consumption based on a non-linear function of total travel, delay, stops, and speed was added.

5. Default values were provided for certain parameters and cards that seldom change.

6. The table containing various measures of effectiveness (Performance Table) was revised to make it easier to read and to facilitate interpretation of results and detection of problems.

7. The capability to output a time-space diagram for any continuous route in the network was added.

8. New signal timing tables were added to the program's output to indicate, for each intersection, all signal timings, by interval, in both seconds and percent of cycle and the offset point (or yield point and yield point reference interval) in seconds and percent of cycle.

3.4 Characteristics of the TRANSYT-7F Program

TRANSYT-7F conforms to the American National Standards Institute (ANSI) FORTRAN 77 subset language. The program requires approximately 288K bytes of addressable memory. If this much memory is not available, the program can be overlayed, which reduces the core size requirement to 172K bytes.

The computer run time varies considerably among computer systems and also depends on the number of traffic signals in the network and the level of optimization requested by the user. As a general guideline, the run time is approximately proportional to the number of nodes in the network. On an IBM-3033 computer, networks of 4, 12, and 45 signals required 5, 22, and 65 seconds of central processing unit time, respectively, for the highest level of optimization. Of course, if the program is overlayed, it will take somewhat longer to run.

The program has executed successfully on the following 32 bit computer systems: IBM-360, 370, and 3033, Amdahl-470, CDC-7700, Digital VAX-11/780, Burroughs-7700 and Honeywell-6220. The program was also subjected to a rather extensive debugging process by both FHWA and the University of Florida.

3.5 Development of the TRANSYT-7F User's Manual and Training Course

In order to enhance the usability of TRANSYT, it was deemed necessary to develop a new, more comprehensive User's Manual (5) which utilizes terminology and units of measure more familiar to American traffic engineers.

The TRANSYT-7F User's Manual is user oriented--it was written to enable practicing U.S. traffic engineers responsible for developing and installing signal timing plans to learn to use TRANSYT-7F easily and effectively. The manual is comprehensive--it not only includes instructions on coding, but also describes the operation of the program, data collection needs and procedures, interpretation of the program outputs, and instructions for installing the program on several computer systems. Furthermore, it contains several examples of applications of TRANSYT-7F.

Even though the User's Manual is comprehensive enough to permit users to learn to use the program without formal training, the availability of the TRANSYT-7F training course should greatly enhance the speed and level of comprehension at which users learn. The objective of the TRANSYT-7F training course is not simply to train individuals to use TRANSYT-7F, but rather to train individuals responsible for signal timing to conduct a signal timing optimization project using TRANSYT-7F. The emphasis is on how to conduct a signal timing optimization project not how to run a computer program.

The course covers all aspects of a TRANSYT-7F signal timing optimization project, including data collection, data reduction, data coding, running TRANSYT-7F, interpreting the program's output, installing and fine-tuning signal timing plans in the field, and evaluating new timing plans. Training is provided on the basics of traffic signal timing and traffic flow theory, as related to TRANSYT-7F.

All lecture sessions include visual aids; mainly 35-mm slides. The User's Manual is the primary reference document. The lecture sessions are supplemented by workshop sessions in which the students gain hands-on experience in how to use the program to conduct a project. These are arranged so that the student experiences increasingly complex applications of the program.

Four pilot presentations of the training course were given in the Spring of 1981. Ten presentations of the course will be given in 1982 and ten more in 1983 through the sponsorship of FHWA's National Highway Institute. More information can be obtained by writing to: Federal Highway Administration, National Highway Institute (HHI-1), Washington, D.C. 20590.

3.6 The Availability of TRANSYT-7F

The TRANSYT-7F program and User's Manual are being distributed by FHWA free of charge to all agencies that request it. Interested organizations should contact: Systems and Software Support Team, Office of Traffic Operations (HTO-23), Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. 20590.

The staff of the Systems and Software Support Team will be providing technical support for the TRANSYT-7F program and User's Manual and technical assistance to users of the program. Periodically, revisions to the program and/or User's Manual, new guidelines on the use of TRANSYT-7F, or new releases of the program will be disseminated to all users. The staff will be available to respond to all questions on the use of the program, including program installation, data collection, coding input data, interpreting program results, installation guidelines for the new timing plans, fine-tuning, and evaluation.

CHAPTER 4

SUMMARY OF ELEVEN CITIES' PROJECTS

4.1 Background

Participation in the National Signal Timing Optimization Project was solicited through a notice in the Federal Register of March 24, 1980. Over 90 cities responded to the notice; however, funding was available to include only 11 of these in the Project. These cities were: Charleston, SC; Denver, CO; Des Moines, IA; Fort Wayne, IN; Gainesville, FL; Milwaukee, WI; Nashville, TN; Pawtucket, RI; Portland, OR; San Francisco, CA; and Syracuse, NY. The cities signed a contract with FHWA to undertake a project to optimize the signal timing in a portion of their street network using TRANSYT-7F, to evaluate the effectiveness of the optimized signal timing plans, and to record the resources necessary to conduct the entire project. The specific terms of the contract required the following:

1. Collecting the data necessary to run TRANSYT-7F.
2. Implementation of the program on a local computer system.
3. Running the program to produce optimal signal timing plans.
4. Installing the optimal signal timing plans on the street.
5. Determining the resources (personnel, time, computer,etc.) required to run the program.
6. Evaluating the effectiveness of the optimal signal timing plans in terms of traffic measures of effectiveness (delay, stops, etc.) and fuel consumption.

The remainder of this chapter describes the work conducted under the cities' projects. Chapter 5 discusses the resources used by the cities and Chapter 6 relates the estimated benefits from the optimized signal timing plans.

4.2 Network and Signal System Characteristics

The following are capsule descriptions of the characteristics of the networks and signal systems found in the 11 cities.

4.2.1 Charleston

The Charleston network consisted of 37 signalized intersections in the southern half of the downtown peninsula. The traffic control system is an Automatic Signal Division PR system and the traffic signal controllers are all transistorized traffic-adjusted PR controllers. Cycle lengths, offsets and splits are selected for four different control periods: AM peak, PM peak, off-peak, and light. The signals were last timed in 1970 using manual methods and time-space diagrams.

4.2.2 Denver

Denver's network included 23 intersections along a major arterial street near the Denver CBD. The traffic control system contains almost entirely solid state, traffic actuated controllers. Thirteen of these are coordinated through the use of an Automatic Signal Company TM-1 master controller and nine are part of a computer controlled system which is interfaced with the TM-1 system. One intersection is controlled by a pretimed electromechanical controller operating independently under three period time-of-day control obtained from a time-based solid state coordination unit. The other 22 signals operate with a single timing plan. The signals were last timed in 1974 using manual methods and engineering judgment and the timings were revised in 1979-80 with the installation of pedestrian actuated controls.

4.2.3 Des Moines

The Des Moines network contained 54 intersections located along major collector-arterial routes in the area north and west of the CBD. The traffic signal controllers are electromechanical, pretimed controllers. The traffic control system is based on a three period, time-of-day strategy implemented by an Eagle Signal Corporation MONOTROL Traffic Control System. The system was last timed in 1973.

4.2.4 Fort Wayne

Fort Wayne's network consisted of 45 intersections in the CBD and western fringe. The traffic signal controllers are a mixture of electromechanical and solid state pretimed controllers. The signals are part of an 110-signal IBM 1800 computer controlled signal system. Eight different timing plans are available for use, five of these were optimized during the project. Three of these were peak period timing plans implemented by time-of-day and two were off-peak timing plans selected by the computer based on system detector data. The old timing plans were developed in 1971 using time-space diagrams and engineering judgment.

4.2.5 Gainesville

The Gainesville network included a total of 33 intersections in the CBD and along an arterial signal system adjacent to the University of Florida. The traffic signal system consists mainly of solid state, full-actuated controllers coordinated by electromechanical coordinating units. There are four pretimed electromechanical controllers. Three timing plans are used on a time-of-day basis. The signals were last timed in 1978 using engineering judgment.

4.2.6 Milwaukee

Milwaukee's network contained 65 intersections along two intersecting major arterials. The traffic control system contains mostly pretimed electromechanical controllers, although there are also two pretimed, solid state controllers and one that is semi-actuated. The signal system is controlled by a system master and two satellite master controllers. System control is based on three-period, time-of-day.

4.2.7 Nashville

The Nashville network consisted of 25 total intersections in three separate signal systems along a major arterial route. The three signal systems are composed primarily of electromechanical pretimed controllers. One controller is solid state, semi-actuated. Each system has a separate master which also controls a local intersection. System control is three period, time-of-day. The systems were last timed in 1973, 1974, and 1977 respectively.

4.2.8 Pawtucket

Pawtucket's network included 29 intersections in the CBD. The signal system consists of mostly pretimed, electromechanical controllers with four actuated controllers with electromechanical coordinating units. System control is based on a two-period, time-of-day strategy. The system was last timed in 1976 using time-space diagrams and engineering judgment.

4.2.9 Portland

The Portland network contained 47 intersections located along nine two-way and eight one-way arterials forming a widely spaced grid near the CBD. The signal system is composed of 46 fixed time controllers and one semi-actuated controller. A single timing plan operates throughout the day. The system was originally timed in 1958 and has been kept current through manual adjustments.

4.2.10 San Francisco

San Francisco's network consisted of 81 intersections in the southern portion of the CBD. All but one of the signalized intersections are controlled by pretimed, electromechanical controllers, the single actuated controller operates like a pretimed controller. System control is provided through a master controller on a three period, time-of-day basis. The system was timed in 1968 using the SIGOP model.

4.2.11 Syracuse

The Syracuse network included 69 intersections in the CBD. The traffic signal controllers are two dial, pretimed electromechanical controllers. The controllers are coordinated by a Crouse-Hinds master controller and time-clock switch. Prior to the project, the system operated with a single timing plan. The signals were last timed 10 years ago.

4.3 Data Collection

Five different types of data were collected by the cities as required by the TRANSYT-7F program. Each of these data collection efforts is briefly described below.

4.3.1 Network Data

The majority of the network description data (link-node numbering schemes, number of links to be coded, and link distances) were obtained from existing records. Several cities performed field studies to measure all or some of the link distances or to verify the accuracy of the data estimated from existing records.

4.3.2 Signal Timing Data

Most of the cities maintain comprehensive signal timing inventories from which the necessary signal timing information for pretimed controllers was extracted. Des Moines obtained and Syracuse verified their data in the field.

For actuated controllers, field studies were conducted to determine the average phase lengths for the specific control periods in order that "equivalent pretimed" signal timing data could be input to TRANSYT-7F for simulating "before" conditions.

4.3.3 Saturation Flow, Lost Time, and Extension of Effective Green Data

These data items, particularly saturation flow, are very important inputs to the TRANSYT-7F program. A majority of the cities estimated these values using the guidelines in the TRANSYT-7F User's Manual. In all of the cities field studies were conducted to either verify or make measurements of these values. The results of the field studies were in general agreement with the suggested guidelines.

4.3.4 Speed Data

Several techniques were employed to gather speed data. Most of the cities used floating car studies on either a sample of links or on all of the links in their networks. Other techniques used included estimating from speed limits or by radar measurement.

4.3.5 Traffic Volume Data

Turning movement counts and link-to-link counts are the traffic volume data required by the TRANSYT-7F program. Existing data, manual counting methods, and machine counting methods were used to obtain turning movement counts. The great majority of the data were obtained by manual counting methods. Link to link counts were mainly obtained using the proportioning procedure outlined in the TRANSYT-7F User's Manual. Several cities obtained sample link-to-link counts to verify the proportioning procedure. The traffic volume data input to the program were derived from peak half-hour or hour turning movement volumes within each control period.

4.4 Application of TRANSYT-7F

The application of TRANSYT-7F in the 11 project cities involved four steps: (1) implementation of the program on the local computer system, (2) coding of the required input data, (3) calibration of the program to existing conditions, and (4) running the program to obtain optimal signal timing plans. Each of these steps is summarized below.

4.4.1 Implementation on Local Computers

TRANSYT-7F is written in the FORTRAN IV language and is readily portable among computer systems with FORTRAN compilers. Most of the project cities used IBM computer systems. Portland used a Digital VAX computer system and Charleston and Denver used Honeywell computer systems. Several machine-specific problems were encountered and corrections were made to the master program code to correct these. The version of the program being distributed to the public contains these corrections. This version has also run on CDC and Burroughs computer systems.

4.4.2 Input Data Coding

Input data coding for TRANSYT-7F is a straightforward, albeit tedious, process. Most of the cities had their data keypunched onto cards, although several entered theirs via a remote computer terminal. Four cities (Des Moines, Milwaukee, San Francisco, and Syracuse) had to code two network sections per control period because their networks contained more than 50 intersections (the maximum that TRANSYT-7F will normally handle).

The project cities all agreed that the input data coding process was extensive and time consuming. It is felt, however, that this time would be reduced in future applications of TRANSYT-7F, since the input data coding scheme will be more familiar to those doing the coding.

4.4.3 Program Calibration

The project cities calibrated TRANSYT-7F by making simulation program runs with their existing signal timing plans. Input parameters (e.g. link speeds and platoon dispersion factors) were adjusted until the simulated traffic flow matched reasonably well with the existing traffic flow in the network. In most cases, the flow profile plots output by TRANSYT-7F (which give a picture of how TRANSYT is actually modeling traffic flow on individual links) were compared with the existing traffic flow on certain links through field observation.

Properly calibrating TRANSYT-7F ensures that the program will accurately optimize signal timing. In addition, with a simulation of existing conditions, it is possible to determine "before-after" improvements in various traffic MOE's using TRANSYT's performance table outputs.

4.4.4 The Optimization Process

Chapter 6 of the TRANSYT-7F User's Manual recommends, and most of the project cities followed to the extent possible and necessary, a comprehensive optimization process. The first step of the process is to calibrate the program, as described in the previous subsection. The next step of the process involves running the program a number of times to determine the "best" phase sequences at intersections in question. Similarly, Step 3 involves running the program a number of times to determine the "best" network cycle length. Step 4 is the base optimization run. Step 5 involves additional optimization runs using corrected input data, if needed, and changes in other input parameters such as the delay and stop weighting factors to fine tune the signal timing plan using the TRANSYT-7F program. Step 6 is installation and fine tuning of the signal timing plan on the street, as discussed in Section 4.5. The following are short summaries of the process followed in each city.

4.4.4.1 Charleston

Charleston examined a number of different cycle lengths for each of three control periods.

4.4.4.2 Denver

Denver made only the base optimization runs for each of three control periods.

4.4.4.3 Des Moines

Des Moines examined phase sequence changes at several intersections and also studied a number of different cycle lengths for each control period. The stop weighting factor input was used in an attempt to provide a greater priority to progression on some routes.

4.4.4.4 Fort Wayne

Fort Wayne also used the stop weighting factor input in an attempt to provide a greater priority to progression on their major one-way pair arterials.

4.4.4.5 Gainesville

Gainesville evaluated a full range of cycle lengths for each control period.

4.4.4.6 Milwaukee

Milwaukee examined retention of the timing at certain intersections by using the grouped-node capability in TRANSYT and by not optimizing the timing at these intersections in some of their runs.

4.4.4.7 Nashville

Nashville examined phase sequence changes at several intersections and also studied a number of different cycle lengths for each control period. Nashville also examined the possibility of double cycling several intersections in their network.

4.4.4.8 Pawtucket

Pawtucket also examined phase sequence changes at several intersections and studied a number of different cycle lengths for each control period.

4.4.4.9 Portland

Portland considered a number of different cycle lengths for each of three control periods. Portland also made simulation runs with each of their three final optimized signal timing plans using their three different sets of network and traffic input data (nine runs altogether) in order to determine the single signal timing plan that would result in the best all-day operation. This was necessary because Portland has a one-dial signal control system.

4.4.4.10 San Francisco

San Francisco evaluated a number of different cycle lengths for each control period.

4.4.4.11 Syracuse

Syracuse also evaluated a number of different cycle lengths for each control period.

4.5 Timing Plan Installation and Fine Tuning

The final step in the optimization process briefly described in subsection 4.4.4 is the installation and fine tuning of the signal timing plan on the street. It is always good practice to observe traffic flow in the network when a new signal timing plan is installed to determine first-hand whether the new timing plan is operating satisfactorily. Although the TRANSYT-7F program is a valuable tool, it is still the responsibility of the traffic engineer to ensure that the signal timing plan installed in the field operates properly.

Installation of the new timing plans produced by TRANSYT-7F mainly involved phase length and offset changes, although there were some changes in cycle length and phase sequence. Since most of the cities had pretimed electromechanical controllers, most of the changes involved pin position changes on the controller dials, although some cycle gear and cam changes were also required.

A minimum of fine tuning was required in the field, most of which involved small changes to phase lengths and offsets. The amount of fine tuning required in the field can be minimized by assuring that good input data is used, that the program is properly calibrated, by first fine tuning the signal timing plan using the program (subsection 4.4.4), and by examining the signal timing plan in the office before installation in the field.

4.5.1 Charleston

Charleston was unable to install their optimized timing plans during the project time limits because of problems with the timing plan selection algorithms of their PR control system. As of this date an off-peak timing plan has been installed. Little fine tuning was required.

4.5.2 Denver

Denver's signal control system allows only a single timing plan to be installed. It was determined that the PM peak optimized signal timing plan provided the best all day operation. The installation of the new timing plan involved mostly pin position changes on the controller dials.

Very little fine tuning was required. At three intersections controlled by actuated controllers, maximum green extension intervals were adjusted in order to maintain progression and clocks were installed in the controllers to permit different maximum green extension interval settings to be used on a time-of-day basis.

4.5.3 Des Moines

Des Moines' installation involved pin position changes plus changing the AM peak cycle gear. The phase sequence was also changed at two intersections.

Little fine tuning was required. The offsets produced by the program were manually adjusted in the office before installation in the field. Several field adjustments were also made. One problem encountered was that several offset adjustments made in Des Moines' first network section necessitated offset adjustments at all locations in section two.

4.5.4 Fort Wayne

Since Fort Wayne owns a computerized traffic control system, installation simply involved keypunching timing parameters onto data cards for each intersection, reading these into the computer, and bringing the new timing plans on-line.

Due to adjustments made in the office prior to installation, very little fine tuning in the field was required. In fact, no fine tuning in the field was required for the low volume off-peak timing plan.

4.5.5 Gainesville

Gainesville's installation involved cycle length and offset (yield point and force-offs) changes to their solid-state actuated controllers and electromechanical coordinating units. Office adjustments were made to the timing plans based on equipment constraints and engineering judgment. Also, several modifications were made in the field after observing the system in operation.

4.5.6 Milwaukee

Most of Milwaukee's modifications involved pin position changes. Some new cam drums and controller dials were also installed. Phasing changes were also made at some intersections, mainly involving pedestrian movements.

Most of Milwaukee's fine tuning consisted of manually adjusting offsets because they had fallen within a clearance interval. Only one controller required fine tuning in the field after installation of the new timing; however, it was expected that additional fine tuning would be required at intersections with actuated controllers.

4.5.7 Nashville

Most of Nashville's modifications involved cycle gear and pin position changes. Phase sequence changes were made at two intersections.

Little fine tuning was required. Only minor offset and phase length changes were necessary. In one case, a change prevented spillover into an upstream intersection from occurring.

4.5.8 Pawtucket

Pawtucket's installation involved mostly pin position changes. Phase sequence changes were made at three intersections. Minor offset and phase length changes were the only fine tuning required.

4.5.9 Portland

Portland's installation of their single new timing plan consisted mainly of pin position changes. Cycle length changes were made at two intersections. Fine tuning led to the installation of a second controller dial at several intersections.

4.5.10 San Francisco

Almost all of San Francisco's modifications involved pin position changes. Almost all of their fine tuning involved changes in phase length, however, a few intersections also required minor offset adjustments.

4.5.11 Syracuse

Syracuse's installation involved changing pin positions on their controller dials. Fine tuning was required on two one-way arterials traversing both network sections due to failure to include stop and delay weights in the optimization runs for one of the sections. It was also observed that increased throughput caused congestion at a downstream intersection that was not part of the optimized network.

CHAPTER 5

RESOURCE REQUIREMENTS

5.1 Types of Resources Required

One of the major objectives of the National Signal Timing Optimization Project was to determine the resources required to conduct a signal timing optimization project using TRANSYT-7F. The following types of resources were used by the cities: personnel, equipment, and miscellaneous other expenses. These are described in the subsections following:

5.1.1 Personnel

Personnel expenses were by far the largest resource requirement. Even though there was a great deal of variation among position titles reported by the cities, the actual skill levels were quite similar and are represented below.

- Senior Traffic Engineer (STE) - the engineer in charge of the project who directs the activities of all other personnel.
- Traffic Engineer (TE) - the engineer responsible to the STE who is typically responsible for portions of a project such as data collection and coding.
- Junior Traffic Engineer (JTE) - the engineer who assisted the TE with project responsibilities.
- Senior Technician (ST) - a skilled and often supervisory technician who typically assists with data collection, input coding, and signal timing plan installation.
- Junior Technician (JT) - technician who assists the ST.
- Systems Analyst (SA) - a computer specialist responsible for implementing the program on the local computer system and interfacing with the computer system thereafter.
- Computer Operator (CO) - person responsible for day-to-day computer activities such as job submissions and retrievals.
- Clerical Technician (CT) - A clerical level person who may assist with data collection, keypunching, drafting, etc.
- Other Personnel (OP) - A category for specialized personnel not covered above.

Not all of the above personnel types worked for the traffic engineering agency. Typically, the systems analyst and computer operator were employed by the ADP agency of the local jurisdiction. It should also be noted that not all of the cities utilized all of the above personnel types. The figures reported in Section 5.2 were derived by totaling the time spent on a given activity and then dividing by 9 (the total number of project cities that reported detailed expenses).

5.1.2 Equipment

A minimum of equipment was used to conduct the projects, most of which was readily available to the traffic engineering agency. The equipment used was:

- Computer system - A 32 bit word size main frame computer with input and output peripheral devices.
- Traffic counters - some type of turning movement and road tube counters.
- Speed measuring equipment - either radar or floating vehicle based.
- Stop watches - for measuring start-up lost time, headways, extension of effective green time, and phase lengths for actuated controllers.

Not all of the above equipment is absolutely necessary. For example, road tube counts are used mainly for checking purposes and speed data can be obtained simply by recording speedometer observations.

5.1.3 Other Expenses

Various other expenses were reported by the project cities. These included:

- Travel to training courses.
- Reproduction costs.
- Equipment rental (excluding payment for computer services).
- Operating costs for vehicles.

5.2 Resources by Project Activity

The following subsections relate the resources required for the major project activities. The resources are described in terms of the time required for each personnel position defined in subsection 5.1.1 and the total cost. Other significant expenses are also noted.

5.2.1 Initial Start-Up

This activity includes receiving and implementing the TRANSYT-7F program on the local computer system. It also includes two people from the agency attending a TRANSYT-7F Signal Timing Optimization training course (see section 3.5). Although not all users of TRANSYT-7F will attend a training course, it is believed that this is, in the long run, a better, easier, and less expensive way to learn to use the program.

POSITION	HOURS
STE	62
TE	37
JTE	36
ST	12
JT	1
SA	14
	162 hr. = 20.3 days

The initial start-up personnel cost averaged approximately $1,925, excluding travel costs to a training course (personnel time at the training course is, however, accounted for). Computer costs must be added if these must be paid. This latter cost averaged about $1,390 for the three cities that paid for computer services from private computer services companies and $272 for the two cities that paid for in-house computer services.

5.2.2 Preparation of Data Collection Plans

This category includes identifying the signals whose timing will be optimized, preparing data collection plans, and organizing and training data collection personnel.

POSITION	HOURS
STE	19
TE	10
JTE	13
ST	13
JT	8
	63 hr. = 7.8 days

The personnel cost for this activity averaged approximately $700. Other costs were negligible.

5.2.3 Data Collection and Reduction

This activity involves field data collection and reducing the data to a form ready for input to TRANSYT-7F. Since the total cost will vary with the number of intersections in a project, the expenses reported below are given on a per intersection basis.

POSITION	HOURS PER INTERSECTION
STE	1.4
TE	1.0
JTE	3.0
ST	4.4
JT	5.5
CT	4.1
OP	0.3
	19.7 hours per intersection

The personnel cost averaged approximately $159 per intersection. The cost of other expenses (vehicle operating costs, traffic counting equipment, and processing of machine counts) averaged approximately $7 per intersection.

5.2.4 Data Coding

This task involves coding input data on coding forms and then keypunching the data onto data cards (or the equivalent). The expenses reported below are given on a per intersection basis.

POSITION	HOURS PER INTERSECTION
STE	0.6
TE	0.2
JTE	1.3
ST	0.6
JT	0.3
CT	0.2
SA	0.1
	3.3 hours per intersection

The personnel cost averaged approximately $36 per intersection. The cost of other expenses was negligible.

5.2.5 Running TRANSYT-7F

This category includes making simulation runs to calibrate TRANSYT-7F to existing conditions, making preliminary optimization runs to analyze alternative phase sequences and cycle lengths, making optimization runs, and making a final simulation run with the signal timing plan installed and fine-tuned on the street. The time required to analyze the above runs is also included. Expenses are again reported on a per intersection basis.

POSITION	HOURS PER INTERSECTION
STE	1.3
TE	1.0
JTE	0.9
ST	0.2
JT	0.6
SA	0.1
	4.1 hours per intersection

The personnel cost averaged approximately $44 per intersection. The other main expense was computer time. For the two cities that reported payment to a private computer services company, the average cost per intersection was approximately $37. For the four cities that reported payment to an in-house computer service, the average cost per intersection was approximately $27.

5.2.6 Installation and Fine Tuning of Signal Timing Plans

This activity involves field installation and fine tuning of the signal timing plans. Additional computer runs made to fine tune the signal timing plans are included. Nominally, three signal timing plans were installed in each city. The expenses are reported on a per intersection basis. Since Fort Wayne owns a computerized signal system where the timing plans can be installed relatively easily by reading data cards into the computer, their costs have not been included below.

POSITION	HOURS PER INTERSECTION
STE	0.8
TE	0.4
JTE	0.7
ST	1.3
JT	0.6
CT	0.1
	3.9 hours per intersection

The average personnel cost was approximately $46 per intersection. Computer expenses for this activity averaged approximately $13 per intersection, while other expenses averaged approximately $19 per intersection. These latter expenses were primarily vehicle operating costs.

5.2.7 Miscellaneous

Miscellaneous expenses included general labor charges, salary add-ons not included previously, lump sum computer charges and various other expenses. Only five cities reported miscellaneous expenses but a nine city average is given here.

POSITION	HOURS
STE	8
TE	4
JTE	17
ST	26
JT	4
OP	1
	60 hr. = 7.5 days

The total nine city average personnel cost was approximately $685. Other expenses (primarily vehicle operating costs) averaged $35.

5.2.8 Summary and Sample Calculation

Table 5.1 summarizes the information in the above subsections and shows a sample calculation for a 46-intersection network, for which the total personnel cost is $16,435 representing approximately 1,714 person-hours or about 214 person-days of effort. About one-half of this time will be professional; the remainder will be mainly technician time. The total project cost is $20,970. On a per intersection basis, approximately 40 hours of labor are required. The total project cost is about $456 per intersection. The assumptions made are explained in the table.

5.3 Additional Projects

The expenses reported in Section 5.2 are probably higher than what would normally be required. Since the cities did the work under contract to FHWA, higher level staff were used for various tasks which lower level staff could probably have performed as well. However, this may be typical for a first-time application of a complex computer model.

Costs for subsequent projects would be lower since the staff would not require the extensive learning process needed for a first project. For example, training would not be required and data coding would be easier due to familiarity with TRANSYT-7F's coding requirements. Both Des Moines and Nashville have conducted subsequent projects with TRANSYT-7F and have estimated 30 percent reductions in staff time.

TABLE 5.1

Summary of Expenses for a 46-Intersection Network

Activity	Personnel Cost	Cost of Other Expenses	Total
Initial Start-Up	$ 1,925	$1,470 (1)	$ 3,395
Preparation of Data Collection Plans	700	--	700
Data Collection and Reduction	7,320	320	7,640
Data Coding	1,660	--	1,660
Running TRANSYT-7F	2,025	1,240 (2)	3,265
Installation and Fine Tuning	2,120	1,470 (2)	3,590
Miscellaneous	685	35	720
Total	$16,435	$4,535	$20,970 (3)

(1) This cost assumes a $1,200 expense for travel to a training course and a $270 expense for payment for in-house computer services.

(2) This cost assumes payment is for in-house computer services.

(3) The average per intersection would be $20,970 : 46 = $456 per intersection.

In order to develop a cost estimate for subsequent projects, the following assumptions were made:

1. No initial start-up effort is required.

2. The time to prepare data collection plans and collect data is reduced by 10 percent.

3. The time to code data and run TRANSYT-7F is reduced by 30 percent.

4. Installation and fine tuning time is unchanged.

5. Personnel time in the miscellaneous category is reduced 40 percent.

6. Expenses are not reduced for efforts that remained part of the project. This is a conservative assumption.

The estimated total project cost is, therefore, reduced 27 percent to $15,400 and the average cost per intersection is reduced to $335.

CHAPTER 6

BENEFITS

6.1 Estimation Process

A primary objective of the National Signal Timing Optimization Project was to quantify typical traffic performance improvements obtainable from a signal timing optimization project. This chapter describes the process followed to estimate these benefits and relates the amount of improvement in traffic performance estimated by the project cities.

One useful feature of TRANSYT is that it can be used effectively to simulate the performance of traffic flow through a signalized street network using any given timing plan. Comparison of TRANSYT-7F traffic performance table outputs from simulation runs using the existing timing plans ("before") and the final timing plans ("after") provided the data for one aspect of the cities' evaluations. The final timing plans included changes in the TRANSYT-7F optimized timing plans due to fine tuning by the traffic engineer in the office and in the field after the timing plans had been installed. The traffic performance MOE's compared were vehicle delay, vehicle stops, and fuel consumption.

TRANSYT-7F estimates and reports traffic performance MOE's for a 1-hour time period. The differences in the "before" and "after" hourly MOE estimates for each control period were multiplied by factors representing the length of time that the traffic conditions represented by the input data actually existed. For example, if the AM peak period timing plan operated for 3 hours, but the 2 hours surrounding the peak hour had only 75 percent of the peak hour traffic demand, the factor used was .75 + 1 + .75 = 2.5. This resulted in an "effective day" that was less than a 24-hour day, but more accurately factored the hourly benefits. The total "effective day" was usually on the order of 12 hours.

The factored difference in each MOE estimate for each control period was combined to produce a total daily benefit for that MOE. This was then multiplied by 300 days (to nominally account for reduced weekend and holiday traffic) to produce a total annual benefit. Fort Wayne and Pawtucket multiplied by 250 days because their systems actually operated this number of days.

6.2 Conversion to Equivalent Dollar Values

In order to determine cost-effectiveness, the annual improvements estimated by TRANSYT-7F in vehicle delay, vehicle stops, and fuel consumption were multiplied by the following unit costs:

1. The average cost of time delay saved was assumed to be $0.50 per vehicle-hour. This is a very conservative value and was used because it was reasoned that small time savings by individual drivers are valued low. The

accumulation of small time delay cost savings by a large number of drivers can nonetheless be significant. It should also be noted that time delay savings to passengers were not considered, resulting in an even more conservative estimate.

2. The average non-fuel cost of a stop eliminated was assumed to be $0.014. This represents savings in vehicle operating costs (other than fuel) due to elimination of stop-and-go driving.

3. Since gasoline costs varied across the Nation, the cities used the cost of full service, unleaded gas in June 1981. The resulting costs varied from $1.25 per gallon in Denver to $1.48 per gallon in Ft. Wayne.

The equivalent dollar annual savings for the above MOE's were then combined to produce an equivalent dollar total annual benefit.

6.3 Estimated Traffic Performance Improvements.

The estimated annual traffic performance improvements reported by the project cities are summarized in Table 6.1 on a per intersection basis. For the average intersection in the project, each year 15,470 vehicle-hours of delay were saved, 455,921 vehicle stops were eliminated and 10,524 gallons of fuel were saved. The equivalent dollar total annual benefit per signal averaged $28,695.

There was quite a wide range of estimated improvements reported by the cities. For example, annual fuel savings ranged from 2,926 gallons per intersection to 31,415 gallons per intersection. The equivalent dollar total annual benefit ranged from $8,101 to $74,598. While it should be expected that the magnitude of improvement will vary between cities (and even networks within a given city), the upper range of the cities' estimates are probably high for the reasons given below.

One reason is the manner in which vehicle delay is calculated in TRANSYT. The delay calculation in TRANSYT is made up of two components: uniform delay, which represents delay due to the predicted queue, and random delay, which accounts for variation in queue length from cycle to cycle and also accounts for the effects of saturation. When the predicted degree of saturation is at or exceeds 100 percent, the predicted value of random delay becomes very large. This value is even larger when 60 minutes is assumed to be the length of time that the input traffic conditions actually exist in the field (an input to the program) when they actually exist for a shorter period of time. Typically, high degrees of saturation do not exist for a full 60 minutes.

TABLE 6.1

Estimated Annual Benefit

CITY	AVERAGE ANNUAL IMPROVEMENTS PER INTERSECTION			
	DELAY(1)	STOPS	FUEL(2)	DOLLARS(3)
Charleston, SC	3,187	437,600	4,345	$13,586
Denver, CO	74,311	-130,439	31,415	74,598
Des Moines, IA	1,915	238,542	2,926	8,101
Fort Wayne, IN	1,499	438,716	3,681	12,339
Gainesville, FL	21,627	-40,091	9,436	23,935
Milwaukee, WI	4,830	413,788	6,126	17,030
Nashville, TN	20,268	1,129,740	21,012	53,266
Pawtucket, RI	26,345	468,857	14,578	38,688
Portland, OR	3,667	382,554	4,351	12,846
San Francisco, CA	36,377	1,007,032	23,987	67,308
Syracuse, NY	6,428	272,901	4,841	13,909
Average	15,470	455,921	10,524	28,695

(1) - vehicle-hours
(2) - gallons
(3) - unit costs as given in Section 6.2

High degrees of saturation that existed with the before signal timing plan may have been reduced below 100 percent with the TRANSYT optimized signal timing plan. This would cause the estimation of vehicle delay savings to be high and since vehicle delay is used in the calculation of fuel consumption, the estimated fuel consumption savings would also be high, although proportionally less so. The estimation of vehicle stops is not affected.

To illustrate the affect of large estimated values of random delay, consider the Gainesville network. In the AM peak period, only 4 of 199 links were saturated, but these 4 links accounted for 51.6 percent of the total network delay and 18.6 percent of the total network fuel consumption.

Another reason that some of the estimated traffic performance improvements are high relates to the speed input for each link. The proper value of input speed is the "free flow" speed that traffic traveling without signal delay might achieve. With the "before" case signal timing plan, traffic never really attains the "free flow" speed, again leading to high predicted improvements in vehicle delay due to optimization, when the optimized timing plan probably allows traffic to reach the input "free flow" speed.

A final reason relates to the factoring process used to determine the length of the "effective day" in the determination of benefits. Several cities may have overestimated the length of their "effective day" thereby inflating the amount of traffic performance improvement and compounding the problems discussed above.

6.4 Cost-Effectiveness

With an average equivalent dollar total annual benefit of $28,695 per intersection and an average cost to conduct a first-time project of $456 per intersection, the benefit/cost ratio is an impressive 63 to 1. Considering only fuel savings, and assuming a gasoline cost of $1.35 per gallon, the benefit/cost ratio is still an impressive 31 to 1.

When the high results reported by some of the cities are eliminated, lower, but still impressive benefit/cost ratios result. It can be assumed that considering fuel savings only, a benefit/cost ratio of at least 10 to 1 can be expected for first-time projects. When the value of time saved and vehicle stops eliminated are included, a ratio of at least 20 to 1 can be expected for first-time projects.

It is emphasized that these are very conservative estimates since they do not consider the delay and fuel saved at intersections which were saturated in the before case. Certainly, optimized signal timing plans can be expected to reduce the degree of saturation and, therefore, delay and fuel consumption significantly, although perhaps not to the extent predicted by the program.

For subsequent projects the average cost can be expected to decline by approximately 27 percent (see Section 5.3). Therefore, the benefit/cost ratios for subsequent projects can, as a minimum, be expected to increase to 15 to 1 considering fuel savings only and 30 to 1 when the value of time saved and vehicle stops eliminated are considered.

6.5 Field Evaluations

Another aspect of the cities' evaluations consisted of limited floating vehicle traveltime studies. Typically, the cities established one or two floating vehicle routes and nominally made three runs on each route during each control period both "before" and "after" installation of the optimized timing plans. The routes chosen were somewhat circuitous to include coverage of major turning movements in the network.

6.5.1 Field Evaluation Results

Link-by-link field evaluation results were reported by nine of the 11 project cities. In general, the TRANSYT-7F estimates of total traveltime were higher than the measured total traveltimes and, in addition, the total traveltime improvements from "before" to "after" were also predicted to be higher by TRANSYT-7F than were actually measured in the field. It is significant, however, that the measured traveltimes improved in every control period in every city with the exception of two cases (San Francisco's PM peak and Portland's single control period system). Measured total traveltime improvements ranged from less than 1 percent to 31 percent and averaged 8.5 percent, as opposed to TRANSYT-7F's estimated average improvement of 15.7 percent. The results are summarized in Table 6.2.

The main reason for the discrepancy between the TRANSYT-7F estimates and the measured total traveltimes was the existence of saturated links, which as discussed in Section 6.3, led to unrealistically high estimates of vehicle delay. When a second analysis was conducted which eliminated consideration of obviously saturated links (links for which the total traveltime "before"/total traveltime "after" ratio was greater than 5), the TRANSYT-7F estimated average improvement was 6 percent compared to an average measured improvement of 5.9 percent, although there was quite a bit of variation in individual link differences. Also, in several cases in the second analysis, the TRANSYT-7F estimated total traveltimes actually showed disimprovement, indicating that, indeed, the saturated links did receive the majority of the benefits from optimization.

Even when the saturated links were eliminated, the field measurements still indicated disimprovements in San Francisco's PM peak period and Portland's single control period system. No good explanation can be found for San Francisco's results other than to assume that the input data were not truly representative of actual field conditions. On the other hand, several explanations can be given for Portland's results. These are summarized below:

1. Portland developed three optimal timing plans (AM peak off-peak, and PM peak) but because of the limitations of their signal system, they were only able to install one of these which operates all day long. Based on analysis using TRANSYT-7F, the off-peak timing plan was chosen to be installed. TRANSYT appears to give more reliable results when it simulates timing plans that are optimal for the input traffic conditions (see Subsection 6.5.2). Thus, the MOE estimates produced by TRANSYT for the other periods when the "non-optimal" off-peak timing plan was simulated may be suspect.

2. Portland did not consider vehicle stops in the development of their timing plans. This probably resulted in too little consideration to thru progression in the installed timing plan.

TABLE 6.2

Total Traveltime Comparisons (VEH-HR/HR)

CITY	CONTROL PERIOD	TRANSYT-7F BEFORE	TRANSYT-7F AFTER	TRANSYT-7F %CHANGE	MEASURED BEFORE	MEASURED AFTER	MEASURED %CHANGE
Denver	AM	426.94	210.72	50.64	166.47	161.82	2.79
	PM	456.53	306.99	32.75	261.70	241.06	7.89
	OFF	752.33	251.54	66.57	253.12	226.46	10.53
Des Moines	AM	343.42	329.98	3.91	379.75	338.27	10.92
	PM	436.64	397.46	8.97	442.04	439.03	0.68
	OFF	421.69	411.61	2.39	457.04	437.31	4.32
Fort Wayne	AM	163.76	153.10	6.51	204.32	167.38	18.08
	PM(Factory)	205.67	193.47	5.93	242.06	236.85	2.15
	PM(Office)	235.08	218.84	6.91	285.29	246.69	13.53
	OFF(Low)	113.59	110.18	3.00	116.99	112.50	3.84
	OFF(High)	157.37	146.13	7.14	177.80	160.90	9.51
Gainesville	AM	231.78	220.72	4.77	270.24	248.98	7.87
	PM	934.80	430.60	53.94	413.63	378.24	8.56
	OFF	63.29	62.99	0.47	73.40	62.95	14.24
Milwaukee	AM	968.47	928.80	4.10	892.99	871.29	2.43
	PM	1,416.79	1,228.01	13.32	1,242.23	1,193.39	3.93
	OFF	849.85	822.67	3.20	898.56	823.27	8.38
Nashville	AM	406.83	333.43	18.04	288.33	276.40	4.14
	PM	580.20	465.08	19.84	355.91	341.96	3.92
	OFF	347.54	314.40	9.54	282.92	274.06	3.13
Portland	AM	733.4	684.2	6.71	879.46	996.35	-13.29
	PM	797.10	735.42	7.74	755.24	783.96	- 3.80
	OFF	485.23	461.50	4.89	471.18	482.64	- 2.43
San Francisco	AM	1,838.53	1,214.28	33.95	1,296.31	1,165.86	10.06
	PM	2,614.15	1,798.64	31.20	1,637.66	1,671.00	- 2.04
	OFF	1,019.55	832.08	18.39	952.32	913.97	4.03
Syracuse	AM	172.22	157.39	8.61	228.12	186.02	18.46
	PM	363.99	319.58	12.20	426.77	295.04	20.87

3. Portland's floating vehicle routes may have been overly circuitous leading to biased total traveltime measurements. When the test vehicle turns a corner, it will usually be entering a link out of synchronization with the progression band, resulting in a stop and delay downstream. Measured average traveltimes will thus be higher than TRANSYT-7F estimated average traveltimes since the TRANSYT estimates account for the traveltimes of both turning and thru vehicles upstream. The effect will be compounded in calculating total measured traveltime since total volume on the link will be multiplied by the artificially high average traveltime.

6.5.2 Statistical Analysis

Statistical studies were conducted on average link traveltimes using the paired t-test. This statistic was used to test whether the difference in link travel times was significantly different than zero at a 95 percent confidence level for the following traveltime comparisons:

. TRANSYT-7F estimates, "before" to "after"
. Measured, "before" to "after"
. TRANSYT-7F minus measured, "before"
. TRANSYT-7F minus measured, "after"

Since inclusion of saturated links would bias the TRANSYT-7F estimates, the results presented here include only the unsaturated links (a conservative comparison). Table 6.3 contains a summary of the statistical analyses.

Measured improvements were statistically significant in ten of 31 cases while TRANSYT-7F estimated improvements were significant in 15 of 31 cases. In some cases the percent improvement was as high as 15 percent but was not significant due to large variances.

In the comparisons between TRANSYT-7F estimates and measured average traveltimes, there were 17 instances of significant differences for "before" conditions and nine instances of significant differences for "after" conditions. This supports the contention made earlier that TRANSYT-7F better simulates traffic with optimal timing plans.

More statistically significant results could probably have been obtained if the cities had been required to do more extensive floating vehicle studies. The FHWA is planning to sponsor such a study for the summer of 1982.

TABLE 6.3

Statistical Analysis of Average Link Traveltimes
(Unsaturated Links Only)

CITY	CONTROL PERIOD	TRANSYT-7F BEFORE	TRANSYT-7F AFTER	TRANSYT-7F % CH.(1)	MEASURED BEFORE	MEASURED AFTER	MEASURED % CH.(1)	TRANSYT-7F MINUS MEASURED % BEFORE(1)	TRANSYT-7F MINUS MEASURED % AFTER(1)
Denver	AM	24.6	24.8	- 1.0	20.4	20.2	1.0	17.1*	18.5
	PM	26.0	28.3	- 8.7	23.7	21.1	11.0*	8.8	25.4
	OFF	17.8	17.3	2.7	20.8	18.5	11.1*	-16.9*	- 6.9
Des Moines	AM	48.5	47.9	1.1	52.0	45.7	12.2*	- 7.2*	4.7
	PM	53.8	50.0	7.0*	53.5	53.9	- 0.8	.6	- 7.8
	OFF	49.7	48.5	2.4*	53.4	51.3	3.9	- 7.4*	- 5.7*
Fort Wayne	AM	20.3	18.8	7.4*	25.0	19.9	20.5*	-23.2*	- 5.9
	PM(Factory)	20.8	20.3	2.4	25.7	25.5	.8	-23.6*	-25.6*
	PM(Office)	22.3	21.5	3.6	27.0	24.3	10.0	-21.1*	-12.9*
	OFF(Low)	18.6	18.3	1.7	18.7	18.2	2.6	- .5	0.5
	OFF(High)	20.0	19.5	2.5	22.8	22.2	2.6	-13.9*	-13.8
Gainesville	AM	24.0	25.1	- 4.6	30.1	26.9	10.6*	-25.4*	- 7.1
	PM	28.7	25.6	10.8*	29.2	27.2	6.7	- 1.7	- 6.3
	OFF	23.8	23.2	2.5	28.0	23.9	14.6	-17.6*	- 3.0
Milwaukee	AM	41.2	39.8	3.5*	37.6	37.1	1.2	8.7*	6.7*
	PM	42.1	39.8	5.5*	39.3	37.6	4.2	6.8*	5.5*
	OFF	38.9	37.6	3.3*	40.0	36.3	9.2*	- 2.8	3.3.

(1) Minor errors in the percentages are due to rounding off the values.

*Significant at the 0.05 level.

TABLE 6.3 (CONTINUED)

CITY	CONTROL PERIOD	TRANSYT-7F BEFORE	TRANSYT-7F AFTER	TRANSYT-7F % CH.(1)	MEASURED BEFORE	MEASURED AFTER	MEASURED % CH.(1)	TRANSYT-7F MINUS MEASURED % BEFORE(1)	TRANSYT-7F MINUS MEASURED % AFTER(1)
Nashville	AM	38.3	34.1	11.0*	26.5	25.5	3.8*	30.7*	25.2*
	PM	38.0	35.9	5.5	26.6	25.6	3.8	30.1*	28.6*
	OFF	34.3	31.4	8.6*	26.4	25.4	3.8*	23.0*	19.1*
Portland (turn links incl.)	AM	38.5	37.4	2.9*	43.2	44.9	- 3.9	-12.5	-20.2
	PM	39.3	38.2	2.8*	41.2	41.4	- 0.6	- 4.7	- 8.4*
	OFF	42.0	39.6	5.7*	37.5	38.7	- 3.1	10.6	2.4
Portland (turn links excl.)	AM	37.8	37.1	1.8	36.6	37.1	- 1.4	3.2	0.1
	PM	39.5	38.0	3.8*	39.3	37.6	4.3	0.4	1.1
	OFF	37.0	35.3	4.7*	35.7	35.5	0.7	3.5	- 0.6
San Francisco	AM	36.8	36.5	0.7	34.0	31.4	7.6	7.6	14.1
	PM	39.4	38.0	3.6	36.3	40.1	-10.5	7.9	- 5.6
	OFF	28.2	26.9	4.5*	32.7	30.9	5.4	-16.0*	-15.0*
Syracuse	AM	20.0	18.7	6.5	27.3	21.1	22.7*	-36.5*	-12.7
	PM	21.2	20.1	5.1	27.1	18.2	32.7*	-27.9	9.4

(1) Minor errors in the percentages are due to rounding off the values.

*Significant at the 0.05 level.

CHAPTER 7

CONCLUSIONS

Several important conclusions can be reached as a result of the activities conducted under the National Signal Timing Optimization Project. These are listed and briefly discussed below:

1. Signal timing optimization can lead to significant reductions in vehicle delay, vehicle stops, and fuel consumption.

   As reported in Chapter 6, based on TRANSYT-7F estimates, for the average intersection in the project, each year vehicle delay was reduced by 15,470 vehicle-hours, 455,921 vehicle stops were eliminated, and 10,524 gallons of fuel were saved. This latter figure represents an average 12.5 percent reduction in fuel consumption for the networks whose signal timing was optimized. Even though savings to the individual driver may be small, when these savings are accumulated for all drivers over a year's time, substantial savings can be achieved. Limited field studies confirmed the improvement in traffic performance. With two exceptions, traffic performance improved in every control period in every city. The average measured improvement in total traveltime was 8.5 percent.

2. TRANSYT-7F is a very valuable tool for signal timing optimization projects.

   The cities were able to successfully use TRANSYT-7F to develop optimal timing plans. In addition to developing optimal phase lengths and offsets for the signals in their networks, the cities also used TRANSYT-7F to evaluate other potential signalization improvements such as different phase sequences and cycle lengths, and double cycling certain intersections. The program was also used by the cities to fine tune the optimized timing plans using the available link weighting factors. Only a small amount of fine tuning was necessary to the TRANSYT-7F timing plans when installed on the street, consisting mostly of small adjustments to offsets and phase lengths. Perhaps the best evidence of the value of TRANSYT-7F was that all of the cities plan to continue to use the program pending the availability of time and personnel.

3. Data collection is the major and key task in conducting a successful signal timing optimization project.

   Data collection, particularly traffic volume data, presented the biggest problem to the cities in terms of the personnel and time resources required over a short period of time. This problem is especially critical since, of course, the results produced by the program are only as good as the data input. The cities were especially interested in the development of better estimating procedures and automated data collection techniques.

4. The provision of technical assistance is very helpful to those conducting project.

   Technical assistance was available to the project cities from both the University of Florida's project staff and FHWA's Office of Traffic Operations' Systems and Software Support Team. Assistance was available on all aspects of the project, including program implementation on the cities' computer systems, data collection and input coding, interpreting the program's outputs, installing the new timing plans on the street, and evaluating the new timing plans. Technical assistance mainly consisted of answering questions by telephone, although several site visits were also made. The availability of technical assistance saved a lot of potentially wasted time and assured that the projects were conducted correctly.

5. Conducting a signal timing optimization project can lead to several side benefits.

   In the process of conducting their projects, the cities discovered certain deficiencies in their signal systems which, when corrected, provided additional benefits. These included bad signal interconnect cable, malfunctioning signal controllers, incorrect settings on some controllers, and the need for additional signal timing plans.

6. Public reaction to signal timing improvements is favorable.

   A number of the project cities reported favorable local media coverage of their projects. In several cities, positive feedback was also received from individual citizens. There was no adverse reaction reported by any of the cities. This substantiates that signal timing optimization is a popular way of achieving fuel conservation. Traveling through urban areas is faster and easier. Tax dollars are spent on a project from which everyone can benefit.

7. Energy conservation through optimization of signal timing plans is a valid national objective which can be realized through the actions of State and local governments.

Signal timing optimization proved to be a very cost-effective way of achieving fuel savings. It is also a painless way, nobody suffers, and driving through urban areas is faster and easier. Considering fuel savings only, a very conservative estimate of the expected benefit/cost ratio for first-time projects is 10 to 1, increasing to 15 to 1 for subsequent projects when costs can be expected to be less. This is akin to saving 7-12 gallons of gasoline for every project dollar invested or saving a gallon of gasoline for a dime invested. When the value of time delay saved and vehicle stops eliminated is considered, a very conservative estimate of the expected benefit/cost ratio is 20 to 1 for first-time projects, increasing to 30 to 1 for subsequent projects. These results are in general agreement with similar results reported by others (6, 7). Larger improvements may well occur, as indicated by some of the results reported by the project cities. The FHWA hopes to encourage State and local governments to give due consideration to signal timing optimization projects through promotional activities, maintenance and distribution of the TRANSYT-7F program, provision of training in the program's use, and the availability of technical assistance from FHWA staff.

REFERENCES

1. "America's Energy Diet Cuts Imports Sharply," The Washington Star, May 24, 1981.

2. "Energy Effects, Efficiencies, and Prospects for Various Modes of Transportation," National Cooperative Highway Research Program Report 43 Report, 1977.

3. Schoene, G. W. and Euler, G. W., "Energy Conservation Through Traffic Signal Timing Optimization," paper presented at 51st Annual Meeting of the Institute of Transportation Engineers, August 1981.

4. Wallace, C. E., et. al National Signal Timing Optimization Project: Final Evaluation Report, prepared for the Office of Traffic Operations, Federal Highway Administration, February 1982.

5. Wallace, C. E., et. al TRANSYT-7F User's Manual, prepared for the Office of Traffic Operations, Federal Highway Administration, December 1981.

6. Wagner, F. A., Energy Impacts of Urban Transportation Improvements, report prepared for the Institute of Transportation Engineers, August 1980.

7. "Preliminary Draft Evaluation of Traffic Performance Impacts of the Computerized Traffic Signal System Implementation in Garden Grove, California," paper prepared for the city of Garden Grove by Wagner-McGee Associates, Inc., August 1981.

*U.S. GOVERNMENT PRINTING OFFICE: 1982-0-361-428/2097

14836