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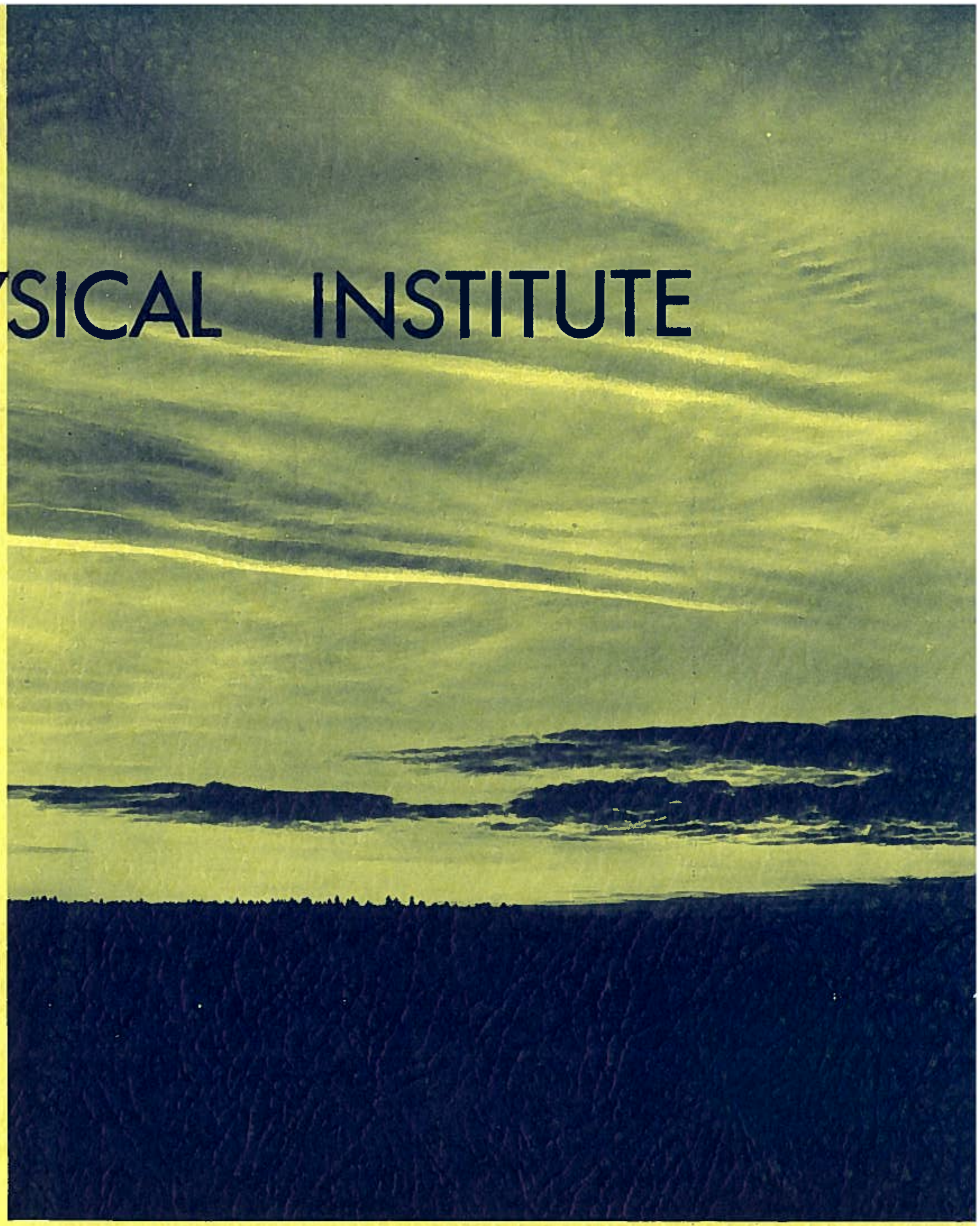

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CARBON MONOXIDE EMISSIONS FROM MOVING VEHICLES
IN FAIRBANKS, ALASKA
VOL. 3

by

L. E. Leonard

August 1977

Prepared for

State of Alaska
Department of Highways

in cooperation with

U. S. Department of Transportation
Federal Highway Administration

CARBON MONOXIDE EMISSIONS FROM MOVING VEHICLES IN FAIRBANKS, ALASKA

VOL. 3
REPORT*

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*Consisting of three volumes:
Vol. 1 "Cold Start Automotive Emission in Fairbanks, Alaska"
Vol. 2 "Multi Restrike Ignition System as a Device to Reduce Cold Start, Etc."
Vol. 3 "Carbon Monoxide Emission from Moving Vehicles in Fairbanks, Alaska"

The opinions, findings and conclusions expressed in this publication are those of the author and not necessarily those of the State of Alaska, Department of Highway or the Federal Highway Administration.

L. E. Leonard
Principal Investigator

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16. Abstract

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1. Driving cycles were developed which are representative of actual driving conditions in the urban area of Fairbanks. Development of two cycles was necessary to demonstrate the effect of traffic control strategies implemented during the summer of 1975. Therefore, the cycles presented here describe traffic conditions both before and after implementation of the new controls, with accompanying qualitative discussion of the effect on CO emissions. In an effort to retain consistency and ease comparison, the cycles developed here were modeled after the CVS-3 cycle used in the Federal Test Procedure.

2. CO emissions from in-use vehicles operating in the moving mode were measured in order to provide quantitative modal emission data for use in conjunction with the driving cycles. Quantitative emissions data for the steady-state mode of operation are presented; however, limitation in the response time of the CO analyzer used in testing precluded acquisition of reliable data for the transient (Acceleration and Deceleration) mode of operation.

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I. INTRODUCTION

This document is the third and final volume in a series of reports dealing with automotive-produced carbon monoxide and the urban environment of Fairbanks, Alaska. The first two volumes, Cold Start Automotive Emissions in Fairbanks, Alaska, (Leonard, 1975) and A Multiple Restrike Ignition System As A Device To Reduce Cold Start Emissions, (Leonard, 1976) dealt mainly with the problem of excessive CO emissions during the cold start phase of vehicle operation caused by the low temperature environment of Fairbanks. The point of investigation in the first two volumes was to determine, why an area like Fairbanks, with such a small vehicle population compared with most other cities in the nation, has such an acute CO pollution problem. The major part of this question was resolved in Vol. 1 with supporting documentation which showed that CO emissions during cold starts have a significant impact on the local environment. However, the explanation was not complete: The cold start portion of this study did not consider vehicles in the moving mode of operation, and therefore the original study was extended to examine the behavior of moving vehicles and their CO emissions. As in the case of the cold start study, the key question was to determine if the cold climate of the area has any special effect on CO emissions from moving vehicles.

To accomplish this task we decided to separate the investigation of moving vehicles into two distinct parts. The first part of the research program would gather data on the driving patterns in the urban area of Fairbanks, which would be used for the development of a driving cycle similar to the CVS-3 Federal Test Cycle. The similarity, however, would pertain only to the way the cycle was constructed and presented allowing easy comparison with the Federal cycle. With respect to information conveyed, the intention was to produce a driving cycle which accurately reflects the driving conditions experienced by Fairbanks motorists.

The second aspect of the investigation would concentrate on gathering quantitative CO emission data from in-use vehicles while operating in the moving vehicle mode under field conditions. These data would be separated into steady-state emission values and transient emission values following our modal method of measuring CO emissions first discussed in Vol. 1.

By comparing the results from the above method of investigation with similar data from other cities, we anticipated being able to isolate any uniqueness Fairbanks might possess with respect to CO emissions from moving vehicles. If the results of such a comparison did not uncover any significant uniqueness, then our conclusion from Vol. 1, that the cold start emission is dominant, would be reinforced. If, however, some behavioral anomaly were found with respect to moving vehicle emissions, a reassessment of the cold-start study's conclusions might become necessary.

II. MOVING VEHICLE EMISSION STUDY

A. Background

During the early CO emission investigations in Fairbanks (Coutts et al., 1973) it became obvious that studying only the warm idle emissions of in-use vehicles was not going to answer the questions about CO pollution in Fairbanks which were being raised. It was also becoming obvious that funded research at the level necessary to make an exhaustive investigation of the subject would not be immediately forthcoming. If meaningful study was to continue it would be necessary to develop a simplified method of investigation which could be supported by a relatively low level of funding and, at the same time, yield useful results. The method considered most feasible, to meet these criteria and the one which has been used for all CO emissions investigations in Fairbanks to-date was one in which vehicle operation was reduced to distinct modes. This technique in usually referred to as the "modal method" of emission analysis.

B. Theory

In the autumn of 1974, when this study was begun, the modal method of measuring emissions was not widely used. Most emission evaluations were employing the Federal Test Procedure's technique using a constant volume sampler; the method is most often referred to as the "FTP" (Federal Test Procedure) or the "CVS Method." Since the CVS method was the only method of emissions testing accepted by EPA at the time, opting for the modal method meant a break with standard practice, but a necessary one because the cost of a CVS system was far beyond the financial means of this project. If, however, a Fairbanks driving cycle were developed, Fairbanks conditions could be simulated at a later date using the Fairbanks cycle and the CVS method, in cold chambers, if necessary.

The development of a Fairbanks driving cycle was therefore the key to the moving vehicle investigation. Quantitative modal emission data could be applied to the driving cycle to provide estimates of the impact of moving vehicle emissions on the environment, or the CVS method could be employed in conjunction with the Fairbanks cycle to obtain similar results. We concluded, therefore, that the modal method would be an acceptable compromise provided the Fairbanks driving cycle was developed as well.

1. <u>The Modal Method</u>:

This method has been discussed in detail in Vol. 1, but is reintroduced here for the sake of continuity. Essentially it is an extension of the work begun by Volz, (Volz, 1972), which was concerned with the measurement of emissions from in-use vehicles at warm-idle. These measurements, begun in the lower 48 states, were continued in Fairbanks with the help of Dr. Volz during the winter of 1972-73 and became the first actual emissions research conducted here. The results of the work in Fairbanks were published by Coutts (Coutts et al., 1973). The tests involved a simple procedure and were inexpensive to perform but, still produced accurate emission data. The modal concept extended the principles of this early work by dividing the duty cycle of a vehicle into distinct modes. The emissions of each mode could then be evaluated separately without the expensive instrumentation required by the CVS method. In this project we defined the following modes for data acquisition and analysis:

a. Cold Start - The cold start mode is defined as the period of vehicle operation beginning with initial start-up and continuing until normal engine operating temperature is reached. The cold start mode assumes that the engine has not been running for some time prior to start-up and that the engine temperature is at, or approaching, ambient.

b. Warm Idle - Defined as the period of operation when the engine is running at normal operating temperature, but the vehicle is not moving under engine power. During this mode the carburetor throttle plate is assumed to be closed, and fuel for combustion is being supplied by the idle jet alone.

c. Moving Vehicle - The mode during which the vehicle is in motion and under load. This mode can be further reduced to its basic components of steady-state and transient operation, to be discussed in detail later.

Each of these modes should produce a distinct level of emission. However, since they blend continuously during the course of vehicle operation, such a breakdown should not be expected to produce absolute emission levels applicable to a specific case. That is, such a method could only produce estimates of emissions produced by the distinct modes, and would lack the continuity of more complex methods like the CVS system. But recalling the fiscal constraints placed on the investigation, and the fact that at the time not even estimates of emissions were available, it appeared that the modal method would be a most practical route to follow. Especially so if the instrumentation which had already proven successful for the warm-idle mode could be used for the other modes.

This brings us to the second major question about the usefulness of the modal method. Can an infrared CO/HC analyzer, which is relatively inexpensive, portable, and simple to use, be useful for measuring emissions from cold-start and moving vehicle modes? The answer to this question is a qualified yes. Problems with instrumentation were discussed in Vol. 1 with reference to the cold-start mode. Details of similar problems with moving vehicles appear below. We were confident at the outset that useful data on emission levels could be gathered using the modal method with the infrared equipment on hand.

2. Moving Vehicle Emissions:

At the time when a method for testing moving vehicles was being formulated, we already knew that the cold temperatures did have a significant effect on cold start emissions. Therefore we could expect a large portion of the total CO in Fairbanks to be resulting from climatic peculiarities alone. But would moving-vehicle emissions also reflect an environmental uniqueness? The warm-idle study of Coutts, et al., (1973) indicated not, at least from a purely mechanical standpoint. That study showed that once an automobile engine reached normal operating temperature the CO emission was very similar to those measured in other parts of the country and largely independent of ambient temperature. It is true that under extreme cold conditions ($\leq$ -40°C) engines do not always reach normal operating temperature (60° to 90°C), but the cold start study found that 20°C was adequate to remove all noticeable cold-start emission effects. Even in the coldest weather engine block temperature always exceed 20°C after only a short period of running. Furthermore, from a pollution control standpoint the most serious CO levels seldom occur during periods of extremely cold ambient temperature, (data from Environmental Services Department, Fairbanks North Star Borough). Hence the emission response during these extreme cold spells is not of special significance. On the basis of emission samplings in the warm-idle mode, it appeared that the thermal control system of the average automobile (coolant temperature thermostat, intake air preheat, etc.) were quite adequate to maintain internal thermal regime suitable to ensure minimum CO emission levels, irrespective of ambient temperature, once a sufficient period of warm-up is provided (see Vol. 1 for warm-up period). However, it is necessary to stubstantiate this idea by field testing.

If cold temperatures are not likely to influence emission levels of moving vehicles, as they did in the case of the cold-start mode, what other environmental anomalies are there to be considered? This question leads to a discussion of the problems with the CVS system.

3. The CVS System and the CVS Driving Cycle

Federal Exhaust Emissions Test Procedures (FTP) for light duty vehicles (under 6000 lb. GVW) for the period 1972-76 assess hydrocarbon, carbon monoxide, and nitric oxide emissions in terms of mass, by integrating the total emission of a vehicle driven on a chassis dynamometer over a simulated course 7.5 miles in length. This simulated course is called a driving cycle. At the end of a test the results are expressed in grams/mile for each of the above emission constituents.

It is not necessary here to discuss the details of the CVS method, since a thorough discussion is presented elsewhere (Henein and Patterson, 1972). Our main concern is the driving cycle and not the constant volume sampling part of the technique. Basically there are two procedures for testing with this method. The first is known as the

CVS-1 system and employs the use of a single bag to collect and integrate the total vehicle emission. This system was used on 1972-74 vehicles to determine compliance with federal emissions standards. The second procedure is the CVS-3 system which is similar to the CVS-1 except that the CVS-3 employes three sampling bags and includes a cold-start phase. This cold start, however, should not be confused with the much more severe cold-start mode treated in Vol. 1.

It is by this method that emissions have traditionally been assessed by EPA. The results are published in various documents such as EPA-AP-42 and then used by State and local government bodies in evaluating emission impact relating to specific cases. Several problems arise in attempts to apply the general results to specific cases. The first problem concerns the driving cycle. Figure 1 shows the driving cycle used for CVS testing. It was developed to simulate California driving conditions, and its usefulness when applied to other areas is open to debate. Since each locale has its own unique driving conditions, and this is especially true in the Fairbanks case, we automatically look with suspicion on data which has been compiled (as in AP-42, using the California cycle) and are reluctant to place much faith in it as being valid for a specific set of conditions.

An example of the dangers inherent in CVS testing without attention being paid to local condition is apparent in Figure 2 which was presented in Vol. 1 where it helped to define the cold-start problem. Here, however, its purpose is to show that variation of ambient temperature can severely affect emission data. Note that the CVS cycle is shown at the bottom of the figure and that each test was conducted using the same cycle. The following emissions results are implicit

CVS-1 and CVS-3 STANDARDIZED DRIVING CYCLE

(Redrawn from Henein and Patterson)

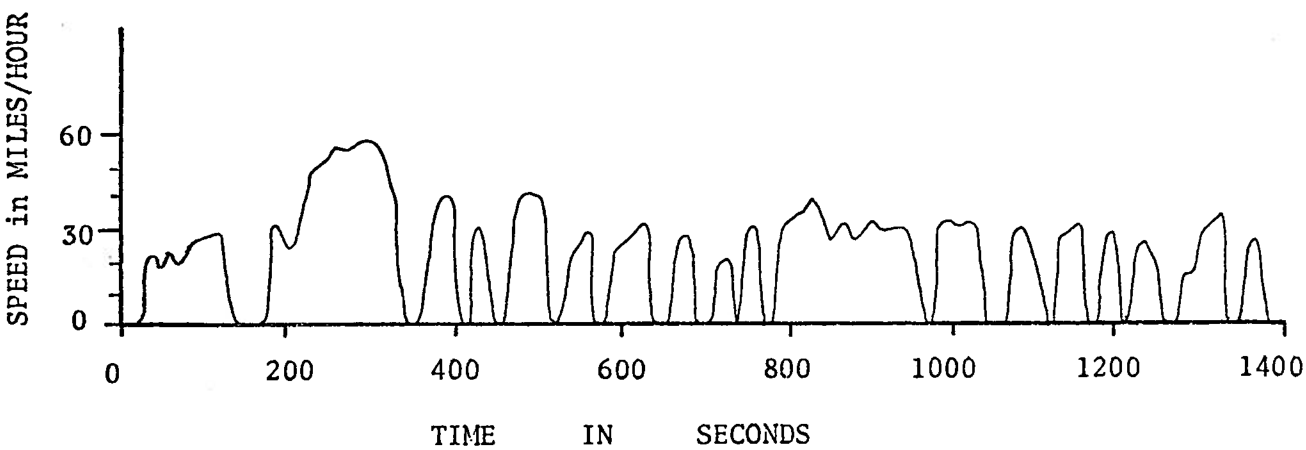


FIGURE 1.

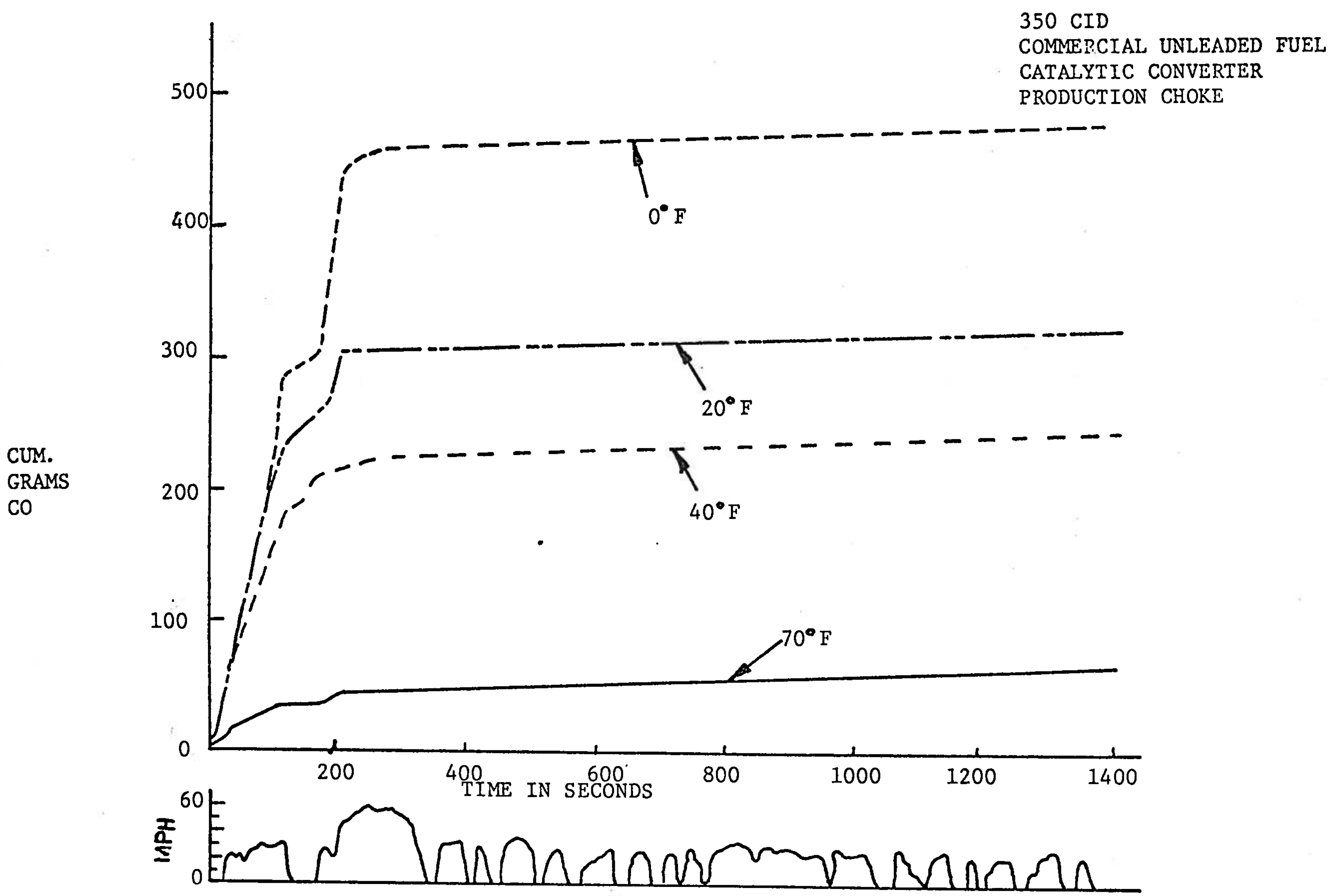


FIGURE 2.

TAKEN FROM GENERAL MOTORS REPORT, MILES (1973) from the graphs:

CO EMISSION FOR TESTS OF FIGURE 2

1. 70°F. - 8.6 grams/mile
2. 40°F. - 29 grams/mile
3. 20°F. - 40 grams/miles
4. 0°F. - 64 grams/mile

Since standard CVS testing begins with the vehicle being "cold soaked" at an ambient temperature of +60° to +86°F for a period of twelve hours, we feel quite justified in our suspicion of the generalized emission data when considering the Fairbanks case. We may conclude that the environmental uniqueness of concern to us is manifest by the method of testing, i.e. driving cycle, and since the standard CVS cycle is probably not applicable to Fairbanks, the emission factors developed in other areas would likewise not necessarily apply.

We note that the problems associated with CVS testing are not dismissed by EPA. It acknowledges in the introduction to the Vehicles Emissions chapter of AP-42 that:

"Note: the emission factor data presented for highway vehicles in this chapter are based on a generalized test cycle that involves operation typical of every-day driving patterns. Because this driving cycle is intended to represent typical driving, it cannot apply in specific instances, i.e. to a particular segment of a particular roadway at a particular time. In order to estimate vehicular emissions under a specific set of conditions, "modal" emission factor data are required. Diving modes include: idle, constant speed, acceleration, and deceleration. Because all driving patterns can be divided into one of these four modes, emissions can be determined by summing the modal emissions for a particular driving pattern.

The Environmental Protection Agency is currently evaluating the use of modal emission data. Emission data for idle, various constant speeds, and various initial and final speeds (accelerations and decelerations) are being collected and analyzed. It is anticipated that these data will be published in Sections 3.1.2 and 3.1.4 of subsequent revisions of this publication. Modal data for light-duty vehicles (Section 3.1.2) will be published during 1973, and data for heavy-duty gasoline vehicles will be published at a later date."

The "modal" method is, of course, the same concept which was used in this investigation; however, we have added the cold start as a separate and distinct mode having special consequence in a cold climate. Unfortunately the "modal data" mentioned as forthcoming by EPA was never published in subsequent revisions of AP-42. EPA has, however, continued with the modal concept and has developed a computer model allowing the insertion of a local driving cycle for analysis (Kunselman et al., 1974). This model still requires the input of known emission factors, which need to be obtained locally, and a local driving cycle.

From the December 1975 revision to AP-42* we have the following discussion of the Federal Test Procedure (FTP):

"The methods used to determine composite automobile emission factors have been the subject of continuing EPA research, and, as a result, two different techniques for estimating CO, HC, and NO_x exhaust emission factors are discussed in this section.

The first method, based on the Federal Test Procedure (FTP), is a modification of the procedure that was discussed in this chapter in earlier editions of AP-42. The second and newer procedure, "modal" emissions analysis, enables the user to input a specific driving pattern (or driving "cycle") and to arrive at an emissions rate. The modal technique driving "modes," which include idle, steady-speed cruise, acceleration, and deceleration, are of sufficient complexity that computerization was required. Because of space limitations, the computer program and documentation are not provided in this section but are available elsewhere."

The modal method we are using in our investigation is consistent with current recommended EPA procedures, even though our methods of data acquisition differ, since we do not have a CVS system.

C. Objectives

The specific objectives of the moving-vehicle aspect of the project were as follows:

1. Develop a driving cycle representative of Fairbanks driving conditions, and make a qualitative comparison between the Fairbanks driving cycle and the federal CVS-3 cycle.
2. Measure CO emissions from in-use vehicles operating in the moving vehicle mode, both steady-state and transient, and quantitatively compare the CO levels measured in Fairbanks to modal CO emission data from more temperate climate areas.

D. Test Procedure

1. Fairbanks Driving Cycle:

To obtain data for the compilation of driving cycle representative of Fairbanks, two field technicians were used. A test vehicle was driven over the route under investigation, which was restricted to that portion of downtown Fairbanks where the most severe ambient CO problem has been observed. While data were also obtained from the suburban arterials, we felt that the complexity of the more heavily trafficked area required the most attention. Thus the limits of driving cycle data were: the Chena River on the north, Dunkle Street on the east, Airport Way on the south and Lathrop Street on the west (see map).

Data were recorded in the following manner. The driver of the vehicle described his journey with respect to vehicle speed and location by keeping an eye on the vehicle speedometer. His oral description was recorded by a portable tape recorder. The passenger continuously followed the second hand of a stop-watch and verbally marked the tape at ten second intervals. The technicians then returned to the office with the pertinent data for their trip recorded on tape and played back the tape to develop a graph of vehicle speed vs. time. Also by noting the locations of the vehicle at any point in time a geographical record of the trip was produced. During the testing, which was conducted during two winter seasons (1974-75 and 1975-76), over 150 miles of driving-cycle data was gathered using this technique.

2. Moving Vehicle Emission Factor

The moving vehicle mode has two internal components and therefore can be further broken down into two distinct modes:

a. Steady-state - A vehicle moving at a constant speed in a given gear, with the engine running at a constant rpm. Under these conditions, the combustion efficiency of the engine would be at its maximum and the CO emission should be at its lowest level. The modern automobile engine is designed to run most efficiently in this mode.

b. Transient - A vehicle moving at a changing rate of speed (accelerating or decelerating) during gear changes and/or with the engine changing rpm. Under transient conditions, the carburetor throttle plate is in the process of opening or closing, manifold pressure is changing, and the amount of fuel supplied to the combustion chamber is changing. Modern internal combustion engines are designed to compensate for these changes so that the most efficient combustion possible will be maintained. However, even in the most ideal engine, these transient processes affect combustion efficiency and thus the CO emission. The older a vehicle and the more poorly adjusted the carburetion and ignition systems, the greater the effect on emissions. In addition, the more accentuated the acceleration or deceleration, the greater the effect on emissions.

To develop a useful moving vehicle emission factor both transient and the steady-state portions of the mode must be considered by the test procedure.

3. Equipment

The vehicles tested were:

1. - 1968 Chevrolet Carryall equipped with a 4-speed manual transmission and a 256 cubic inch 6-cylinder engine.

2. - 1971 GMC (Jimmy) 4-wheel drive equipped with a manual 4-speed transmission and a 250 cubic inch, 6-cylinder engine.

3. - 1974 Ford Club Wagon equipped with an automatic transmission and a 302 cubic inch V-8 engine.

4. - 1974 Chevy Nova equipped with a automatic transmission and 250 cubic inch, six-cylinder engine.

The following parameters were continuously monitored during the testing:

1. Engine Speed in rpm: A standard clip-on type tachometer was used.

2. Manifold Vacuum in Inches of Mercury: A Bourdon type vacuum gauge was used.

3. Vehicle Speed in mph: The standard equipment vehicle speedometer was used.

4. Exhaust Gas CO Concentration in % by Vol: An Olsen Horiba Mexa 300 Analyzer was used.

5. Exhaust Gas HC Concentration in ppm: Same as 4.

120v. AC power for the gas analyzer was obtained from a Powercon 250W inverter, connected to the vehicle storage battery.

4. Method:

Two persons were used for testing. The driver of the test vehicle monitored speed and engine rpm. The passenger monitored vacuum, CO and HC concentrations, and recorded the data. During the testing various routes were used; however, a typical test involved the following route:

A vehicle was driven from the University campus, down College Road to Cushman Street via Illinois Avenue and up Cushman to about 18th Street, back down Cushman right onto Gaffney, left onto Noble Street, left onto Third Avenue, and back to Cushman, then back up Cushman, and right onto Airport Way, then back to the University via Airport Way and University Avenue (see map). Such a route afforded practically every driving condition which might be encountered in the Fairbanks area. Data obtained were then organized and analyzed.

E. Problems in Testing

No problems were experienced in data acquisition for the driving cycle portion of the study. However, the major difficulties, associated with the Olsen-Horiba CO/HC analyzer arose during the measurements of moving-vehicle emissions. Some of these difficulties were discussed in detail on pages 16 and 17 of Vol. 1, and will not be repeated here. However, the major instrumentation problem which we have not been able to quantify, but which does cause inaccuracies in the moving vehicle CO data is related to scale ranges on the indicating meters. The low-range scale on the Olsen/Horiba analyzer is 0-2% CO concentration by volume. This means that 1% CO was read at mid scale and since almost all readings taken during the moving-mode tests were less than 1%, practically all readings fell somewhere below half-scale. Since such a small portion of the scale was utilized there is some question as to the precision of the recorded results. An attempt was made to correct this by changing the internal circuitry to produce a lower reading range, but nonlinearity in the circuit would have required extensive factory modification, with consequent unacceptable time delays. We therefore retained the original scale (0 to 2%) and exercised care in reading the meter, but recognize the possibility of inaccurate values by as much as 0.1%.

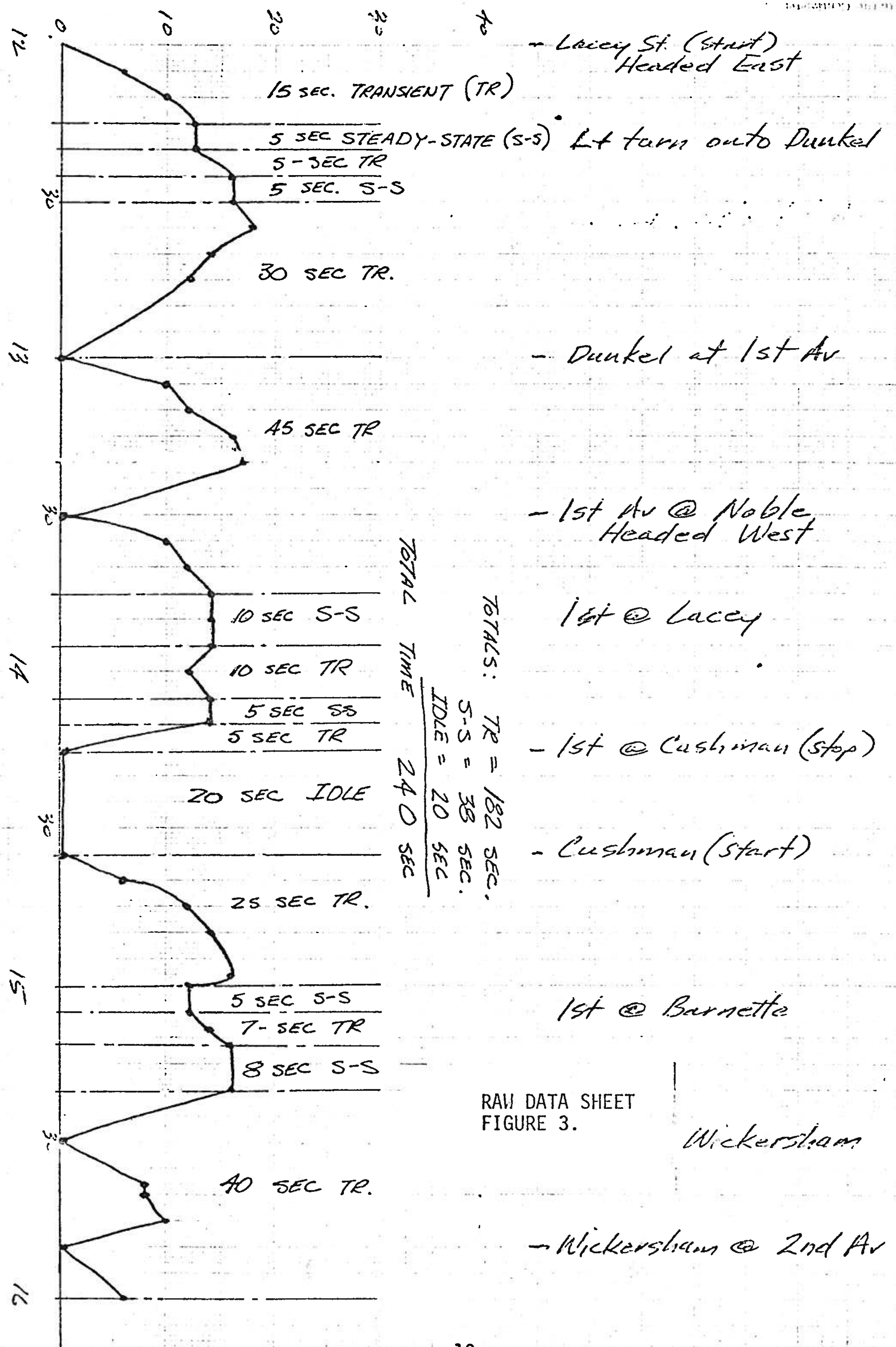
III. -MOVING VEHICLE STUDY RESULTS

A. Fairbanks Driving Cycle

Data were gathered for compilation of a Fairbanks Driving cycle over a period of two winters (1974-75 and 1975-76). However, during the summer of 1975 considerable changes were made in traffic routing patterns and traffic signals in the downtown area. For this reason the routes covered during the winter of 1974-75 for which data were taken could not be retraced when taking data the following year. As a result it proved necessary to develop two independent cycles which reflect the changes in traffic routing. First, however, we describe briefly the method of reducing the data into an estimated driving cycle representative of driving conditions in downtown Fairbanks.

1. Data Reduction

Following the procedure discussed earlier, graphs of vehicle speed vs. time were generated for all routes covered. Many of these routes were covered repeatedly. The locations of different points along the routes were recorded in order to have a consistent reference frame for all the graphs. A sample of one of the raw data plots is shown in Figure 3. The motion of the vehicle through traffic appears as a series of speed pulses over time. These pulses consist of acceleration, cruise, deceleration, and eventual stop at a signal light or other such obstacle. Five parameters were measured on each graph: we counted the number of pulses; estimated the percentage of time spent at idle and, for the moving mode, in transient and steady-state operation; and calculated the average speed by dividing the distance covered by the travel time.



RAW DATA SHEET
FIGURE 3.

2. <u>Data Summary</u>

Once the above information has been obtained from each route segment, average values were calculated for each parameter. The results are shown below for each of the two years in which the data were obtained.

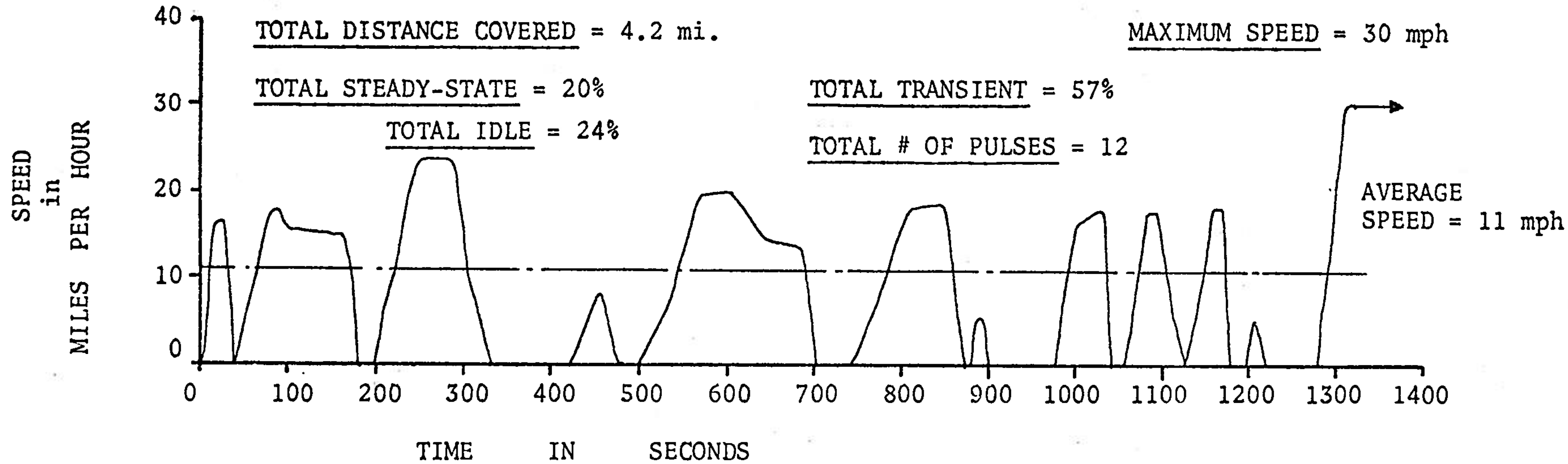
SUMMARY OF DRIVING CYCLE PARAMETER DATA

NOTE: Values are listed by route segment. 1 route segment = 1370 sec.

Parameter	1974-75	1975-76
Average No. of Pulses	12	9
% Idle	24%	7%
% Moving Mode	76%	93%
% Transient Mode	56%	51%
% Steady-State Mode	20%	42%
Average Speed	11 mph	17.6 mph

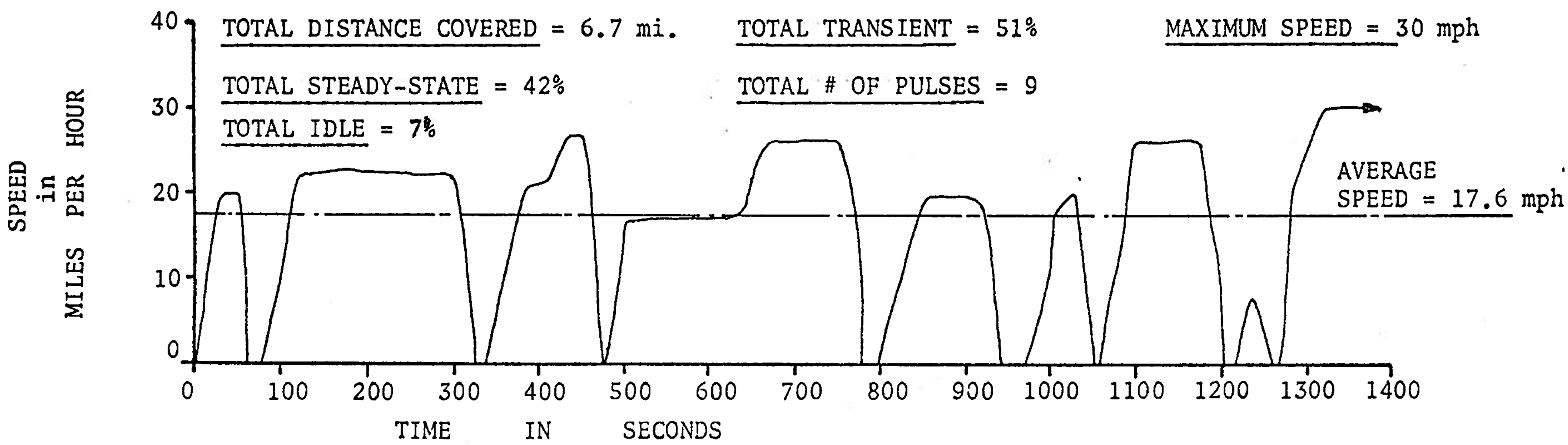
A driving cycle was compiled from the above data. There is no denying the fact that compiling a cycle of this kind is a subjective task, and no pretense is made to establish its statistical integrity. It is agreed that the method may be statistically questionable but we believe that for a first estimate it should yield Fairbanks cycles which are representative of much of the driving taking place daily in the downtown area.

The two cycles which were finally compiled as representative of Fairbanks driving conditions are shown in Figure 4 plots a and b. The duration of each cycle was set at 1370 sec., which is the same as the CVS cycle of Figure 1. This duration has no significance other than to facilitate comparison between these cycles and the Federal cycle.



WINTER 1974/1975 FAIRBANKS DRIVING CYCLE

FIGURE 4 (a)



WINTER 1975/1976 FAIRBANKS DRIVING CYCLE FIGURE 4. (b)

3. Discussion of Results

During the time that data were being collected for development of a typical driving cycle, the city of Fairbanks was experiencing the impact of pipeline construction which saw an approximate doubling of the number of vehicles operating on the existing street and highway network. During the winter of 1974-75 traffic congestion in the downtown area was increasingly becoming a problem, as is apparent from Figure 4a. In an effort to ease the congestion experienced during the winter of 1974-75, traffic control measures were implemented by State and City personnel. These measures mainly involved the creation of a series of one-way couplets and implementation of a revised traffic signaling system. As a result congestion was considerably eased, a conclusion born out by the driving cycle data shown in Figure 4b. Note in Figure 4 that during the winter of 1974-75 a nominal 1370 sec., automobile trip, required eleven full stops and the time spent idling during the stops amounted to 24% of the entire trip. On the other hand, after traffic control modifications were implemented, the number of stops was reduced to eight with total time spend idling only 7% of total trip time. Thus the average trip speed was increased from 11.0 mph to 17.6 mph as a result of the new traffic controls. Another interesting feature is that while the total time spent in the transient mode only decreased from 56% to 51%, the time spent in the steady-state mode increased from 20% in the 1974-75 cycle to 42% in 1975-76. A qualitative discussion is helpful to place both cycles in perspective with respect to their effect on CO emissions.

a. Idle Mode - After the implementation of new traffic controls, the driving cycle's idle time was reduced by 17%. Since CO emission during idle tends to be greater than during steady-state operation (see Theory Section), the implementation of traffic controls had a positive effect on the reduction of automotive CO emission.

b. Steady-State Mode - The time spent in steady-state moving mode increased by 22% from winter 1974-75 to 1975-76, and since it is in the steady-state mode that a vehicle produces its lowest possible CO emission rate, we again conclude that the traffic controls had a positive effect with respect to CO emission.

c. Transient Mode - The time spent in the transient mode decreased, but only by 5%. The transient mode is one in which higher than normal levels of CO are often produced. Therefore, any decrease in operating time while in this mode is beneficial from the CO emission standpoint. Therefore implementation of the new traffic controls had a positive effect, although not nearly as significant as with the other modes of vehicle operation.

d. Average speed - Average speed increased as a result of the new traffic controls. This is a very positive result since the increased freedom of movement permits vehicles to pass through, rather than congest, a given section. This situation reduces traffic density thus reducing CO emissions discharged in the area.

In general we may conclude that, qualitatively at least, the modifications to the traffic control system during summer 1975 had a beneficial effect on the reduction of CO emissions in the downtown area.

e. Fairbanks Cycles vs. CVS cycles as used by FTP - Since one of the reasons for development of a driving cycle for Fairbanks was to point out the uniqueness of the Fairbanks situation with respect to other areas of the nation, a comparison of the standard Federal cycle with the Fairbanks cycles developed here is in order. The Federal cycle is shown in Figure 1. The Fairbanks cycles are shown in Figure 8. The table below compares several parameters for the three cycles.

DRIVING CYCLE COMPARISON

Parameter	Federal CVS Cycle	Fairbanks Cycle 1974-75	Fairbanks Cycle 1975-76
Time duration	1370 sec.	1370 sec.	1370 sec.
Length	7.5 mi.	4.2 mi.	6.7 mi.
Max Speed Reached	56.7 mph	30.0 mph	30.0 mph
Average Speed	19.7 mph	11.0 mph	17.6 mph
% Idle Time	19.0	24.0	7.0
% Steady-State	25.0	20.0	42.0
% Transient	68.0	56.0	51.0
No. of Stops	18	11	8

The cycles differ considerably. As noted in the next section the effect of this difference on the prediction of automotive CO has not been adequately revealed by our study, except in a qualitative sense. A quantitative comparison of the CO emissions associated with the three cycles would require use of the CVS technique, which unfortunately was beyond the scope and finances of the project.

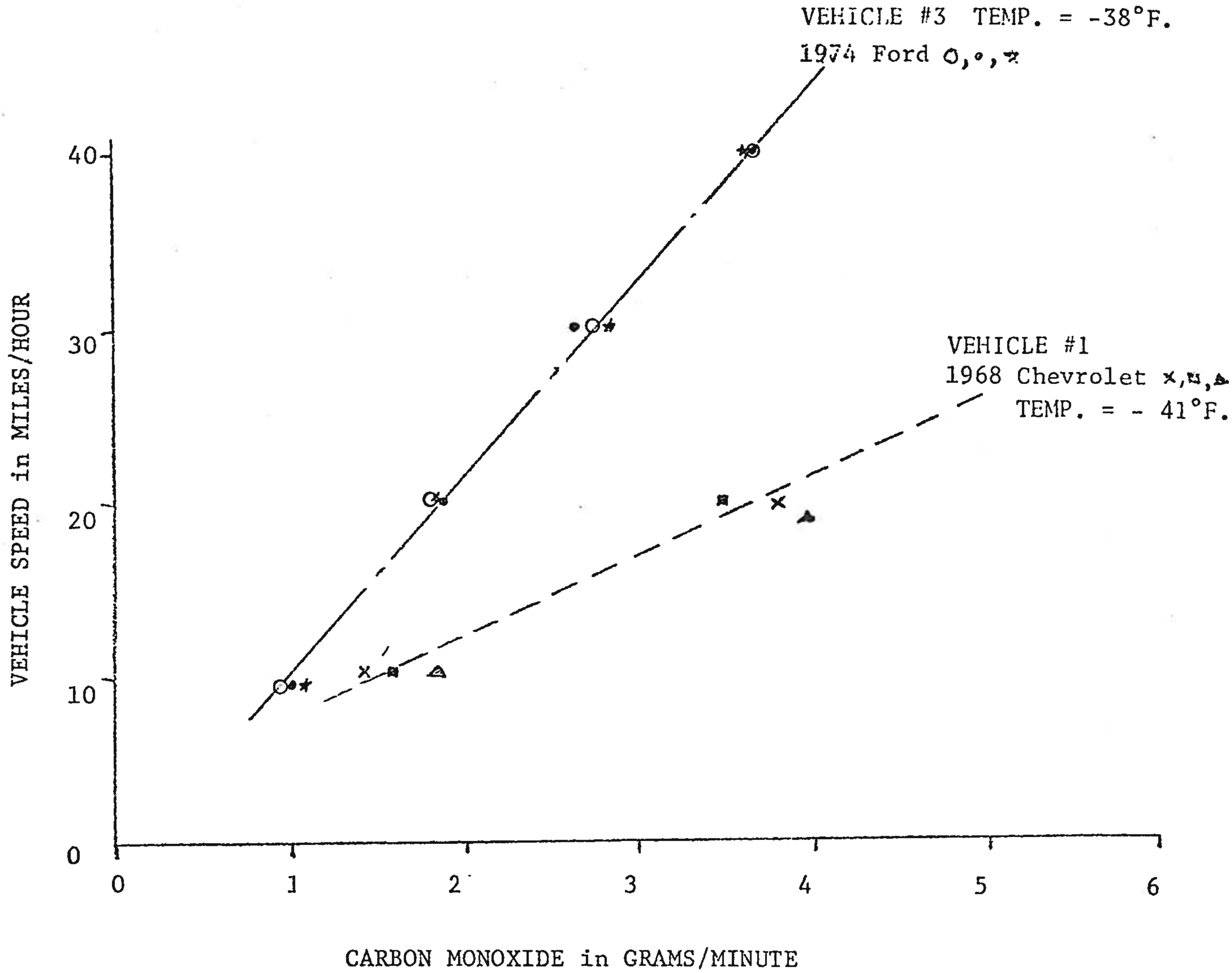
B. Moving Vehicle Emission Factor

1. Steady State Response

The steady-state response for two vehicles is shown in Figure 5. The ambient temperatures occurring at the time of each test is also noted on the plot. Qualitatively, the results are as expected for these particular test vehicles. Note that vehicle No. 1, being of pre-control vintage, produces a greater CO emission through the total range of moderate cruising speeds than does vehicle No. 3, despite the fact that vehicle No. 3 has a larger engine displacement. We also expect to find the warm-idle emission of the older vehicle to be considerably higher than that of the new vehicle, which is the case. Therefore, a general conclusion based on this limited sample suggests an expected emissions behavior on a qualitative basis.

With respect to quantitative assessment of the results shown in Figure 5, it is necessary to compare our data with similar data from other regions of the United States. From the outset of this study it was assumed that EPA was actively pursuing a similar course of research as evidenced by the citations from AP-42 previously quoted in this report. However, such data were not forthcoming as planned by EPA. As a result the compilation of this report has been delayed in the hope that comparative modal emissions data would eventually be published. As late as July, 1977 private communications with Mr. F. Peter Hutchins, (Project Manager, Technology Assessment and Evaluation Branch, E. P. A. Ann Arbor, Michigan) suggested that such data would be forthcoming but, no firm publication date was given. We are therefore presenting our steady-state response data without benefit of comparison.

RESULTS OF STEADY-STATE MOVING VEHICLE
CO EMISSIONS



——— — ——— 6.0 g/mi. @ 20 mph , 5.2 g/mi.@ 40 mph , Idle = 2.5 g/min.

— — — — — — — — 7.8 g/mi. @ 20 mph , 8.5 g/mi. @ 40 mph , Idle = 12.6 g/min.

FIGURE 5.

a. Discussion of Steady-State Data - The steady-state data were the first data collected from moving vehicles as part of this project. While all four vehicles were used for data collection in the transient mode, Nos. 1 and 3 were the only vehicles tested repeatedly in the steady-state. We had used these vehicles during the cold-start tests and found that they were quite representative of their model, type, and vintage with respect to CO emissions. We were confident that the test results would prove reliable as typical CO emissions for comparison with emissions of similar vehicles tested in other areas. We expected that on the basis of such a comparison we would be able to form an opinion as to whether or not the ambient temperature of Fairbanks was affecting CO emissions in the steady-state mode. We anticpated that the comparison would quantify any disparity which might exist. We were aware, of course, that the validity of such a quantitative disparity, if indeed one were shown to exist, would depend on the similarity of test procedures used by ourselves and others. It would also depend on the error inherent in our method of calculating the mass of CO emission from the raw data:

$$E_t = Pd \frac{s}{2} \dot{e} \qquad (1)$$

where E_t = The volume of CO in liters which is converted to grams by multiplying by 1.25 g CO/liter

P = Manifold pressure in atmosphere

d = Engine displacement in liters

s = Engine speed in RPM

$\dot{e}$ = CO concentration in % by volume

(This formula is discussed in some detail in Vol. I, pg. 18, 19). We did not know whether the test procedures of other researchers would be compatible with ours, but we did know that the mass calculation contained an error range of +26 to -41 percent, and therefore we considered any resulting quantitative comparison to be an estimate and perhaps a crude estimate at best. We were actually looking for trends in the data and retaining the quantitative difference as a first approximation subject to more precise future investigations. Unfortunately the unavailability of the comparative data from the contiguous United States makes such analysis a moot point.

2. Transient Response

Attempting to measure transient emissions during periods of acceleration and deceleration proved to be considerably more complex than the steady-state tests. This was mainly due to the time-lag inherent in the response of the emission sampling system. Since the exhaust gas must be drawn up the sample tube from the vehicle exhaust pipe into the analyzer over a distance of approximately three feet, any change in CO level is indicated on the meter only after a several second lag following the change in engine performance. At first we thought that we could accommodate our measurements to the time lag once we became accustomed to it, assuming that it would remain constant. But we soon found that the changing pressures within the exhaust system, which normally occur during transient operation, caused variation in the time lag. For this reason we were never quite sure of the time relationship of analyzer response to change in engine performance. Figures 6 and 7 show the results of acceleration and deceleration tests,

ACCELERATION TEST CURVE

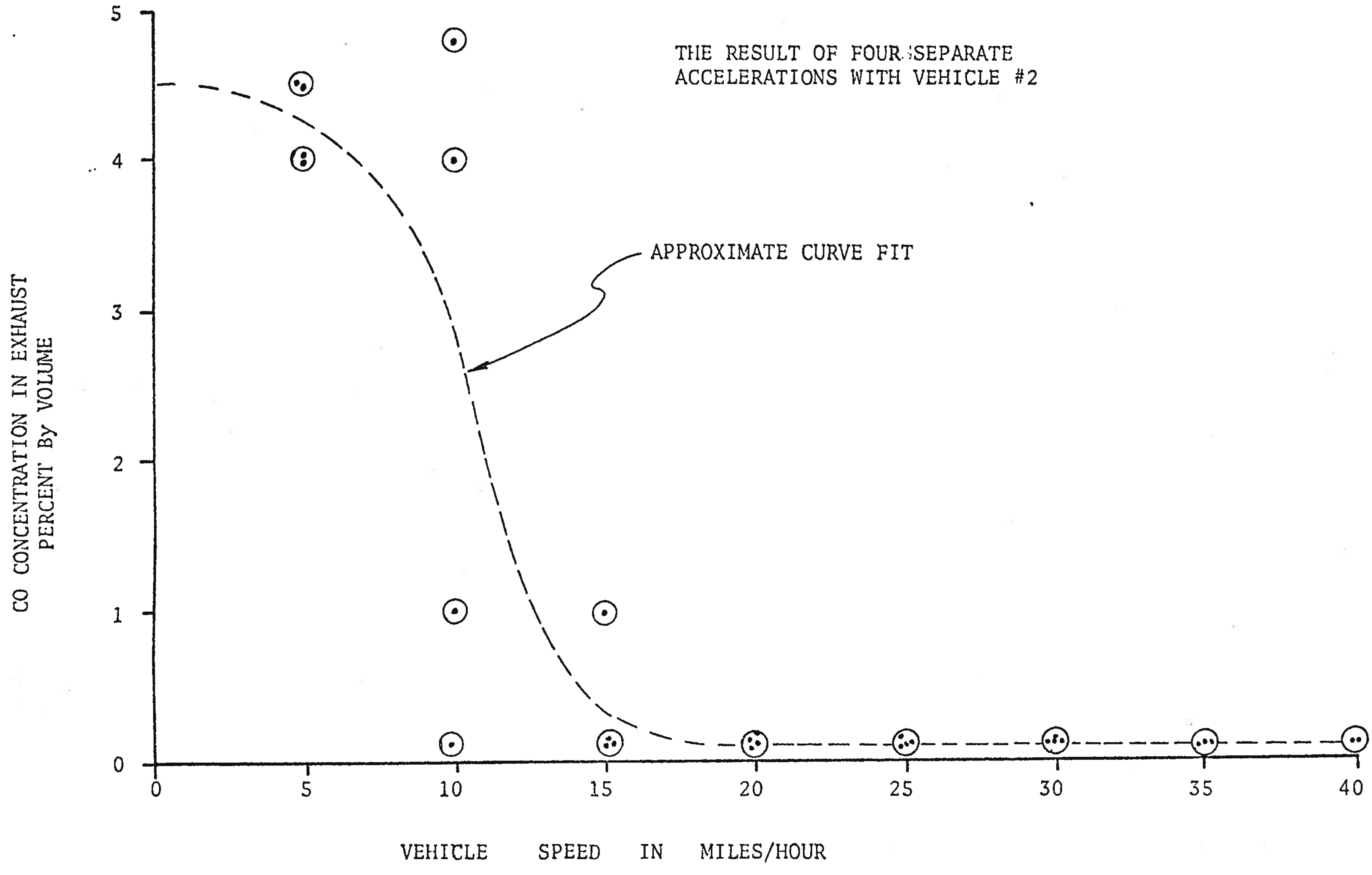


FIGURE 6.

DECELERATION TEST CURVE

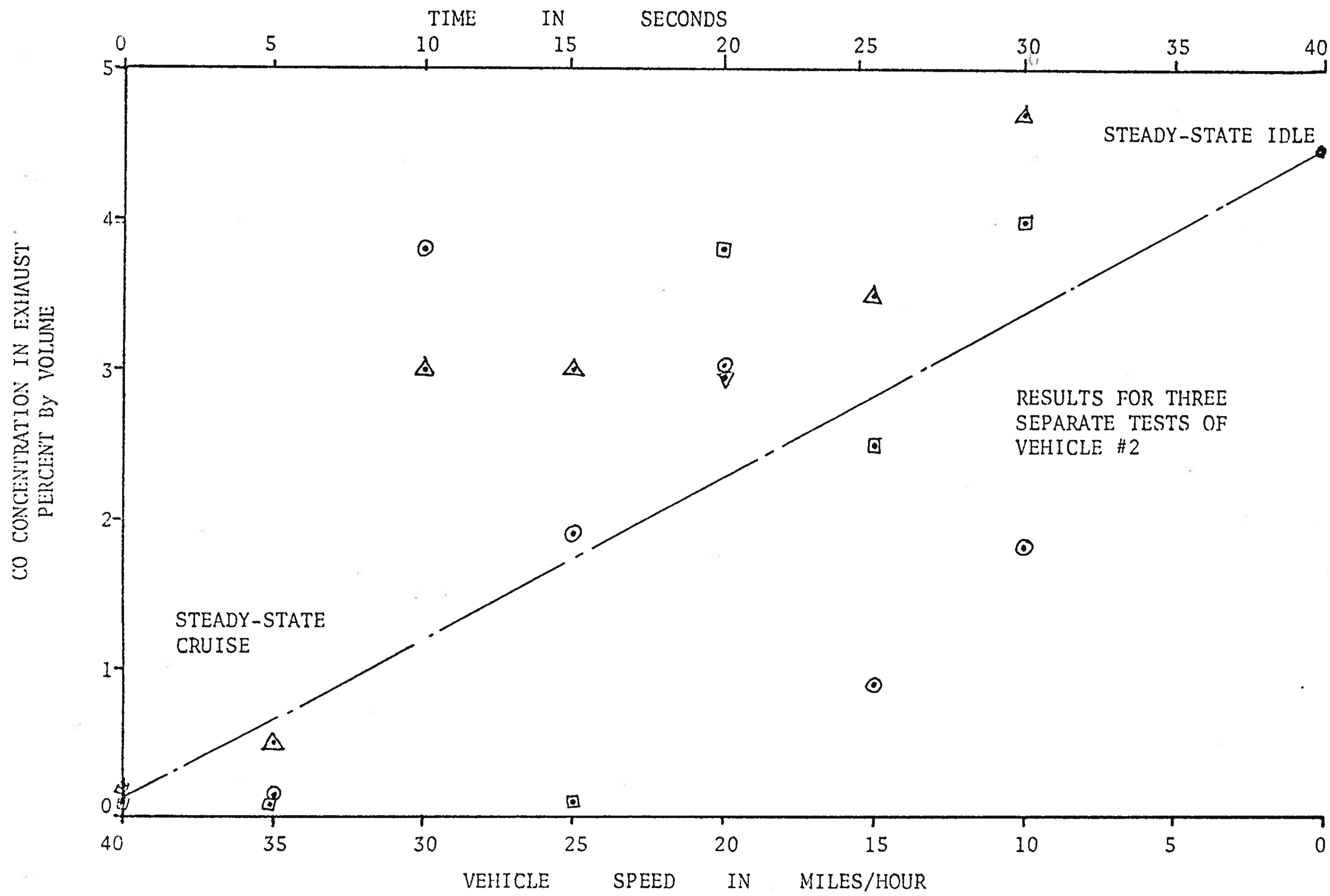


FIGURE 7.

respectively. Note that, while the data points are somewhat scattered, four successive acceleration tests yielded data that are reproducible. However, owing to the time-lag problem we cannot say with any certainty that the time scale is properly aligned with the data, and would concede that any single data point could be shifted as much as 15 seconds. In the case of deceleration (Figure 7,), the same would be true with regard to possible variation in the time reference. Here, however, the data are more widely scattered and less reproducible than in the case of acceleration so that it is not possible to fit a curve to the data points. (The straight line between steady-state cruise and idle is drawn for reference only and is not intended to be a fitted curve.)

During transient conditions equation 1 still applies to the calculations of CO emissions at any distinct point in time and theoretically one could calculate the mass CO emission for any transient episode by equation 2.

$$E_t = \frac{d}{2}\int_{t_0}^{t} P(t)e(t)s(t)dt \qquad (2)$$

where E_t = the total mass of CO emitted for a transient episode beginning at time t_0 and continuing to time t, at which point steady-state operation is reached. As a practical matter however, the functional representation of the variables in (t) is not readily accessible and some iterative evaluation must be made. Therefore equation 2 becomes:

$$E_t = \frac{d}{2} \sum_{i=0}^{n} p_i \dot{e}_i s_i \Delta t \qquad (3)$$

Where Δt = some discrete time interval acceptable to the form of calculation.

The problem in attempting such a calculation would be to reliably record p_i, $\dot{e}_i$, and s_i. During the course of the testing both p and s could be obtained instantaneously, but $\dot{e}_i$ lagged in time by several seconds. Therefore we were never able to assign an $\dot{e}_i$ to any values of s_i, and p_i since this time lag was not constant. This meant that any attempt to quantitatively evaluate transient response by applying equation 3 would be meaningless.

These problems with the transient data appeared early in the tests; but, while it quickly became apparent that quantitative analysis of the transient response would be impossible unless the time lag problem could be compensated for, we had some reason to remain optimistic. During the first few tests we noticed only a slight change in CO emission level during transient conditions (acceleration and deceleration) while driving in the downtown area. This appeared to be related to the very slippery road surfaces, common in Fairbanks during most of the winter period.

Road surfaces were far too slippery to permit rapid loading of the engine. In order to cause significant change in CO level, the accelerator pedal had to be depressed very rapidly. When this was done, the rear wheels would immediately lose traction on the slick pavement, and the vehicle would "fishtail" severely with the attendant danger of losing control. To cause significant response during decelerations it was necessary to abruptly release the accelerator pedal when traveling at about 30 to 40 mph. This process would not normally occur under Fairbanks driving conditions, since the sudden loss of power and the accompanying drag of stiff transmission lubricants might cause the vehicle to skid out of control.

Slow and gradual accelerations and decelerations were the rule when driving in close traffic and were also practiced on the less congested thoroughfares. A good description of the practice is to imagine driving with an egg between one's foot and the accelerator pedal. Due to slippery surface conditions, ice fog and other hazardous Fairbanks driving conditions, this cautious technique is followed by the vast majority of resident drivers. During these gradual changes in speed, increases in CO emissions were not detectable with our instrumentation as mentioned above. In the heaviest of stop-and-go traffic on Cushman Street, no variance in CO emissions from the low-speed steady-state condition was observed while the vehicle was in motion. Once fully stopped, the emission would return to the idle level and remain there for the duration of the stop, dropping back to the steady-state level when the vehicle again began to move.

Assuming this type of response to be the normal condition when driving in the urban area, we anticipated that it might yet be possible to obtain meaningful transient-mode data by employing equation 3 but modifying it by considering $\dot{e}$ to be constant over time. This would avoid the time lag problem. Unfortunately, later testing showed that as road surface conditions changed, in response to weather conditions, the CO levels began to change more dramatically during transients.

Figure 8 demonstrates conclusively the importance of transient emissions under normal driving conditions in the downtown area of Fairbanks. Here, a driving profile is plotted in the lower half of the graph and, in the upper half, a corresponding plot of the mass of CO emission calculated for discrete points in time along the route. Again a time lag is inherent here, but for the purpose of general comparison it can be ignored. Note the low correlation between the emission levels and the speed profile. Also note the lack of steady-state conditions. The lack of correlation is, of course, due to the transient mode, (speed, gear, horse power load, manifold pressure, all continuously varying). To effectively analyze this type of data and establish detailed and quantitative cause/effect relationships would have required a much more sophisticated testing technique than was within our capability, i.e. dozens of parameters would need to have been measured independently and simultaneously.

IV. - CONCLUSIONS & RECOMMENDATIONS

As in the previous volumes the conclusions and recommendations presented here will deal only with the work covered by this volume. However, since this is the last volume in the final report an overall project summary will be presented at the end of this volume.

A. Conclusions

1. The bulk of the work accomplished in this part of the project was the development of the Fairbanks driving cycles. Because of the changes in traffic controls during the period of investi-

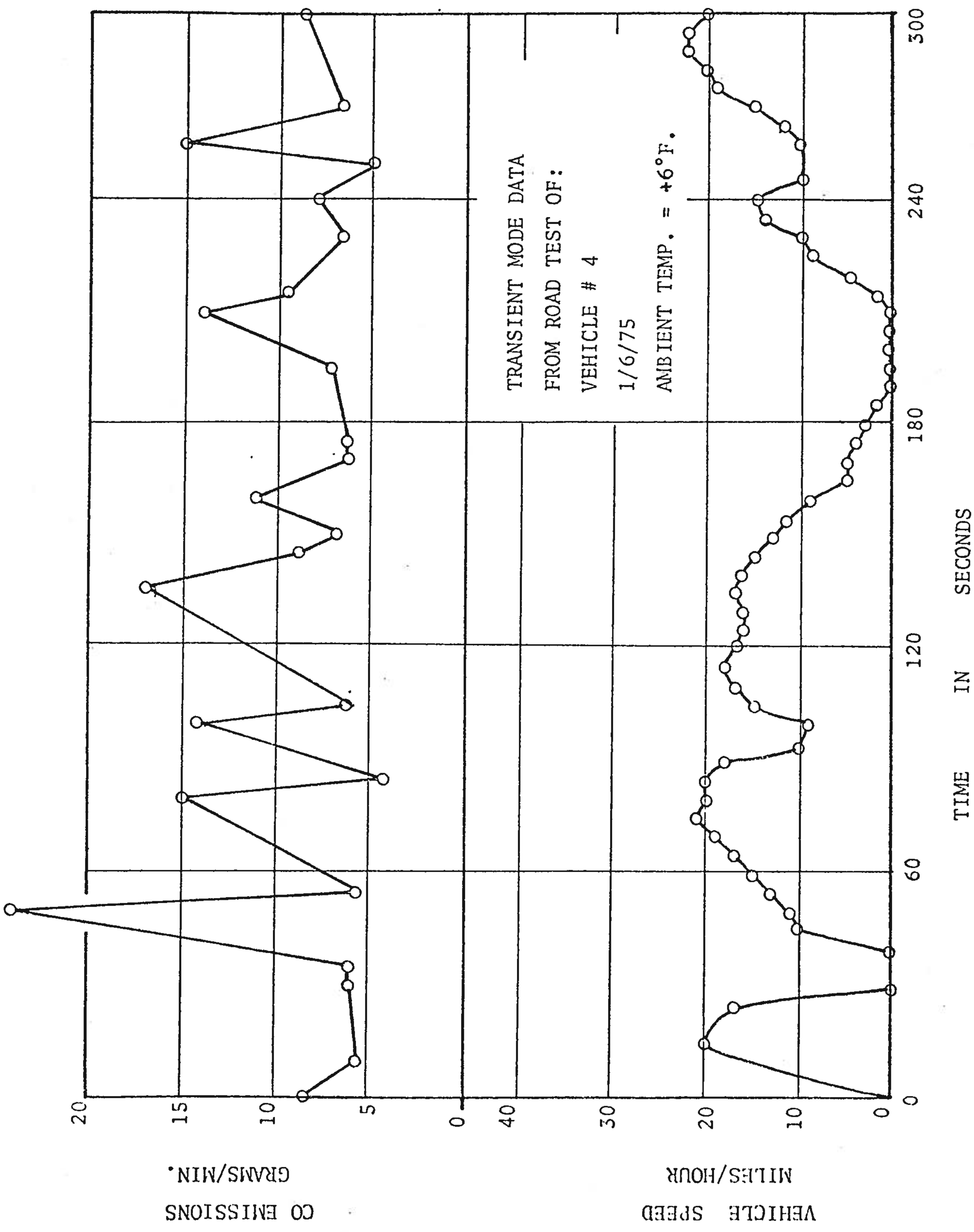

CO EMISSIONS
GRAMS/MIN.
20
15
10
5
0
VEHICLE SPEED
MILES/HOUR
40
30
20
10
0
TRANSIENT MODE DATA
FROM ROAD TEST OF:
VEHICLE # 4
1/6/75
AMBIENT TEMP. = +6°F.
0
60
120
180
240
300
TIME IN SECONDS

FIGURE 8.

gation it was necessary to develop two independent cycles. Two driving cycles representative of driving conditions in the urban area of Fairbanks were successfully developed and are presented in Figure 4 of this report. Both cycles are compatible with Federal Test Procedures and can be used to evaluate CO emissions representative of Fairbanks driving conditions if used in conjunction with the CVS testing method. They are also compatible with modal analysis methods for evaluating emissions specifically related to Fairbanks conditions.

2. Steady-state moving vehicle CO emission levels were measured using in-use vehicles. All measurements were made under winter driving conditions typical of the Fairbanks environment. The results of this testing are presented in Figure 5 of this text. However, it was not possible to say whether or not the Fairbanks environment is affecting steady-state CO emissions since no comparative data is presently available from other areas in the United States. Therefore, this aspect of the investigation remains inconclusive.

3. The infrared CO analyzer used for emission sampling during this investigation proved to be inadequate for effective measurements of CO emission levels from vehicles operating in the transient portion of the moving-vehicle mode. The results from this portion of the investigation remain inconclusive.

B. Recommendations

1. The development of a representative Fairbanks driving cycle has been a major step toward assessing the impact of moving-vehicle CO emissions on the urban area. The comparison between the Fairbanks

cycles and the CVS-3 cycle, which has been presented in this report, clearly suggests differences in driving conditions. An extremely valuable experiment could be conducted by testing the emission levels of a single vehicle using the CVS system and comparing the driving cycles on an emission basis. This would first point out any disparity between the Fairbanks cycle and the CVS-3 cycle and also clearly show the impact on CO emissions caused by the new traffic control strategy.

2. When modal emission data is finally published by EPA or others, a limited study should be undertaken to compare the steady-state CO emission data presented in this report with the data from other areas.

3. It is clear from the experience of this study that the simple infrared analyzer is inadequate when attempting to measure CO emissions in the transient moving-vehicle mode. However, the need for these data has not diminished and work should continue in this regard. We note, therefore, that future attempts to collect such data be funded at a level sufficient to allow acquisition of proper instrumentation.

4. We strongly recommend that further effort and adequate resources be devoted to quantifying modal emission factors for moving vehicles in Fairbanks. During our study Fairbanks has clearly accelerated its expansion in a manner reminiscent of the Los Angeles growth patterns of the 1950's. The opening of three new suburban shopping plazas in the past few months is evidence that urban sprawl will continue to compound the problems of air

quality management within an area which, like Los Angeles, has a meteorological environment tending to amplify the adverse impact of such growth. For this reason planners and government officials charged with protection of air quality will need, more than ever before, accurate tools to predict environmental impact. The Atmospheric CO Simulation Model (ACOSP) which was developed by the Institute of Water Resources at the University of Alaska is just such a tool. However, any model is only as good as its input data and realization of the full potential of the model will require accurate emissions input data. We therefore recommend that further investigation continue the attempt to quantify those emission factors which have been obtained as a result of this study. It is further suggested that a modal analysis model such as the Automobile Exhaust Emission Modal Analysis Model (Kunselman and McAdams, 1973) be incorporated in the ACOSP model to refine the model's sensitivity to new and more accurate emissions data as they become available.

V. SUMMARY

The investigation of moving vehicle CO emissions in Fairbanks consisted of two separate parts:

1. The development of a driving cycle representative of Fairbanks driving conditions.
2. The measurement of CO emission levels from in-use vehicles under winter driving conditions in Fairbanks.

Both of these original objectives have been accomplished and the results are presented in the test of this report.

Two independent driving cycles were developed. They offer a graphic presentation of driving patterns in the urban area of Fairbanks both before and after the implementation of a revised traffic control strategy. These cycles also make it possible to simulate driving patterns representative of Fairbanks for emission testing using the CVS Method.

Emission measurements were made and results presented for the steady-state portion of the moving-vehicle mode. Quantitative analysis of these results, however, were precluded due to the unavailability of comparative data from the contiguous United States.

Transient CO emissions were measured in the moving mode; however, limitations in the time response of the CO infrared analyzer precluded the acquisition of reliable quantitative results.

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7. U. S. EPA AP-42*, "Compilation of Air Pollutant Emission Factors" Environmental Protection Agency, Triangle Park, North Carolina, as revised December 1975.
8. F. Peter Hutchins, telephone conversation with author, July 1977.

9. "A Mathematical Model for Simulation of Carbon Monoxide in the Atmosphere," Institute of Water Resources, University of Alaska, Fairbanks, March 1976.

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VII. OVERALL PROJECT SUMMARY

This study began in October of 1974 with its major emphasis aimed at determining the impact of automotive CO emissions produced during cold-start operation on the Fairbanks environment. Early in the project, (Jan. 1975) the limits of investigation were expanded to include exploration of the impact of moving-mode CO emissions as well. And finally a third aspect was incorporated when a Multiple-Restrike Ignition System was evaluated for its acceptability as a cold-start CO emission control technique. The following table indicates the approximate percentage of project time and resources which were expended on each aspect of the investigation:

PROJECT OBJECTIVE	% OF TOTAL RESOURCES COMMITTED	
Cold-Start Study:		
Control vehicles	30	
Random vehicles	30	
Sub-Total		60%
Multiple-Restrike Evaluation		6%
Moving-Vehicle Study:		
Driving Cycle Development	22%	
Steady-state emission analysis	6	
Transient emission analysis	6	
Sub-Total		34%
TOTAL		100%

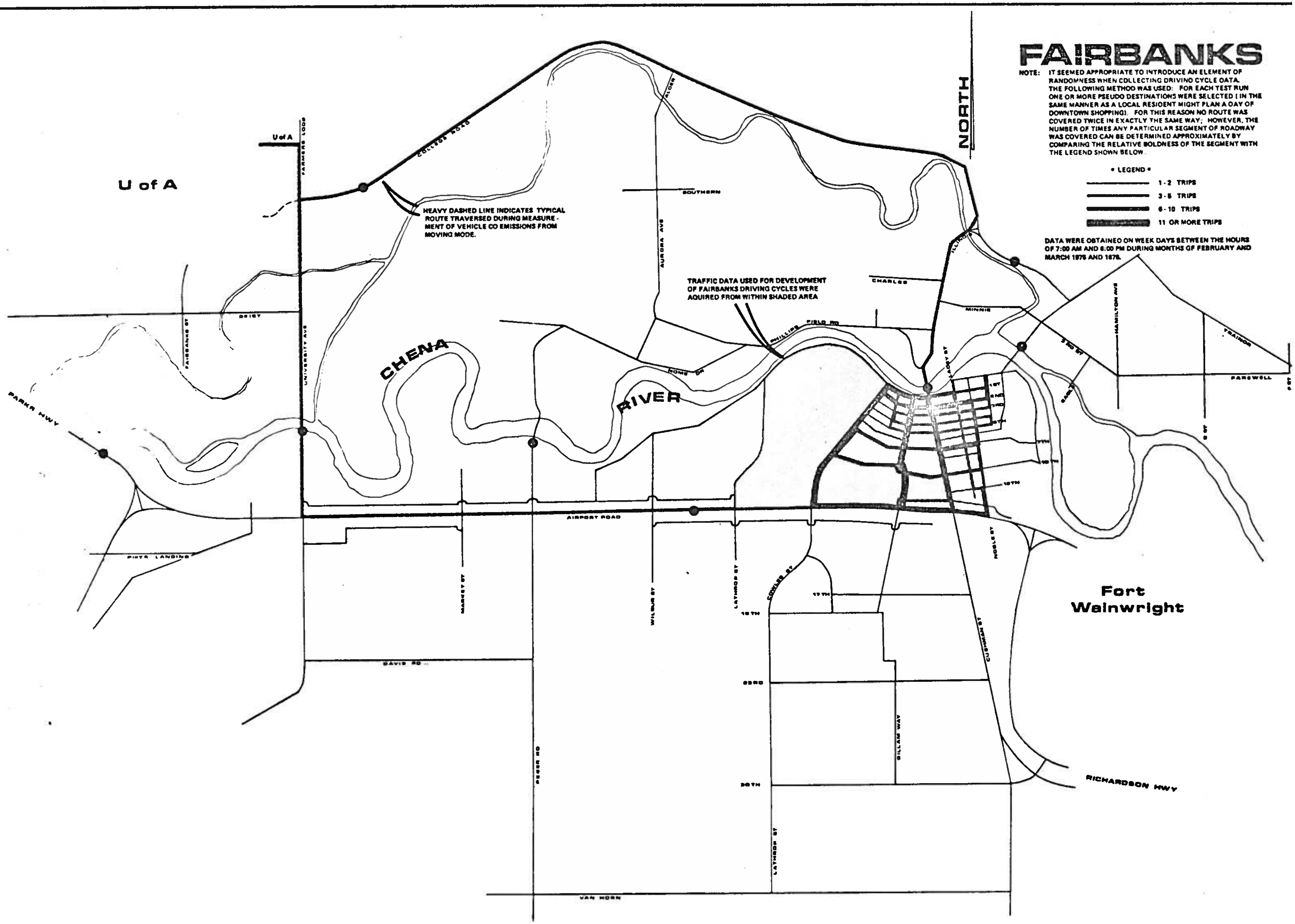
By far the largest single effort was expended in the area of the cold-start impact. This portion of the study was completely successful. All of the initial objectives were realized and a significant conclusion, presented in the first volume of the report, showed that as much as 76% of the ambient CO emitted in the downtown area of Fairbanks may be the result of cold starts.

The development of a driving cycle representative of Fairbanks driving conditions was the project goal which received the second greatest attention. Again, as with the cold-start study all objectives were accomplished. In fact, in this case, original goals were exceeded when two separate cycles were developed permitting comparative evaluation of newly implemented traffic control strategies in the urban area of the city. These cycles are also designed to be compatible with Federal Test Procedures for emissions evaluation using the CVS method.

The evaluation of the Multiple Restrike system proved to be a constructive effort despite the fact that its ability to control cold-start CO emissions proved negative.

Measurements of moving-vehicle emissions proved to be less than successful. While we did have some success with measurements in the steady-state portion of the moving mode, the unavailability of comparative data leaves the results inconclusive. Measurement of transient CO emission proved to be beyond the capabilities of the infrared analyzer used in this study, and all attempts to record reliable data from this mode failed.

Overall we feel that this project has proved very successful. All of the more significant aspects of the study achieved their projected goals. What disappointments did occur in no way impaired the overall integrity of the project and have proved valuable in themselves as part of the learning process. We feel also that there remains much work to do if we are to ever fully understand the relationships between ambient CO in Fairbanks and the motor vehicle.


FAIRBANKS
NOTE: IT SEEMED APPROPRIATE TO INTRODUCE AN ELEMENT OF RANDOMNESS WHEN COLLECTING DRIVING CYCLE DATA. THE FOLLOWING METHOD WAS USED: FOR EACH TEST RUN ONE OR MORE PSEUDO DESTINATIONS WERE SELECTED (IN THE SAME MANNER AS A LOCAL RESIDENT MIGHT PLAN A DAY OF DOWNTOWN SHOPPING). FOR THIS REASON NO ROUTE WAS COVERED TWICE IN EXACTLY THE SAME WAY; HOWEVER, THE NUMBER OF TIMES ANY PARTICULAR SEGMENT OF ROADWAY WAS COVERED CAN BE DETERMINED APPROXIMATELY BY COMPARING THE RELATIVE BOLDNESS OF THE SEGMENT WITH THE LEGEND SHOWN BELOW.
* LEGEND *
1-2 TRIPS
3-5 TRIPS
6-10 TRIPS
11 OR MORE TRIPS
DATA WERE OBTAINED ON WEEK DAYS BETWEEN THE HOURS OF 7:00 AM AND 6:00 PM DURING MONTHS OF FEBRUARY AND MARCH 1975 AND 1976.
NORTH
HEAVY DASHED LINE INDICATES TYPICAL ROUTE TRAVERSED DURING MEASUREMENT OF VEHICLE CO EMISSIONS FROM MOVING MODE.
TRAFFIC DATA USED FOR DEVELOPMENT OF FAIRBANKS DRIVING CYCLES WERE AQUIRED FROM WITHIN SHADED AREA
U of A
Fort Wainwright
CHENA
RIVER
COLLEGE ROAD
FARMERS LOOP
UNIVERSITY AVE
AIRPORT ROAD
AURORA AVE
SOUTHERN
ALDER
CHARLES
MINNIE
ILLINOIS
PHILLIPS FIELD RD
NOME DR
LACEY ST
NOBLE ST
CUSHMAN ST
LATHROP ST
WILBUR ST
MARKET ST
PEGER RD
DAVIS RD
VAN HORN
GILLAM WAY
COWLES ST
17TH
19TH
23RD
30TH
1ST
2ND
3RD
5TH
7TH
9TH
10TH
3RD ST
HAMILTON AVE
TRAINOR
FARWELL
GABLE
RICHARDSON HWY
PARKS HWY
PIKES LANDING
FAIRBANKS ST
GEIST