Traffic Signal Timing as a Transportation System Management Measure: The California Experience

ELIZABETH A. DEAKIN, ALEXANDER SKABARDONIS, and ADOLF D. MAY

ABSTRACT

Traffic signal retiming has long been suggested as a means of improving traffic operations and reducing fuel consumption and emissions. However, few local agencies have been able to muster the resources to systematically retime their signals. In California, a statewide program--the Fuel Efficient Traffic Signal Management (FETSIM) Program--was established to address this need. The FETSIM Program provides funds, training, and technical assistance to local agencies to retime their signal systems for greater operating efficiency. To date, 62 local jurisdictions have participated in the program, receiving grants totaling $4 million (1983-1985). In 1986 and 1987 an additional $2 million will be available for grants. The objectives, design, and results of the FETSIM Program's first three funding cycles are described. The program was intended both to produce immediate transportation benefits and to develop within local agencies the skills needed to use state-of-the-art methods for longer-term signal systems management. The transportation benefits have been substantial, with average first-year reductions of 16 percent in stops, 15 percent in delays, 7.2 percent in travel times, and 8.6 percent in fuel use in the retimed systems. Training benefits to local agency personnel also have been positive. However, the program has not had a major influence on local priorities; basic problems in funding and staffing for local transportation activities, including signal work, remain. These problems appear likely to work against long-term maintenance of efficient signal-timing plans unless state funding continues to be made available.

Traffic signal retiming has been proposed as a transportation system management (TSM) measure because it can reduce stops and delays and thus increase the operational efficiency of local streets as well as save travel time and cut down on fuel use and emissions. However, relatively few local agencies have been able to muster the resources to systematically retime their signals on their own. Thus, despite advances in techniques for optimizing signals as a system, many traffic engineers only adjust signal timings one at a time when equipment failure or complaint-generating operating problems occur.

California's traffic engineers have been well aware of the need for periodic retiming of their traffic signal systems, but many have also found that tight city budgets and the daily pressure of work make it difficult or impossible for them to undertake the necessary efforts. One result has been higher-than-necessary fuel use. In California, 65 billion vehicle-mi, or one-third of the state's total vehicle miles of travel, occur each year on streets controlled by traffic signals. Fuel consumption on signalized streets accounts for nearly 20 percent of the state's annual petroleum use, and almost 1.5 billion gal of fuel are burned up each year during stops and delays at traffic lights (1). As shown in Figure 1, about one-third of the fuel used in the widely spaced signal systems in suburban California is lost in stop-and-go driving and in idling. In downtowns, where signals are closer together, fully 43 percent of the fuel is consumed in stops and delays (data from California Department of Transportation, May 1984).

Institute of Transportation Studies, University of California, Berkeley, Calif. 94720.

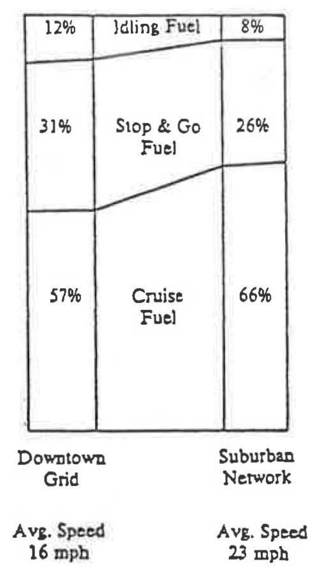

FIGURE 1 Use of fuel on signalized streets in California.

Although many of the stops and delays along signalized streets are necessary or unavoidable, some could be reduced or eliminated by more efficient signal timing. In response to this opportunity, the Fuel Efficient Traffic Signal Management (FETSIM) Program was initiated. Through 1985, 61 cities and one county have participated in this statewide initiative, retiming nearly 3,300 signals. The FETSIM

Program's design and implementation are described and its impacts are discussed. An evaluation of the program is made and signal timing's potential as a TSM measure is considered.

PROGRAM OBJECTIVES AND DESIGN

The FETSIM Program's primary objective is to reduce stops, delays, and fuel consumption through the implementation of more effective signal-timing plans. The program thus provides California cities and counties with both the financial resources and the technical assistance necessary to retime their signals. A second objective of the program is to enhance the capability of the state's traffic engineers to continue to manage their traffic signals effectively; consequently, the program provides training in signal-timing techniques and strategies.

The FETSIM Program is funded through petroleum account monies via the California Energy Resources Conservation and Development Commission; it currently is administered by the California Department of Transportation (Caltrans). Grants have been made available to cities or counties through annual program cycles. To be eligible for a grant, the local jurisdiction was required to have 10 or more signals in a coordinated system capable of multiple timing plans. Beginning in 1986, somewhat less restrictive eligibility criteria were applied. Local agencies are permitted to participate in more than one program cycle if they have additional eligible signal systems. Expenditures have been allowed for all aspects of signal-timing optimization: data collection, data processing, time-plan development, implementation, and field evaluation; grantees also have been permitted to pay in-house staff salaries under the program or to elect to contract with consultants. In the 1983-1985 programs, however, grant funds were not authorized for purchasing signal equipment or control system software or for conducting studies of the potential benefits of coordinating or upgrading signal systems. In 1986, a program testing the cost-effectiveness of funding signal equipment upgrades was initiated.

Each program cycle is of 12 months' duration, during which grantees are given training and technical assistance in the design and implementation of improved timing plans for their signal systems.

THE TRAINING PROGRAM

Training activities for the program have the dual objective of enabling participating traffic engineers and their consultants to use state-of-the-art signal system timing techniques and encouraging longer-term local commitments to signal retiming. The training is conducted through a series of workshops covering principles of fuel-efficient traffic signal management, project design and organization, practical use of traffic signal-timing and evaluation tools, and methods for implementing and maintaining improved timing plans. Basic knowledge of traffic signal timing is assumed, but no previous experience in computer use or fuel-efficient traffic management is required.

The Traffic Network Study Tool (TRANSYT) computer model has been used for optimizing signal settings and for analyzing the resulting traffic impacts (2). TRANSYT was selected because it is capable of handling complicated networks, because it has been thoroughly field tested, and because it directly produces estimates of delay, stops, and fuel consumption. The publicly available TRANSYT-7F version of the model (3) has been emphasized in the FETSIM Program.

TRANSYT is a macroscopic (platoon-based), deterministic model that simulates existing conditions in a system of signals and then optimizes the timing plans. Use of TRANSYT requires coding the network into links and nodes, and accurate data on traffic volumes, saturation flows, speeds, and existing signal settings are needed. TRANSYT's traffic model is applied to these inputs to produce estimates of degree of saturation, travel time, delay, stops, and fuel consumption, as well as flow profiles and queueing estimates. These outputs are compared with observed conditions, and input data and model parameters are adjusted until the model reasonably represents actual operations. TRANSYT then generates alternative timing plans for the signal system. The alternative plans are evaluated using stops, delays, and fuel consumption as the measures of effectiveness, and the best plan is implemented in the field. In-place studies of performance then are carried out to make sure the desired results are being obtained; minor adjustments often are necessary.

The TRANSYT model was used in the program to optimize signal timings for minimum fuel consumption. Several studies have shown that along arterials and in networks, the fuel minimization strategy also tends to minimize delays and stops (4,5). In comparison, delay minimization tends to minimize fuel and reduce stops but may not produce good progression, particularly along arterials. Stop minimization may result in unacceptable timings because it tends to produce long delays on low-volume approaches.

It was recognized at the outset that most participants would need considerable training to be able to apply the TRANSYT model. The workshops thus were designed to provide step-by-step guidance through lectures and laboratories in which participants gained hands-on experience in model use. Orientation workshops are held shortly after the awarding of grants, to assist local agencies in the planning and organization of their projects and to familiarize participants with TRANSYT's data collection, coding, simulation, and calibration requirements. Implementation workshops, 5 months later, cover traffic signal optimization techniques, procedures for installing and fine tuning improved timings, and methods for field studies.

At a third workshop, held at the conclusion of each program cycle, the local agencies present their results. An important purpose of this final workshop is to allow participants an opportunity to evaluate the program; this feedback has been used to refine the workshops and grant conditions in subsequent years.

TECHNICAL ASSISTANCE

Technical assistance during project implementation is also a key design feature of the FETSIM Program. Centers established in Berkeley and Los Angeles coordinate these efforts. Assistance has ranged from advice on data collection procedures and evaluation approaches to help in setting up, running, and interpreting computer programs. In addition, local agencies that do not have in-house computing facilities are provided access to computers through the two centers.

Participating agencies are visited at least twice by the center's staff, who examine each project area, answer questions, and assess progress. Ongoing telephone contact is used to assure that the agencies' projects are proceeding on schedule and to discuss any technical problems that may have arisen. In addition, a newsletter, the FETSIM Bulletin, is mailed to all participants as a way to distribute information on the schedule of events and transmit technical advice.

TABLE 1 FETSIM Program: Three Funding Cycles

	1983	1984	1985
No. of grants	41	22	18
No. of signals	1,535	937	700
Avg grants per intersection[a] ($)	1,037	1,025	970
Total grants to cities ($)	1,592,000	862,882	637,251
Costs for technical assistance, training, research, evaluation, and administration ($)	470,000	203,100	190,772
Total expenditures ($)	2,062,000	1,065,982	828,023

[a]Actual costs when available; otherwise grant awards.

LOCAL PARTICIPATION

Summary data are given in Table 1 on participants' projects and budget allocations (along with costs of training, technical assistance, research, and administration). A total of 81 grants were awarded, but only 62 separate jurisdictions are represented; a number of cities participated in two or more program cycles.

Costs per signal were slightly lower in the second and third program cycles than in the first. In part, this reflects the fact that local jurisdictions were strongly urged to participate in program costs in the later cycles. On average, local contributions were 5 percent of grant amounts. It should be noted, in addition, that most participants adhered to the state's guideline of $1,100 per signal rather than budgeting each task in detail.

Consultants were employed in about three-fourths of the FETSIM projects, with assignments ranging from only data collection to the full range of project activities. Only 11 jurisdictions undertook model application in house; these included 5 of the 6 largest participating jurisdictions, plus 4 other jurisdictions whose staff had substantial previous experience with the TRANSYT model. Only two jurisdictions whose staff had not previously used TRANSYT extensively did the modeling aspects of their projects in house.

In each funding cycle to date, the majority of the local agencies were able to complete their projects with little difficulty. However, some local agencies experienced problems. For example, a number of participants in the first funding cycle discovered that their signal equipment was in serious need of repair, which delayed their projects. In subsequent cycles, a field check and problem correction were required before the cities commenced data collection. Also, several first-cycle cities experienced changes in traffic patterns because of construction, which seriously hindered the development of optimal signal timings. This problem has been largely eliminated by restricting grants to those cities that do not expect such changes. In all three cycles, inadequate data collection procedures caused difficulties in the application of the TRANSYT model in a few cities. The technical assistance teams have been increasingly on the alert for such problems and now review data and coding sheets before modeling begins.

PROGRAM RESULTS

Transportation Benefits

Results from the participating jurisdictions show that in nearly every case, the program has produced major transportation benefits (6,7). On the basis of TRANSYT outputs, the retimed signal systems have attained average first-year reductions of 16 percent in stops throughout the day and 15 percent reduction in delays. Travel times through these systems have declined an average of 7.2 percent, and fuel use has dropped 8.6 percent. (Because benefits often are overestimated at intersections when oversaturation occurs, such intersections have been eliminated from this estimate of average improvements. This may result in a slight underestimation of overall program benefits.)

Field measurements of benefits were estimated from data produced by 11 cities that conducted thorough floating car studies in the 1983 cycle. These studies were conducted during the a.m. peak, midday, and p.m. peak for 2 weeks before and 2 weeks after the implementation of the new timing plans along test routes selected to represent the overall flow patterns in the study areas, including turning movements. Travel times, stops, and delays were recorded for each test run. On the basis of these field tests, stops and delays both were reduced by more than 14 percent, and travel time was cut by 6.5 percent; using these results to calculate fuel consumption produced an estimated decline of 6 percent. Comparison of TRANSYT predictions with field measurements showed that TRANSYT generally overestimated benefits by 1 to 4 percent (Table 2).

To provide an additional check on estimates of benefits from TRANSYT and floating car studies, an instrumented vehicle was used in the 1983 cycle to measure actual traffic performance and fuel consumption in the city of Berkeley's grant project area, consisting of 28 signals in a dense central business district (CBD) grid pattern. The instrumented vehicle was driven before and after implementation of the new signal timings on routes selected to reflect the overall pattern of traffic movements in the area (8). The results of the instrumented-vehicle test were within 2 percent of the TRANSYT outputs and verified that significant fuel savings and improvements in the quality of traffic flow were obtained from the optimization of the signal timings.

TABLE 2 Comparison of TRANSYT and Field Results

Control Period	Travel Time		Delay		No. of Stops		Fuel Consumption	
	TR	FLD	TR	FLD	TR	FLD	TR	CALC[a]
A.m. peak	-6.6	-5.4	-14.5	-14.0	-14.9	-9.4	-8.3	-4.2
Midday	-7.5	-6.9	-15.1	-1.47	-11.6	-15.6	-7.7	-6.0
P.m. peak	-8.0	-7.0	-14.7	-12.3	-13.5	-11.9	-7.8	-6.4

Note: Values given are percent changes, averages based on results reported in 11 cities, 1983. TR = TRANSYT results; FLD = field results.

[a]Calculated from the field-measured travel times, delays, and stops.

Field studies were not required by the state in subsequent program cycles, because of the heavy time and resource commitments required to obtain statistically significant results. A number of local jurisdictions have carried out field tests voluntarily, however, and these field tests have consistently found TRANSYT predictions to be within 2 to 4 percent of measured values.

Annual benefits of the FETSIM Program for each funding cycle, based on the TRANSYT model results, are given in Table 3. Benefits have declined somewhat in later cycles, in large part because in the later cycles local jurisdictions entered the program with more recently timed signal systems. Nevertheless, at average fuel costs of $1.10 to $1.15 per gallon, avoided fuel expenditures during the first cycle outweigh program costs by a factor of nearly 6 to 1.

Other transportation benefits of the program include reduced vehicle wear and tear and travel-time savings. On the basis of AASHTO figures (9) for the costs of vehicle wear and tear due to stops and delays, an additional $30.55 million is being saved by motorists each year. AASHTO's method for estimating value of time would produce an annual savings equivalent to another $22.5 million. Other benefits, including air quality and safety improvements, are believed to have been produced by the program but these benefits have not been quantified.

Training Program Benefits

The benefits of the training program were assessed through surveys conducted at the completion of grant activities. Here, significant differences among the participating agencies were observed. In the jurisdictions that carried out most aspects of their projects in house, participating staff generally believed that they would be able to use the TRANSYT model for future signal retiming on their own. It is noteworthy, though, that in at least half of these cases, the assigned staff were already experienced TRANSYT users. In the cities that tended to rely on consultants for most of the project work, most staff members failed to gain enough expertise in the use of the model to apply it independently in the future; nevertheless, a majority of them believed that they were sufficiently well versed in the model application to design future projects and closely supervise consultants. Cities in which the staff lacked background in computer use (and, in many instances, in traffic engineering) did not fare as well. For these participants--about one in five--much of the content of the training program was at too advanced a level for them to assimilate more than the general principles, and most believed that they would continue to be dependent on consultants in project design and management.

Cities' consultants were also encouraged to participate in the training program. Although many of the consultants already had basic knowledge of the TRANSYT program, the training allowed them to develop expertise. City staff, moreover, believed that training for consultants helped assure a high-quality product.

Although the training program was favorably received by all participants, it is important to note that most local jurisdictions did not avail themselves of the opportunity to become model users. Instead, the majority of city personnel utilized the training sessions as an opportunity to become knowledgeable managers of signal-timing projects.

THE FUTURE OF THE PROGRAM

The California energy commission and Caltrans estimate that there are some 20,000 signals in California, more than 90 percent under city or county control. Because only about 15 percent of these signals have been retimed under the FETSIM Program to date, a substantial market for additional program cycles is believed to exist. To assess this market and the level of future interest in the program, telephone interviews were conducted with the traffic engineers in a sample of 101 California cities, including both nonparticipants and those who had received one or more grants (10).

The interviews revealed a number of reasons that nonparticipating cities had not pursued grants from the FETSIM Program. Among the larger cities (populations of 50,000 or more), almost one in five was not aware of the program. (This is in spite of annual program announcements to all city and county traffic engineering departments, plus announcements and presentations at meetings of professional societies such as the Institute of Transportation Engineers and the American Society of Civil Engineers.) About one-third of the nonparticipating cities could not meet the program requirements of 10 or more signals in a coordinated system capable of multiple timing plans; for example, many had single-dial controllers or lacked signal interconnections, or both. Sixteen percent did not apply for a grant because their cities were making major construction changes or were currently conducting transportation studies, and another 16 percent was satisfied with their present timings. Nine percent did not apply for a grant because of staff limitations.

In the smaller nonparticipating cities (population less than 50,000), 60 percent was not aware of the FETSIM Program. For those who were aware of it, one of the most important reasons for nonparticipation was lack of personnel capable of supervising a signal-timing project; in 75 percent of the small cities there is no engineer on the staff and less than 10 percent of consulting engineers' time is denoted to signal work. Inability to meet the program signal system requirements was a second major barrier; in 85 percent of the smaller cities there are fewer than 10 signals in any one system, and most of these cities also lack signal interconnections or multiple timing-plan capabilities, or both.

TABLE 3 FETSIM Program: Annual Benefits

	1983	1984	1985
Signals retimed ($)	1,535	937	700
Savings in fuel costs ($)	12,800,700	6,700,000	4,600,000
Savings in operating costs ($)			
Due to reduced delays	800,000	400,000	250,000
Due to reduced stops	16,300,000	7,700,000	5,100,000
Value of time saved ($)	12,400,000	6,200,000	3,950,000
Total money saved ($)	42,300,000	21,000,000	13,950,000

Note: Benefits are based on TRANSYT model outputs.

On the basis of the interview findings, only about half of the traffic signals in the state appear to be eligible for retiming under the current FETSIM Program criteria. It would take 8 to 10 years to retime all these signals at current funding levels and annual rates of participation. However, the interviews also suggested that modifications to the program would allow additional signals to be retimed. Such modifications are currently under consideration. One restriction that currently limits signal retiming is the requirement of 10 or more signals in a coordinated system. The interviews found that an estimated 1,800 signals, or about 10 percent of the total signals under local control, are in simple systems that include fewer than 10 signals. Although these small systems could be retimed by using the TRANSYT method, simpler techniques (such as PASSER-II) also would be suitable and would be preferred by local officials. Trial programs assessing PASSER-II and TRANSYT for retiming these small, simple signal systems are currently under consideration.

Also, at least 2,500 more signals could be retimed if improvements in signal equipment, including coordination capabilities and multiple-timing plan capabilities, were funded. Costs for signal hardware vary considerably, depending on the existing equipment, the type of new equipment desired, and the system configuration. Increasing the number of timing plans could cost on average $1,200 if the system is already coordinated, whereas costs could be $1,000 to $3,500 per controller for interconnection (10). Replacing controllers requires a larger investment ($4,500 to $9,000 per intersection) but would be essential in some cities. Although funding such hardware improvements would increase the average cost per signal substantially, benefits also might be considerably higher in those systems that would find coordination and multiple-timing plans advantageous. Furthermore, a number of the cities that lack signal hardware report that their signal-timing plans are in serious need of improvement, so that potential gains could exceed those achieved to date. On the other hand, areas with little traffic peaking may not benefit substantially from multiple-timing plans, and areas where signals are widely spaced may gain little from coordination. Because of the uncertainties over cost-effectiveness of hardware investments, more detailed analysis will be carried out before a commitment is made to a full-fledged hardware assistance program.

Table 4 gives cost estimates for three program options currently under consideration for future years.

EVALUATION

Experience with the FETSIM Program provides an opportunity to evaluate the potential of traffic signal timing as a TSM measure. The program has clearly demonstrated that traffic signal-timing improvements are a cost-effective way to reduce stops, delays, and fuel consumption, and thus to increase the operating efficiency of local streets. Benefits outweigh costs by almost six to one, even when 1 year of avoided fuel consumption is taken as the only measure of benefit. Using a broader but widely accepted estimate of benefits, which includes travel-time and vehicle wear and tear savings, a 19:1 first-year benefit-to-cost ratio results. Both the percent improvement attained and the benefit-cost measures compare very favorably with the performance of other TSM strategies.

TABLE 4 Future FETSIM Program Options, Markets, and Costs

Program Options	No. of Signals[a]	Cost per Signal[b] ($)	Total Costs ($)
Continue current program	6,500	1,375	8.9 million
Retiming plus equipment	2,500	7,500[c]	18.8 million
Small systems	1,800	500	1.8 million

[a]Estimated number of signals eligible for retiming assistance under each program option—excludes signals already retimed (1983-1985).
[b]Includes cost of retiming and cost for training and technical assistance.
[c]Includes an average cost for equipment ($6,000).

But the benefits of the program do not appear to be sufficient to induce major shifts in priorities in favor of signal timing. Indeed, surveys of former participants indicate that there has been little or no change in local commitment to signal-timing efforts. In large part this may be due to the lack of visibility of the benefits that accrue. For example, from the perspective of the California motorist who drives 20 mi a week on signalized streets that have been retimed, the annual fuel savings may amount to $5 or so--10 cents a week. This is not an amount that is likely to be noticed, let alone one that is likely to generate citizen support. Although the motorist also benefits from travel-time savings and reduced vehicle wear and tear, the savings for any one individual are similarly small; it is only when aggregated across the many motorists who travel in these signal systems daily that the benefits are found to be substantial.

Ironically, though, commonly used methods of assessing benefits can also make signal retiming appear to be of minor statewide importance. Recalling that about 20 percent of total petroleum use in California is on signalized streets and that about 15 percent of these signals have been retimed to date, the 8.6 percent average decline in fuel use from retiming has reduced the state's fuel bill by only (20 percent) (8.6 percent) (15 percent) = 0.26 percent. Furthermore, the dollar savings accrue to individual motorists, whereas the costs of retiming must be borne by government--whose tax revenues decline as fuel consumption is reduced.

Another problem facing signal timing as a TSM measure is the uncertainty over how long the stream of benefits will continue. The answer obviously will differ from place to place, depending on the rate of change in traffic volumes and patterns. Other studies have suggested that 2 to 3 years of benefits are likely (11). Of course, with regular data collection and model updating, signal timings could be adjusted periodically at minor cost to maintain program benefits indefinitely. However, few participating cities have concrete ideas about how quickly traffic changes might offset the improvements obtained through the program, and even fewer have developed strategies for periodic retiming of their signal systems. Again, this reflects the low level of local resources being devoted to signal timing, which appears not to have been changed by the demonstrated benefits of the program. Thus, the same forces that led to the sizable benefits from state-funded retiming--lack of resources or initiatives at the local level to do the job on their own--may lead to degradation of timings in the future, so that benefits are lost.

Maintenance of efficient timings is further complicated by the fact that few local staff are able to use state-of-the-art signal-timing methods such as TRANSYT. Although the FETSIM Program offered intensive training in TRANSYT to all participants, few city staff members gained enough knowledge to continue the use of the traffic signal-timing method on their own; the majority relied almost entirely on consultants for the signal-timing optimization work. Because most of these local agencies lack the local funds to hire consultants, future opportunities for

signal retiming are likely to be rare unless state funds remain available.

In short, then, the California experience indicates that traffic signal timing is highly cost-effective but does not appear able to generate a strong constituency. Maintenance of signal timing is likely to be hampered by lack of local funding commitments, coupled in many cases with a lack of local staff capable of handling such efforts in house. Continuing state assistance may be the only way to assure long-term signal-timing efficiency.

Other findings of the FETSIM Program also deserve notice. In particular, the program has revealed a need for greater attention to the way in which local agencies select and utilize signal equipment. In each program cycle, it became apparent that a number of cities had purchased highly sophisticated signal control systems but had not used many of the systems' features. In other cities, an assortment of signal equipment had been installed over the years, and the various makes and models were incompatible. Furthermore, a number of cities that lack hardware for coordinated, multiple-timing plans reported that they had been unable to convince their city councils that improved equipment would be worth the cost. Good signal management requires appropriate equipment; providing help in sorting out equipment issues may be a prerequisite to efficient signal timing.

One strategy that has been suggested for maintaining signal timings would be to use the TRANSYT model to evaluate traffic impact and mitigation measures for new developments requiring environmental impact reports (EIRs) (12). Because most large public projects and many private ones require EIRs under California law, a number of cities would be able to at least partially update their timing plans in this way. However, although most of the participants believed that such a practice would be apt, considering that major new developments and projects are a primary factor in traffic changes that render existing timings inadequate, they also thought that their city councils would be reluctant to require such work as part of the development approval process.

A final note on the impact of the program: when the FETSIM Program was initiated, concerns were raised that retiming signal systems might lead to induced travel and mode shifts, which in turn could cancel out the traffic flow, fuel savings, and air quality benefits initially obtained. Examination of the participants' results showed that the aggregate travel-time benefits of the program are large, but from the perspective of the individual traveler they are too modest to be likely to induce additional trips; even in the cities that gained the most from the project, automobile travel times for the typical trip through the network improved by less than a minute. Also, bus travel times generally improved as much as automobile travel times; some cities even used the program as an opportunity to weight signal timings to favor bus routes. Thus, it appears safe to say that the benefits of the program will not be canceled out by program-induced, short-run traffic increases or shifts to automobile. To the extent that cities consider the program benefits as "room for development," however, a return to previous traffic performance may occur.

CONCLUSIONS AND RECOMMENDATIONS

California's FETSIM Program has produced positive results, both in transportation impact and in personnel training. However, experience suggests that refinements may be in order. For example, the current program design emphasizing multiple-timing plan, coordinated signal systems appears to be capable of reaching only 50 percent of the total signals statewide. Program modifications including use of a variety of signal-timing methods or providing funds for signal equipment or both could extend the reach to up to 80 percent of the total signals. But the cost-effectiveness of such modifications will need to be considered carefully, with detailed analyses and demonstration projects preceding full-fledged program offerings.

Although the program was designed to give local agency staff the skills to maintain fuel-efficient signal timings, follow-up surveys indicate that only a few local agencies will be able to act unassisted in the future. Many participants relied on consultants for most of the work, and although some gained enough knowledge to independently design and supervise future projects, others gained relatively little from the training programs. Incentives to encourage more meaningful local involvement deserve consideration, but it must be recognized that some local stall members lack the background needed to meaningfully participate in a program of this complexity. Alternative program designs explicitly recognizing that many local agencies prefer consultants to do the work should be considered.

Lack of resources may be a barrier to the maintenance of efficient timing plans, because the benefits of the program have not had a discernible impact on local funding for signal-timing efforts. It may thus be necessary to develop more explicit strategies for encouraging local long-term maintenance and renewal of signal-timing improvements. Alternatively, it may be necessary for the state to provide repeat assistance to localities wishing to update their signal timings.

Other states considering the development of traffic signal-timing programs are advised to consider the following:

1. The program should be designed for the kinds of traffic signal systems in the state. For example, a state having very few systems of 20 or more signals probably should not base its program solely on TRANSYT. Consideration also should be given to the status of signal equipment. If the California experience is borne out in other states, inadequate equipment may be a major barrier to efficient signal operations.

2. The program should reflect staff capabilities among local jurisdictions. Unless a substantial portion of the target audience for the program is capable of handling the technical aspects of signal timing (and is interested in doing so), a detailed training program may not be justified. An alternative program design might be to establish technical assistance teams to provide services to local agencies, rather than to train local staff and their consultants.

3. Attention should be given to long-term maintenance of efficient signal-timing plans. Possibilities include development of strategies for assuring local updating of timings or establishment of an explicit policy to repeat state-assisted efforts every few years.

ACKNOWLEDGMENTS

Work performed in 1983-1985 in support of the FETSIM Program by the Institute of Transportation Studies, University of California, Berkeley, under contract to the California energy commission is described. In 1984 and 1985 this contract was administered by the California Department of Transportation.

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The contents of this paper reflect the views of the authors and do not necessarily reflect the views or policies of the California Energy Resources Conservation and Development Commission or the California Department of Transportation.

Publication of this paper sponsored by Committee on Transportation System Management.