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Energy savings effectiveness of pretimed traffic control compared to actuated control at signalized intersections

by

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ABSTRACT

Fossil fuel consumption by vehicles is an issue of economical, environmental, and political concern. Reducing excessive energy consumption at isolated signalized intersection can reduce the dependency upon fossil fuels. Guidelines are needed to help in the selection of the most energy efficient form of traffic signal control. A computer simulation program called NETSIM is used to develop guidelines for choosing the form of traffic signal control that minimizes fuel consumption.

The results of 675 runs of the NETSIM simulation program are examined to determine the relationship between traffic volume levels and the most energy efficient form of traffic signal control. A prototypical four-leg intersection is selected as the test intersection. Simulation runs are made for both actuated and pretimed signal control strategies. For each run the NETSIM program's traffic volume input is changed incrementally. The program is run and the predicted fuel consumption is noted. The resulting data are utilized to develop guidelines for selecting the most energy efficient traffic signal control.

CHAPTER 1. INTRODUCTION

The purpose of this research is to develop guidelines for selecting energy efficient traffic control at signalized intersections. Currently, there are no guidelines for choosing the most energy efficient form of intersection traffic signal control. The guidelines presented in this paper are developed by examining the results of a multitude of computer simulation program runs. The fuel consumption estimated by the computer program for varied form of control and traffic volume levels are compared.

Signal improvements that help reduce fuel consumption lead to a decrease in the nation's dependency on fossil fuels. This is important for the following three reasons:

1. Saving motorists time and money: One way of reducing fuel consumption is to reduce the time that vehicles spend at red lights waiting for a green indication. Reduced waiting time saves the motorist time as well as associated fuel costs.

2. Reducing the adverse environmental effects of burning fossil fuels: When fuels burn, they emit harmful gasses, such as carbon dioxide and carbon monoxide, and particulate matter into the air. Vehicles burn more fuel at an intersection when they accelerate from a stopped position, than when they coast through that intersection. Likewise most pollutants are released at the start-up acceleration stage (2). Reducing the number of start-ups cuts down the levels of pollutants released into the environment.

3. Reducing the impact of imported oil on global politics: Reduction in fuel consumption reduces the nation's dependency on foreign oil. This should

lessen the importance of oil in the international political scene.

Deciding on the most energy efficient form of control is a problem traffic engineers commonly face. The Traffic Control Devices Handbook states that there is no direct method of determining the most efficient mode of intersection operation (3). Developing guidelines for selecting the most energy efficient form of control will help reduce unnecessary fuel consumption at signalized intersections.

A computer simulation program is utilized to examine the relationship between the fuel efficiency of various traffic control strategies and traffic volume levels. This is done using the following sequence:

1. Selecting a prototypical intersection for the purpose of the simulation runs
2. Simulating actuated and pretimed intersection control,
3. Evaluating the estimated fuel consumption at various volume levels and cycle lengths.

A four-leg intersection with two-lane approaches and two-way traffic movement is used as the test intersection. Fuel consumption at different traffic volumes and control strategies is measured. Examining the most energy efficient type of traffic signal control against the volume levels reveals that the most fuel efficient form of traffic signal control changes as the rate of vehicle flow increases or decreases changes. This finding has important implications for traffic engineers. It will help them in selecting the most efficient intersection control given existing or forecasted traffic volumes. It will also assist them design modifications to existing traffic signals.

Traffic signals are controlled by electrical mechanism that are mounted in a cabinet for controlling the flow of vehicles through a signalized intersection. They are called controller assemblies. This mechanism serves as a control by which the duration and sequence of signal indications are timed. A complete sequence of all signal indications is called a cycle. Cycle is a timing property of controller programming. There are three basic types of traffic signal controls for intersection. They are pretimed, semi-actuated, and actuated control.

In pretimed controls, a programmed cycle is continuously repeated regardless of the fluctuations in traffic volume and demand. Right-of-way is assigned on the basis of a predetermined fixed cycle length and phase timing.
In actuated controller unit, a complete cycle is dependent on the presence of calls on all phases. In actuated control detectors are used. Detectors are devices for indicating the presence or passage of vehicles or pedestrians. These indications are called Calls. A Call is a registration of a demand for right-of-way by traffic at a controller unit (1).

The Semi-Actuated type of signal control is one that responds to traffic demand for some of the phases. It responds to traffic demand, and changes phases and their duration accordingly. Information from vehicle or pedestrian detectors is used to select phases and their times. For example, signals may rest in green in one phase until a traffic or pedestrian detector is actuated. These detectors are devices for indicating the presence or passage of vehicles or pedestrians. The indications are referred to as "calls". Calls may be registered in a controller to indicate a demand for right-of-way by certain traffic movement 1).

Finally, in Fully-Actuated control signals receive actuations for all phases from all legs of an intersection. They then respond accordingly.

This research is based on the assumption that there should be a relationship between volume levels of traffic and the most energy efficient form of traffic control.

The following chapter contains a description of the problem. The result of the literature review and the research objective are discussed in Chapter Three. Chapter Four states the methodology used in this research, followed by Chapter Five which contains the results and analysis of the data. Conclusion and recommendations of this study are presented in Chapter Six.

CHAPTER 2: STATEMENT OF PROBLEM

In an effort to save motorists fuel, in 1988 the state of Iowa undertook a project called the Iowa Motor Vehicle Fuel Reduction (IMVFR) program. This program was funded by the petroleum overcharge funds in Iowa. These funds were paid by EXXON to the State of Iowa due to court actions that was taken against EXXON for overcharging for petroleum products. Three million dollars of the money paid to the State of Iowa were assigned to a traffic improvement demonstration program (4).

The aim of the program was to provide restitution to motorists in the form of fuel savings which would be realized through improved traffic operations. Upgrading of both traffic signal hardware and traffic signal timings were needed. The project sponsored a wide range of traffic signal improvements including upgrading a central distributive system, installing several closed loop systems, upgrading pretimed signals to actuated signals, and retiming signals. As part of this project, several isolated intersections were modified in four cities. The following modifications were added to existing traffic signal controls at signalized intersections:

1. Upgraded from pretimed control to fully actuated control,
2. Upgraded from semi-actuated control to fully actuated control, and

3. Upgraded from pretimed control to semi-actuated control.

The purpose of the IMVFR project was to reduce fuel consumption at selected project sites. The studies that were conducted at these intersections before and after the project revealed a poor overall performance. The following questions emerged from the IMVFR program:

1. Was it justifiable to upgrade the form of intersection traffic control from pretimed to actuated?; and if so,

2. Under what conditions is upgrading to actuated control most effective for reducing fuel consumption?

A literature review indicated that there are no guidelines for the selection of a fuel efficient traffic control strategy at isolated intersections.

Results of the IMVFR program

Fuel consumption was estimated before and after the IMVFR program modification at twenty five intersections where isolated intersection control had been upgraded. To estimate fuel consumption at each intersection, the number of stops and idling delays were measured before and after the project. Fuel consumption was then estimated by assigning fuel equivalent values to the number of stops and delays.

Figure 2.1 shows the total delay before and after the control improvements were implemented at each intersection.

Table 2.1: Intersections that had increased delays or number of stops after the IMVFR program

NO.	INTERSECTION NAME	CITY	INCREASED NUMBER OF STOPS	INCREASED DELAYS
1	HARDING AND EUCLID	DES MOINES	YES	YES
2	BEAVER AND FRANKLIN	DES MOINES		
3	W. 1ST AND CEDAR,	MONTICELLO	YES	YES
4	N. MAIN AND E. 1ST	MONTICELLO		YES
5	BEAVER AND URBANDALE	DES MOINES		
6	McGREGOR AND HWY 169	ALGONA	YES	
7	DELAWARE AND EUCLID	DES MOINES	YES	YES
8	E.14TH AND MADISON	DES MOINES		YES
9	18TH AND TANGLEFOOT	BETTENDORF	YES	YES
10	BEAVER AND MADISON	DES MOINES		YES
11	S.W.24TH AND PARK	DES MOINES	YES	YES
12	44TH AND FRANKLIN	DES MOINES		
13	13TH AND GRANT	BETTENDORF	YES	
14	14TH AND STATE	BETTENDORF	YES	YES

Figure 2.2 shows the total number of stops before and after the control improvements were implemented at each location. In contrast to the expectation of increased efficiency, these results indicate a general trend toward increasing fuel consumption after the control upgrading. Table 2.1 shows the intersections that had increased delays and number of stops after the IMVFR program. These results could have been affected by several factors, some of which may have nothing to do with the type of control. These factors are discussed in the following pages of this chapter.

The original form of control and signal timings

The cycle length in pretimed operation is fixed. The

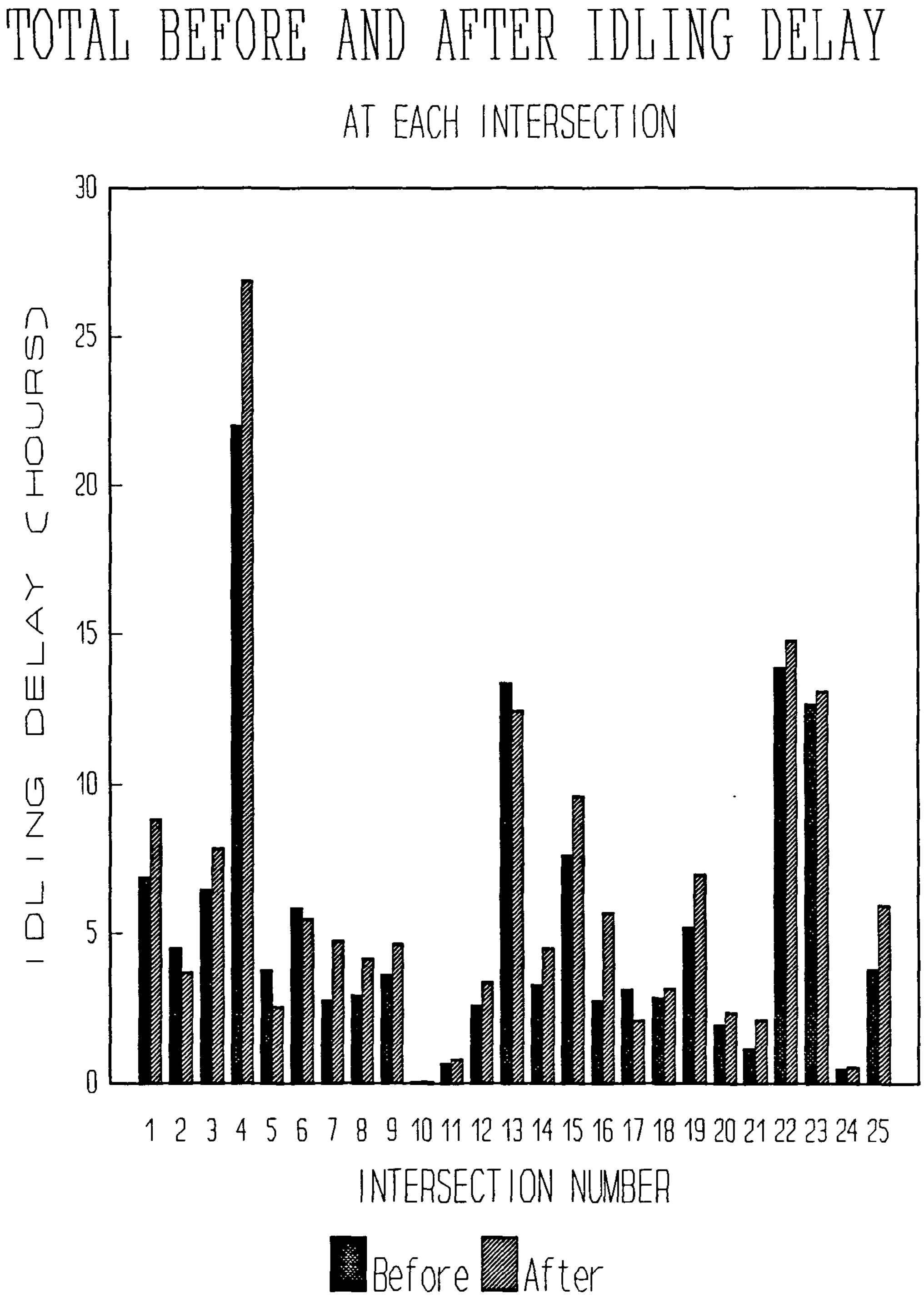


Figure 2.1: Total before and after idling delay of IMVFR project at each intersection

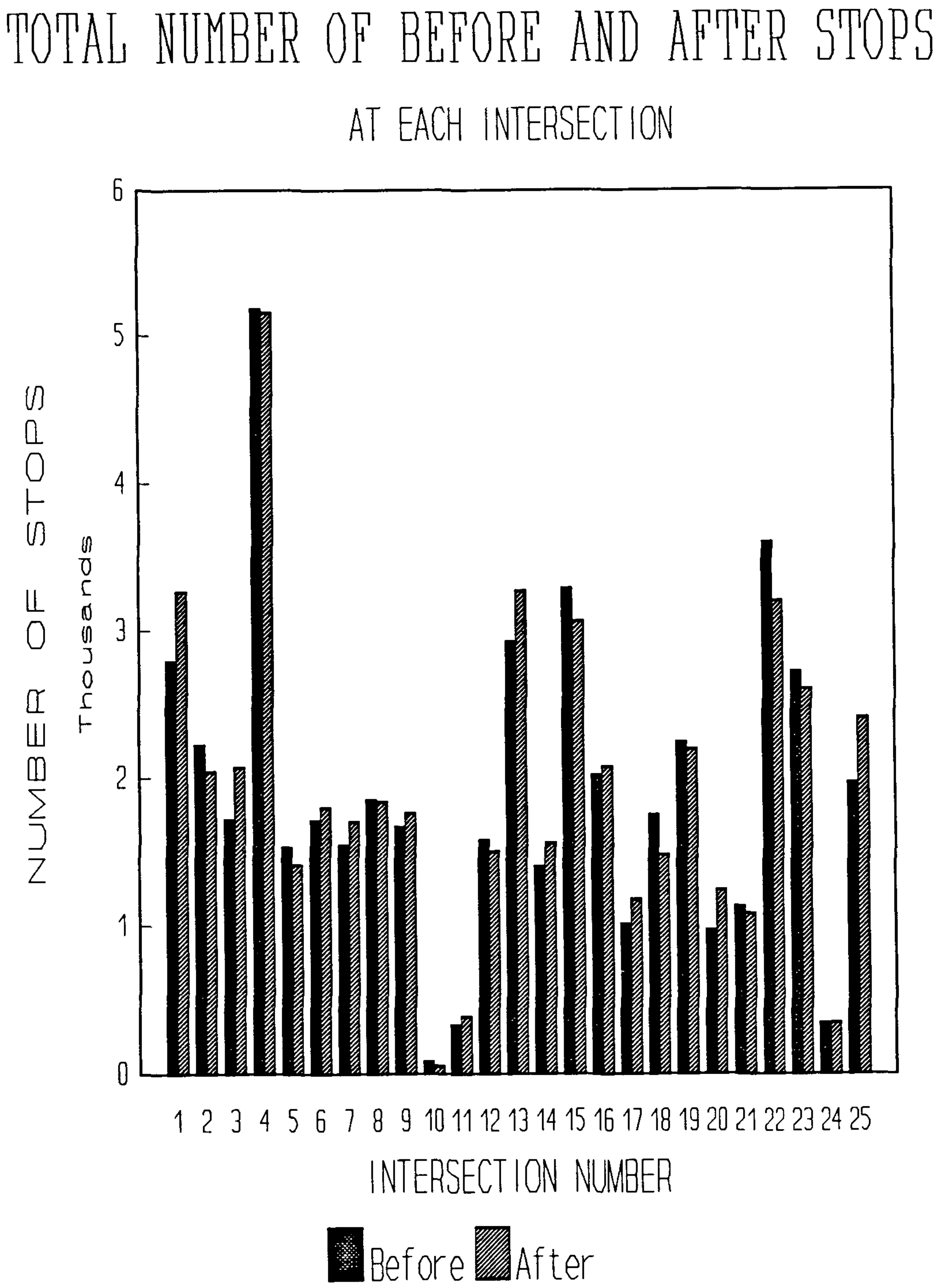


Figure 2.2: Total before and after number of stops of the IMVFR project at each intersection

cycle length may vary in actuated operation. The cycle length in actuated control changes from a predetermined minimum to a predetermined maximum, based primarily on the traffic volumes. If the volumes are low, shorter cycle lengths are produced. The cycle length increases as the traffic volume increases.

There is a start up and slow down delay associated with each cycle length. This occurs when vehicles slow down to stop as they approach a red light and when they begin accelerating at the beginning of the green light. If the signal timing is such that the cycles are very short, these delays occur repeatedly and more frequently than when cycles are longer. Delays caused by short cycle lengths may be detrimental to the smooth operation of an intersection. The number of stops may also be higher for shorter cycle lengths. This is especially true for low volume actuated control situations. Here, traffic signals change quickly to assign right of way to conflicting traffic based on vehicle arrivals.

Before and after time of study

Traffic volumes and patterns may fluctuate depending on the time of the day, day of the week, and time of the year. This may cause changes in fuel consumption that are reflected in the IMVFR study but are not related to intersection improvement.

Adjustment Period

Drivers not yet familiar with new settings would be more likely to use caution and cause sluggishness of traffic flow.

The results of the IMVFR program, therefore, may have partially been the result of factors other than the upgrading of the traffic signal control.

This research is undertaken to develop guidelines for selecting the most fuel efficient type of traffic signal control. The amount of fuel consumed at various timings and volume levels are examined by using a computer software program called Network Simulation (NETSIM) (5). NETSIM can simulate different traffic control types and estimate fuel consumption. Fuel consumption is measured by simulating actuated and pretimed controls at various traffic volume levels and cycle lengths. The results are examined to determine whether there is a relationship between traffic volume levels and the most fuel efficient form of control.

CHAPTER 3. LITERATURE REVIEW AND RESEARCH OBJECTIVE

Literature Review

The _Transportation and Traffic Engineering Handbook_ chapter on the "Selection of Controller Type" compares controller types, but does not provide any designated guidelines for the selection of a traffic control type at specific locations (6).

"Common practice," "rules-of-thumb," and similar phrases are commonly used to refer to recommended practices for selecting the form of traffic signal control. Homburger and Kell indicate that properly timed actuated signals reduce delay when compared with pretimed signals. They state that the actuation feature is used primarily on streets with varying and sporadic traffic patterns. Fully actuated controls are used when traffic volumes on both crossing streets are about equal(7).

The Institute of Transportation Engineers' notes for a seminar titled _Selection of Traffic Signal Control and Timing at Individual Intersection_ state that pretimed control equipment is best suited in situations where traffic volumes and patterns are predictable and steady (8). Semi-actuated signals work best where cross street traffic varies significantly and is unpredictable, or where pedestrian actuation is needed. The actuated controller provides varying cycle lengths to accommodate changes in demand.

Kell and Fullerton suggest that very sophisticated types of control can handle almost any type of situation (9). None of the available literature addresses the benefits and costs associated with each control type under varying volumes or other conditions.

Kahng and May examined the energy and emissions consequences of improving traffic signal systems using a computer simulation model (10). They demonstrated that passenger delays and vehicle emissions are reduced by shorter cycle lengths, but that total stops are reduced by longer cycle lengths. This implies that there may be an optimal cycle length at which the combined effect of stops and delays on fuel consumption are minimized.

A National Highway Cooperative Research Program study was conducted to develop guidelines for the "most appropriate" type of signal control at intersections (11). It demonstrated that fuel consumption and emissions at intersections are reduced most significantly by the type of control that most reduces delays and number of stops. The project was conducted using NETSIM simulation software. Results of the simulation were checked using field data. The researchers found that NETSIM's accuracy of estimating delays and number of stops is greater than eighty five percent. They showed that as traffic volume approaches capacity, pretimed controls become more efficient than actuated controls.

The Highway Capacity Manual (HCM) indicates that the pretimed control is less efficient at certain locations where it cannot respond to changing demand (12). According to the HCM, the fully actuated control makes the most efficient use of the available green time as demand changes.

When traffic engineers design new signals or upgrade existing signals, they are frequently faced with the problem of choosing one type of signal control over another. There is a different cost associated with each type of control. Pretimed signals are the least expensive to implement, while fully actuated signals are the most expensive. Homburger and Kell categorize the higher cost of actuated control as follows (7):

1. The installation cost of actuated signals are two to three times the cost of pretimed signals.
2. Actuated controllers are more complicated than pretimed controllers and require more inspection and maintenance.
3. Actuated controllers require detectors which are expensive to install and require maintenance.

Guidelines will assist the engineer in selecting the proper form of control. A properly selected control will avoid the unnecessary expense of more costly alternatives. As The National Highway Cooperative Research Program Report Number 233 indicates, the properly selected form of control will bring about savings in user costs that will often justify the additional investment in more expensive choices (11).

The signal operator is the engineer or technician who is in charge of day to day operation of the signals. The operator may find a lack of guidelines for selecting control type to be a dilemma. If an intersection is set up properly, state of the art control equipment will allow for switching from operating in a pretimed mode to an actuated mode. The operator's problem lies in selecting the most efficient mode of control at a given time.

Research Objective

As noted in the literature review, the existing rules for selecting a form of traffic control do not adequately address the economic significance of savings which may be produced by energy efficient traffic signal control. It is highly likely that, in the absence of rules to choose fuel efficient control, the IMVFR intersections were upgraded to obtain smoother traffic flow. The goal, however, was to save the motorist money by reducing fuel consumption by upgrading the form of control. If energy savings is the goal, then guidelines are needed for selecting the most fuel efficient form of control, or for deciding to upgrade control.

The purpose of this research is to develop guidelines for selecting an energy efficient signal control strategy. Using computer simulation, fuel consumption implications of signal control and signal timing are estimated at different traffic volume levels.

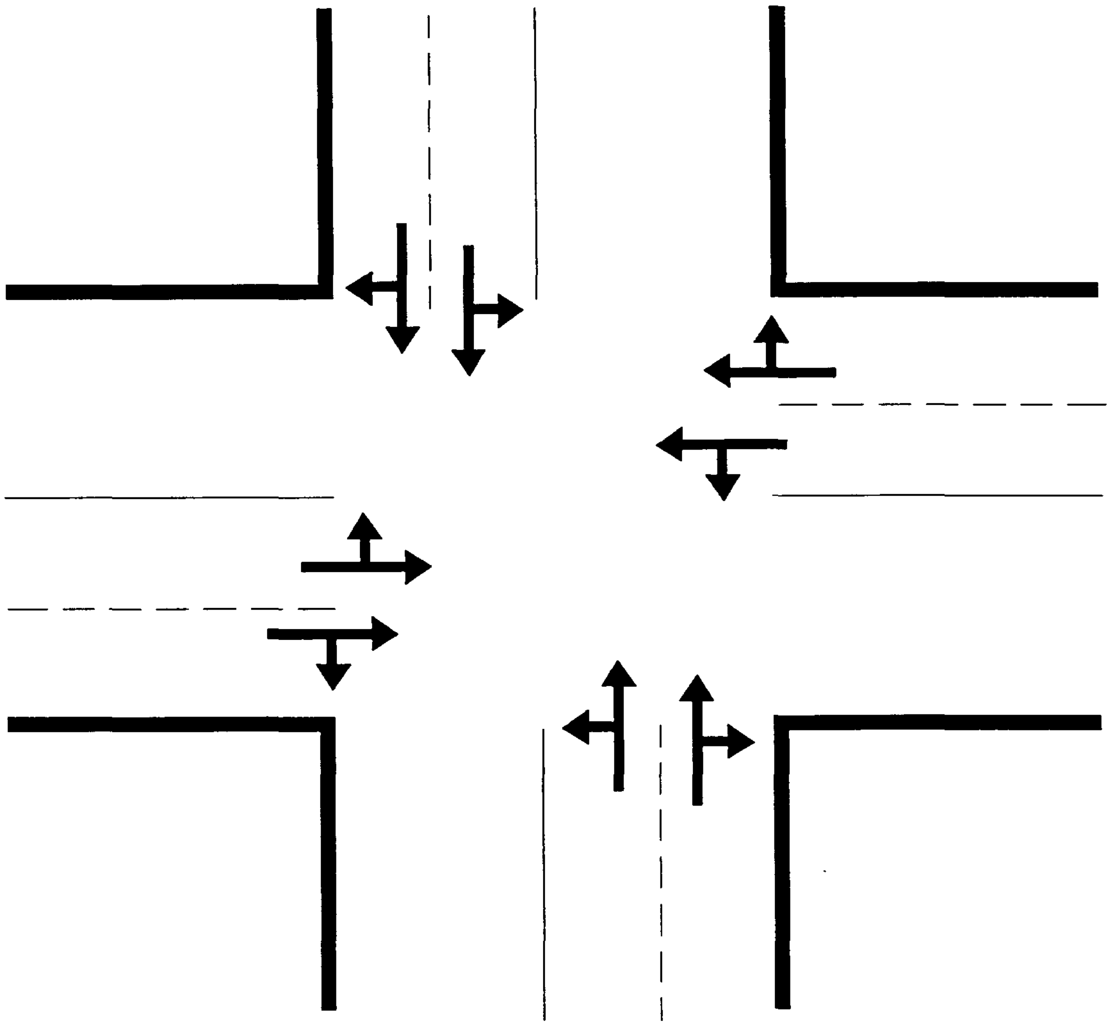
CHAPTER 4. RESEARCH METHODOLOGY

The objective of this research is to examine the effect of traffic signal control strategies on the amount of energy used by vehicles at various volume levels. Energy consumption is directly related to the number of stops and length of stops. This research is based on the assumption that there is a volume dependent point at which the control should be switched from one mode to another in order to realize energy savings.

The effects of timings for vehicle energy consumption and control settings are evaluated using the NETSIM computer simulation. To examine the effect of signal timings on fuel efficiency, various cycle lengths are evaluated utilizing a microcomputer based simulation program. The operation of a prototypical 4-leg, 2-way, 2-lane approach intersection is analyzed. Left turns share the left lane with the through traffic. Figure 4.1 shows the geometric layout of this intersection. A two phase operation with permitted left turns is assumed. Figure 4.2 shows the phasing scheme.

Simulation runs are repeated with different left turn/total approach volume ratios, in the following manner:

1. Ten percent of the total approach volume is assumed to turn left.
2. Twenty percent of the total approach volume is assumed to turn left.



ARROWS INDICATE DIRECTION OF MOVEMENT.

Figure 4.1: Assumed number of lanes and traffic movements

3. Thirty percent of the total approach volume is assumed to turn left.

The left turn volume is not increased beyond thirty percent of the total traffic volume. Higher left turn ratios, would call for an exclusive left turn bay, or more complicated

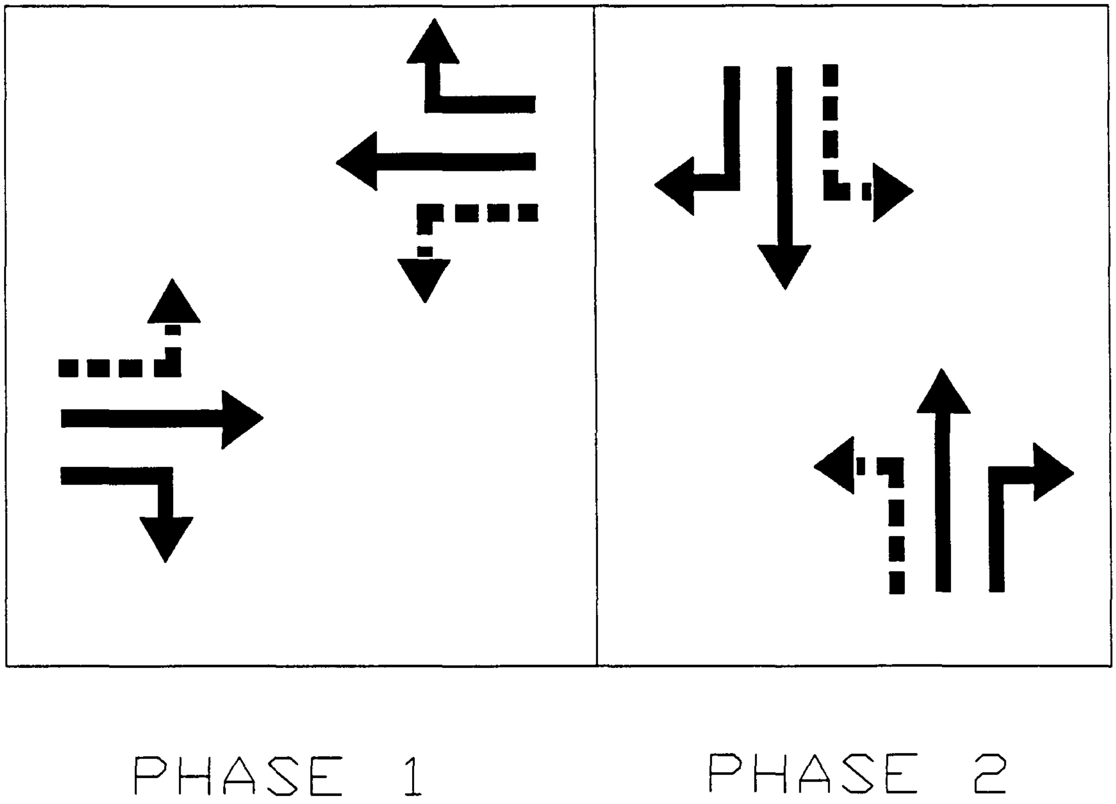


Figure 4.2: Assumed traffic signal phasing scheme

phasing schemes.

Volumes and cycle lengths are changed depending on the type of control, as indicated below:

1. **Pretimed intersection:** The range of cycle lengths simulated is from twenty seconds to 140 seconds, at 10 second increments. For each cycle length the total entering volume is started at 200 vehicles per hour and is increased to 2,600 vehicles per hour, in steps of 100 vehicles per hour. A total of 325 runs are made for pretimed control.

2. **Actuated control:** A simple fully actuated signal control with one detector loop on each approach, maximum phase time of sixty seconds, minimum green time of ten seconds, and yellow time of four seconds was assumed.

> Variation in settings of an actuated control, such as maximum or minimum times, can affect the operation of signals. In this research three different control strategies are being compared. The effects of changing timings are not of interest to this research. For this reason the time settings of the actuated control are kept constant. The computer runs are done with equal volumes on both streets. The approach volumes are changed from 200 to 2,600 vehicles per hour. A total of 50 runs are made.

Two further sets of runs are made with twenty percent and thirty percent left turn ratios, respectively. These totaled 286 runs. The total number of runs used in this research is 661.

The results are analyzed by comparing average fuel consumption under pretimed and actuated controls. Among the pretimed control cycle lengths, the most fuel efficient cycles are plotted against volumes. The same is done for the least efficient pretimed control cycle lengths. These curves are then compared to the fuel consumption curve for actuated control. The actuated control fuel consumption curve is obtained by plotting average fuel consumption per vehicle against volume levels.

CHAPTER 5. RESULTS AND ANALYSIS

Many factors affect the operation of a signalized intersection. They include the channelization scheme of traffic lanes, the slopes of approach lanes, the percent of heavy vehicles in the stream of traffic, the controller settings, traffic volume levels, flow patterns, and sight distances. While not every combination of these factors could be studied, effects of changes in the controller settings and the traffic volume levels on energy consumption are examined.

One of the goals of this research has been to examine the relationship between traffic volume levels and energy efficient control type. A prototypical intersection is selected to be studied. It should be kept in mind that if it is determined that the energy efficiency of a control strategy is related to the volume levels, then further study is necessary for other types of intersections.

A total of 675 simulation runs are performed on an intersection with the following assumed characteristics:

1. 4-leg right angle intersection
2. 2-lane approaches
3. 2-way streets on all four approaches
4. zero gradient
5. 2-phase pretimed or actuated control
6. three percent trucks

7. ten percent, twenty percent, and thirty percent of the total volume turning left.

NETSIM uses two random seed numbers. One number is used as a seed number to produce random numbers that characterize the random elements of traffic flow. This number is intentionally held constant for all runs to eliminate differences in fuel consumption due to random variance in traffic flow. The second random number is used to generate traffic volume arrivals. Various random numbers and simulation times are used. The simulated time ranged from 12 minutes to one hour.

Figure 5.1 shows the relationship between average fuel consumption and volume levels for the actuated control. Figure 5.2 displays the same relation for selected pretimed cycle lengths. By examining Figures 5.1 and 5.2, it is noted that, as volume changes, the type of control that causes the least fuel consumption also changes. At low volume levels, actuated control results in higher fuel consumption. As volumes are increased, actuated control becomes more fuel efficient than pretimed control. Hence, for this intersection, the most energy efficient control is dependent on volume levels. This may also be true for other types of intersections.

Figure 5.3 demonstrates a comparison between the fuel

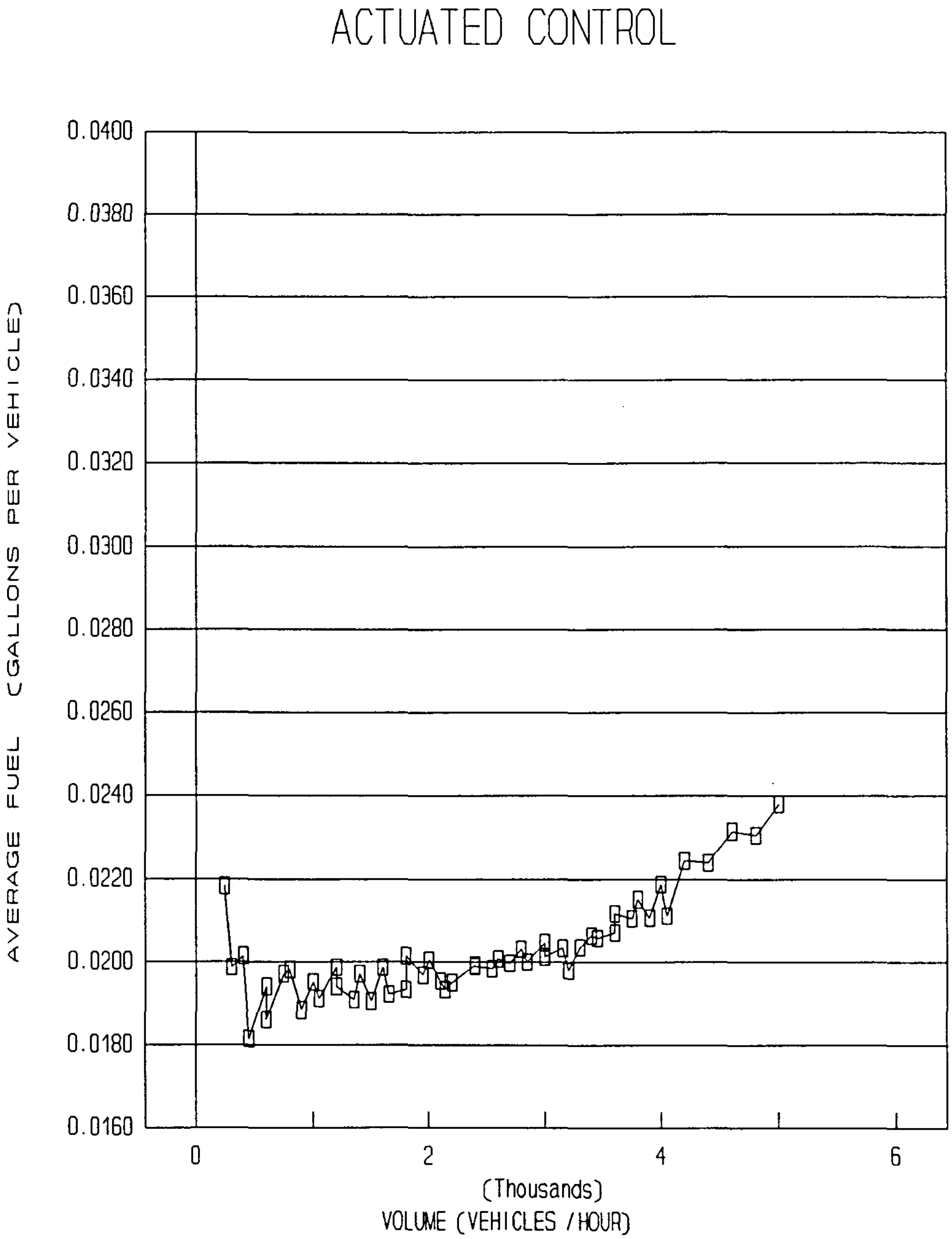


Figure 5.1: **NETSIM's fuel consumed versus volumes, actuated control, ten percent left turn**

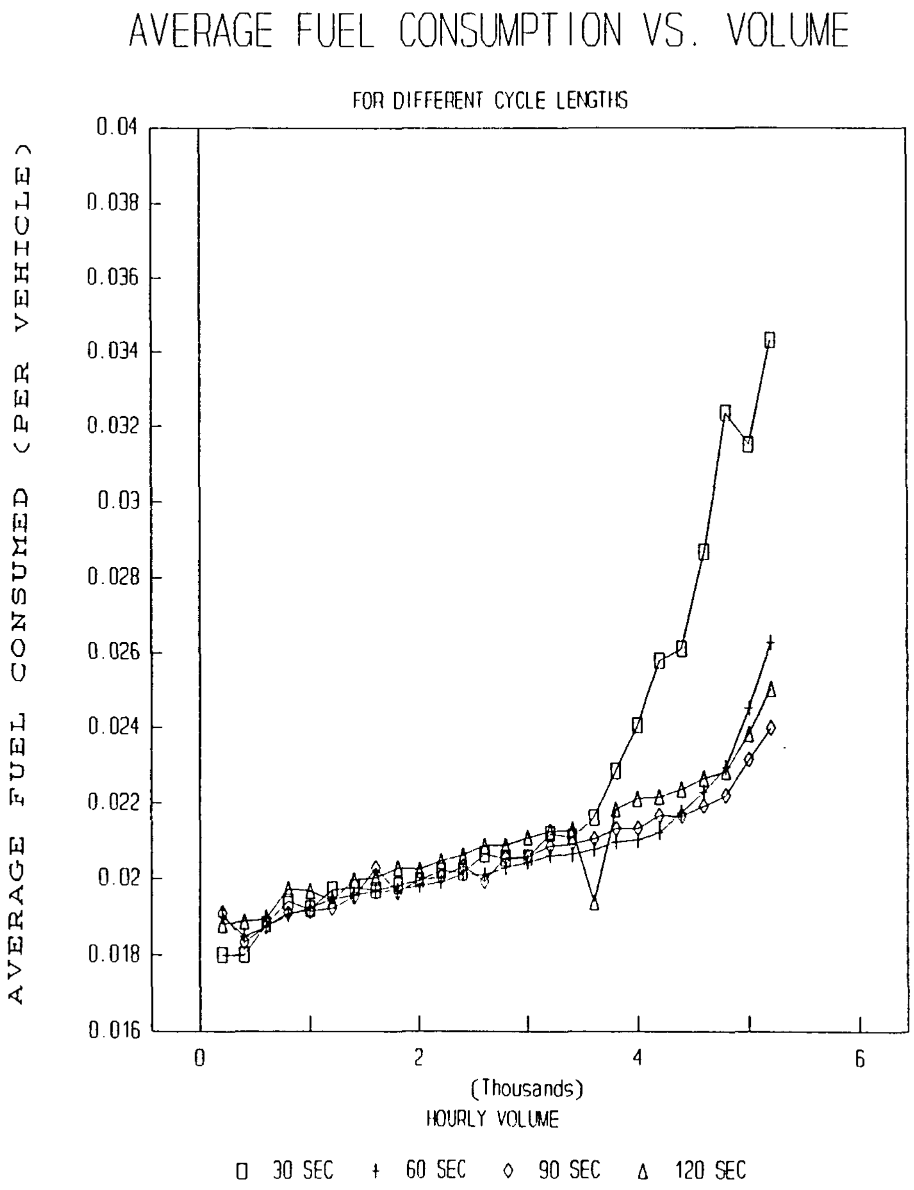


Figure 5.2: NETSIM's fuel versus volume for pretimed cycle lengths of 30 to 120 seconds

efficiency of pretimed traffic control and actuated traffic control. It shows NETSIM's pretimed minimum and maximum, and actuated control fuel consumption curves. Figure 5.3 is obtained by plotting three curves as follows:

1. The pretimed minimum fuel consumption curve: At each volume level various cycle lengths are simulated by the computer program. The average fuel consumption per vehicle for each cycle length is then calculated using the simulation's output. The minimum of these average fuel consumption numbers is plotted versus the volume. This procedure is repeated for all the traffic volume levels to obtain the minimum fuel consumption curve. This curve represents pretimed cycle lengths with the least fuel consumption at any given volume. Table 4.1 shows the cycle length used at each volume level.
2. The actuated fuel consumption curve.
3. The pretimed maximum fuel consumption curve: Points on this curve represent the maximum fuel consumption for a given volume.

Four distinct zones are noted on this curve, which indicates that an energy efficient form of control is related to the volume level:

Zone 1, volume of less than 400 vehicles per hour:
Actuated control resulted in the highest fuel consumption. This is the case regardless of the pretimed cycle length.

Zone 2, volume of 400 to 1000 vehicles per hour:
Actuated control results in fuel consumption levels that are close to the pretimed maximum fuel consumption curve. In this volume range, even if a non-optimum cycle length is selected, it is more likely that a pretimed cycle length will result in better operation. This can be seen on Figure 5.3.

Table 4.1: NETSIM pretimed cycle lengths producing min fuel consumption for the given volumes

AVERAGE FUEL CONSUMED (GALLONS)	MINIMUM FUEL CYCLE LENGTH (SECOND)	HOURLY VOLUME (TOTAL)
0.01800	50	200
0.01798	50	400
0.01825	50	600
0.01861	50	800
0.01862	50	1000
0.01888	50	1200
0.01895	50	1400
0.01912	50	1600
0.01931	40	1800
0.01928	40	2000
0.01948	50	2200
0.01963	50	2400
0.01986	50	2600
0.01999	50	2800
0.02000	50	3000
0.02026	50	3200
0.02046	50	3400
0.02059	50	3600
0.02078	50	3800
0.02101	60	4000
0.02123	60	4200
0.02166	90	4400
0.02193	90	4600
0.02222	90	4800
0.02316	90	5000
0.02374	100	5200

Zone 3, volume of 1000 to 3500 vehicles per hour:
In contrast to zone 2, actuated control results are consistently close to the pretimed minimum fuel consumption curve.

The operating pretimed cycle lengths are determined by the engineers or technicians. Due to the variation of traffic levels and patterns with the time of day, day of week, and day of year, the prediction and determination of the most efficient pretimed cycle length may be difficult. The number of cycle lengths that a traffic controller can accommodate is limited. In this volume

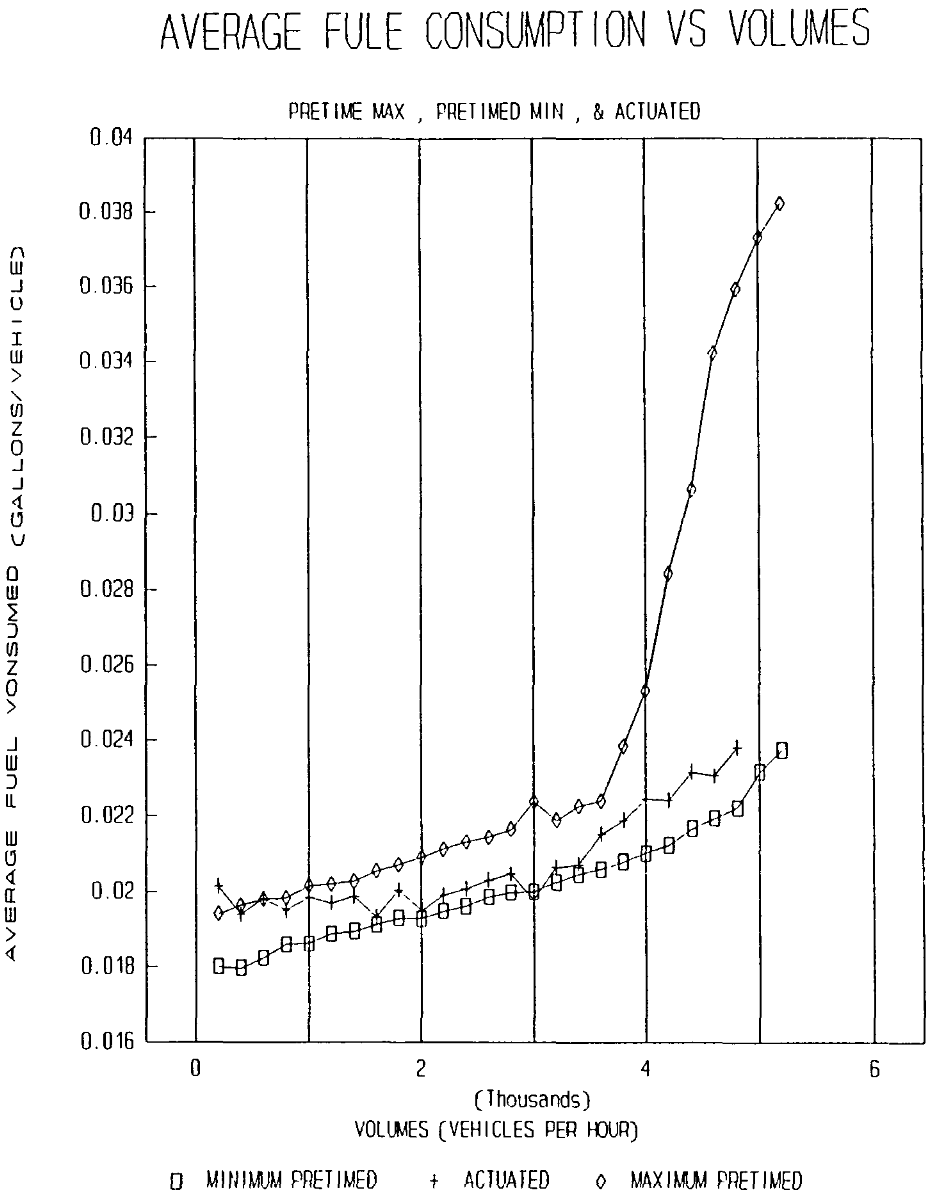


Figure 5.3: NETSIM pretimed minimum and maximum, and actuated control fuel consumption curves

range it is more likely that the choice of a pretimed cycle length will increase fuel costs.

Actuated control automatically adjusts the cycle length. It emulates the most fuel efficient pretimed cycle lengths. Therefore, actuated control is the best choice.

Zone 4, volume of more than 3500 vehicles per hour:
Where volume exceeds 3500 vehicles per hour pretimed control can produce more fuel efficiency than actuated control. In this range additional research is needed before deciding on the form of control. This is because at these high volumes, small inefficiencies will add up to high total fuel consumption.

The analysis suggests that, for the type of intersection used in this research with ten percent left turning volumes:

1. Pretimed control should be used when volumes are less than 400 vehicle per hour.
2. Pretimed control should be considered for volumes of 400 to 1000 vehicles per hour.
3. Actuated control should be considered for volumes of 1000 to 3500 vehicles per hour.
4. Pretimed control is desirable when volumes exceed 3500 vehicles per hour.

Further analysis is then conducted, using twenty percent and thirty percent left turn volumes, respectively. The minimum and maximum pretimed, and actuated control fuel consumption levels versus hourly volumes for twenty percent left turns and thirty percent left turns are shown in Figure 5.4 and 5.5, respectively. Examining these figures also reveals that, for those particular settings and left turn ratios, there is a relationship between traffic volumes and

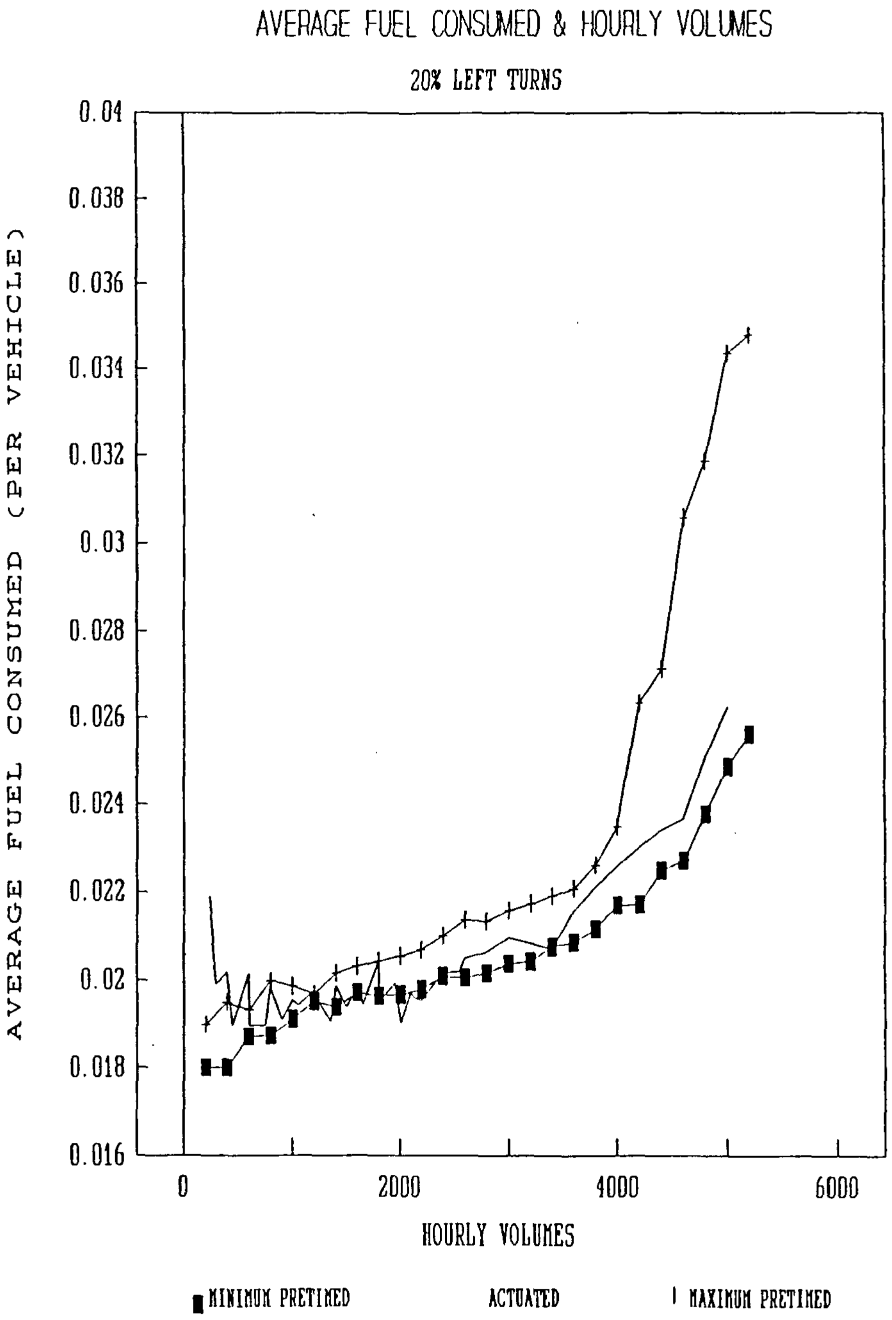


Figure 5.4: NETSIM pretimed min and max, and actuated control fuel curves, 20 percent left turns

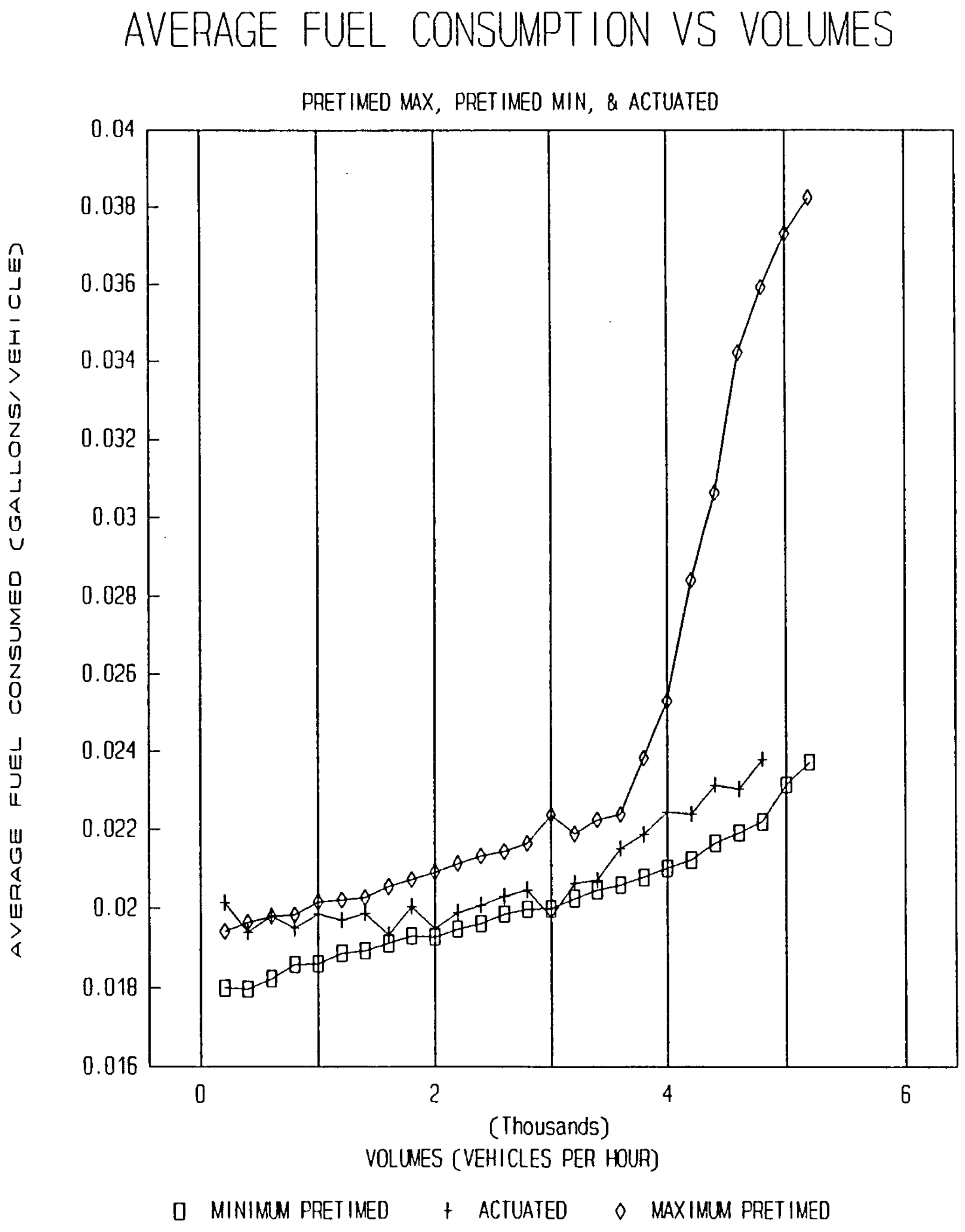


Figure 5.5: NETSIM pretimed min and max, and actuated control fuel, thirty percent left turn

the type of control that is energy efficient. As the left turn ratio increases and the traffic volume exceeds 1200 vehicles per hour, the choice of actuated control becomes more desirable. Here the actuated control closely emulates the most energy efficient pretimed cycle lengths.

CHAPTER 6. CONCLUSION AND RECOMMENDATION

The result of this study indicate that energy efficiency at signalized intersections depend upon traffic volume and type of signal control. It is recommended that the same type of analysis be performed for a variety of intersections. This should be done in order to obtain a quantitative estimate of the energy savings obtained by choosing the most energy efficient form of control. This information can be published in tabular form. It can then be used in conjunction with current recommendations. Most of the IMVFR isolated intersections showed more fuel consumption after upgrading. This poor performance could mean that the signal control should not have been upgraded to actuated control.

The energy efficient form of control produces savings in fuel costs. These savings should well offset the extra expenditures on construction and maintenance of the energy efficient control. Part IV of "The Traffic Devices Hand Book" cites a National Cooperative Highway Research Program Project findings as follows (3, p4-24):

> " ...it was found that the difference in the annual costs for equipment acquisition, installation, operation, and maintenance between the control alternatives were significantly less than the differences in benefits. For this reason, the control alternative that minimized stops and delays also proved to be the most cost effective."

The recommendations of this study are summarized as follows:

It is recommended that, when feasible, simulation runs and methodology similar to that used in this research be used for an intersection for which a form of control is being considered.

It is also recommended that the relationship between traffic volume levels, energy consumption, and form of control be investigated for different types of signalized intersections. The results should be published to provide for easy quantitative comparison of the benefits of various signal control strategies.

Finally, it is recommended that the current procedures in choosing a form of traffic signal control at isolated intersections be used in conjunction with the results from part 1 and 2 mentioned above.

Upgrading from pretimed control to actuated control without consideration of volume levels will not assure significant fuel savings. In comparison to efficient pretimed control, actuated control may even harm the fuel efficiency of intersection control.

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