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MICRO2

AN AIR QUALITY INTERSECTION MODEL

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16. Abstract

This report describes the MICRO2 computer model and how to use it.

This program models traffic at an intersection based on Webster's Formulation. Delay, stops, pollution emissions and fuel consumption are determined. In addition, a file is created which can be used directly by the California Line Source Model (CALINE 3) to determine carbon monoxide concentration at a receptor.

The model can model multi-lane turns, overcapacity condition, and traffic arriving at the intersection in platoons.

Predictions by MICRO2 and CALINE3 were compared to a limited amount of monitoring data at a Denver intersection. After considering background concentration, the results compared favorably.

17. Key Words

Air Quality, Traffic Signals, Emissions, Delay, Pollution

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INTRODUCTION

Program MICRO2 estimates pollutant emissions, fuel consumption, and delay at a signalized intersection. It can be used by traffic engineers to determine the impact of signal change before it is implemented. It can also be used to estimate impact of an intersection for an Environmental Impact Study. Because this program is an analytical model rather than a simulation model it can be executed within a few computer second and costs only a few dollars per run.

The model uses standard traffic engineering formulas to determine stops, delay, and queues for each leg of an intersection. Based on this data, the model estimates fuel consumption and air pollution emissions. A file is also created which can be used by CALINE3 (a line source model) to determine carbon monoxide concentrations near the intersection.

MICRO2 is an analytical model rather than a simulation model, and therefore, cannot simulate the effect of demand actuated signals. It can, however, determine the optimum signal timing for a given intersection with specified traffic volumes, although the user has the option of specifying his own timing plan.

The model can estimate emissions for the car when the intersection is over capacity. It can also analyze an intersection with multiple turn lanes. Further, a routine is available which can adjust stops and delay for the case when vehicles arrive in a platoon (a platoon could exist when the signal is syncronized with a signal upstream). Other features include right turn on red option and a permissive left turn arrow option.

MICRO2 METHODOLOGY

MICRO2 is an analytical model rather than a simulation model. That is results are based on formulas derived from simple models rather than stepping through the movements at an intersection moment by moment. The basic assumption is that all vehicles arrive uniformly and behave as some "average" vehicles. This assumption allows establishing of a model from which pure formula for delay, stops, and queue can be derived. This section is devoted to these formulas and how they are used in MICRO2.

Phase Times:

MICRO2 computes total cycle time with the following equation:

$$TCT = \frac{6.75 * NP + 5.0}{1 - SVC}$$

where: TCT is total cycle time in seconds
NP is number of phases
SVC is the sum of the critical volume to capacity ratios

The 6.75 seconds corresponds to 4.75 seconds of start-up delay for the first few vehicles plus 2 seconds clearance delay for each phase. The 5.0 second term increases the time beyond the minimum to prevent breakdown of the intersection flow as traffic deviates from the average level. For the case of practical over capacity, when SVC is greater than .84, MICRO2 sets the total cycle time to an arbitrary value which is represented by the variable named OCTCT.

Green time is allocated first to each critical phase and the remainder is given to the other phases. For example, heavy volume approaching from the north requires long green time. The traffic approaching from the south gets the same total green time as the north approach even though the traffic does not demand it. The approach from the north is the critical approach and also controls the phase time for the south approach. Setting phase times when left turn arrows are used becomes more complicated but the same principle applies.

For a permissive left turn arrow MICRO2 adds capacity based on an imperical formula. Added capacity ranges from 40 to 1000 vehicles per hour per lane. The minimum capacity results when there is very heavy opposing traffic while the maximum capacity results when there is no opposing traffic. The added capacity is considered in determining total cycle time and phase times. It is then reevaluated after phase times are set.

Similarly, MICRO2 adds extra capacity for right turn on red. There are two ways a driver can execute a right turn on red. First, drivers may procede continuously (after a stop) while a left turn arrow is on for the approach to the right. During other times, drivers must wait for any approaching traffic to clear the intersection before turning right on red. The number of vehicles that can make a right turn on red is, therefore, based on volume-capacity ratio of the approach link to the left plus the length of the left turn arrow for the approach to the right.

You may also select a right turn arrow. If selected, MICRO2 sets the green time for the arrow to correspond to the <u>left</u> turn arrow of the approach on the right. This method allows additional green time for right turns without adding to the red time for the other legs.

<u>Over Capacity</u>

When MICRO2 determines an intersection is over capacity, it warns the user and asks him for values of the delay parameter. This parameter is the length of time a driver will tolerate waiting before she changes her route. For example, if another route existed which normally takes 5 minutes longer, the driver will begin using this other route when delay due to over capacity exceeds 5 minutes.

Other alternatives to the driver are changing the time of day of his trip or not making the trip at all. Extremely long delays result where none of these alternatives are reasonably available to the drivers. For example, you should specify a large value for the delay parameter when analyzing a nearby intersection after a major sporting event. Twenty minute delays may not be unreasonable because the driver has no alternatives.

MICRO2 reduces the traffic through the intersection to the capacity value, but adds extra idle emissions and delay for each vehicle based on this delay parameter.

Stops, Delay, and Queue

MICRO2 computes stops, delay, and maximum queue length for each approach of the intersection. The following equations are used:

$$STOPS = \frac{TCT-PT+4.75}{1-VC} * VOL$$

$$DELAY = \frac{STOPS * (TCT-PT+4.75)}{2}$$

$$QUEUE = \frac{S*TCT}{3600}$$

where: STOPS is number of stops per hour
TCT is total cycle time in seconds
PT is phase time for the approach in seconds
VOL is volume of approach in vehicles per hour
DELAY is delay in vehicle-seconds per hour
QUEUE is size of queue in vehicles

Platooning Vehicles

MICRO2 will adjust these computed volumes if the traffic arrives in a platoon, that is, when traffic is released by a syncronized signal upstream. You must, however, specify the fraction of the traffic in the platoon and the time during the cycle it arrives.

MICRO2 determines the stops and delay adjustment by considering how the queue size changes throughout the cycle. This queue pattern can take on five different forms depending on when the platoon begins arriving and how long its passage lasts. Figure 1 is a diagram of the queue pattern for case 4. (For a complete set of curves and equations for adjusting queue, stops, and delay refer to the Appendix A). The delay is the area under the curve and the number of stops is the arrival rate times the time when a queue exists or the signal is red; that is, each vehicle that arrives before the queue clears or during the red must stop.

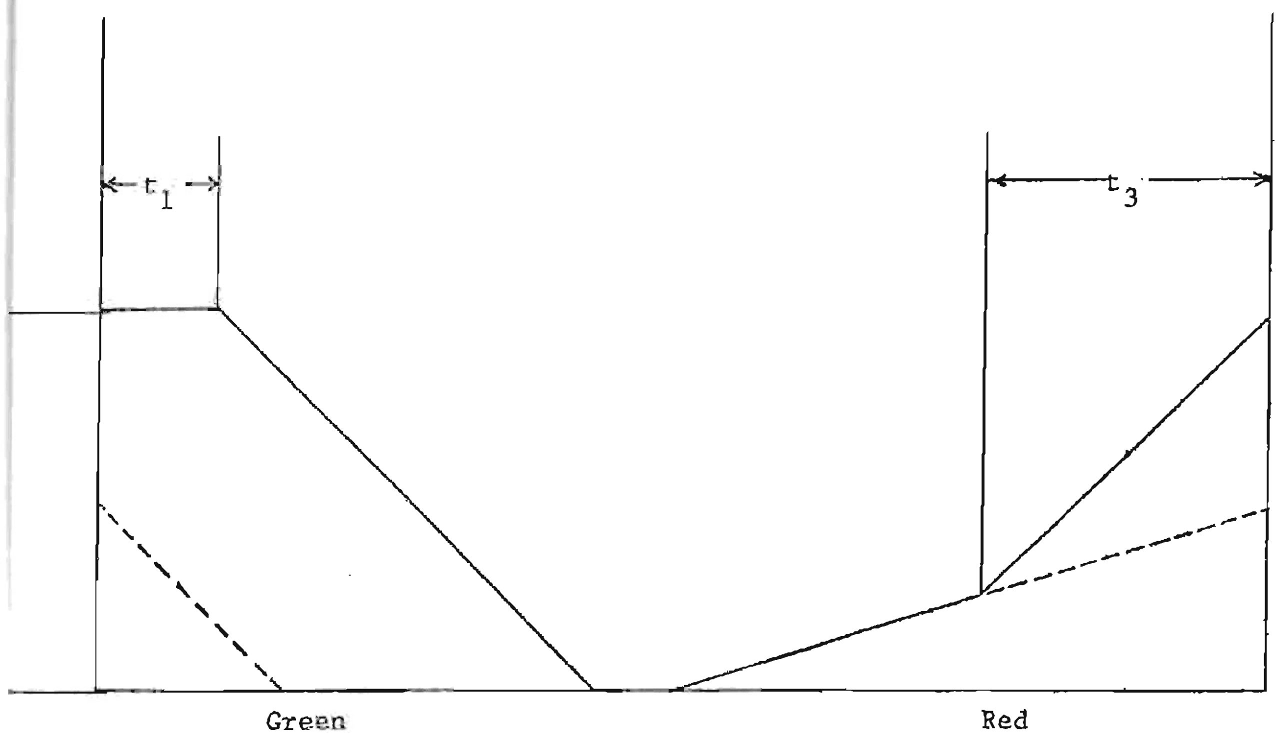
Air Pollution Emissions

Only after the stops, delays, and queue size are determined can MICRO2 determine emissions and fuel consumption near the intersection. The emissions are determined by first considering the four modes each vehicle passes through when stopped. Each vehicle that stops must first be in a steady-state cruise[1], then decelerate[2] to a stop, idle[3] for an undetermined amount of time and finally accelerate[4] back up to a speed returning to the stead-state cruise mode[1]. Vehicles which do not stop remain in the steady-state cruise mode. MICRO2 computes total emissions by applying an emission rate to the number of vehicles in each mode and the time they remain in each mode.

The emission rates are determined by equations that relate emissions to the product of acceleration multiplied by speed (AS). As discussed in reference 1, emissions versus AS is reasonable because the AS is related to engine power. The more power an engine produces, the more air and fuel it processes and, therefore, the more pollution it emits. Figure 2, 3,

Figure 1

Case 4 Platoon Arrives in Red and Ends in Green



Note: Delay is area under the curve.

Number of Stops is the rate of approaching vehicles times the periods when vehicles must stop.

and 4 show this relationship for hydrocarbons, carbon monoxide, and oxides of nitrogen. When a vehicle is accelerating, it is assumed that its AS is constant at 80.7 ft^2/sec^3. A vehicle accelerating at this constant AS takes 12 seconds to reach 30 mph and compares to a constant acceleration rate of 2.5 mi./hr-sec. By reading the graph or using the equation on Figure 2, it is apparent that 80.7 ft^2/sec^3 corresponds to 0.1 g/sec hydrocarbons. Since it takes 12 seconds to accelerate to 30 mi/hr. each stopped vehicle will omit 1.2g of hydrocarbons while accelerating. MICRO2 computes carbon monoxide and oxides of nitrogen acceleration emissions in the same way.

For the idle and cruise modes, the acceleration rate is zero and, therefore, the value of AS is zero. MICRO2, therefore, uses the zero of the emission curves for the idle and cruise emission rates. Finally, for the deceleration mode, it assumed that the value for AS was just the negative of the acceleration case. Therefore, on the average and for a cruise of 30 mi./hr., the deceleration will take 12 seconds. For the case of hydrocarbons and carbon monoxide, the emission rate is the same as the idle rate when AS = 0.0. While for oxides of nitrogen, the equation or curve on Figure 4 predicts the emission rate.

Average vehicle emission rates vary over the years because of changes in vehicle population. As new vehicles with controlled emission replace older vehicles, the average emission rates go down. Altitude and ambient temperatures also affect emission rates along with speed and mode of operation. In order to have a standard of comparison, EPA has established a standard test cycle called the Federal Test Program cycle (FTP). The average emission rate when a vehicle goes through this cycle is known as the FTP rate. By averaging the exact FTP rate of all the vehicles on the

Figure 2

EFFECT OF ACCELERATION X SPEED ON HYDROCARBON EMISSIONS

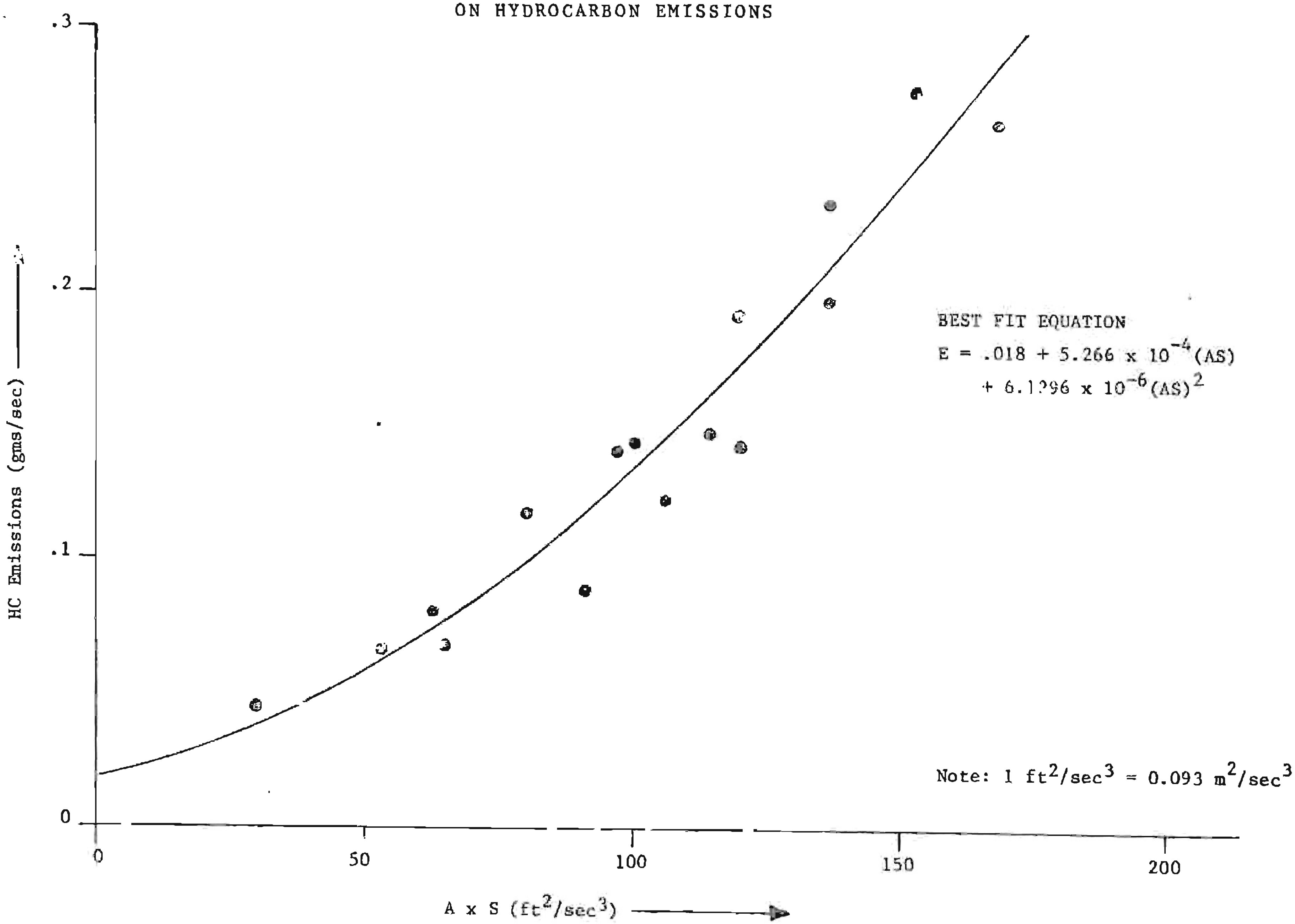


Figure 3

EFFECT OF ACCELERATION X SPEED
ON CARBON MONOXIDE EMISSIONS

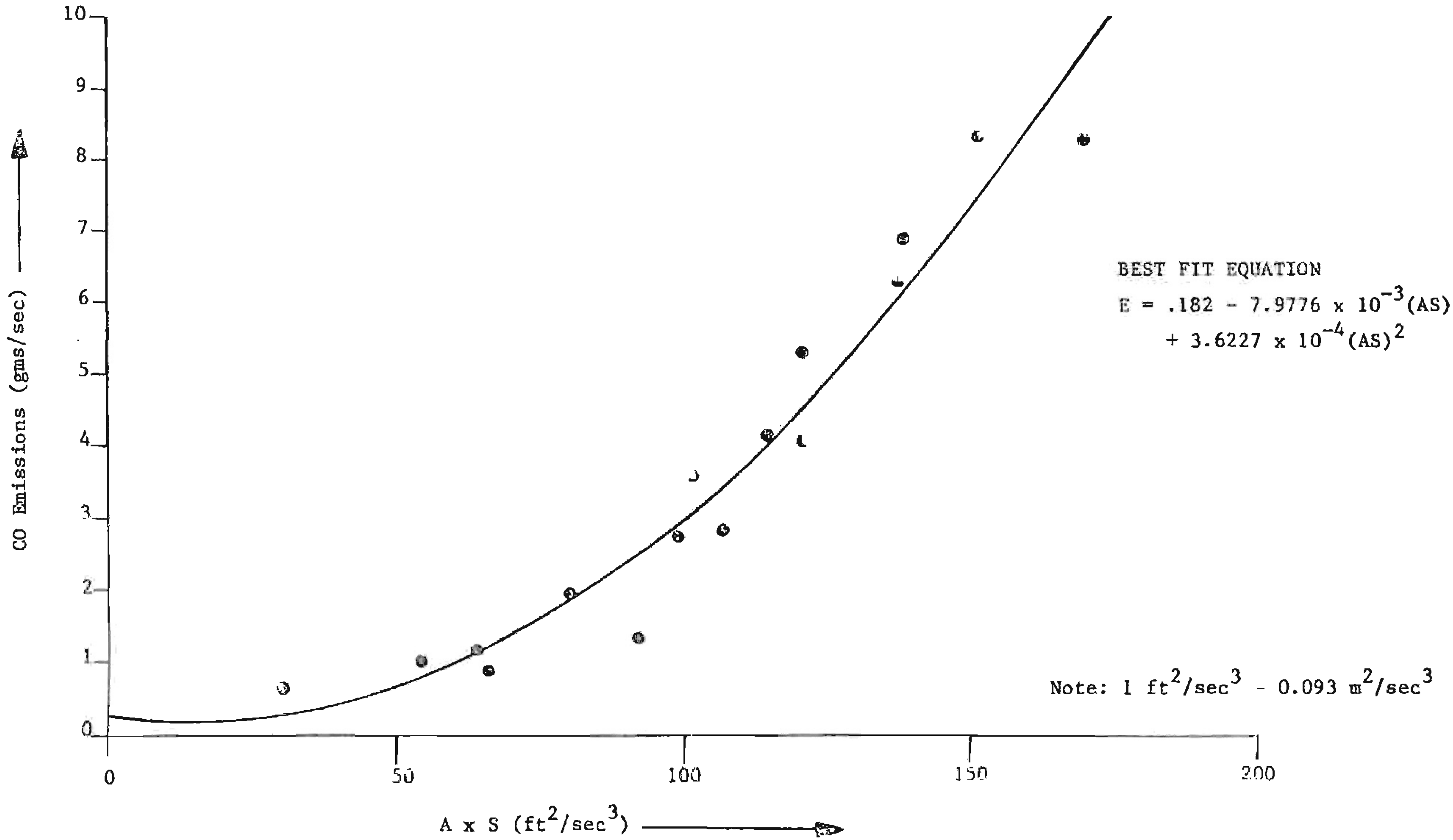
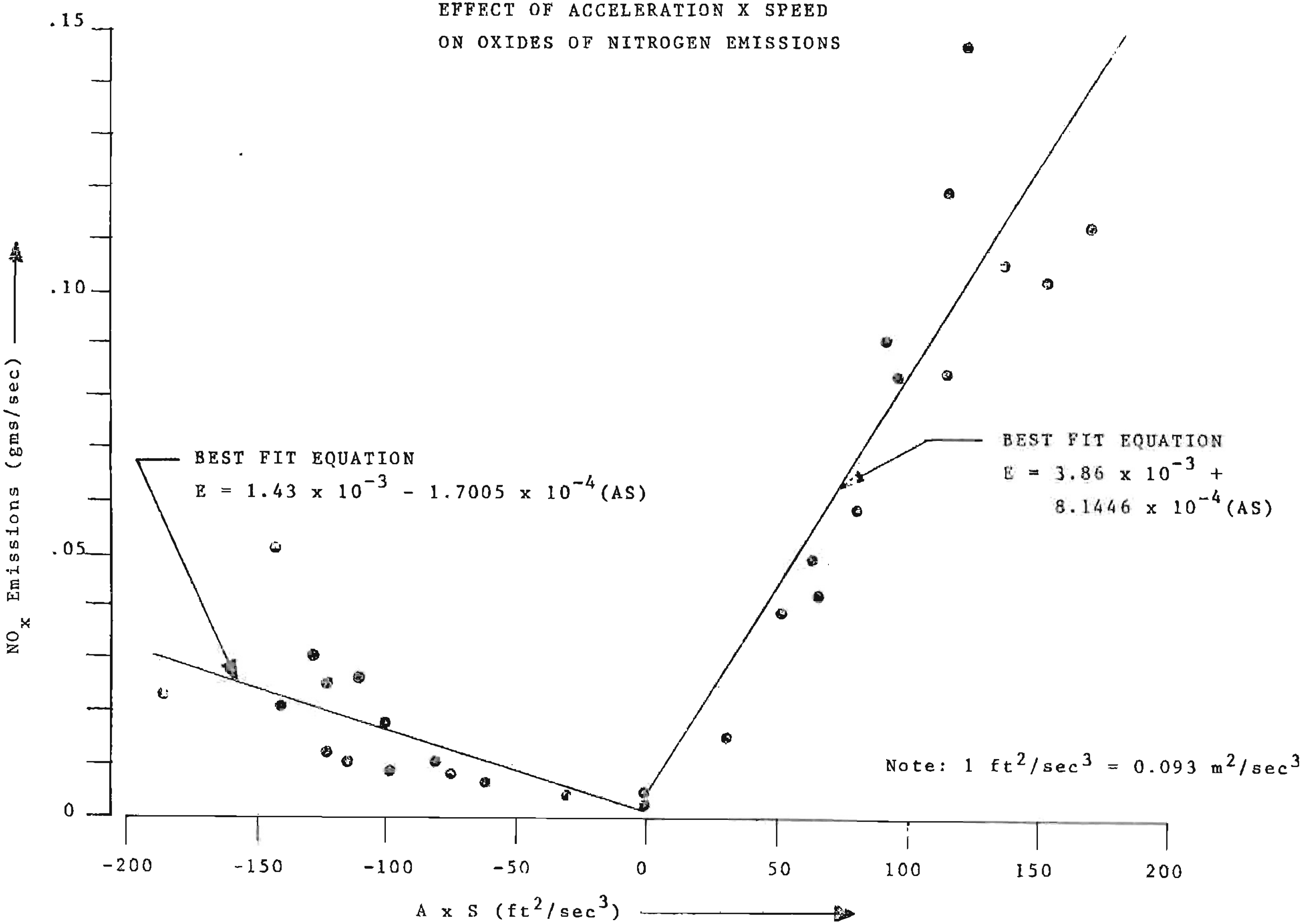


Figure 4

EFFECT OF ACCELERATION X SPEED ON OXIDES OF NITROGEN EMISSIONS



road an overall average FTP rate can be determined. MICRO2 bases its emissions on typical values of this FTP for Denver, Colorado in the early 1980s. They are:

FTP(1)	Hydrocarbons	10 g/veh-mi.
FTP(2)	Carbon Monoxide	100 g/veh-mi.
FTP(3)	Oxides of Nitrogen	2 g/veh-mi.

For lower altitudes than Denver or later years, emission rates may be lower and should change from these initial values. This may be done with the $$CHANGE Command.

Fuel Consumption

Fuel consumption is based on the sum of the following:

1. The fuel required for each vehicle to cruise through the intersection.
2. The excess fuel for each stopped vehicle to start and stop.
3. The fuel for each delayed vehicle to idle the average amount of delay.

Similar to the pollution emission average fleet fuel economy is based on fuel consumption tests run through the FTP cycle. The initial value used in MICRO2 is 17 mi./gal. In future years, as more fuel efficient vehicles are integrated into the fleet, this value should go up. Changes in this parameter can also be done with the $$CHANGE command.

Carbon Monoxide Concentrations

MICRO2 only computes the air pollution emissions near an intersection. The concentration of these pollutants in the air around the intersection is not computed. In order to determine the pollution concentration you must use a dispersion model. A dispersion model takes weather conditions, such as wind, speed, and direction, into account to determine how the pollution will disperse in the air. The California Line Source Model (CALINE3) is one such computer-based model which is widely accepted by both highway and air pollution agencies (Reference 2). Because of its wide acceptance I designed MICRO2 to produce an output file which can be inputted directly into the CALINE3 computer program.

Only concentrations of carbon monoxide is important near an intersection. Hydrocarbons and oxides of nitrogen, on the other hand, must travel for awhile and participate in chemical reactions before they contribute to an air quality problem. MICRO2, therefore, only determines the distribution of carbon monoxide emission for input into CALINE3 while computing only emission total for the other two pollutants.

Emission Distribution

In order to determine pollution concentrations you must determine both the amount of emissions and the distribution of the emissions along each link. MICRO2 has an elaborate scheme for determining where these emissions occur.

MICRO2 divides up each approach link into 5 sections and each discharge link into 2 sections. Each section was given a name that characterizes the mode of operation of stopping vehicles within it. They are as follows:

Steady state decel section
decel-idle section
accel-idle section
acceleration section
steady state section

The steady state decel sections are the areas of the approach links upstream of where the queue forms. The area where the queue forms on the approach link is arbitrarily divided in half. The half further from the intersection is the decel-idle section while the closer half is the accel-idle section. The names of these two sections are somewhat misleading because stopping vehicles undergo all four modes of operation (acceleration, deceleration, idle, and cruise) in both sections. The discharge links are divided up into two sections. Closest to the intersections is the acceleration section and further from the intersection is the steady state section.

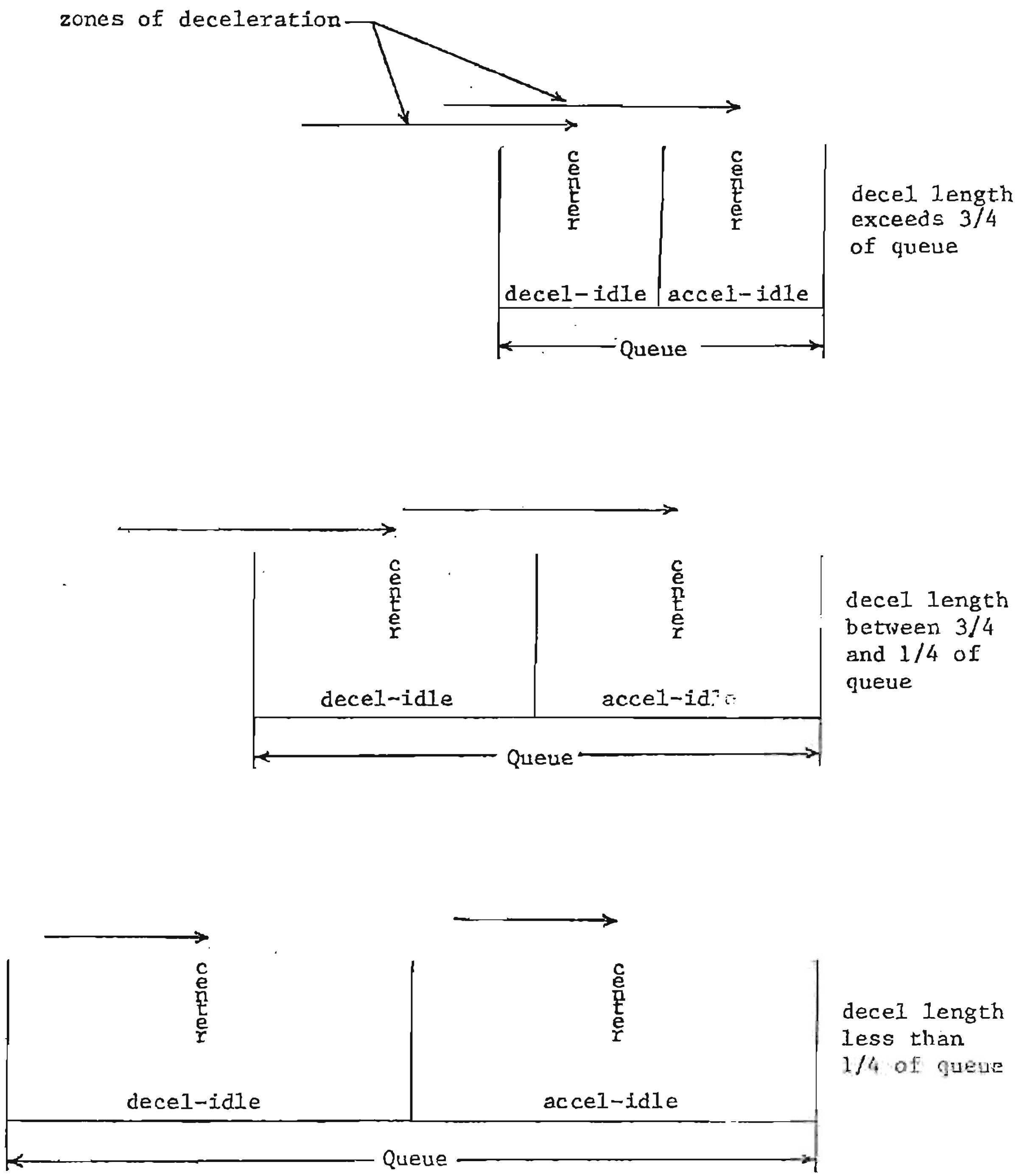
Idle Emissions

The idle emissions are distributed between the decel-idle section and the accel-idle section. Seventy-five percent of the idle emissions is appropriated to the accel-idle section and the remaining 25 percent is appropriated to the decel-idle section. This split reflects the fact that the vehicles in the first half of the queue idle much longer than those in the second half.

Deceleration Emissions

The deceleration emissions are distributed among the steady state, decel-idle, and accel-idle sections. For simplicity, half of the stopped vehicles are assumed to stop at the midpoint of the decel-idle section and half at the midpoint of the accel-idle section. For vehicles that stop in the accel-idle section, part of their deceleration will take place in that section and part in the decel-idle section. The amount of deceleration in each section will depend on the relation of the nominal deceleration distance and the queue length. If the deceleration length is greater than 3/4 of the queue length then part of the deceleration of the vehicle stopped in the first half of the queue will take place in the deceleration section. On the other extreme, if the deceleration length is less than one-fourth of the queue length then the entire deceleration will be contained within the section (See Figure 5). The total deceleration emissions are distributed into these sections according to what portion of the deceleration "vector" overlaps each section.

Figure 5


zones of deceleration
center
center
decel-idle
accel-idle
Queue
decel length exceeds 3/4 of queue
center
center
decel-idle
accel-idle
Queue
decel length between 3/4 and 1/4 of queue
center
center
decel-idle
accel-idle
Queue
decel length less than 1/4 of queue

Acceleration Emissions

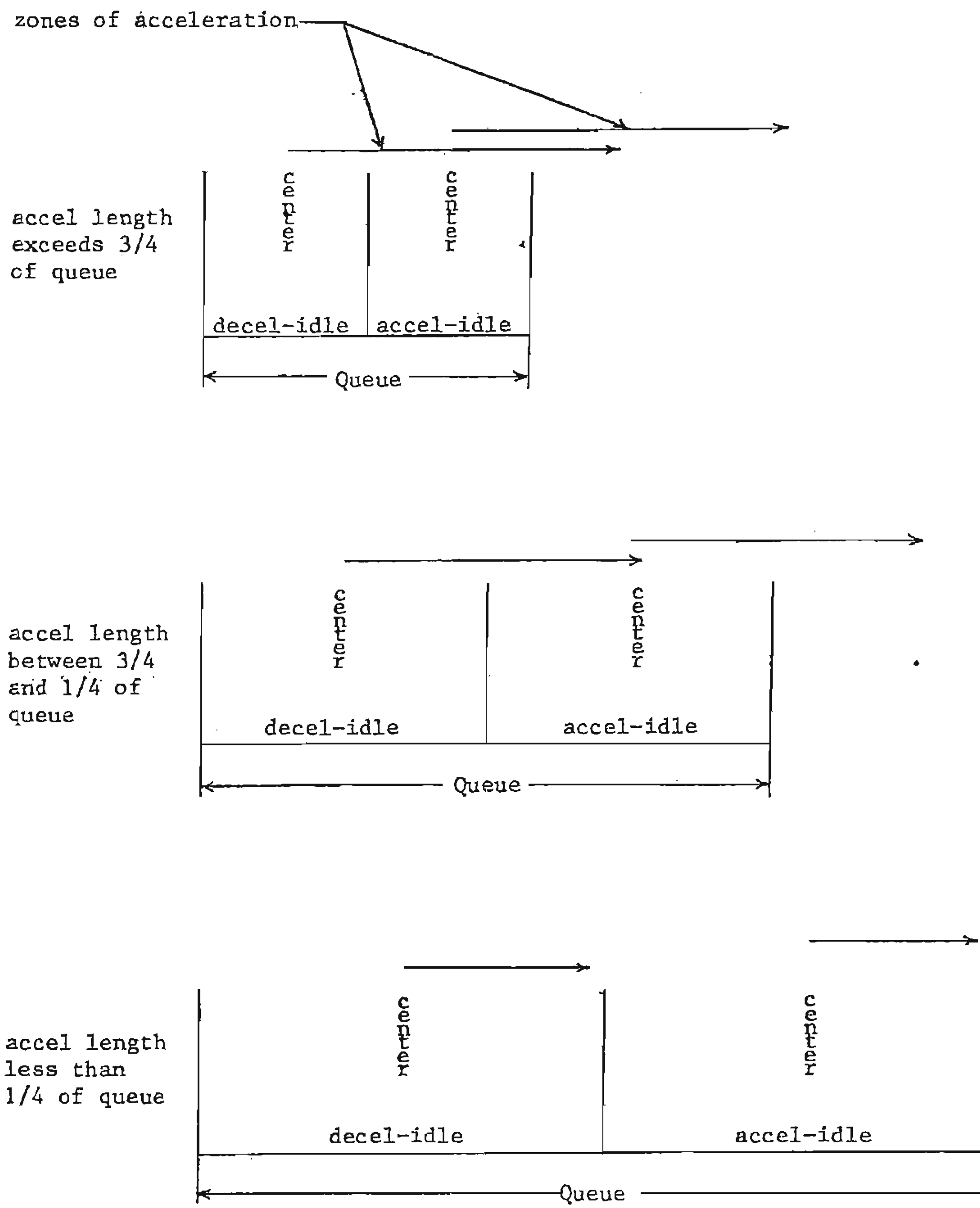
The acceleration emissions are distributed among the decel-idle and accel-idle sections of each approach link and the acceleration section of the corresponding discharge link. Similarly to the deceleration case, all vehicles stopped in the decel-idle section are assumed to begin their acceleration at the midpoint of that section. Continuing vehicles stopped in the accel-idle sections begin their acceleration at the midpoint of their section. The acceleration mode of vehicles from each section will lap into other sections to varying degrees similarly to the deceleration case (See Figure 6). Acceleration emissions will be distributed into section according to the amount of lap of the acceleration vectors.

Steady-State Emissions

Steady-state emissons are incorporated into all sections of each link. Firstly, the vehicles which are not stopped will cruise through all five sections emitting pollutants at a constant rate. Emissions from these vehicles will depend only on the cruise emission rate and the length of each section. Secondly, the stopping vehicles travel at the cruise rate except when they are accelerating or decelerating. Emissions from these vehicles will be proportioned to each section in accordance to absence of acceleration or deceleration vectors.

MICRO2 takes the emissions assigned to each of these sections and creates a file for CALINE3. As much as 44 roadway sections are possible for any one intersection. The large number of sections is due to the fact that turning lanes are considered as separate approach and have their own emission sections.

Figure 6


zones of acceleration
accel length exceeds 3/4 of queue
center
center
decel-idle
accel-idle
Queue
accel length between 3/4 and 1/4 of queue
center
center
decel-idle
accel-idle
Queue
accel length less than 1/4 of queue
center
center
decel-idle
accel-idle
Queue

EXECUTING MICRO2

Input

For best results you should execute MICRO2 on an interactive terminal. The program provides cues to guide you through the input process and tells you what to input next. Variable values not requested explicitly have been given initial values which should cover most situations. The initial value for each of these variables is shown in Appendix A. The input required after each cue will be discussed below. (Refer to Appendix C for a sample run.)

VIDEO TERMINAL OPTION--T or F

If T is entered MICRO2 will write a copy of the terminal activities on a file called "TAPE6." After the program is complete this file may be disposed to a printer or saved as a permanent disk file. This option will provide a record of the input that will not be lost when the video terminal scrolls the data off the screen. For a printing terminal a permanent record is made along the way so "F" is usually specified.

ENTER COUNT ARRAY (COUNT (1,1), COUNT (2,1)...COUNT (3,4))

This is where you should enter the traffic volumes approaching the intersection. Twelve volumes must be entered and separated by commas or blank spaces. The first three entries are for the hourly traffic volume coming from the north. The first of these three is for the hourly traffic approaching from the north and proceeding straight through heading southbound. The second entry is hourly traffic volume turning right and the third entry is the hourly volume turning left. Similarly the next 3 entries (4-6) specify the traffic coming from the east. Continuing around the intersection clockwise, entries 7-9 are for the south approach and 10-12 are for the west approach.

ENTER LANES ARRAY (LANES (1,1,), LANES (2,1)...LANES (3,4))

This is where you must specify the number of lanes available for each turning movement on each approach. Twelve single digit numbers must be keyed in with no spaces. Each digit specifies the number of lanes for each turning movement on each approach. Similar to the traffic volume the first three digits specify lanage for the north approach. This first digit is for straight through lanage, the second digit is for right turn lanage, and the third for left turn lanage. Proceeding clockwise around the intersection the final digit is for left turn lanage of west approach.

ENTER PHASE ARRAY (PHASE (1,1), PHASE (2,1)...PHASE (3,4)) T S and F S

You should indicate which approaches and movements have their own phase or green arrow. A total of 12 Ts and Fs must be entered without spaces or commas. The same sequence is used here as with the traffic volume and lanage.

USER SUPPLIED PHASE TIMES T OR F

MICRO2 can determine the best green time for each phase based on minimum overall delay. If you have a special situation where these computed times are not appropriate you should enter T.

ENTER TIMES FOR STRAIGHT AND LEFT TURN PHASES FOR EACH APPROACH
(PTS (1,1), PTS (3,1)...PTS (1,4), PTS (3,4))

If you entered T on the line before, this statement will appear. Right turn arrow times are not selectable but are controlled by the length of the left turn arrow on the approach to the right. Each phase time selected must include any clearance interval of all red or amber associated with that phase.

ENTER PROCESSING CODE

Whenever you encounter this prompt MICRO2 is at a decision point of what to do next. You have 5 choices:

1 - Stop processing
2 - Determine stops, delay, emissions, and fuel consumption
3 - Read changes in data
4 - Print current values of all variables
5 - Create file for CALINE3 dispersion model on TAPE7

You may select any of these options except that 5 cannot be selected until emissions are computed (selection 2).

If you select 3, only a question mark will appear or the generic prompt for your system. Now you may change the values of any variables by entering: $$CHANGE variable name = new value, variable name = new value ...$

You may change an unlimited number of variables. Each entry must be separated by commas and the statement may continue on for several lines. The CHANGE command must be terminated with a "$" on the last line of entries. If a variable has subscripts the appropriate subscripts must be included in parentheses after the variable name. However, if you wish to change all the elements of a subscripted array drop the parenthetical reference and enter all the new values of the array to the right of the equal sign, separating them by commas. For example, $$CHANGE LANES = 2,1,1,3,1,1,2,1,1,3,1,1 $ is a legal entry because LANES is an array with 12 (3 x 4) elements. The number of values in the list must correspond exactly to the array size or a fatal error will result. Note, variables that you can change are listed in Appendix A.

ENTER PROCESSING CODE

Once the change command or any other processing code instruction is complete this cue will reappear. Code 2 is usually entered at this time but other codes can be entered as you desire. For example, you may want to enter code 4 to review the values of all the variables. Eventually, though, you'll want to enter code 2 to direct MICRO2 to perform its calculations. After reviewing the output generated you may then want to use code 5 to direct MICRO2 to create a file for direct input into the CALINE3 line source model. This way you can obtain carbon monoxide concentration near the intersection.

Platooning Vehicles

In order to depict a syncronized signal upstream you must set two parameters with the CHANGE command. They are PFRAC and RELART. PFRAC is the fraction of vehicles which arrive in the platoon an RELART is the relative arrival time of the platoon with respect to the start of the green light. If PFRAC = .6 and RELART = 5, then the 60 percent of the traffic is traveling in a platoon which will begin arriving at the intersection 5 seconds after the start of the green light for the straight through phase. The remaining 40 percent of the traffic arrives uniformally during the rest of the cycle. PFRAC and RELART are actually arrays with 4 elements each depicting traffic from the north, east, south, and west respectively.

Output

The first output element is a list of computed phase times. Notice that the times for the right turn phases are the same as for the straight through phases. This reflects the fact that right turns can proceed whenever the light is green. For the case when you have selected a right turn phase (arrow) the right turn phase time will be the sum of the straight through phase plus the time for the left turn arrow on the next approach. Finally, remember that the listed phase times include the time the signal is green plus any clearance time associated with that phase.

The next output element is a list of hourly volumes which can actually be serviced by each approach of the intersection. Usually the values will be slightly more than the actual volumes. A few movements, however, may be able to service much more traffic than actually present because their phase time may be controlled by higher volumes on a complementary movement. For example, if heavy traffic is approaching from the north the traffic from the south will also realize a long phase time and, therefore, more capacity even if its volume is low.

The next output element lists stops, queue length, and delay for each approach and turning movement. Also listed is the length and the carbon monoxide emission for each section of each link. Three lines are used for each approach link--one for each turning movement. Approaches are listed in order of north, east, south, and west. Links 5-8 are discharge links corresponding to traffic discharging to the north, east, south, and west respectively. Obviously, there are no stops, queues, or delays on these links so that section of the table was left blank. The last line on this table indicates total stops and vehicle-seconds delay experience over one hour.

The final element of the output is the grand total emission rate for each pollutant and the fuel consumption rate. For the case when the intersection is over capacity additional emissions and fuel consumption are added in, to realize the effect of longer idle times.

TO THE PROGRAMMER

Description of MICRO2 and Its Subroutines

MICRO2 is composed of the main program and numerous subroutines. The main program cues the user and inputs data. The subroutines handle the calculations and output as required. Subroutine INSEC computes phase time, vehicles delay, stops, and queue size for each leg of the intersection. If some of the vehicles arrive in a platoon subroutine PLATOON adjusted the stops, delay and queues approximately.

Based on the stops and delay values subroutine EMITX determines air pollution emissions and fuel consumption. An elaborate scheme is used to locate these emissions into sections along each link. EMITX lists stops, delay, queue size and emissions by sections for each link plus grand totals for these and for fuel consumption. If requested subroutine LSPREP develops an input set for CALINE3. Each section for each turning movement is called a link for CALINE3 purposes. Occasionally, the length of a roadway section is smaller than its width since CALINE3 cannot handle that situation subroutine ROTATE takes over. Subroutine ROTATE rotates the sections about its centroid and reverses the length and width parameters. After each stage of calculation the program determines what to do next by the "processing code" entered by the user.

Installing MICRO2 on Your System

MICRO2 is a Fortran program that was developed and tested using two different compilers on a Control Data Corporation Cyber 70 computer. MICRO2 is functional under both the MNF and RUN compilers. Being compatible with two different compilers should increase MICRO2's chances of operating under a third compiler without any source code modifications. Unique features of the compilers and the system were avoided in order to further improve its compatibility with other compilers.

MICRO2 uses two disk files in addition to INPUT and OUTPUT. TAPE6 is used to maintain a copy of all the screen activity on a video terminal because output on a video terminal is lost as the data is scrolled off the screen. Provisions should be made to print this file or place it on permanent storage for later reference. TAPE7 is used for input data for the CALINE3 line source model. CALINE3 can process this data on TAPE7 immediately or TAPE7 can be stored for later processing.

Modifying MICRO2

Modify MICRO2 any way which will meet your particular needs. Program modifications may be necessary to meet your individual input/output requirement or to make improvement in this program.

Two items are available to ease your job of modifying the program. First, the source code has many comment statements which should help you understand what's happening at a particular point in the program. More important, Appendix D contains a description of all the variables used in MICRO2. The first list describes all the variables within the common blocks. While, subsequent lists describe variables in the main program and each subroutine. These lists should be a valuable tool for following the program code and update this list as you modify the code. Good Luck.

Installing MICRO2 on a Microcomputer

With the proliferation of microcomputers, it would be worthwhile to install MICRO2 on a microcomputer. The program is small enough and short enough that this would be feasible. However, a cursory attempt at this failed because the microcomputer Fortran compiler available did not have Namelist capabilities. Additional codes would have to be developed to substitute for Namelist, or a microcomputer compiler with Namelist capabilities would have to be procured.

MICRO2 VERIFICATION

Validation of this model was limited because of a lack of comprehensive monitoring data near a major intersection. Because of the limited scope and the inappropriateness of the data set, the word "Validation" was not used as the title of this section. In the technical air quality community, validation is considered to be a much more comprehensive testing of a model.

In order to compare results of the model to the monitoring data background, carbon monoxide concentrations must be known. This can be accomplished in two ways. First, an intersection can be selected that is so far from other sources of carbon monoxide that the background concentration is always insignificant. The other way is to monitor carbon monoxide both upwind and downwind from the intersection so both background and traffic contributions are known. This would require at least four monitors to ensure a background reading for most wind configurations. Even then, if the wind is parallel to one of the highways, none of the monitors would be quite measuring actual background. No data set in Colorado meets these qualifications.

Complete validation of this model is not crucial because it does not depend on entirely new principles or methodology. MICRO2 itself is based on accepted traffic engineering formulation for stops, queues, and delay. The distribution of emissions along each link is simply a logical extension of where the vehicles are as they pass through each mode of operation. Finally, dispersion modeling is accomplished with the CALLINE3 line source model which is well validated and accepted.

Monitoring Site

Santa Fe Drive and Dartmouth Avenue represent a major intersection in the Denver area some distance away from other major intersections. Carbon monoxide was monitored here during the winter of 1981-82 for an environmental study of a highway project. Figures 7 and 8 show the location of the intersection and the single monitor.

Since there was only one monitor at this site, it does not represent the best configuration for model validation. In spite of the relatively remote location, substantial background concentrations have been experienced at this site. In fact, some of the higher readings were encountered when the monitor was upwind of the intersection. Unfortunately, this site represents the best available for the model assessment.

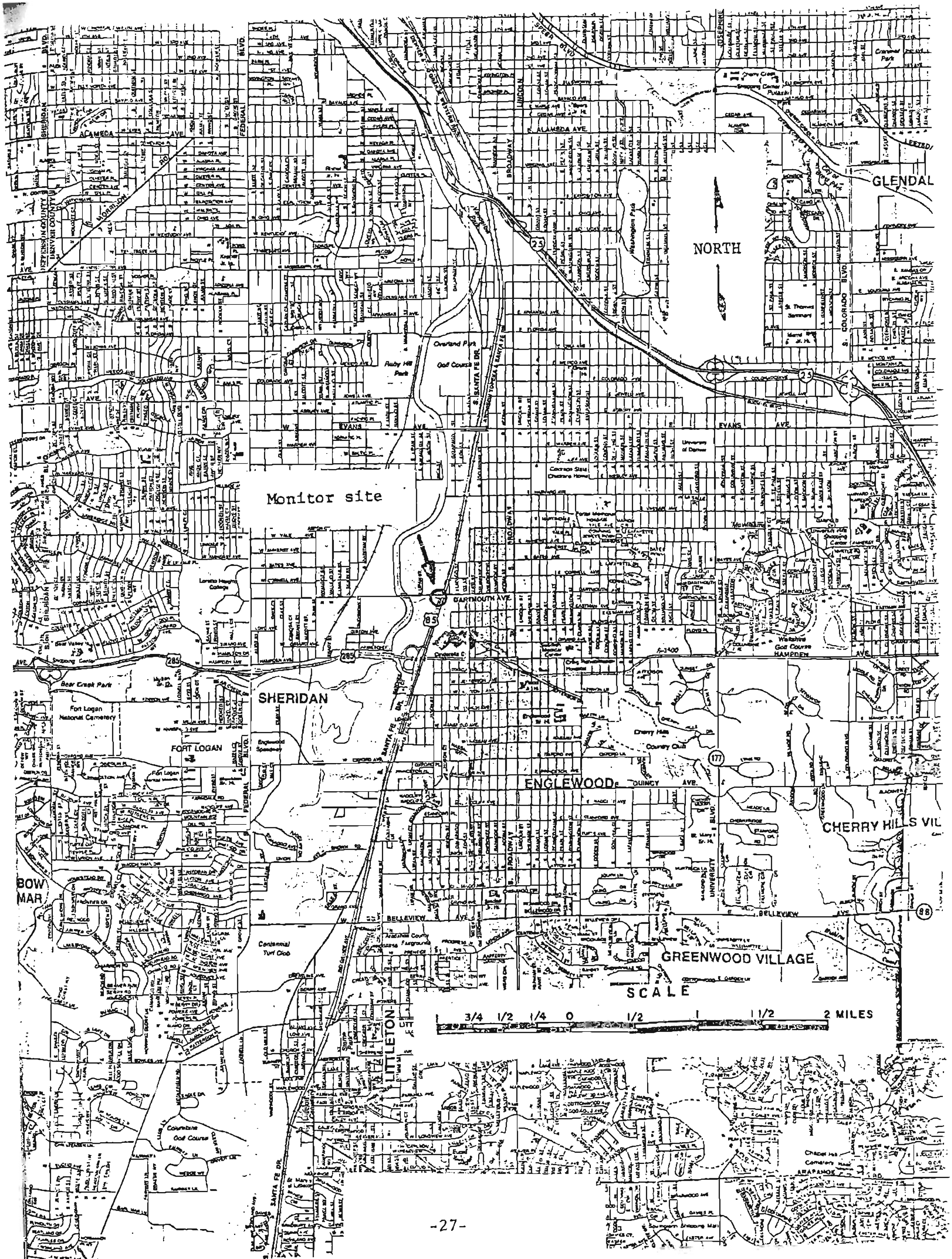
All approaches to the intersection have two straight through lanes and exclusive left turn lanes. The Santa Fe Drive approach from the north is the only approach with an exclusive right turn lane. An exclusive left turn phase is provided on all legs with left turns allowed on green arrow only (non-permissive). While, right turns on red (after stop) are allowed from all approaches.

Because of the railroad on the east side of Santa Fe, the signal goes into a special mode when a train passes. Although the trains are quite frequent no record was available as to when their passage occurred.

Available traffic data was limited to two weekdays during the monitoring period. This was mainly due to the difficulty in maintaining traffic counting hoses during winter snowplowing season.

Data Set

In order to get at least a cursory check of the model's performance, a small data set from this monitoring period was selected. Selection was based on (1) when the monitor was downwind from the intersection and (2) when wind speeds were between 2 and 10 miles per hour. Only weekdays were considered because weekend traffic data was not available. Days near Christmas and New


Monitor site
NORTH
SHERIDAN
FORT LOGAN
Fort Logan National Cemetery
Bear Creek Park
ENGLEWOOD
GREENWOOD VILLAGE
LITTLETON
GLENDAL
CHERRY HILLS VIL
BOW MAR
Cherry Hills Country Club
Centennial Turf Club
Columbine Golf Course
Englewood Speedway
Overland Park Golf Course
Ruby Hill Park
Washington Park
University of Denver
BROADWAY
S. SANTA FE DR.
FEDERAL BLVD.
SHERIDAN BLVD.
S. COLORADO BLVD.
UNIVERSITY BLVD.
ALAMEDA AVE
EVANS AVE
DARTMOUTH AVE
HAMPDEN AVE
QUINCY AVE
BELLEVIEW AVE
ARAPAHOE RD
25
85
285
177
88
SCALE
3/4 1/2 1/4 0 1/2 1 1 1/2 2 MILES

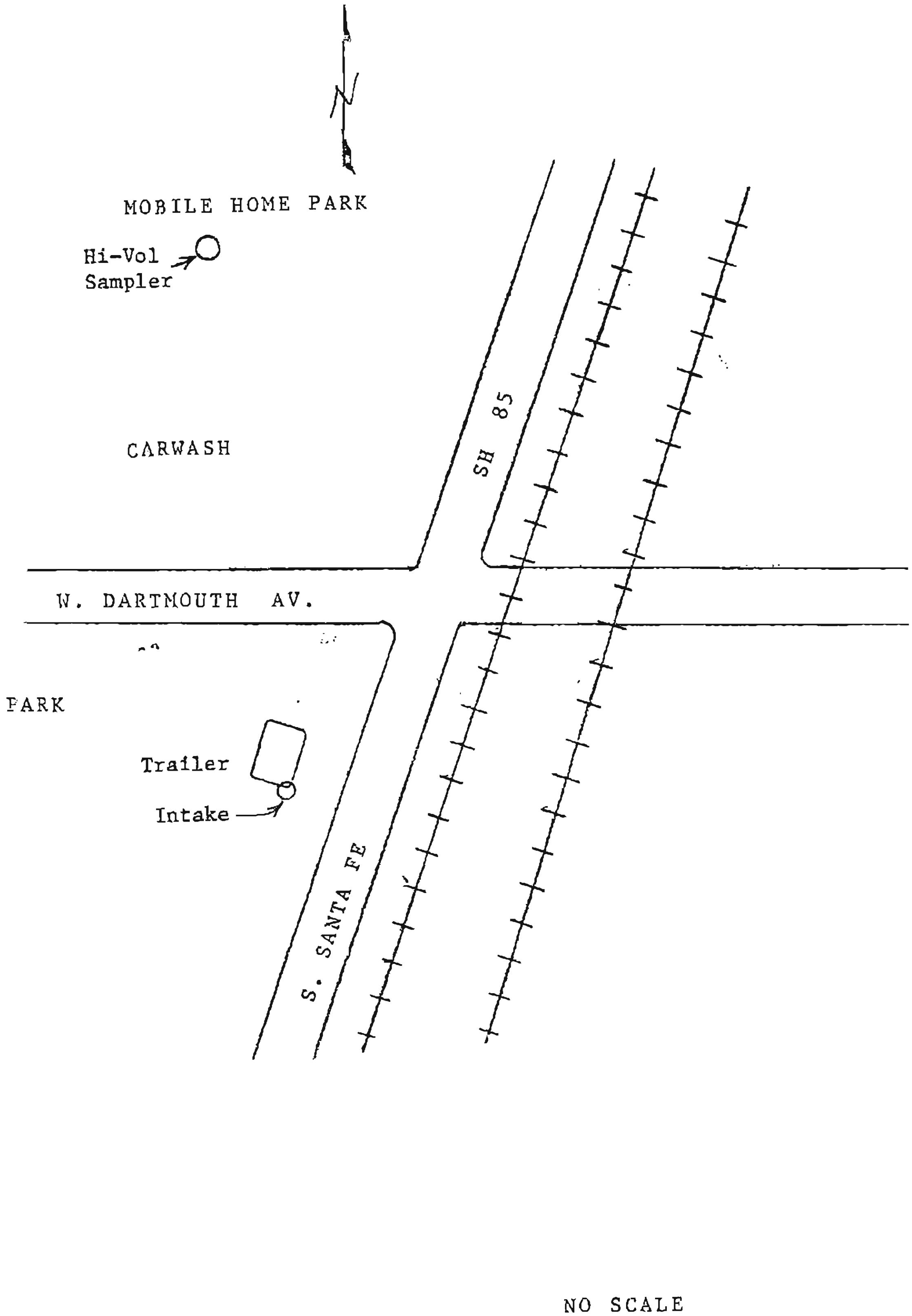

N
MOBILE HOME PARK
Hi-Vol Sampler
CARWASH
SH 85
W. DARTMOUTH AV.
PARK
Trailer
Intake
S. SANTA FE
NO SCALE

TABLE A

MONITORING DATA USED TO CHECK THE MICRO 2 MODEL

DATE	HOUR	WIND speed (mph)	WIND dir. (deg)	STAB. CLASS	CO CONCENTRATIONS pred.	CO CONCENTRATIONS monit.	TRAFFIC FROM north	TRAFFIC FROM east	TRAFFIC FROM south	TRAFFIC FROM west
12/21/81	19	5	80	4	4.1	20	1299	176	1013	189
12/21/81	20	3	90	4	3.8	17	700	168	707	119
12/22/81	1	12	22	4	.4	2	191	27	142	21
12/22/81	2	10	22	4	.4	2	105	13	99	14
12/22/81	3	9	22	4	.4	1	79	9	92	13
12/22/81	4	9	22	4	.4	1	55	6	77	9
1/11/82	21	7	20	4	1.6	11	514	124	488	95
1/11/82	22	9	45	4	.5	7	522	118	424	90
1/11/82	23	6	310	4	0	4	465	58	378	45
1/11/82	24	10	30	4	.4	3	218	41	223	48
1/12/82	5	3	50	4	.5	1	107	8	129	18
1/12/82	6	5	105	4	.4	3	219	32	418	40
1/12/82	7	6	125	4	3.3	6	686	127	1646	200
1/12/82	8	4	130	4	8.3	9	1173	263	2011	400
1/12/82	9	5	65	4	5.3	13	1203	260	1629	365
1/12/82	12	10	65	3	2.4	9	1185	302	1301	336
1/14/82	10	6	190	4	3.8	11	1134	234	1330	228
1/14/82	11	7	135	4	3.8	13	1188	255	1336	260
1/22/82	14	6	45	4	2.2	12	1142	381	1354	400
1/22/82	15	6	70	4	6.7	12	1323	393	1405	380
1/22/82	16	2	115	3	12.1	15	1609	456	1593	500
1/28/82	13	4	30	3	4.3	12	1199	432	1288	400
1/30/82	17	6	180	4	5.2	9	1865	521	1481	500
1/30/82	18	6	65	4	6.6	6	1860	414	1279	428

Year's Day were also avoided because the available traffic data is probably not appropriate. See Table A for the selected hours.

Atmospheric stability class was determined by the Pasquil method based on sky and ceiling reports from Stapleton Airport (9 miles northeast of intersection) and wind data measured on the site.

Since the signal is demand actuated, the model was allowed to determine the phase time based on minimum delay. This probably under estimates the total cycle time during low traffic periods where minimum green time settings predominate. Because of the question of appropriateness of the monitoring data, a detailed determination of the phase times imposed by the controller would not have been fruitful.

The default value of 100 grams per mile was used for the carbon monoxide emission rate. This level is a reasonable one for this year and Denver's altitude. Here again, a detailed determination of the average emission rate would be inappropriate considering the monitoring data available.

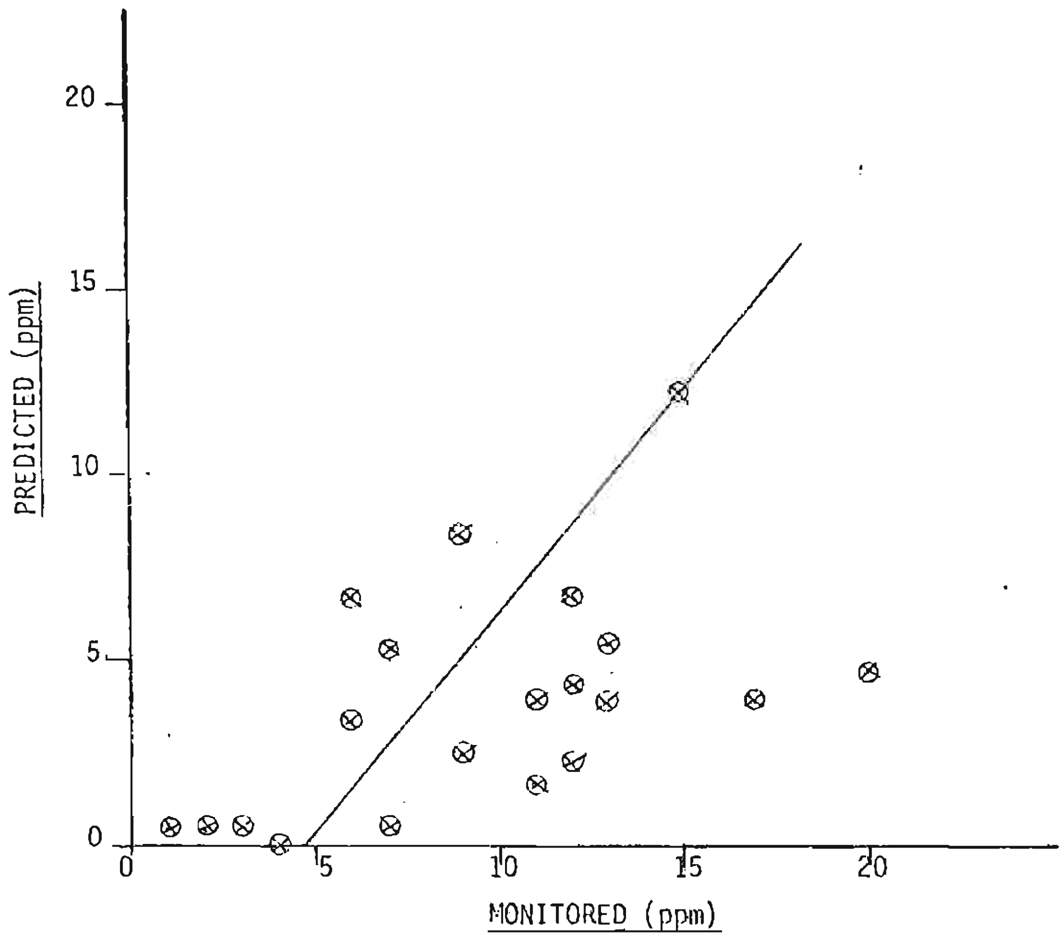
Results

The modeling results are shown in Table A and also on Figure 9. It is apparent that the model typically predicts lower concentrations than are monitored. For a few hours though, predictions are very close to the monitored value.

The generally under prediction is due to the background concentration. It was demonstrated in reference 3 that background carbon monoxide concentrations can be significant. High concentrations were often monitored even when the monitor was upwind of the intersection. Further it was noted that on several occasions, concentrations remained constant even with a dramatic change in the wind direction.

Figure 9

PREDICTED versus MONITORED CO CONCENTRATIONS



The ability for the model to predict monitored concentrations is demonstrated two ways. First, on a few occasions, the predicted and monitored concentrations were very close. This is probably when the background concentration was not significant. Finally, the best fit straight line for the data was a slope close to unity indicating the model's predictive capability. The non-zero intercept could be explained as the average background concentration.

REFERENCES

1. "Air Quality Impact of Signaling Decisions" by Richard Griffin, Colorado Department of Highways, (Report No. CDOH-DTP-R-80-12, October 1980)

2. "CALINE3 - A Versatile Dispersion Model for Predicting Air Pollution Levels Near Highways and Arterial Streets" by Paul Benson, California Department of Transportation, (Report No. FHWA-CA-TL-79/23, November 1979)

3. "Mobile Ambient Air Monitoring Laboratory W. Dartmough Av./S. Santa Fe Dr. November 1981 - March 1982" Colorado Department of Highways

APPENDIX A

INPUT VARIABLES
FOR PROGRAM MICRO 2

Name	Description	Initial Value
AMB	Input variable for CALINE 3 specifying background CO concentration (in PPM)	0.0
ATIM	Input variable for CALINES 3 indicating averaging time for pollutant concentration (in minutes)	60.
BRG	Input variable for CALINE 3 indicating azimuth of wind direction (in degree)	0.0
CAP (1)	Lane capacity for straight through traffic (in veh/hr./lane)	1500.
CAP (2)	Lane capacity for right turning traffic (in veh/hr./lane)	800.
CAP (3)	Lane capacity for left turning traffic (in veh/hr./lane)	1000.
CLAS	Input variable for CALINE 3 specifying stability class of weather	6.
COUNT (I,J)	Traffic volume for turning movement I and approach J (in veh/hr.)	none
FTP (1)	Average hydrocarbon emission rate for vehicles based on the Federal Test Program	10.
FTP (2)	Average CO emission rate in g/mi.	100.
FTP (3)	Average oxides of nitrogen emission rate in g/mi.	2.0
HL	Input variable for CALINE 3 specifying height of emission source in feet	0.0
JOB	Input variable for CALINE 3 specifying name of job	MICRO INTR
LANES (I,J)	Number of lanes for turning movement I and approach J	none

Name	Description	Initial Value
LTPERM (J)	Permissive left turn for approach J. True if vehicles are allowed to turn left on solid green signal.	.T. For J=1-4
MIXH	Input variable for CALINE 3 specifying height of inversion layer in feet	1000.
MPG	Average fuel economy for the Federal City driving cycle in mi/gal.	17.0
OCTCT	Total cycle time used when intersection is overcapacity in seconds	150.
PFRAC (J)	Fraction of vehicles that arrive on approach J in a platoon	0.0 For J=1-4
PHASE (I,J)	Logical variables indicating if turn I on approach J has its own phase	None
PTS (I,J)	Logical variables indicating if turn I on approach J has its own phase	None
PTS (I,J)	Phase time for turn I and approach J in seconds. Includes any clearance intervals. UPT must be set to .T. for program to accept changes in this variable.	None
RELART (J)	Relative arrival time of platoon on approach J with respect to beginning of green.	0.0 For J=1-4
RTOR (J)	True is right turn on red is allowed on approach J.	.T. For J=1-4
RTSCAP	Lane capacity for right turns if each vehicle must stop in veh/hr.	500.
TYP	Input variable for CALINE 3 which indicates if roadway is (1) at grade (2) fill, (3) bridge or (4) depressed	1.
U	Input variable for CALINE 3 which indicates wind speed in m/sec.	1.0
UPT	True if user supplies phase times	None
VEL (J)	Cruise velocity of vehicles on link J in mi/hr.	40. For J=1-8
VELINT (1,J)	Maximum velocity that straight through vehicles can travel through intersection in mi/hr.	40. For J-1,4

APPENDIX A (cont'd)

Name	Description	Initial Value
VELINT (2,J)	Maximum velocity that right turn vehicles can travel through intersection in mi/hr.	15. For J=1,4
VELINT (3,J)	Maximum velocity that left turn vehicles can travel through intersection in mi/hr.	20. For J=1,4
XDELAY (J)	Extra time a driver will wait when an intersection if overcapacity for approach J	none
XR (RCP) YR (RCP)	Input variables for CALINE 3 specifying coordinates for receptor number RCP in feet	See Diagram
X1 (J) Y1 (J)	Input variables for CALINE 3 specifying coordinates of upstream endpoint of link J	See Diagram
X1 (J) Y2 (J)	Input variables for CALINE 3 specifying coordinates of downstream endpoint of link J	See Diagram
ZR (RCP)	Input variable for CALINE 3 specifying height of receptor number RCP in feet	5. For RCP=1-4
ZO	Input variable for CALINE 3 specifying surface roughness in cm.	10.

NOTE: I is index of turning movement:

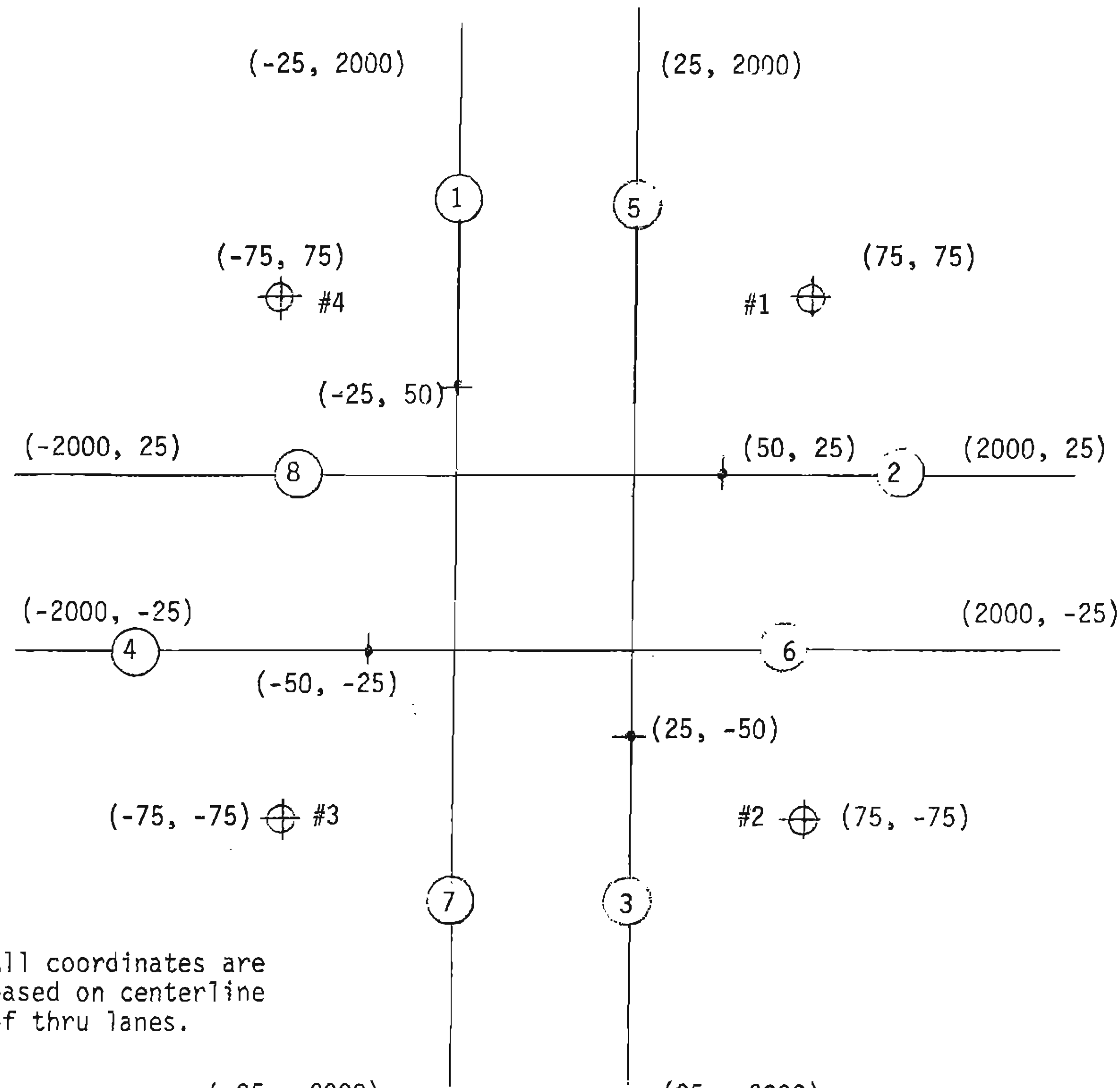
(1) Straigh through, (2) right turns, and (3) left turns.

J is index of approach:

(1) North, (2) East, (3) South, and (4) West.

DEFAULT LINE ARRANGEMENT

FOR MICRO 2



NOTE: All coordinates are based on centerline of thru lanes.

Downstream endpoint of approach and Upstream endpoint of discharge line

Location of CO receptors

Appendix B

EQUATIONS FOR DELAY, QUEUE, AND STOPS FOR PLATOONING TRAFFIC

t_4 = time after platoon comes before green

y = queue size during platoon

t_1 = time platoon is coming during green before queue clears

t_3 = time platoon is coming during red

q_1 = flow rate when there is no platoon

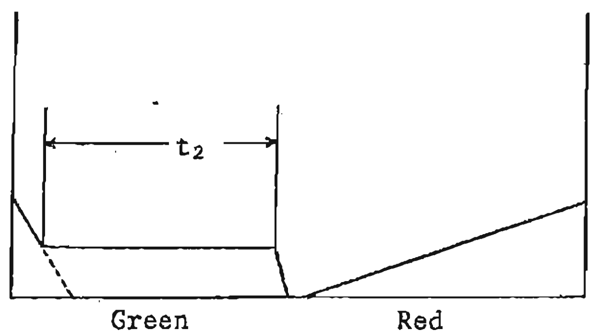
q_2 = excess flow rate over q_1 when platoon passes

t_2 = time for platoon to pass

relart = relative arrival time of platoon

$q_1 + q_2$ = capacity

Case 1: Platoon starts and terminates in green



$y = q_1 R - (q_1 + q_2)(\text{relart})$

$t_3 = 0$

$t_4 = 0$

if $y > 0$, $t_1 = t_2$

additional delay = yt_1

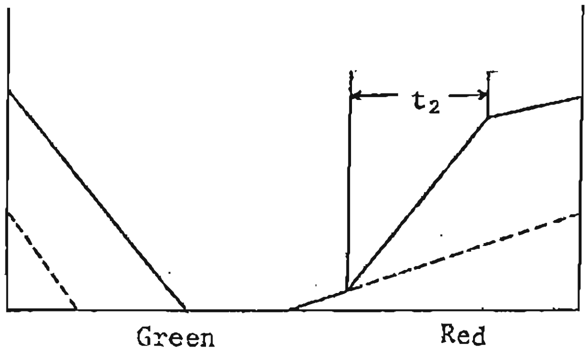
additional vehicle stops $= (q_1 + q_2)t_1$

additional queue = 0

if $y \leq 0$, $t_1 = 0$

no additional delay, queue, or stops

Case 2: Platoon arrives and terminates during red



$t_4 = C_y$ - relart t_2

$t_3 = t_2$

$t_1 = 0$

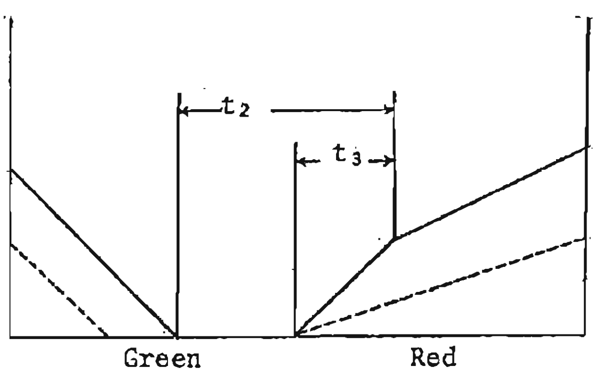
$y = t_3 q_2 + R q_1$

additional vehicle delay $= \frac{1}{2} q_2 t_3^2 + \frac{\frac{1}{2}(q_2 t_3 + R)^2}{(q_1 + q_2)} + t_4 t_3 q_2 - \frac{\frac{1}{2}(q_1 R)^2}{(q_1 + q_2)}$

additional vehicle stops $= t_2 q_2 + \frac{t_2 q_1 q_2}{(q_1 + q_2)}$

additional vehicle queue $= t_3 q_2$

Case 3: Platoon arrives in green and terminates in red



$t_4 = C_y$ - relart - t_2

$t_1 = 0$

$y = 0$

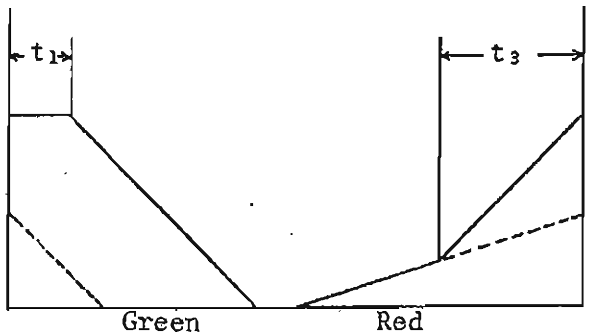
t_3 = relart + t_2 - G

additional vehicle delay $= \frac{1}{2} t_3^2 q_2 + t_3 q_2 t_4 + \frac{\frac{1}{2}(t_3 q_2 + R q_1)^2}{(q_1 q_2)} - \frac{\frac{1}{2}(R q_1)^2}{(q_1 + q_2)}$

additional vehicle stops $= t_3 q_2 + \frac{t_3 q_2 q_1}{(q_1 + q_2)}$

additional vehicle queue $= t_3 q_2$

Case 4: Platoon arrives in red and ends in green



$$y = q_2 t_3 + q_1 R$$

$$t_3 = Cy - relart$$

$$t_1 = t_2 - t_3$$

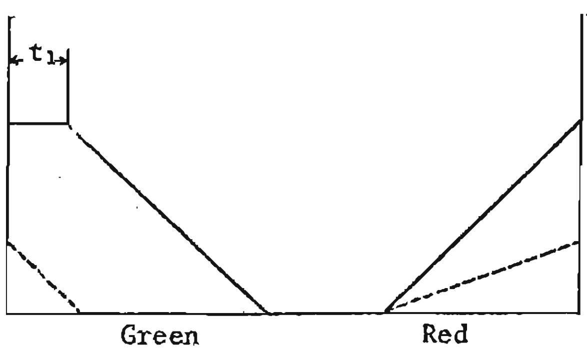
$$t_4 = 0$$

$$\text{additional vehicle delay} = \tfrac{1}{2} t_3^2 q_2 + t_1 y + \frac{\tfrac{1}{2}(t_3 q_2 + R q_1)^2}{(q_1 + q_2)} - \frac{\tfrac{1}{2}(q_1 R)^2}{(q_1 + q_2)}$$

$$\text{additional vehicle stops} = t_3 q_2 + t_1 (q_2 + q_2) + \frac{q_1 q_2 t_3}{(q_1 + q_2)}$$

$$\text{additional vehicle queue} = t_3 q_2$$

Case 5: Platoon arrives in green continues through red and ends in green



$$y = q_2 t_3 + q_1 R$$

$$t_4 = 0$$

$$t_3 = R$$

$$t_1 = t_2 - Cy + relart$$

$$\text{additional vehicle delay} = \tfrac{1}{2} q_2 t_3^2 + t_1 y + \frac{\tfrac{1}{2}(q_2 t_3 + q_1 R)^2}{(q_1 + q_2)} - \frac{\tfrac{1}{2}(q_1 R)^2}{(q_1 + q_2)}$$

$$\text{additional vehicle stops} = q_2 t_3 + \left[t_1 + \frac{q_2 t_3 + q_1 R}{(q_1 + q_2)} - \frac{q_1 R}{(q_1 + q_2)} \right] q_1$$

$$= q_2 t_3 + t_1 (q_1 + q_2) + \frac{q_1 q_2 t_3}{(q_1 + q_2)}$$

$$\text{additional vehicle queue} = q_2 t_3$$

APPENDIX C

Sample Run of MICRO2

```
VIDEO TERMINAL OPTION -- T OR F
T
ENTER COUNT ARRAY (COUNT(1,1),COUNT(2,1)...COUNT(3,4)
 1300.  130.  130.  800.   50.   50. 1500.  150.  150.  300.     0     0
ENTER LANES ARRAY (LANES(1,1),LANES(2,1)...LANES(3,4)
211211211100
ENTER  PHASE ARRAY (PHASE(1,1),PHASE(2,1)...PHASE(3,4) T S  AND  F S
TFTTFTTTTTFF
USER SUPPLIED PHASE TIMES -- T OR F
F
ENTER PROCESSING CODE
 3
$CHANGE PFRAC(1)=.8,RELART(1)=5. $
ENTER PROCESSING CODE
 2
INTERSECTION IS OVER CAPACITY.
HOW MANY  SECONDS WILL DRIVERS WAIT BEFORE DIVERTING
FOR EACH APPROACH (1-4)
  300.  300.  300.  300.
PHASE TIMES COMPUTED BASED ON DEMAND ARE
  74.   74.   21.   44.   44.    7.   78.   84.   25.   44.   44.     0
VOLUMES WHICH CAN ACTUALLY BE SERVICED BY THE INTERSECTION ARE--
 1348.  388.  123.  755.  298.   54. 1415.  457.  154.  377.     0     0
TOTAL CYCLE TIME IS 150. SECONDS

LINK STOP QUEUE  DELAY    ACCEL SEC     S.S. SEC     DECEL-IDL    IDL-ACCEL
     /HR.  (FT.) (SEC/    -CO- LNGTH   -CO- LNGTH   -CO- LNGTH   -CO- LNGTH
                  STOP)    G/S  (FT.)   G/S  (FT.)   G/S  (FT.)   G/S  (FT.)

1 1  1300.  712.   40.                  1.7 1239.    2.7  356.    6.8  356.
1 2   130.  142.   40.                   .2 1808.     .2   71.     .5   71.
1 3   123.  135.   67.                   .2 1815.     .2   67.     .5   67.
2 1   755.  414.   55.                  1.2 1536.    1.2  207.    3.2  207.
2 2    50.   55.   55.                   .1 1895.     .0   27.     .1   27.
2 3    50.   55.   74.                   .1 1895.     .1   27.     .2   27.
3 1  1415.  775.   39.                  1.7 1175.    3.1  388.    7.8  388.
3 2   150.  164.   35.                   .3 1786.     .2   82.     .7   82.
3 3   150.  164.   65.                   .3 1786.     .2   82.     .7   82.
4 1   300.  329.   55.                   .5 1621.     .4  164.    1.1  164.
4 2      0     0     I                    0     0      0     0      0     0
4 3      0     0     I                    0     0      0     0      0     0
5                          8.5  641.    1.7 1409.
6                          2.7  752.     .3 1298.
7                           .5  821.     .1 1229.
8                          1.4  793.     .2 1257.
TOT   4423.      200146.

    BACKUP SECTION OF VEHICLES DUE TO OVER-CAPACITY INTERSECTION

 APPROACH LINK  1    APPROACH LINK  2    APPROACH LINK  3    APPROACH LINK  4

DELAY  -CO- LNGTH  DELAY  -CO- LNGTH  DELAY  -CO- LNGTH  DELAY  -CO- LNGTH
(SEC) (G/S) (FT.)  (SEC) (G/S) (FT.)  (SEC) (G/S) (FT.)  (SEC) (G/S) (FT.)
 300.  23.6 1702.   300.  13.0  937.   300.  26.0 1880.   300.   4.6  657.
GRAND TOTAL: HC= 11.600 CO= 140.69 NOX=  1.671 G/SEC AND FUEL = 205.06 GAL./HR.

ENTER PROCESSING CODE
 5
CALINE INPUT NO.    1 HAS BEEN WRITTEN TO TAPE7
ENTER PROCESSING CODE
 1
```