consistently been a major problem in our system's optimization reviews. We plan to replace the Van Dyke interconnect with time-base coordinators that will ensure proper offset and also allow more flexibility in timing plans. Flasher schedules at some intersections were lengthened. Yellow intervals were lengthened at several intersections. We are pursuing extended flasher operation or possible removal of two poorly spaced signals on the south end of the section.

It is safe to conclude that motorists will save at least 100 000 gal of fuel yearly on Van Dyke and more if the plans are implemented. Considering only fuel savings, the cost of this project, completed in February 1981, was returned to the taxpayers by the end of April in the same year.

System Timing Optimization and Evaluation of US-12, Detroit

R.E. Maki and J.J. Saller

This report is a summary of the analysis that led to the recent publication of the final report entitled "Michigan Avenue Traffic Flow Study" by Ross Roy, Inc., and the Traffic Safety Association of Detroit. One of the original purposes of this study was to evaluate improvements to a traffic signal system that would save fuel and travel time and reduce accidents. The study was modified to identify other energy-saving improvements. The results could be used for project selection and improvement.

The corridor selected for review consists of a 4.8-mile section of Michigan Avenue (US-12) within the city of Detroit. This portion of Michigan Avenue extends from the fringe of the central business district (CBD) at 6th Street to the city limits at Wyoming Avenue. It is a principal link in the street network and serves as an alternate route to Interstate 94. The adjacent land use is commercial-industrial.

Michigan Avenue average daily traffic (ADT) varies from approximately 20 000 vehicles near the CBD to 33 000 vehicles near Wyoming Avenue. Typical directional peak-hour volumes are about 1500 vehicles/h. See Figures 1 and 2 for directional flow by hour. The existing laneage on Michigan Avenue can adequately serve this volume. In the section from 6th Street to Livernois, seven lanes are provided including a center lane for left turns. From Livernois to Wyoming the cross section is five lanes. In addition, parking is provided on both sides with a peak-hour prohibition that theoretically should provide another travel lane for each direction. There are 64 intersections in this section of Michigan Avenue of which 25 are signalized. The posted speed limit is 35 mph.

DATA COLLECTION

In order to conduct this study and provide input to the NETSIM model, it was necessary to collect a vast amount of data relevant to current traffic on Michigan Avenue. The following briefly describes the data collection, sources, and reliability.

Traffic volumes in the form of 8-h manual turning movement counts were obtained at 16 signalized intersections. Pedestrian counts were conducted at the major intersections. Traffic estimates were prepared for those intersections where manual counts could not be taken due to staff limitations.

The existing signal system on Michigan Avenue throughout the study area is a two-dial hardwire interconnected system. The average life of the 25 intersectional controllers is 24 years, with the operating time ranging from 6 to 31. At the present time these controllers receive little or no preventive maintenance.

In addition to the equipment data, it was necessary to obtain a physical description of Michigan Avenue. These data included the distances between intersections, laneage, existing traffic signal timing plans, and parking control. The average peak-hour speeds on Michigan Avenue are 20-23 mph, and stops averaged 1.2/mile.

The speeds obtained from the NETSIM runs are weighted average speeds (bidirectional) for the entire system and are figured by total distance of travel (all vehicles) divided by total travel time. These speeds would not agree with the speeds obtained from test vehicles in the field.

NETSIM BACKGROUND

The practicing traffic engineer has long needed a problem-solving aid to evaluate the cost and benefits of alternative methods of traffic control. Simulation modeling has evolved as a tool with the advent of the high-speed computer. By approximating real-world conditions, modeling gives the engineer the ability to inexpensively choose the best alternatives before actually committing financial resources.

NETSIM is one such tool developed by FHWA for traffic engineers. The NETSIM model has been formally validated against field data. The model has been used successfully by the Michigan Department of Transportation and throughout the country for the last few years.

The first step taken in the use of the model is construction of a link-node diagram that represents the actual street network. Links are stretches of roadway-connecting nodes. They are directional and may be either entry or exit type or internal to the system under study. Nodes are points at which vehicles enter, exit, or are controlled, such as signalized intersections.

The next step is to gather the input data. These include entering counts, turning movements, road and intersection geometrics, channelization, types of control, operational signal timing desired, and detector placement if used. The network is then coded onto a 80-column FORTRAN card and the network is ready for simulation.

The NETSIM output shows the following:

1. Listing of input card deck,
2. Link and network statistics,
3. Number of stops per vehicle,
4. Stopped delay,

5. Total delay,
6. Travel time and speed,
7. Signalized cycle failure,
8. Fuel consumptions in gallons,
9. Mileage, and
10. Emissions generated (hydrocarbons, carbon monoxide, and nitrous oxide) in grams.

By controlling the variables, such as signal split, offset, laneage, etc., the effects of any change to a system are simulated and benefits are derived by comparing alternatives.

NETSIM RUNS

As with any simulation program, it is necessary to make some realistic assumptions to correspond with the specific conditions in the field. The assumptions used and the bases for those assumptions are as follows:

Figure 1. Directional flow by hour: 6th Street and Michigan Avenue.

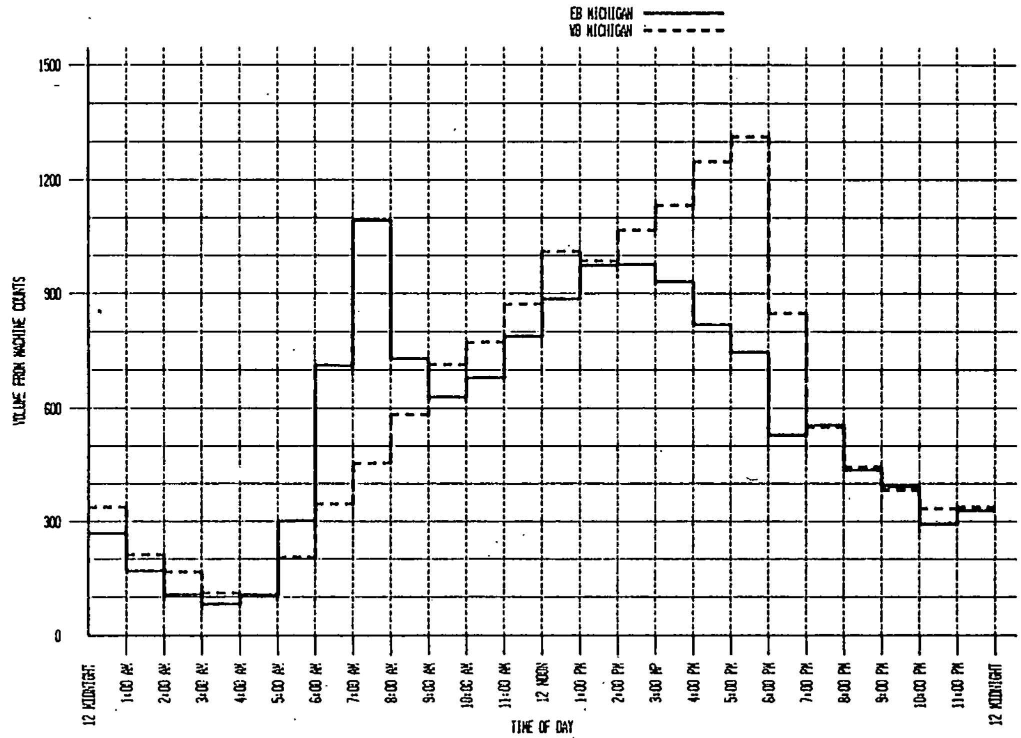
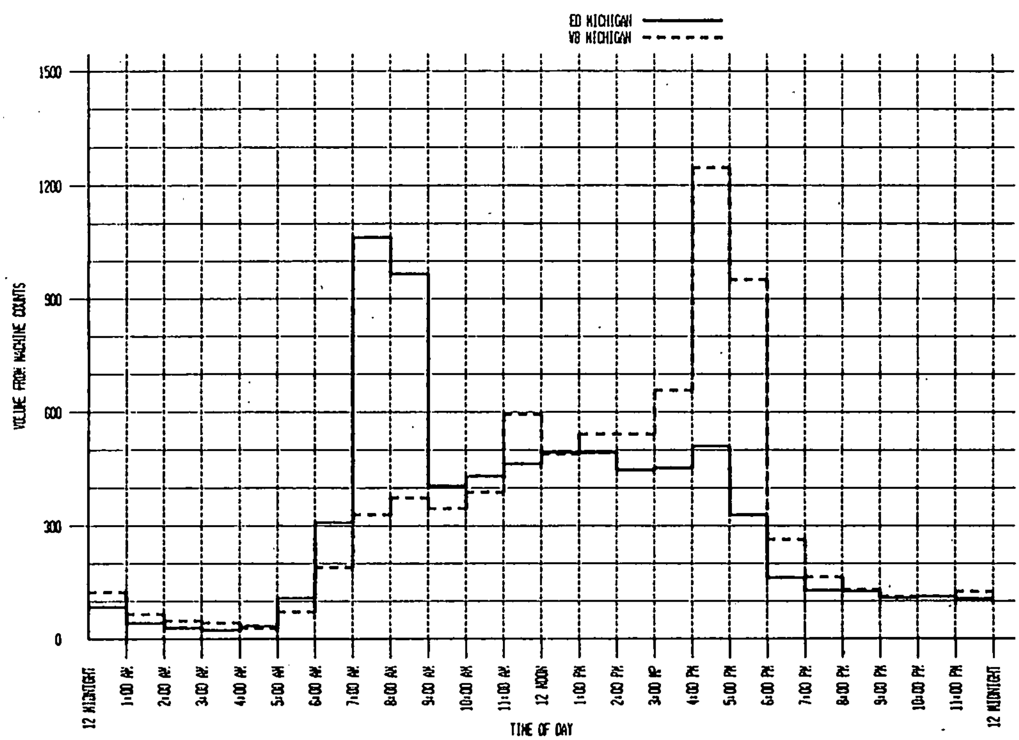


Figure 2. Directional flow by hour: Wyoming and Michigan Avenue.



1. The evening peak hour is from 4:30 to 5:30 p.m., obtained from manual and machine counts taken during February and March 1980. The peak period ranges from 3:45 to 6:00 p.m.
2. Only signalized intersections were used in the simulation due to the maximum number of nodes allowed in the program.
3. A 3.0-s starting delay and 1.9-s headway were used. These figures are based on previous studies.
4. The speed used was 35 mph, which corresponds to the posted speed limit.
5. Some intersections did not have machine or manual counts, so it was assumed that 100 vehicles/h enter the system at these points. This was approximated from field observation and comparisons with adjacent intersections for which counts were available.
6. It was observed that parking violations were substantial enough during the evening peak that no use was made of the extra lane provided during the outbound peak.

It is our belief that the above assumptions are reasonable, based on observations of the study area. Any other assumptions made are so noted.

There were nine alternative, plus the existing (as installed), timing plans tested. The alternatives tested were in-field timing (assumes failed interconnect), existing with no-parking areas properly enforced, using timing permit offsets, timing permit with no parking enforced, timing for bidirectional flow, timing for directional flow (no parking enforced), timing for 100 percent outbound (westbound), timing for 100 percent outbound no parking enforced, timing for bidirectional flow eight-signals removed, and timing for 100 percent outbound flow eight-signals removed. The results of the NETSIM runs are shown in Table 1.

CONCLUSIONS AND RECOMMENDATIONS

It is obvious that at least portions of the interconnect system have failed due to the age of the equipment. Most of these controllers are about 24 years old. The greatest benefits can be achieved by reinstalling a good interconnected system.

Benefits can be derived by not operating, by relocating, or by removing the existing signals on Michigan Avenue at Trenton, Cecil, 35th-Greusel, 31st-Lockwood, 23rd, 16th, 6th, and Cochrane. All of these signal locations have very minor cross-street volumes and are poorly spaced for efficient progressive movements on Michigan Avenue. The successful resolution of any or all of these signal locations will produce substantial energy, pollution, and time benefits.

In order to do a cost/benefit estimate, gasoline was assumed to be $1.25/gal and dollar value of delay to motorists was set at $3 per person/h. Peak-hour fuel consumption and delay were multiplied by 10 to give the daily value and by 300 to give a yearly value. A summary of user savings is given in Table 2.

A cost estimate of $40 000/intersection was used for complete modernization including controller replacement and new interconnect. A 20-year life is assumed with zero salvage value. For simplicity, maintenance costs are assumed to remain unchanged. An interest rate of zero was used due to uncertainties of inflation and fuel prices.

Upgrading the existing system of signals would produce a yearly fuel savings of 130 000 gal and savings of about 170 000 h of delay. The dollar value is $620 000 with a cost/benefit ratio of 12.5. Upgrading would also reduce hydrocarbon emissions by 10 percent, carbon monoxide by 10 percent, and nitrous oxides by 5 percent.

Table 1. Results of NETSIM runs.

Alternates	Vehicle Trips	Stops per Vehicle	Avg Speed (mph)	Avg Delay per Vehicle (s)	Total Delay (min)	Fuel Used (gal)	Vehicle Emissions (g/mile) HC	CO	NOX
In-field timing (existing)	9760	3.08	18.44	93.73	15 247.5	1076.86	3.05	48.16	4.82
Existing no parking enforced	9776	2.88	19.15	84.01	13 688.7	1051.62	2.92	45.71	4.70
City's timing from permits	9767	2.47	19.72	76.03	12 375.8	1033.32	2.89	44.86	4.75
City's timing, no parking enforced	9780	2.22	20.45	67.61	11 020.9	1002.09	2.75	42.45	4.58
Offsets for bidirectional flow	9781	2.73	19.45	79.54	12 966.2	1043.33	2.91	45.29	4.74
Offsets for bidirectional flow, no parking enforced	9802	2.44	20.32	69.32	11 325.0	1014.99	2.78	42.90	4.63
Offsets for 100 percent outbound flow	9787	2.50	19.79	75.11	12 252.4	1032.16	2.88	44.55	4.74
Offsets for 100 percent outbound flow (no parking)	9803	2.23	20.62	66.32	10 834.8	1005.30	2.75	42.37	4.63
Offset for bidirectional flow, eight signals removed	9781	2.32	20.11	71.26	11 617.0	1009.71	2.78	42.93	4.57
Offset for 100 percent outbound flow, eight signals removed	9768	2.15	20.58	65.91	10 730.1	995.09	2.75	42.91	4.60

Table 2. Savings per year compared with existing in-field timings.

Alternates	Fuel Gallons (000s)	Fuel Cost ($000s)	Delay in Person-Hours (000s)	Cost of Delay ($000s)	Total Savings Cost of Delay and Fuel ($000s)	Benefit/Cost Ratio
In-field timing, existing						
Existing no parking enforced	76	95	78	230	330	Unknown
City's timing from permits	130	160	140	430	600	11.7
City's timing, no parking enforced	220	280	210	630	910	Unknown
Offsets for 100 percent outbound flow	130	170	150	450	620	12.5
Offsets for 100 percent outbound flow, no parking	200	270	220	660	930	Unknown
Offset for 100 percent outbound flow, eight signals removed	250	310	230	680	990	20

The greatest benefit can be derived by signal system upgrading with signal removal or relocation as previously stated. Nearly $1 million in benefits can be returned each year to the public from an initial investment of $1 million. Therefore the cost/benefit ratio is about 20.

Signal System Modernization and Timing Optimization Study: Ludington Street, Escanaba

Kenneth L. Slee

The major function of the Community Assistance subunit is to provide traffic engineering assistance to local governments for improving safety at problem locations. By request from the city of Escanaba, Michigan, a complete engineering study was performed with recommendations for improving traffic flow and reducing accidents.

The city's entire signal system was studied focusing on Ludington Street, which is the major arterial street through the central business district. Existing Ludington Street is a narrow four-lane, two-way facility with angle parking on both sides of the street and functions basically as a two-lane, two-way roadway due to restrictions and narrow laneage. The network studied is a 30-block area with the major portion of the traffic in the seven-block central business district.

DATA COLLECTION

The existing signal system in Escanaba included 10 outdated, one-headed signals centered on the main streets, all working independently. The six signals along Ludington Street operate on a two-dial system.

Traffic volume data include 24-h machine counts as well as 8-h turning movement counts at the 10 signalized locations. The Ludington Street corridor averaged 15 000 vehicles/24-h period. The speed limit is posted at 25 mph.

Ludington Street is 64 ft wide from face-of-curb to face-of-curb. The cross streets are 54 ft wide with 12-ft radii in all quadrants of each location.

Accident patterns for the three-year study period included head-on, left-turn, and rear-end accidents. The major accident pattern involved angle-parked cars.

NETSIM ANALYSIS

The network simulation model was used to provide measures of effectiveness for existing traffic flow statistics. The proposed alternative included signal modernization, interconnection, removal of unwanted signals, parallel parking, and a five-lane facility with a center lane for left turns. The "existing" and "proposed" NETSIM analyses were compared for improvements in the traffic flow. The major statistics compared were average speed ("proposed" indicated a +72 percent), average delay per vehicle ("proposed" indicated a -72 percent), total delay ("proposed" indicated a -72 percent), and stops per vehicle ("proposed" indicated a -25 percent). These statistics appear along with the remainder of the measures of effectiveness in Table 1.

Table 1. NETSIM analysis: Escabana.

Measure of Effectiveness	Existing	Proposed	Change (%)
Stops per vehicle	2.37	1.77	-25
Avg speed (mph)	11.07	19.06	+72
Avg delay per vehicle (s)	133.5	37.03	-72
Total delay (min)	10 379.9	2953.6	-72
Hydrocarbon (g/mile)	4.23	2.78	-34
Carbon monoxide (g/mile)	74.63	42.69	-43
Nitrous oxide (g/mile)	4.52	4.24	-6
Fuel consumption (gal)	399.77	282.39	-29

CONCLUSIONS AND RECOMMENDATIONS

Cost/benefit analyses were computed by using projected accident reductions. Project costs were estimated at $120 000 with a 0.66 year time-of-return based on accident reduction.

Benefits were estimated by using a cost of $1.25/gal and $3 per person/h of delay. A factor of 3000 (a factor of 10 for daily x a factor of 300 for yearly) was multiplied by the hourly fuel and delay consumption to estimate a yearly value. The yearly benefits are $440 000 in fuel consumption and $1 336 000 in delay reduction. This reflects a 352 140-gal reduction in fuel consumption and 445 312 h of delay reduction.

NETSIM provides a more real-world view of existing and proposed traffic characteristics than other methods available. It makes available other measures of effectiveness that were not previously considered. NETSIM helps sell many safety projects to the use of the general public because the model outputs statistics into common terminology.