Fuel Savings Through Traffic Signal Hardware Improvements

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The Wisconsin Fuel Efficient Transportation (FET) program was funded with $1.5 million in "oil overcharge" funds to reduce fuel consumption by implementing computer-optimized traffic signal timing plans. The FET program provided funds to the 24 participating communities to be used only for traffic signal hardware improvements. Data from 28 signal networks were used to develop regression models of the fuel savings generated by the hardware improvements. The results of various network-level benefit-cost measures are also presented. Finally, the potential for adoption of the FET program by other states is explored. Under the FET program, optimal signal timing plans were developed using the TRANSYT-7F microcomputer program. TRANSYT-7F provided estimates of fuel and travel time savings and stop reduction. Most of the communities required significant hardware improvements to achieve full interconnection with three-dial capability. On average the program resulted in fuel savings of 4,350 gal/year per intersection and total annual savings of $28,450/intersection. Considering only the hardware improvement costs, the overall benefit-cost ratio for a 10-year project life and a 10 percent discount rate was 44.0. The most significant independent variables for the regression models of fuel savings per signal were cost per signal, average volume, population, percentage difference in interconnection, and percentage actuated signals. The best multivariate model included cost per signal and population.

Microcomputer programs for optimizing traffic signal timing are now readily available in user-friendly formats. The latest generation of microprocessors enables the timing of large signal networks—of even 50 more signals—to be optimized in minutes rather than hours. Studies of signal timing projects in a dozen states have demonstrated the cost-effectiveness of signal timing improvements. Most of these studies, however, provide little more than overall estimates of effectiveness. More information is needed on the factors that are important in determining the benefits of signal timing improvements for individual networks.

In this study, data from 28 signal networks were used to develop regression models of the factors that best explain fuel savings from traffic signal timing optimization. The results of various benefit-cost measures are also presented. In addition, the potential for adoption by other states of the signal timing improvement program used in Wisconsin is explored.

PREVIOUS STUDIES

From 1973 to 1981 U. S. oil consumers were systematically overcharged by domestic oil companies in violation of the Emergency Petroleum Allocation Act of 1973. Funds from suit settlement against the oil companies have been placed in the U. S. Department of Energy's Petroleum Violation Escrow Account ("oil overcharge funds"). Because an estimated 60 percent of the oil overcharge was for automotive fuel, a logical means of providing restitution would be to fund signal timing programs that reduce automotive fuel use. At least 12 states have initiated traffic signal timing programs in recent years, funded in most cases with oil overcharge money. Arnold (*1*) has categorized 10 of these programs into four groups: (a) training and technical assistance by lead agency with local responsibility for signal timing, (b) grant program for local governments, (c) contracts with consultants, and (d) state transportation agency responsibility. Information on the programs for all 12 states is summarized in Table 1.

Program-level estimates of benefits are available for five states. Fuel savings per intersection ranged from 930 gal/year in Iowa to 12,400 gal/year in North Carolina. Annual benefit-cost ratios ranged from 7 to 143 for the same two states. Estimates of benefits and benefit-cost ratios vary widely—in part because of different assumptions about the value of travel time savings, but more importantly because of the types of expenditures allowed and the different mixes of project types and city sizes. Only signal retiming, not hardware improvements, was included in the North Carolina program. In contrast, hardware improvements were incorporated in all of the signal retiming projects in Iowa. The lower overall initial benefits from the Iowa program hardware improvements should be partly offset by the much longer duration of the benefits compared with only signal timing improvements.

The potential for wide variations in benefit-cost ratios is illustrated by the Iowa program. One of the arterial system retimings in Des Moines produced a benefit-cost ratio of 300 whereas the second arterial system had negligible benefits (*2*). Overall, for the 15 projects in which significant benefits were found, benefit-cost ratios ranged from 1.75 to 55.6.

Most of the 19 signal timing and hardware upgrade projects in the Iowa program can be classified into three categories of hardware improvements: (a) upgrade pretimed controls at isolated intersections to fully actuated, (b) interconnect arterial controllers with time-based coordinators (TBCs), and (c) upgrade arterial controllers with full closed-loop interconnected controllers. Benefit-cost ratios for the Iowa projects were tabulated by city population category (very small, small, medium, and large) for each type of hardware improvement. The fully actuated and TBC projects were concentrated in the smaller categories, so no estimates of the effects of city size on benefit-cost ratios could be made. For the closed-loop projects, however, the benefit-cost ratios tended to increase with city size.

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TABLE 1 STATE TRAFFIC SIGNAL TIMING PROGRAMS

State	Training & Technical Assistance Only	Grant Program for Local Governments	Contracts with Consultants	State Transportation Agency
California-FETSIM		X		
Florida-GASCAP	X			
-STSRP			X	
Illinois-SCAT			X	
Iowa		X	X	
Maryland-STSSP				X
Michigan-TSOP			X	
-TSMP			X	
Missouri-TRANSYT-7F	X			
New York-STOP		X		
North Carolina-TSMP				X
Pennsylvania		X		
Virginia			X	
Wisconsin-FET		X		

FET PROGRAM GOALS

This research is based on data from the Wisconsin Fuel Efficient Transportation (FET) program. The FET program was initiated by the Wisconsin legislature in April 1987 with a $1.5 million grant of oil overcharge funds. The overall goal of the program was to reduce fuel consumption by implementing computer-optimized signal timing plans. The program was modeled after the highly successful FETSIM program in California (*3*). The California program provided training and technical assistance to local community staff in the use of the signal timing optimization program, TRANSYT-7F. Participating communities were reimbursed, at a rate of $1,000/intersection, for the staff time required to collect field data, apply TRANSYT-7F, and implement new timing plans. A fully interconnected traffic signal network was required for participation in the FETSIM program. No funds were available for any hardware improvements.

In contrast with the FETSIM program, the Wisconsin FET program focused on funding hardware improvements. Communities participating in the FET program received a grant of $1,000/intersection that could be used only for traffic signal equipment and installation expenses. A microcomputer to run the TRANSYT-7F program could also be purchased under the program. Additional funds for more extensive hardware improvements were to be allocated on the basis of fuel savings-to-hardware cost ratios.

Three secondary goals of the FET program were (a) to train local staff and consultants to use TRANSYT-7F, (b) to provide a wide distribution of the available hardware funds among the participating communities, and (c) to maximize the fuel saving effectiveness of the hardware improvements. The only constraint placed on participation in the program was that the traffic signals be reasonably interconnected. Communities were also encouraged to keep the data collection work load within the capability of their own staffs unless local funds were used to hire a consultant.

FET PROGRAM IMPLEMENTATION

Invitations to all Wisconsin communities with traffic signals to participate in the FET program resulted in contracts with 24 communities covering 518 intersections. The participants included all but two of the largest communities in the state: one of the two had recently upgraded and retimed its signal system; the other declined to participate because of staff limitations.

All of the communities were required to use TRANSYT-7F to develop optimal signal timing plans and to evaluate alternative hardware improvements for three time periods: morning peak, midday, and evening peak. Before-and-after travel time field studies were also required. TRANSYT-7F was used because of the need to model signal networks as well as single arterial systems. The computer program PASSER could be used to determine optimum phasing on individual arterial systems, but for consistency in developing performance measures, TRANSYT-7F analysis was also required.

The initial grants of $1,000/intersection left about $725,000 in unallocated hardware funds. These funds were set aside in a separate supplemental hardware grant program based on a comparison of hardware cost and the effectiveness of the hardware improvements in saving fuel. To estimate the hardware-generated fuel savings, three TRANSYT-7F runs were required for each time period (see Figure 1). The simulation run was used to calibrate the model so that it accurately reproduced existing conditions. Next, the calibrated model was optimized given the limitations of the existing hardware. Finally, the signal network was optimized on the basis of the capabilities of the new hardware alternatives.

If a FET community's existing signal system was fully interconnected and capable of three-dial, multiphase operation, little or no additional fuel savings would result from new hardware. The only additional hardware required might be the signal heads and rewiring needed for additional turn phases. Most of the FET communities, however, did not have fully

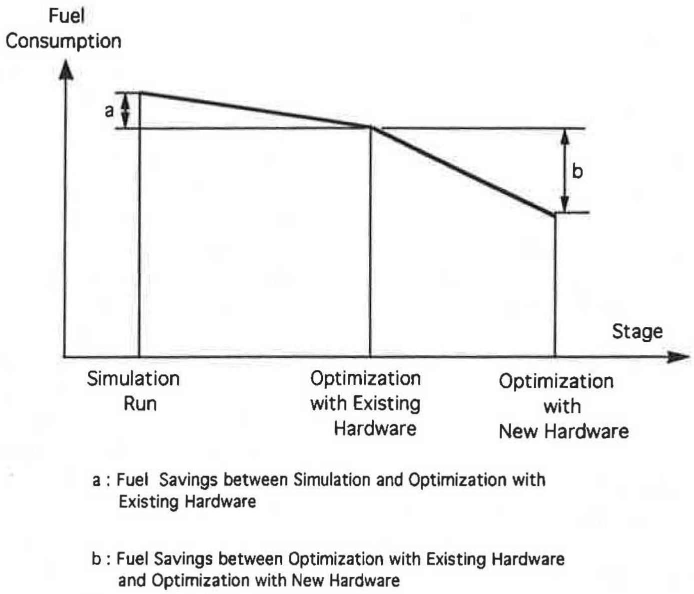

FIGURE 1 Fuel savings from optimizing traffic signal timing.

interconnected signal systems, and many did not have full three-dial, multiphase capability. Thus, the communities proposed a wide range of hardware improvements. Some communities were satisfied with adding TBC rather than more costly hardware to achieve interconnection. A few communities wanted the flexibility and other operating benefits of the even more expensive closed-loop systems. Nearly all communities needing to upgrade to three-dial capability chose to replace electromechanical controllers with solid-state controllers. The communities were not required to select the hardware alternative that would provide the highest fuel saving–to–hardware cost ratio, but they did run the risk of not being competitive with other communities in the allocation of the supplemental hardware grant funds if their fuel-effectiveness ratio was too low.

Application of TRANSYF-7F to simulate and optimize existing conditions was complicated by the lack of full interconnection for most of the networks. Noninterconnected signal systems can be modeled with TRANSYT-7F by "delinking" the signals; that is, the input flows to the intersections are assumed to be uniform—to arrive randomly rather than in platoons. This should be a reasonable assumption unless offsets among the signals are maintained continuously by signal technicians. Traffic-actuated signals can also be modeled by delinking and using average phase lengths.

Preliminary results for the TRANSYT-7F estimated benefits of the hardware improvements are available for 404 of the 518 signals. The average benefits per intersection include (a) fuel savings of 4,350 gal/year, (b) savings from fewer stops of $2,800/year, and (c) travel time savings of $21,300/year (based on value of travel time of $6.00/hr). Using fuel costs of $1.00/gal, the total annual benefits equal $28,450/intersection compared with hardware improvement costs of about $4,000/intersection. Thus, the benefit-cost ratio considering only 1 year's benefits is 7.1. For a 10-year project life and a 10 percent discount rate, the total benefit-cost ratio is 44.0.

The annual fuel savings generated by the FET program intersections are near the middle of the 930- to 12,400-gal range cited earlier (Iowa and North Carolina programs, respectively). The benefit-cost ratios are highly dependent on the costs required to generate the benefits. The North Carolina benefit-cost ratio is very high in part because no hardware improvements were made and relatively small amounts of staff time were used.

Overall, the FET program succeeded in meeting its overall goal of reducing fuel consumption, and the program effectiveness measures compare favorably with measures for similar programs in other states. The secondary goals of the program were also met, although much higher levels of fuel savings per dollar of hardware expenditures could have been achieved if only TBC and not more costly hardwire and closed-loop systems had been funded.

ESTIMATION OF FUEL SAVINGS

Fuel savings effectiveness ratios (fuel saved per dollar of program expenditure) can be increased by limiting expenditures, but for hardware-based programs, selection of the least-cost hardware, such as TBC, may not be possible because local communities have other objectives to consider. For example, TBC will not minimize staff costs for system operation and maintenance. At the state program level, selection of the most fuel effective projects might better focus on the characteristics of traffic signal networks that are likely to affect fuel savings. Data from 28 networks in the FET program are available for developing models to estimate fuel savings from unconstrained hardware improvements.

Fuel savings are the difference between the fuel consumption for the TRANSYT-7F optimized timing plan with existing hardware and the TRANSYT-7F optimized timing plan with the hardware improvement. TRANSYT-7F estimates of fuel consumption are used in both cases. Possible dependent variables for fuel savings models follow:

- FUEL/SIG—Fuel savings per signal (gallons per day),
- FUEL/TVM—Fuel savings per thousand vehicle miles (gallons per 1,000 vehicle miles), and
- FUEL-DAY—Fuel savings per day (gal).

Of the three possible dependent variables, fuel savings per signal was selected because it is not biased by network size and is generally more highly correlated with the available independent variables (Figure 2).

Possible independent variables are

- GRID-ART—Binary code for grid (=1) versus arterial (=2) network;
- NET-SIGN—Number of traffic signals in the network;
- POPULATN—Population of the community (thousands);
- SPACING—Average distance between intersections (ft);
- %-ONEWAY—Percentage of the link miles that are one-way;
- B/C-RATI—Fuel savings-to-hardware cost ratio;
- AVVOL-TO—Average approach volume summed over three peak hours (morning, midday, and evening);
- PER-DIF—Percentage difference in the number of interconnected signals (IS) after versus before the hardware improvement, $[(IS_a - IS_b)/IS_a] \times 100$ percent;
- PER-ACT—Percentage actuated signals before the hardware improvement; and
- COST/SIG—Average cost per signal for the hardware improvement.

On the basis of the correlations shown in Figure 2, four independent variables should initially be considered for explaining fuel savings per signal: (a) cost per signal (COST/SIG), (b) average volume (AVVOL-TO), (c) percentage actuated (PER-ACT), and (d) percentage difference in interconnection (PER-DIF).

All four possible independent variables have a logical relationship with fuel savings. Higher levels of expenditure per signal should be associated with larger urban areas, which tend to have higher traffic volumes and more complex phasing arrangements. These higher demands on the signal system should provide the potential for greater fuel savings. As shown in Figure 3, fuel savings per signal does tend to increase with cost per signal. Although there is substantial variance in the relationship, the variance is relatively constant. And four outliers exist that have much higher fuel savings than indicated by the general relationship.

One of the outliers shown in Figure 3 is a miscode. For Neenah, the fuel savings should be zero because the basic network was fully interconnected. No additional hardware was required to implement the optimal timing plan that generates fuel savings of 30 gal/day per signal compared with the initial timing plan. Thus, the incremental fuel savings that are the result of new hardware are zero. In contrast, the La Crosse–Western and New Berlin networks both required relatively low cost hardware improvements on moderate-volume arterials but generated large fuel savings. The La Crosse–Western network was nearly fully interconnected, but it required upgrading from two to three dials. The New Berlin network initially had only traffic-actuated signals. Interconnection was achieved in the hardware upgrade with low-cost TBC. The Madison–East Washington network had the second highest traffic volumes of all the networks. The results show that even very high cost, closed-loop systems can be extremely cost-effective.

Average traffic volume has the next highest correlation with fuel savings per intersection. As shown in Figure 4, there is

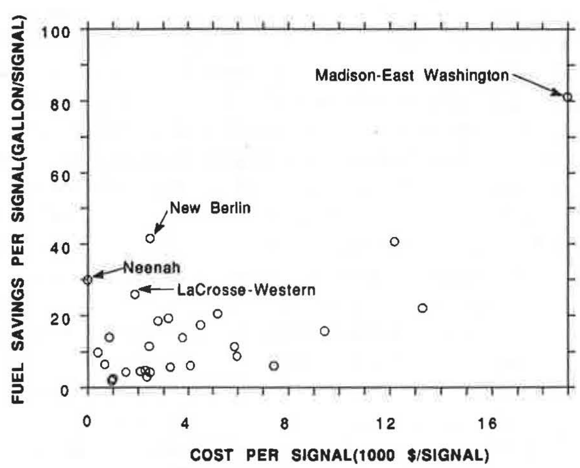

FIGURE 3 Fuel savings per signalized intersection versus hardware cost per signalized intersection.

	FUEL/STG	FUEL/TVM	FUEL-DAY	GRID-ART	NET-SIGN	POPULATN	SPACING
FUEL/TVM	0.710						
FUEL-DAY	0.710	0.728					
GRID-ART	0.263	0.086	0.029				
NET-SIGN	-0.135	-0.023	0.405	-0.505			
POPULATN	0.026	-0.174	0.035	0.272	-0.099		
SPACING	-0.074	-0.384	-0.280	0.224	-0.254	0.382	
%-ONEWAY	0.123	0.384	0.448	0.082	0.344	-0.118	-0.346
B/C-RATI	0.204	0.220	0.075	0.036	0.027	-0.188	-0.022
AVVOL-TO	0.656	0.468	0.761	0.399	0.197	0.198	-0.180
PER-DIF	0.437	0.250	0.266	0.359	-0.237	0.049	0.248
PER-ACT	0.590	0.423	0.375	0.476	-0.282	-0.082	-0.046
COST/SIG	0.671	0.440	0.550	0.398	-0.118	0.290	-0.007

	%-ONEWAY	B/C-RATI	AVVOL-TO	PER-DIF	PER-ACT
B/C-RATI	0.159				
AVVOL-TO	0.388	0.234			
PER-DIF	0.011	-0.211	0.349		
PER-ACT	0.088	-0.066	0.467	0.769	
COST/SIG	0.025	-0.326	0.594	0.517	0.590

FIGURE 2 Correlation matrix for dependent and independent variables.

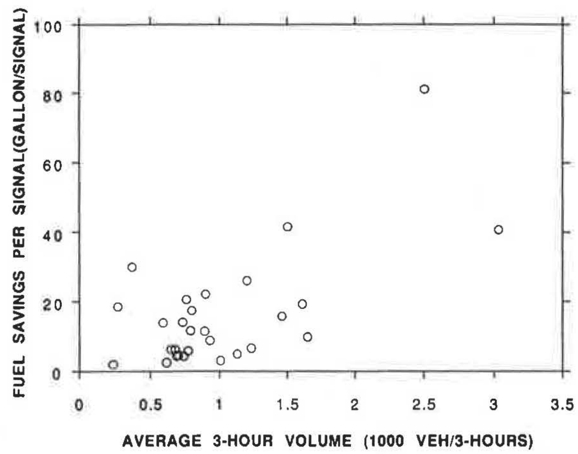

FIGURE 4 Fuel savings per signalized intersection versus average traffic volume per three peak hours.

a generally linear relationship between the two variables, but the variance increases with increasing volume. Thus, a regression model for the relationship will tend to overestimate the goodness of fit. Also, there are few data points for networks with high traffic volumes.

The last two possible independent variables, percentage actuated and percentage difference in interconnection, are highly correlated (r = .769). Consequently, only percentage difference will be examined in detail. After the hardware improvements were implemented all but two of the networks were fully interconnected. Each of those two networks included one isolated intersection that functioned better as a separate node. An increase in the percentage difference indicates a greater change in the extent of interconnection as a result of the hardware improvement. In general, a greater degree of interconnection change should result in a greater potential for fuel savings. As shown in Figure 5, there is a general but small trend toward higher fuel savings as the percentage difference in interconnection increases. The trend is more evident if the three outliers are removed. Three of

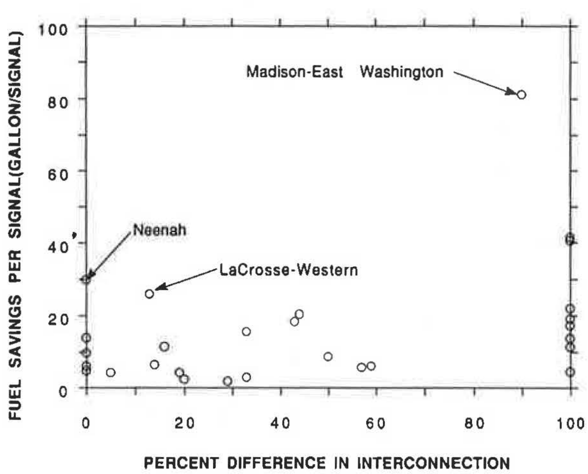

FIGURE 5 Fuel savings per signalized intersection versus percentage difference in interconnection.

the four networks found to be outliers for the cost per signal relationship are also outliers here (Neenah, La Crosse–Western, and Madison–East Washington). Only the Neenah outlier was deleted in subsequent analysis. Without the data points for Neenah and Milwaukee County (see later discussion), the correlation between fuel savings and percentage difference increases modestly, from .437 to .506. As with the average traffic volume relationship, the variance in fuel savings increases moderately with increasing percentage difference.

Population should have a reasonably high correlation with fuel savings per signal, but the correlation shown in Figure 2 is only .026. Population is also essentially uncorrelated with average traffic volume (r = .198). The reason for the lack of correlation is shown clearly in Figure 6. The three Milwaukee County networks (population 608,000) all have traffic volumes generally found in cities with populations of less than 100,000. In fact, the Milwaukee County networks are located in suburban communities with populations less than 50,000. Clearly, county-level population cannot be compared with city-level population. Consequently, the Milwaukee County networks are deleted from subsequent analysis when population is included as an independent variable.

REGRESSION MODELS OF FUEL SAVINGS

Single-variable regression models for fuel savings per intersection are presented as follows; the Neenah network is deleted from each regression model.

$$\text{FUEL/SIG} = 3.17 + 2.76\ (\text{COST/SIG})$$
$$(t = 0.97) \quad (t = 5.27)$$
$$R^2_{\text{adj}} = 50.7\%,\ n = 27$$

$$\text{FUEL/SIG} = -6.90 + 0.0209\ (\text{AVVOL/TO})$$
$$(t = -1.48) \quad (t = 5.50)$$
$$R^2_{\text{adj}} = 53.9\%,\ n = 26$$

$$\text{FUEL/SIG} = 5.34 + 0.207\ (\text{PER/DIF})$$
$$(t = -1.16) \quad (t = 2.84)$$
$$R^2_{\text{adj}} = 21.4\%,\ n = 26$$

The relatively low explanatory power of the models is consistent with the large variation in the basic data. The variability can be explained in part by the wide range of initial traffic signal hardware capabilities ranging from one-dial to multidial and two-phase to multiphase and the varying degrees of interconnection. Clearly, fuel savings generated by such a wide range of improvements are likely to be highly variable. Nevertheless, reasonably consistent relationships are found between fuel savings and the independent variables cost per signal, average traffic volume, and percentage difference in interconnection.

When the data for the three Milwaukee County networks are deleted, the correlations of the key independent variables with fuel savings per signal increase somewhat, as shown in Figure 7. And, as expected, population is now highly correlated with fuel savings per signal. Population now provides a

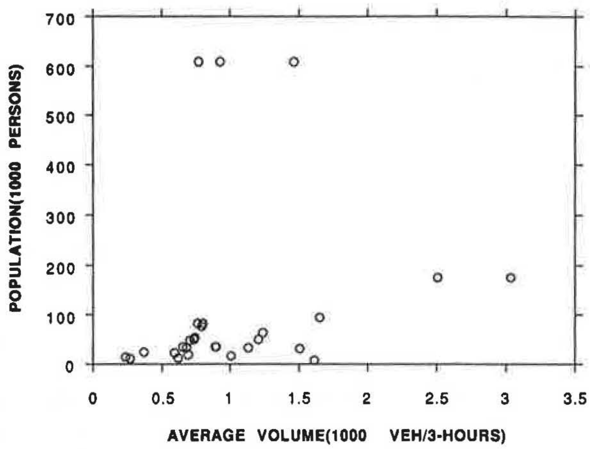

FIGURE 6 Population versus total traffic volume per three peak hours.

	FUEL/SIG	POPULATN	AVVOL-TO	PER DIF
POPULATN	0.694			
AVVOL-TO	0.718	0.771		
PER-DIF	0.506	0.229	0.336	
COST/SIG	0.756	0.627	0.569	0.533

FIGURE 7 Correlation matrix of variables for multiple-variable regression models.

reasonable single-variable model and the best multivariate model includes population and cost per signal, as shown in the following:

$$\text{FUEL/SIG} = 2.03 + 0.272\ (\text{POPULATN})$$
$$(t = 0.49) \quad (t = 4.52)$$
$$R^2_{adj} = 45.8\%,\ n = 24$$

$$\text{FUEL/SIG} = 0.05 + 0.141\ (\text{POPULATN})$$
$$(t = 0.02) \quad (t = 2.19)$$
$$+ 2.05\ (\text{COST/SIG})$$
$$(t = 3.20)$$
$$R^2_{adj} = 61.8\%,\ n = 24$$

Because population and cost per signal are highly correlated ($r = .627$), the values of the regression coefficients are highly interdependent. The relative importance of population could have changed easily as the result of minor changes in population or cost per signal values.

The multivariate model provides a reasonable basis for estimating fuel savings per signal that can be generated by traffic signal hardware improvements. Higher population values reflect more traffic and congestion, which lead directly to greater fuel savings when signal timing is optimized. The positive coefficient for cost per signal reflects the need for more complex and sophisticated signal hardware in larger communities. The equation models the choices made by traffic engineers when reducing fuel consumption was not necessarily the most important objective. In many cases, similar levels of fuel savings could have been achieved with less costly hardware improvements, such as TBC.

An attempt was also made to identify one or more stratifying variables that would provide additional explanation for the variation in fuel savings per signal. Average intersection spacing appeared to provide the best stratification with a breakpoint of 1,800 ft. Only the constant term was statistically significant for the long average spacing regression model. For the short average spacing model, only one independent variable, cost per signal, was significant with an adjusted R^2 of 74 percent.

BENEFIT-COST RESULTS

The results of the benefit-cost analysis for the 28 Wisconsin networks are presented in Table 2. The total benefits include savings in travel time ($6.00), reduced stops ($0.01/stop), and fuel ($1.00/gal). The benefit-cost ratio considering only fuel savings for 1 year ranges from 0.25 to 5.0. Thus, even the network with the lowest level of fuel savings has a payback period of only 4 years. When the value of all savings is included, the benefit-cost ratios increase substantially. All of the network improvements are now cost-effective with a 1-year benefit-cost range of 1.78 to 40.0.

The hardware improvements will have a useful life of at least 10 years. The long-term benefits of the fuel savings alone during that time using a 10 percent discount rate are substantial: all the network hardware improvements can be justified on fuel savings alone. The lowest network benefit-cost ratio is 1.51. For the overall program, the long-term benefit-cost ratio for fuel savings alone is 6.73; considering all long-term benefits, the benefit-cost ratio is 44.0.

SUMMARY AND CONCLUSIONS

The $1.5 million Wisconsin FET program clearly was able to meet its primary goal of reducing fuel consumption through implementation of computer-optimized signal timing plans. The annual fuel savings of 4,350 gal/year per intersection compare favorably with the results of signal timing programs in other states (savings from 930 to 12,400 gal/year for Iowa and North Carolina, respectively). The FET program was also highly cost-effective: the overall benefit-cost ratio was 1.1 considering only fuel savings for the first year. When all first-year savings are included (adding travel time and stop reduction benefits), the benefit-cost ratio jumps to 7.2. Over a 10-year period with a 10 percent discount rate, the total benefit-cost ratio is 44.0.

The FET program focused on improving traffic signal timing through traffic signal hardware improvements. Traffic signal timing plans were optimized and the additional fuel savings attributable to the hardware improvements were modeling by using the TRANSYT-7F microcomputer program. Data for 27 traffic signal networks were used to develop regression models of the fuel savings. Fuel savings per signal in the network was selected as the independent variable because it is independent of network size. Initially, cost per signal and average volume were found to produce the best single-variable models. When illogical population data for Milwaukee County were deleted, population also produced a good single-variable model and the best multivariate model together with cost per signal.

TABLE 2 NETWORK-LEVEL BENEFITS AND COSTS

NETWORK NAME	TRAVEL TIME SAVINGS PER YEAR ($/YEAR)	STOP SAVINGS PER YEAR ($/YEAR)	YEAR-FUEL SAVINGS (GAL/ YEAR)	TOTAL COST ($)	ONE YEAR B/C[a] RATIO (FUEL)	ONE YEAR B/C[b] RATIO (ALL)	TEN YEAR B/C[c] RATIO (FUEL)
APPLETON	574,200	50,049	96,900	33,970	2.85	21.23	17.53
BELOIT- HENRY	64,836	9,108	13,647	23,500	0.58	3.73	3.57
BELOIT-PRAIRIE	351,882	32,330	39,618	79,750	0.50	5.31	3.05
CUDAHY	86,400	53,682	38,700	19,500	1.98	9.17	12.19
DePEER	63,000	22,350	7,950	21,145	0.38	4.41	2.31
KENOSHA	288,000	-13,530	110,400	78,000	1.42	4.93	8.70
MADISON-EW	1,396,764	82,612	243,357	190,000	1.28	9.07	7.87
MADISON-JSN	1,460,466	371,550	390,093	390,000	1.00	5.70	6.15
MIL CTY-GH	230,400	-948	28,200	56,600	0.50	4.55	3.06
MIL CTY-P WASH	50,400	13,728	12,000	22,940	0.52	3.32	3.21
MIL CTY-76TH ST	111,600	27,558	36,600	83,540	0.44	2.10	2.69
RACINE-DURAND	135,000	10,794	31,200	27,000	1.16	6.56	7.10
RACINE-16 NODES	462,600	62,694	98,100	83,000	1.18	7.51	7.26
SHEBOYGAN	10,800	60,399	35,100	54,500	0.64	1.95	3.96
WAUKESHA	270,000	-8,208	20,400	24,400	0.84	11.57	5.14
WAUSAU	181,134	21,039	34,353	55,000	0.62	4.30	3.84
WEST BEND	330,300	19,347	45,600	41,466	1.10	9.53	6.76
WISCONSIN RAPID	82,080	21,465	25,377	49,400	0.51	2.61	3.16
BEAVER DAM	34,200	-804	3,900	6,726	0.58	5.55	3.56
BELOIT-CBD	214,470	36,036	40,485	90,000	0.45	3.23	2.76
GREEN BAY	153,000	32,127	43,800	6,200	7.06	36.92	43.41
MANITOWOC	135,900	24,015	25,500	104,000	0.25	1.78	1.51
MARINETTE	10,800	4,014	3,600	5,000	0.72	3.68	4.42
NEENAH	428,400	75,684	107,400	0	****	****	****
NEW BERLIN	469,800	49,203	74,700	14,860	5.03	39.95	30.89
SHAWANO	172,800	28,146	28,800	15,990	1.80	14.37	11.07
LA CROSSE-CBD	396,846	29,870	58,581	12,000	4.88	40.44	30.00
LA CROSSE-WES	421,704	18,598	62,133	15,000	4.14	33.50	25.45
TOTAL	8,587,782	1,132,908	1,756,494	1,603,487	1.10	7.16	6.73

[a]Benefit cost ratio considering only one year fuel savings
[b]Benefit cost ratio considering all one year savings
[c]Benefit cost ratio considering only ten year fuel savings with 10% discount rate

The regression models for fuel savings per signal must be interpreted in view of the way in which the hardware improvement decisions were made. Initial hardware grants of $1,000/intersection were not constrained by considerations of fuel savings effectiveness. Subsequent supplemental hardware grants, however, were allocated on a competitive basis using fuel savings-to-hardware cost-effectiveness ratios. Some communities chose low-cost hardware in order to maximize their opportunity for receiving additional hardware funds. Other communities, particularly larger communities that expected high fuel savings, chose more costly hardwire interconnect and closed-loop hardware. Thus, the cost of the hardware improvements reflects the multiple objectives of communities for traffic signal hardware improvements rather than simple cost minimization.

Despite the wide latitude given to the FET communities in making their hardware improvements, all the network improvements were cost-effective using fuel savings alone over a 10-year period. When travel time and stop reduction savings are included, all the network improvements were cost-effective during the first year: the lowest first-year benefit-cost ratio was 1.78. Thus, at least for communities that need substantial hardware improvements—typically, an upgrade from partial or no interconnection to full interconnection—hardware improvements combined with signal timing optimization using TRANSYT-7F are highly effective in saving fuel and generating other benefits to motorists.

The FET program methodology should be highly effective when applied to similar communities in other states. Whereas signal timing improvements alone have been shown in other states to be effective in saving fuel, much greater fuel savings can be realized by funding the hardware improvements needed to achieve full interconnection with three-dial operation. For many smaller communities with simple linear networks, PASSER should be used for signal timing optimization instead of TRANSYT-7F. In either case substantial staff time is required to learn how to use the computer programs, to collect the required traffic count and other field data, and to apply the computer models. Providing training and technical assistance to the participating communities is essential. Direct funding for local staff time and funding for consultant support may be as important as funding hardware improvements in many communities.

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