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DETERMINATION OF PERCENTAGES OF VEHICLES OPERATING IN THE COLD START MODE

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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DETERMINATION OF PERCENTAGES OF VEHICLES OPERATING IN THE COLD START MODE

by

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ABSTRACT

Estimates of the percentages of vehicles operating in less than the stabilized condition (i.e., cold mode) have been made for 60 locations in the Pittsburgh and Providence regions. These estimates were derived using detailed regional travel data for both regions.

Accurate knowledge of the percentages of vehicles operating in the cold mode at a particular study location is a key factor in estimating carbon monoxide emissions. That carbon monoxide emission rates are severely affected by operation in the prestabilized condition has been well documented through numerous laboratory studies. While these laboratory studies have served to characterize carbon monoxide emissions from cold operating vehicles with respect to variables such as ambient temperature and cold soak duration, the study being reported here examines specific traffic streams to identify the actual percentages of vehicles that are operating in the cold mode.

Cold start percentages are presented for the morning commuter hours, the mid-day period, the evening commuter hours, and the evening and early morning off-peak period for each of the 60 traffic streams analyzed. Results indicate that the percentage of cold operating vehicles is highly variable both among locations within an urban area, and during different time periods at any specific location. It is also indicated that the actual percentages of vehicles operating in the cold mode may be somewhat different from the percentages assumed in the Federal Test Procedure.

CONTENTS

Abstract iii
Figures vi
Tables vii
Acknowledgments ix
Executive Summary x

1. Introduction 1
   Background and Purpose 1
2. Technical Aspects of the Cold Mode Phenomenon. 3
   Cold Mode Characterization. 3
   Definition of Cold Mode Operation 10
   References. 14
3. Technical Aspects of the Data Used in the Cold Mode Analysis . 15
   Primary Data Base 16
   Supplementary Data Base 19
   References. 29
4. Study Methodology. 30
   General 30
   Selection of Study Links. 30
   Analytical Procedure. 30
   Limitations of the Procedure. 32
5. Results of the Analyses. 33
   Pittsburgh. 33
   Providence. 39
6. Conclusions of the Study 50
   Generalization Regarding Cold Mode Distribution 50
   Conclusions 53
   Recommendations for Further Study 55

Appendices

A. Federal Test Procedure 56
   References 61
B. Overview of the Comprehensive Planning Process 62
   Introduction. 62
   Background 62
   Travel Forecasting. 64
   References. 75
C Example of the Method Used to Identify the Percentage of Vehicles Operating in the Cold Mode. 76

Glossary 97

FIGURES

Number		Page
1	Representation of choke-on time as a function of ambient temperature	4
2	Cumulative HC and CO emissions during FTP driving cycle - Car A	6
3	Cumulative HC and CO emissions during FTP driving cycle - Car B	6
4	Cumulative HC and CO emissions during FTP driving cycle - Car C	7
5	Cumulative CO emissions during FTP driving cycle - Car G	7
6	Cumulative CO emissions during FTP driving cycle - Car I	8
7	Cumulative CO emissions during FTP driving cycle - Car J	8
8	Average vehicle CO percent deviation versus start-up temperature	9
9	Temperature dependency of carbon monoxide emissions - varied categories of vehicles	11
10	Cumulative distribution of the probable error for travel time runs made in Providence, Rhode Island	24
11	Study-link locations map, Pittsburgh, Pa.	35
12	Study-link locations map, Providence, R.I.	43

TABLES

Number		Page
1	Comparison of Cold Mode Cycle Length in Minutes as a Function of Soak Duration for Ambient Temperatures of 75°F and 20°F	12
2	Travel-Time Analysis Results - Providence, Rhode Island	20
3	Minimum Sample Size Requirements for Travel Time Studies With A Confidence Level of 95.0 Percent, Presented as the Number of Observations Required	21
4	Assessment of the Reliability of the Travel Time Data Compiled For Providence	23
5	Relative Volumes on Radial Arterials by Time Period and Direction, Shown as a Percentage of ADT	25
6	Computed 24-Hour Composite Average Speeds for Providence	26
7	Comparison of the Derived and Assigned Network Speeds for Providence	27
8	Analysis Link Descriptions, Pittsburgh	34
9	Percentage of Vehicles Operating in the Cold Mode, by Time Period, For 24 Locations in Pittsburgh	36
10	Analysis Links by General Category, Pittsburgh	37
11	Percentage of Vehicles in Cold Mode Operation by Time Period and by Location Group For Pittsburgh	38
12	Volumes of Cold and Stabilized Vehicles by Time Period and by Location Group For Pittsburgh	38
13	Percentage of Vehicles in Cold Mode Operation With 1 Minute Additional Access Time, Pittsburgh, Pa.	40
14	Percentage of Vehicles in Cold Mode Operation With 2.5 Minute Additional Access Time, Pittsburgh, Pa.	40

TABLES (continued)

Number		Page
15	Distribution of Trips by Time-From-Trip-Origin - Pittsburgh . . .	41
16	Analysis Link Descriptions, Providence	42
17	Percentage of Vehicles Operating in the Cold Mode, by Time Period, For 36 Locations in Providence	44
18	Analysis Links by General Category, Providence	45
19	Percentage of Vehicles in Cold Mode Operation, by Time Period and by Location Group For Providence	47
20	Volumes of Cold and Stabilized Vehicles by Time Period and by Location Group For Providence	47
21	Distribution of Trips by Time-From-Trip-Origin, Providence, R.I.	48
22	Percentage of Vehicles in Cold Mode Operation With 1 Minute Additional Access Time - Providence, R.I.	49
23	Percentage of Vehicles in Cold Mode Operation With 2.5 Minutes Additional Access Time - Providence, R.I.	49
24	Percentage of Vehicles in Cold Mode Operation by Distance From Central Business District For Two Corridors in Providence, R.I.	51
25	Percentage of Vehicles in Cold Mode Operation by Distance From Central Business District For Three Corridors in Pittsburgh, Pa.	52
26	Suggested Ranges of Values of the Percentage of Vehicles Operating in the Cold Mode For Various Conditions of Time and Location. .	54

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EXECUTIVE SUMMARY

STUDY OBJECTIVES

Numerous laboratory studies have shown that the emission rate of pollutants such as carbon monoxide and hydrocarbons is significantly higher during the first several minutes of vehicle operation compared with the emission rate after the vehicle has warmed up. In fact, the emission rate during the cold mode cycle can be several times higher than the rate during stabilized operation. Owing to its strong influence on emission rates, cold operation must be accounted for in any analysis of local or areawide vehicular emissions.

Laboratory studies have parameterized cold mode operation so that effects can be accounted for in air quality analyses if the extent of the actual cold mode operation is known. To date, little effort has been expended on defining the fraction of automobile travel that typically occurs in the cold mode. In response to this lack of information regarding the likely distributions of cold operating vehicles that occur on urban street systems, GCA/Technology Division, under contract to the U.S. Environmental Protection Agency, has undertaken an analysis that focuses on determining the diurnal distributions of cold operating vehicles that occur on urban street systems. This report describes the methods used in and the results of the analysis.

TECHNICAL ASPECTS OF COLD MODE OPERATION

The excess emissions associated with cold operation occur as a result of temporary imbalances in various combustion system parameters. For instance, when an automobile's choke mechanism is actuated, extra fuel is drawn into the combustion area. This extra fuel creates an imbalance in the air-to-fuel ratio, which results in incomplete fuel combustion, and hence, high emission rates of carbon monoxide and hydrocarbons. Other factors such as cylinder wall quenching and the temperature rise-time of catalytic converters also contribute to high emission rates during initial operation.

Numerous studies have defined the emission patterns during cold operation. These studies indicate that the rate of both carbon monoxide and hydrocarbon emission are much greater during the first 200 to 300 seconds of operation compared to the emission rate after temperatures have stabilized. Testing also has shown that the magnitude of the emission rate associated with cold operation is a function of ambient temperature; colder temperatures result in much higher emission rates during cold operation. Also, these tests indicate that ambient temperature has a relatively small effect on emission rates beyond the first several minutes of operation.

Recent analysis by the Environmental Protection Agency, Office of Mobile Source Air Pollution Control, have resulted in defining the duration of the cold mode cycle as a function of soak duration and ambient temperature. These relationships show, for instance, that at an ambient temperature of about 75°F, the duration of cold mode operation for a vehicle that has soaked for 30 minutes is about 2.4 minutes, while the duration for a vehicle soaked for 5 hours is about 5.5 minutes; at 20°F, the corresponding cold mode durations would be about 3.3 minutes and 6.0 minutes. The relationships developed from EPA's research were used extensively in the analysis being reported here.

STUDY APPROACH

General

The general procedure used in the study was to identify certain characteristics of trips occurring on each of a number of specific highway sections, and relating these characteristics to cold mode operation as defined by the previously mentioned EPA analyses. Specifically, the trip characteristics that were considered included (1) the elapsed time from the trip origin to the study site, and (2) the duration of the cold soak prior to beginning the trip. The primary source used to derive this information was comprehensive planning data obtained from the regional planning agency in each study area. These data were supplemented with field data collected by GCA/Technology Division, where required.

Study Scope

The scope of the study permitted analyses to be conducted in two cities. Selection of the cities was based on population and the availability and adequacy of the necessary data elements. The Cities of Pittsburgh, Pennsylvania and Providence, Rhode Island, were selected for study.

The intent of the study was to define the diurnal patterns of cold mode distribution on various types of roadways and in different urban settings. To accomplish this, a total of 60 highway sections were analyzed. Included were expressways, major arterials, minor arterials, and collector streets located in the central business district, outer fringe areas, residential areas, etc.

Study Procedure

The analysis of each study link was based on identifying the diurnal patterns of trips occurring on each link, as a function of the travel time from each trip origin, and cold soak duration.

Regional planning data were used to identify the origin of each trip occurring on each study link. The travel time from each origin to each study link was then determined using both regional planning data and the results of field studies conducted by GCA. Data files developed by the planning agencies were then utilized to determine the diurnal trip generation patterns and parking duration characteristics for various areas within the vicinity of the study links.

The data described above were used as the basis for disaggregating the total trips occurring on each link, into over 200 individual categories, which ultimately described each trip in terms of (1) time that it occurred, (2) travel time from its origin to the study link, and (3) the cold soak duration prior to beginning the trip. These distributions and the data developed by EPA regarding defining cold mode as a variable function of soak duration, were used directly to determine the percentages of cold operating vehicles on each study link.

STUDY RESULTS

A total of 60 separate highway links (24 in Pittsburgh and 36 in Providence) were analyzed and the cold mode distributions for each were identified. The percentages of cold operating vehicles identified were generally much higher than originally expected. For instance, several links in both cities were shown to have more than 70 percent cold operating vehicles during various time periods. Individual links were combined in each city to derive a composite estimate of the percentage of vehicles operating in the cold mode by location (e.g., central business district) and time period (e.g., during the morning peak hours).

These analyses showed wide variations in the percentage of cold operating vehicles from location to location and by time period. For example, in Pittsburgh, the percentages during the morning peak hours ranged from 0.4 (for an expressway link) to 26.8 (for links located near non-CBD generators); for the entire day, the percentages on links within the CBD ranged from 9.8 during the morning peak hours, to 38.3 during the afternoon peak hours.

Sensitivity analyses were performed to determine the effect of increasing the travel time between trip origins and study links by relatively small amounts. These analyses indicated that the computed percentages of cold operating vehicles were indeed sensitive to small changes in travel time. For example, the computed percentage of cold operating vehicles in the central business district of Providence during the morning peak hours was reduced from 20.7 to 11.7 by increasing travel time by 1 minute; by adding 2.5 minutes, this percentage was reduced to 1.0.

CONCLUSIONS

A primary conclusion of the study is that a wide range in the percentages of vehicles operating in the cold mode can be expected within an urban area and that these percentages can be expected to vary significantly by time of day. Also, it can be concluded that definite patterns may not necessarily exist in the distribution of cold operating vehicles from city to city; in fact, strong patterns may not exist from location to location within a particular city.

The data derived in the study were used as the basis for developing general recommendations for estimating the percentage of vehicles operating in the cold mode for various time periods and traffic environments. The recommended process consists of selecting a value from a range of values provided for several sets of conditions (urban setting and time period). The appropriate ranges are shown in Table 26, which appears on page 54 of this document.

CONTENT OF THIS REPORT

The report provides detailed information on a number of aspects of (1) the cold start mode in general; (2) the techniques used in the analysis; (3) the data base used; and (4) the results of the entire study. Section 1 provides a general introduction including discussion regarding the background and purpose of the study.

The technical aspects of cold mode operation are discussed in Section 2. Included are discussions concerning the primary relationships between cold operation and emission rates, and the factors that are instrumental in determining the impact of operating in the cold mode. Discussion is also provided regarding the definition of cold operation.

Section 3 provides a discussion of the general techniques used in the study. Included are descriptions of the mechanics of the procedure as well as the data and data sources used. A more technical discussion of the study methodology is provided in Section 4.

The results of the study are presented in Section 5. This section includes discussions of the results of analyzing the 60 study links both separately and in groups. Separate discussions are provided for Pittsburgh and Providence. The results of the sensitivity analysis are also discussed in this section. Section 6 discusses the conclusions of the entire analysis and offers several recommendations for further study.

Three technical appendices are provided. Appendices A, B, and C describe (1) the Federal Test Procedure; (2) the comprehensive planning process; and (3) an example computation of the percent of vehicles operating in the cold mode on a study link, respectively.

A glossary defining a number of technical terms used throughout the report is also provided.

SECTION 1

INTRODUCTION

BACKGROUND AND PURPOSE

Many techniques have been developed for analyzing the impact of vehicular traffic on ambient concentrations of pollutants such as hydrocarbons and carbon monoxide. A common element among all of these techniques is the expression of the rate that the pollutant is emitted into the ambient atmosphere. Numerous studies have resulted in the identification of factors that affect pollutant emission rates and have provided the basis for estimating the impact that these factors have, both separately and collectively, on the actual emission rate.

A factor that is of particular importance, especially with regard to the analysis of carbon monoxide, is the relationship between: (1) a vehicle's emission rate and ambient temperature, (2) the amount of time that the vehicle has been operating, and (3) the engine temperature prior to starting. During the first few minutes that a vehicle is operated, the rate of carbon monoxide emission is significantly higher than when the vehicle has warmed up. In fact, the rate that carbon monoxide is emitted during the first few minutes of cold operation can be several times greater than the rate after the engine has been operating for several minutes. The quantity of carbon monoxide produced within an area, then, may be strongly affected by the amount of travel that occurs by vehicles operating in a cold condition. Owing to its potentially strong influence on emissions, cold operation must be accounted for in any analysis that requires dimensioning the quantity of carbon monoxide generated by vehicular traffic.

Numerous laboratory studies have been conducted to define the impact of cold operation on emission rates. Also, studies have been conducted that characterize the cold operating phase as a function of several operational and environmental parameters. It can be concluded that cold vehicle operation has been adequately parameterized so that its effects can be accounted for in air quality analyses if the extent of the actual cold mode operation is known. To date, very little effort has been expended on either defining the fraction of automobile travel that occurs in the cold phase, or identifying a process that could be used to make this determination. In response to this apparent lack of information regarding the distributions of cold operating vehicles that actually occur on urban street networks, GCA/Technology Division, under contract to the U.S. Environmental Protection Agency, has undertaken an analysis that focuses on determining the types of cold mode distributions that occur in several characteristically different areas and during different time

periods. The analysis focused entirely on the portion of the vehicle population consisting of light-duty, noncommerical vehicles. Throughout the study, the primary concern was the effect of cold operations on carbon monoxide emissions; however, the results of the analysis can be applied directly to hydrocarbon emissions as well. The purpose of this report is to present a discussion of both the procedures used for the study and the results.

SECTION 2

TECHNICAL ASPECTS OF THE COLD MODE PHENOMENON

COLD MODE CHARACTERIZATION

Cold mode operation is defined in general terms as the first several minutes that a vehicle is operated after having not been operated for several hours. The primary manifestation of cold mode operation is an extraordinarily high emission rate of both carbon monoxide and hydrocarbons.

The excess emissions associated with cold operation occur as a result of a temporary imbalance in the combustion system parameters. In order for ignition to occur in a gasoline engine, the fuel introduced into the cylinder must be vaporized and there must be present an appropriate balance or ratio* between the quantities of air and vaporized fuel. Gasoline does not vaporize as well at lower temperatures as it does in the relatively high temperature ranges that are typical of stabilized engine operation. Therefore, when a "cold" engine is being started, the rate of gasoline vaporization that occurs in the combustion area is much less than when the engine is operating at normal temperature. As a result, an imbalance occurs in the air-to-fuel ratio; this imbalance can be so severe that ignition will not occur. To compensate for this temporary imbalance in the air-to-fuel ratio, the fuel delivery system is equipped with a choke mechanism, which, when activated, restricts the flow of incoming air to the point where a vacuum occurs in the intake manifold. The vacuum causes additional fuel to be drawn into the manifold resulting in extra fuel being delivered to the combustion areas. The increase in the total amount of fuel delivered to the cylinder compensates for the reduction in the rate of vaporization, so that the net result is an air-to-vaporized fuel ratio that is suitable for ignition. Although the ratio of air-to-vaporized fuel becomes balanced when the choke is functioning, the ratio of air to total fuel becomes imbalanced owing to an insufficient quantity of combustion air being present. This imbalance results in incomplete fuel combustion; two major products of incomplete combustion are carbon monoxide and various unburned hydrocarbon compounds.

The choke mechanism on most vehicles is actuated automatically by a heat sensor incorporated into a temperature-sensitive engine component such as the exhaust manifold. The rise-time from ambient to stabilized temperature for the heat sensitive components generally lags the rise-time in the entering fuel temperature and combustion chamber temperature by various amounts of time, thereby assuring adequate choke-on time. Studies have shown the

*This ratio is commonly referred to as the air-to-fuel ratio.

choke-on time to be a function of ambient temperature. Figure 1 provides an indication of choke-on time as a function of ambient temperature.

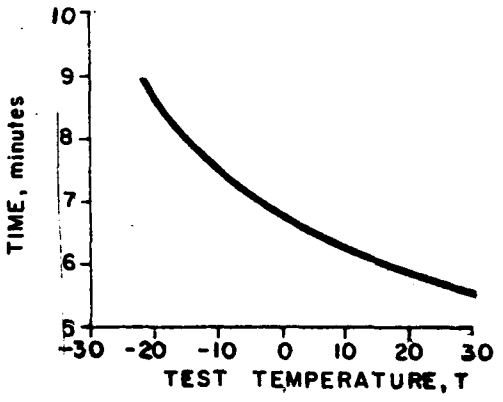

Figure 1. Representation of choke-on time as a function of ambient temperature.

Production of excess emissions during the cold stages of vehicle operation occurs also as a result of a phenomenon known as wall quenching. Wall quenching is a combustion phenomenon that occurs when a flame moves towards a relatively cool cylinder wall. The cool cylinder wall slows and effectively stops combustion in the vicinity, thus a layer of unburned and partially burned fuel remains at the wall surface at the end of the combustion stroke. The thickness of the layer is a function of several parameters including the cylinder temperature and pressure, the presence of cylinder deposits, and the wall temperature itself. Obviously, the cylinder and wall temperatures are much lower during initial operation than after warm-up. These lower temperatures result in a thicker layer of unburned or partially burned fuel during each stroke, which contributes to the total excess emissions associated with cold-mode operation.

Emissions from newer vehicles equipped with catalytic converters are affected by cold operation because of an additional factor. The converter, which functions as the primary emission control device, does not begin to operate efficiently until it reaches a certain temperature. The time required to reach the most efficient operating range is generally around 200 to 300 seconds, regardless of the ambient temperature.[2] Therefore, during the several minutes that it takes for the converter to reach optimum operating temperature, carbon monoxide and hydrocarbons emission rates are somewhat higher than during warmed-up operation.

Temperature obviously has a considerable effect on cold mode emission characteristics. The relative impact that ambient temperature has on emission rates has been analyzed in the laboratory during several studies. Of particular importance is the fact that these studies conclude that the effects of varying ambient temperatures are apparent only during the first several

minutes of operation. In one set of tests,[2] the effect of ambient temperature on carbon monoxide and hydrocarbon emission rates for three configurations of standard 1970 production cars, and three 1970 production cars equipped with advanced (with respect to the 1970 model year) emission control devices, was analyzed. The testing involved measuring the emissions produced by each vehicle as it was operated from a cold condition* through the Urban Dynamometer Driving Schedule, which is included in the Federal Test Procedure (see Appendix A). Tests were performed at several different ambient temperature conditions for each vehicle. Cumulative emissions were then identified as a function of elapsed operating time and temperature; test results are illustrated in Figures 2 through 7, below.

These figures show quite vividly that the emission rates of both hydrocarbons and carbon monoxide for the test cars† are generally not sensitive to changes in ambient temperature beyond, say, the first 200 to 300 seconds of operation, but within the first 200 to 300 seconds, temperature has a marked effect on emission rates.

In another series of investigations[3] on the effects of cold ambient temperatures on light-duty vehicle emissions, nine 1973 vehicles were considered. These tests involved a standard 23-minute FTP driving schedule during which exhaust samples were collected for three cycles of operation. The first cycle included the first 505 seconds of the schedule representing the "cold" operating phase. The second cycle involved the stabilized phase, which represents the remainder of the 23-minute cycle. The third cycle represents a "hot start" condition, which involves repeating the first 5.5 seconds of the driving schedule after a 10-minute engine-off period. For this series of tests, an ambient temperature of 60°F was established as a baseline condition. Comparisons were made of carbon monoxide emissions for each mode at ambient temperatures ranging from 0°F to 80°F.

The results of the tests are shown in Figure 8. This figure shows the relative effect of temperature differences (with respect to an ambient temperature of 60°F) for each of the three test phases and the composite.** Figure 8 shows, again, that the relative effect of various ambient temperatures is insignificant beyond the first few minutes of operation; this is shown by comparing temperature effect on Bag 1 emissions (the first 505 seconds of operation) to the Bag 2 emissions.

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*Cold condition implies that the vehicles had not been operated for at least 12 hours prior to testing.

†HC emissions for Test Cars G, I, and J (Figures 5 to 7) were conducted but are not reported here.

**The composite is computed using the sum of 43 percent of Cycle 1 emissions, 100 percent of Cycle 2 emissions, and 57 percent of Cycle 3 emissions (see Appendix A).

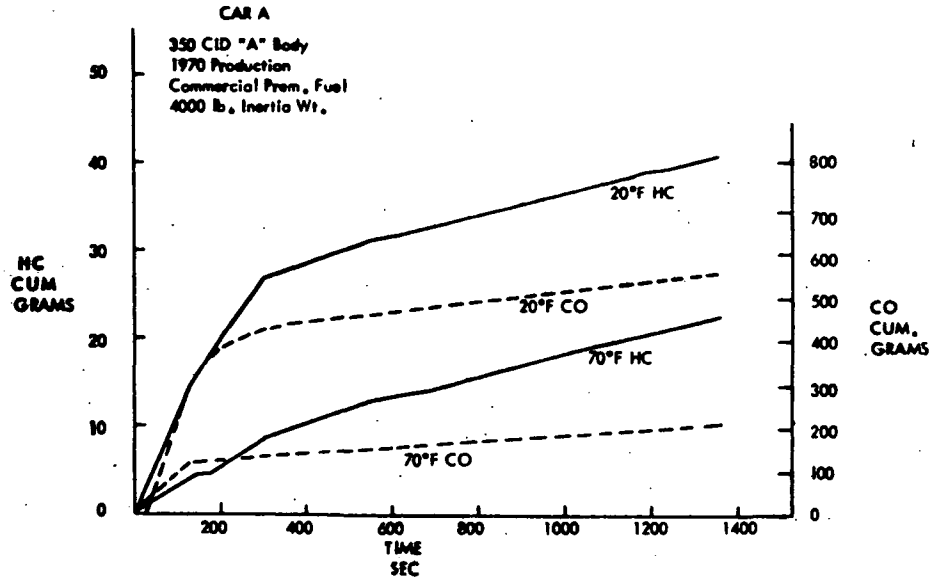

Figure 2. Cumulative HC and CO emissions during FTP driving cycle - Car A.

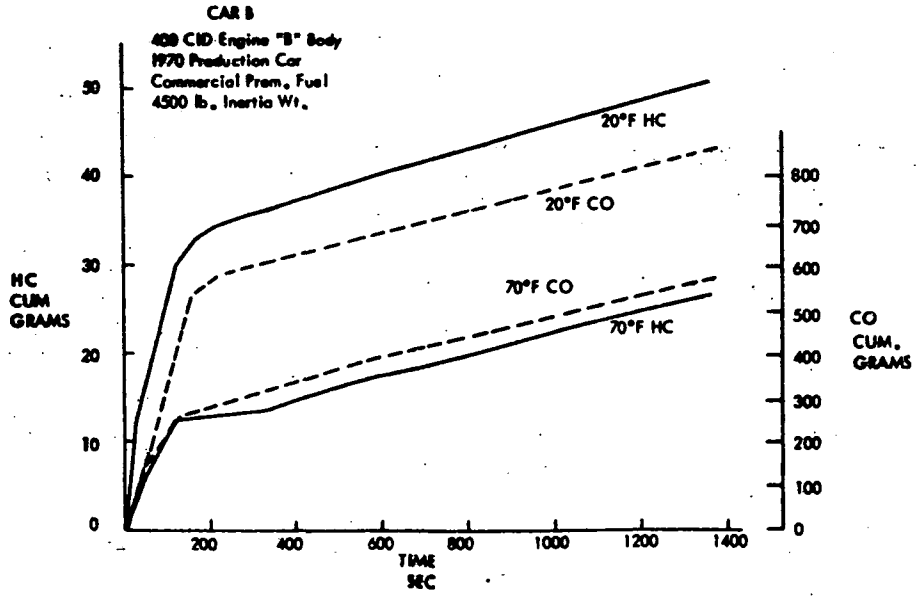

Figure 3. Cumulative HC and CO emissions during FTP driving cycle - Car B.

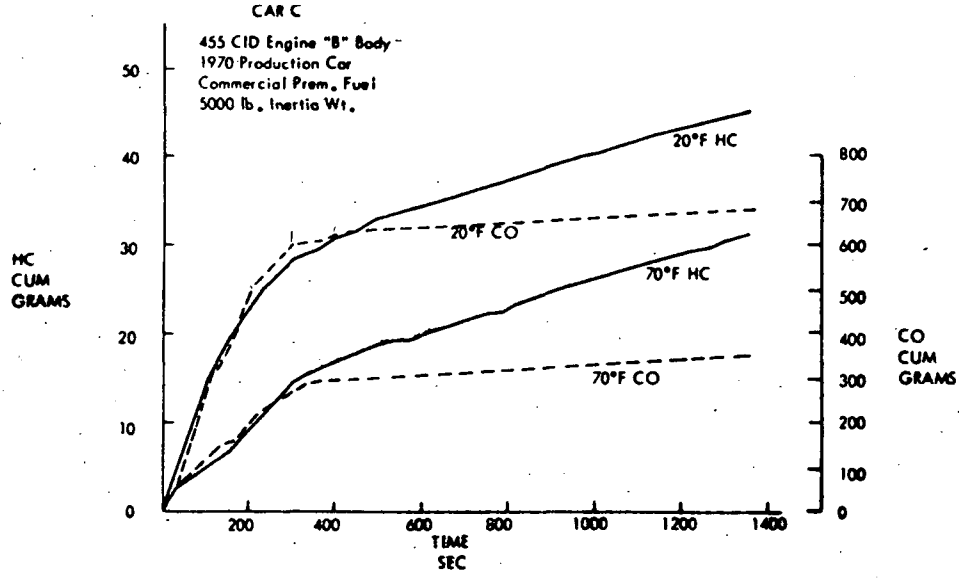

Figure 4. Cumulative HC and CO emissions during FTP driving cycle - Car C.

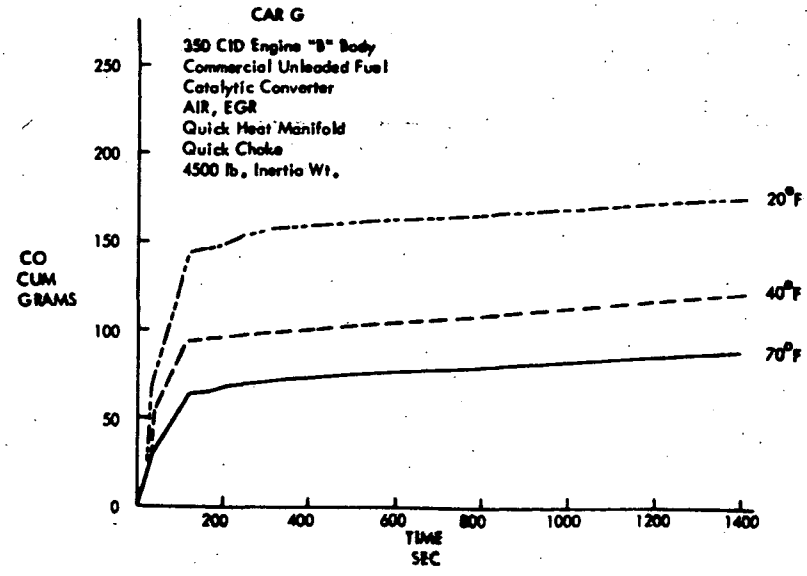

Figure 5. Cumulative CO emissions during FTP driving cycle - Car G.

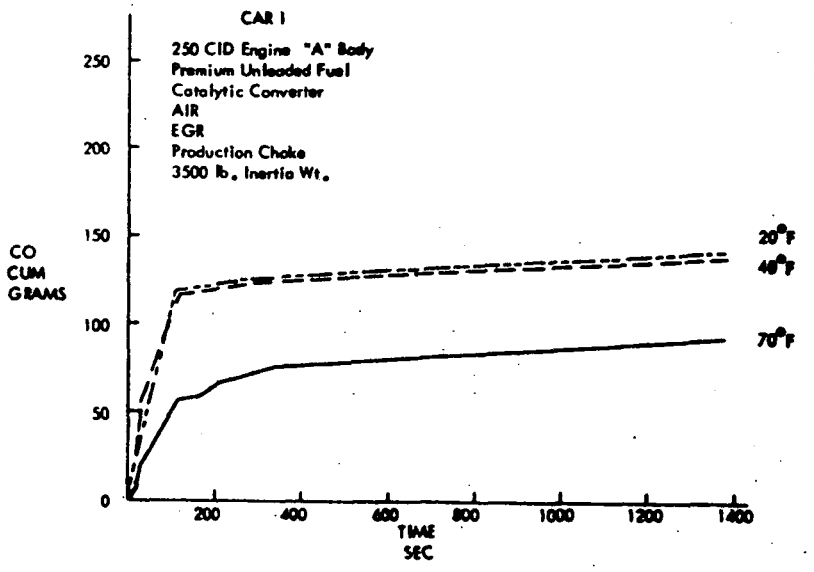

Figure 6. Cumulative CO emissions during FTP driving cycle - Car I.

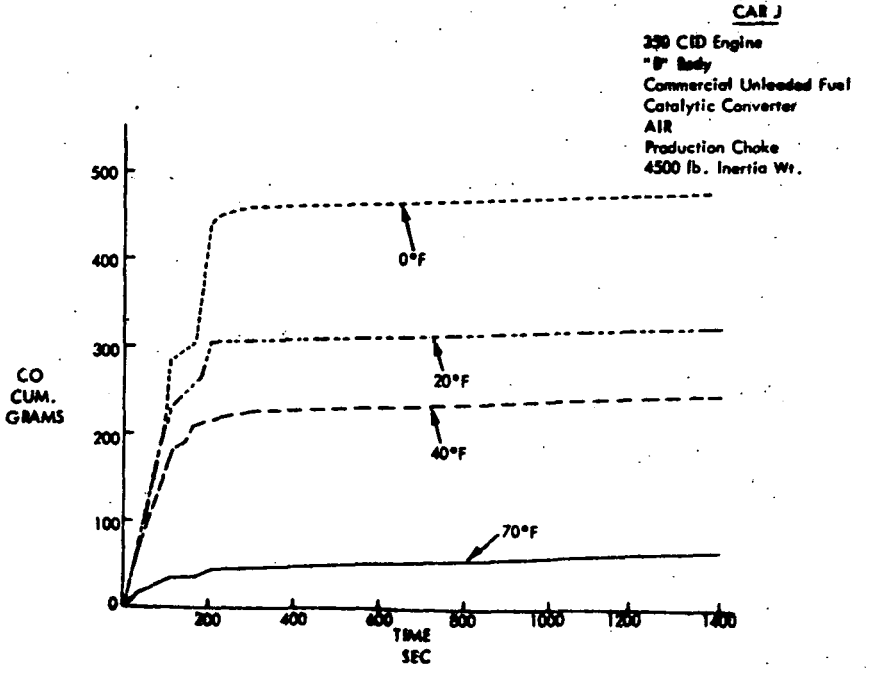

Figure 7. Cumulative CO emissions during FTP driving cycle - Car J.

What about based on temperature of coolant in the engine?

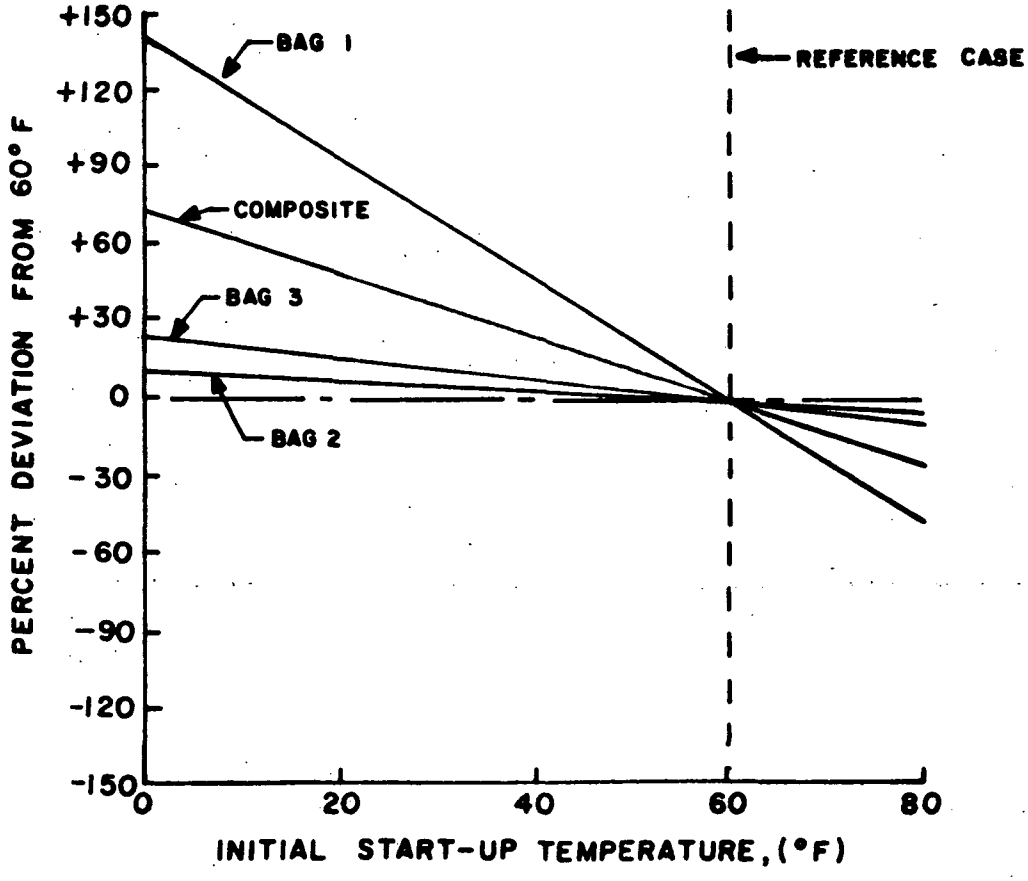

Figure 8. Average vehicle CO percent deviation versus start-up temperature.

The results of a third study[4] also indicated the significance of the first few minutes of cold operation. In this study, 26 production vehicles of various model years and configurations were tested using the FTP driving cycle. The testing was conducted at ambient temperatures of 20°F, 50°F, 75°F and 110°F. The average emission rates for each phase of the FTP driving cycle and a composite emission rate were defined for various groupings of vehicles; these are shown in Figure 9.

Figure 9 provides a good indication of the magnitude of the effect that cold mode operation has on emission rates. The effect is best illustrated by directly comparing the Bag 1 and Bag 2 emission rates. The curves for catalyst vehicles operating at 20°F indicate that during the first 505 seconds of operation, the emission rate is about 130 grams per mile while the Bag 2 rate is about 3 or 4 grams per mile. The importance, then, of accounting for cold mode operation in any analysis of carbon monoxide is obvious. As an illustration, if emissions were computed for a specific location first assuming (1) an ambient temperature of 20°F, (2) a vehicle mix whose emission characteristics were similar to those for 1973 - 1974 model year vehicles shown in Figure 9, and (3) all vehicles operating in the warmed-up (stabilized) mode, the result might yield the quantity X, which would represent the product of an average emission rate (in this instance, about 60 grams per mile based on Figure 9) and a travel factor defining the quantity of travel (in vehicle-miles). If a second analysis were performed using the same assumptions except that all vehicles were operating in the cold mode (obviously an extreme assumption), the results would be the quantity 3.8 X; this reflects the difference in emission rates for cold and stabilized operating modes for the representative vehicle population. If it were assumed that the vehicle population was comprised of all catalyst vehicles, the difference would be much greater (again, based on Figure 9).

DEFINITION OF COLD MODE OPERATION

It can be concluded from the previous discussion that cold-mode operation is a time-dependent function. The standard definition of cold mode operation is that it represents *the first 505 seconds of vehicle operation following a 4 hour (minimum) engine-off period.*[5] This definition implies that a discrete function exists between cold mode operation and the cold soak period.* Recall, however, that in the previous discussion it was indicated that both ambient and engine temperatures appear to be critical determinants of cold mode operation. The figures presented in that section indicate that ambient temperature does not have a large effect on the time required to stabilize (ambient temperature does have a very significant effect on the rate of emissions, however). Apparently, then, the rise-time to stabilized operating temperature is not affected to a large extent by a differential in ambient temperature of, say, 50°F (20°F to 70°F). However, the temperature within an engine ranges from ambient up to about 2000°F in the combustion area (cylinder walls) and over 200°F for fuel delivery components. Obviously, when an engine is shut down, these components begin to cool down to the ambient temperature. If the

*Cold soak is defined as the time interval that a vehicle's engine is not operated.

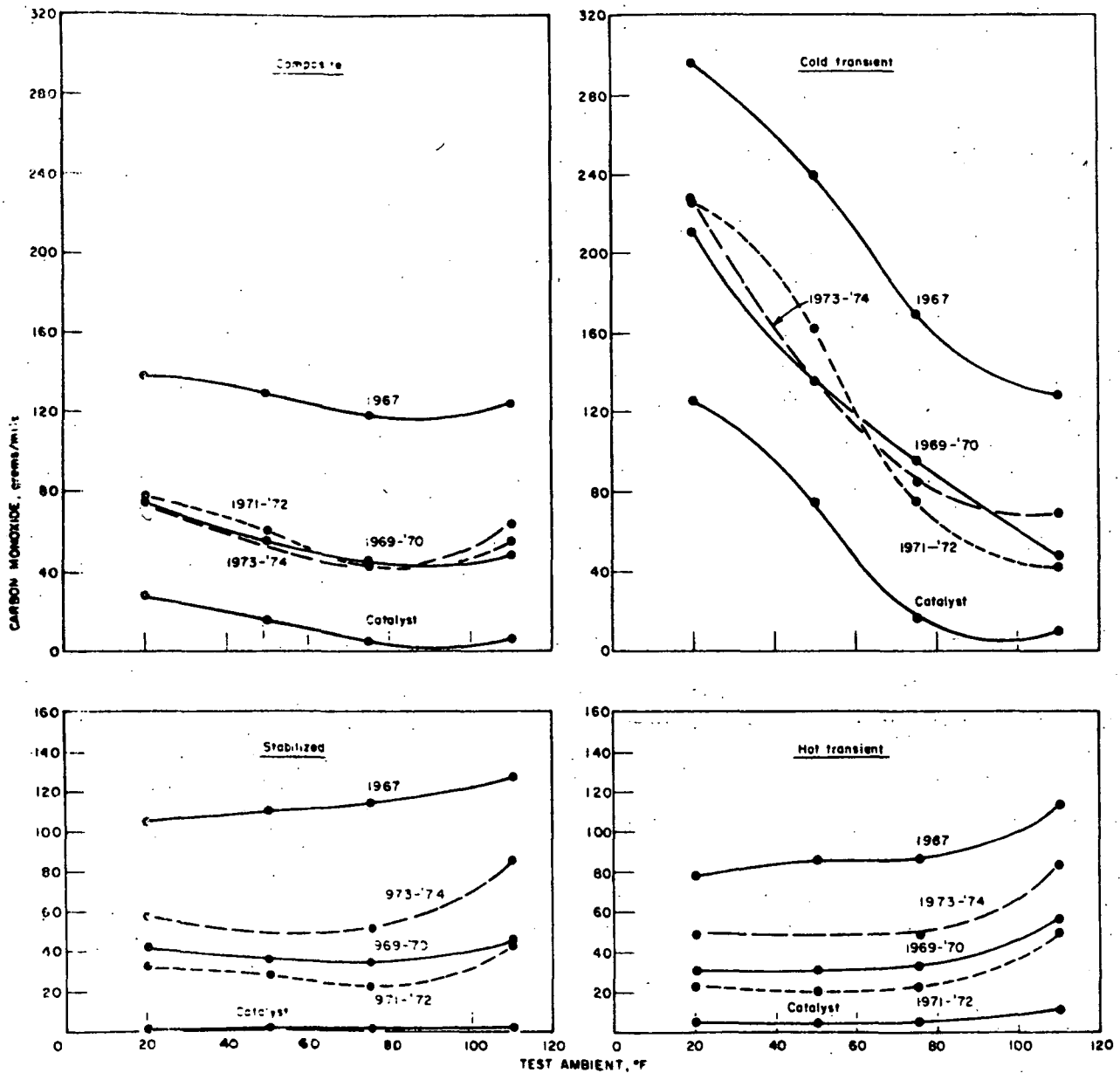

Figure 9. Temperature dependency of carbon monoxide emissions - varied categories of vehicles.

engine is restarted before the components reach ambient temperature, the amount of time required to again reach the hot stabilized condition would be reduced. Limited testing[6] by the U.S. Environmental Protection Agency, Office of Mobile Source Air Pollution Control, has indicated that the time required to reach the hot stabilized mode is indeed a continuous function of the engine starting temperature. In these analyses, the starting temperature is considered implicity to be a function of the soak time. In this connection, equations were developed describing the required time to reach the stabilized mode as a function of cold soak period; one of these equations is

$$t = 3.11\ S^{0.36} \qquad (1)^*$$

where t = time in minutes to reach the stabilized mode

S = soak time in hours.

The time t defined in equation 1 represents the time to stabilize when the ambient temperature is about 75°F. Testing was also performed at temperatures of about 20°F and an equation was derived representing the time required to stabilize (t′) again as a function of the cold soak duration; this equation is

$$t' = 2.61\ S^{0.36} + 1.32 \qquad (2)$$

where t′ = time in minutes to reach the stabilized mode at an ambient temperature of 20°F

S = soak time in hours.

The effect of ambient temperature on the cold mode cycle length can be seen by comparing the results of equations 1 and 2 applied to a set of arbitrary cold soak durations; this is presented in Table 1, below.

TABLE 1. COMPARISON OF COLD MODE CYCLE LENGTH IN MINUTES AS A FUNCTION OF SOAK DURATION FOR AMBIENT TEMPERATURES OF 75°F and 20°F

Ambient temperature, °F	Cold soak duration, hours								
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5
75	2.4	3.6	4.3	4.9	5.3	5.8	6.1	6.4	6.7
20	3.3	4.4	5.0	5.4	5.8	6.1	6.4	6.8	7.0

Table 1 clearly shows that the effect of ambient temperature on the cold mode cycle length is not nearly as severe as is the cold soak duration.

*This equation has been normalized to reflect assumptions in AP-42; for analyses not associated with the emission factors presented in AP-42, a slightly different equation applies.

Basic guidance in accounting for cold mode operation in air quality analyses is provided in AP-42.[5] Contained in AP-42 are equations for computing cold mode adjustment coefficients to be applied to composite emission factors for light-duty vehicles.

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SECTION 3

TECHNICAL ASPECTS OF THE DATA USED IN THE COLD MODE ANALYSIS

BACKGROUND OF THE STUDY METHODS

As indicated in Section 1, the primary objectives of this study were to determine the distributions of "cold" vehicles operating in traffic streams at various urban locations and, based on these determinations, develop a general statement regarding the distributions that would be expected at similar locations in any urban area.

The general procedure used in the study was to identify certain characteristics of all trips occurring on each of a number of specific street sections in two major U.S. cities, and relate these characteristics to cold mode operation. From the previous discussion regarding the nature of the cold mode phenomenon, it is apparent that two trip characteristics that would be of particular importance in the analysis of cold mode operation are (1) the elapsed operating time from starting the vehicle, and (2) the duration of the cold soak cycle prior to starting the vehicle. A primary task in this study, then, was to identify these two characteristics for each trip occurring on each of the street sections analyzed.

The primary data source that was used in the study was comprehensive transportation and land-use planning data (details of this data will be provided later); only limited field studies were required to supplement this data.

The scope of the study permitted analyses to be conducted in two cities. Selection of the cities was based on two criteria. First, the comprehensive planning data base had to be both accessible and adequate. In this connection, numerous metropolitan planning organizations were contacted and it was determined that several apparently had adequate data and were willing to accommodate any requests for it. The second criterion concerned the desire to analyze cities of different population categories. Specifically, the intent was that one city (actually, the urbanized area) be within the population range of 500,000 to 1 million, while the other city's population would be greater than 1 million. From a rather extensive list of possible sites, the Cities of Pittsburgh, Pennsylvania, and Providence, Rhode Island were selected. It is noted that there were no compelling reasons for selecting these two particular cities over others identified as potential study sites; Providence and Pittsburgh appeared to offer only minor advantages over several of the other cities.

PRIMARY DATA BASE

A most crucial aspect of any study is the data that are used. The reliability of the results of a study is obviously closely related to the quality of the data used. It is appropriate, then, that a study report include a complete description of the data including its sources, methods of derivation, reliability and limitations, and application in the study.

The following presents descriptions of both the comprehensive planning programs for Pittsburgh and Providence (an overview of the entire comprehensive transportation planning process is provided in Appendix B) and of the individual data elements from the comprehensive planning programs that were used in this study. Also included is a description of supplementary data developed for the study.

Pittsburgh Regional Planning Process

During March 1966, the Southwestern Pennsylvania Regional Planning Commission (SPRPC), in cooperation with the U.S. Bureau of Public Roads, the U.S. Department of Housing and Urban Development, and the Pennsylvania State Highway Department, began a comprehensive land use and transportation planning program for the region comprised of the Counties of Allegheny, Armstrong, Beaver, Butler, Washington, and Westmoreland. The stated objectives of the program were to develop a comprehensive land use and transportation plan for southwestern Pannsylvania and, at the same time, to qualify the region for continued federal funding by satisfying the requirements of Section 134 of the Federal-Aid Highway Act of 1962.

The initial effort focused on developing a detailed data base describing various features and characteristics of the 4,500 square mile region. The first task undertaken was a housing unit survey, which established the geographic location of all housing units in the region. This base provided the universe from which a sample was drawn for conducting home interviews.

The home interview survey was designed as a 4 percent sample of all dwelling units in the urbanized portion of the planning region. Interviews were conducted during 1966 at each household in the sample to obtain information regarding population, employment, household socioeconomic characteristics, and travel patterns of members of each household.

Additional inventories and surveys were conducted to obtain information on travel parameters. These included truck and taxi surveys, roadside interviews (external travel surveys), on-board transit surveys, and inventories of the regional transit system and the highway system.

The data obtained from the initial surveys and inventories were utilized in the trip generation, trip distribution, modal split, and traffic and transit assignment procedures. The results of these and other analyses were used to forecast travel patterns for future years to the year 2000 based on various "sketch planning" scenarios; these travel patterns have provided the basis for developing specific transit and highway improvement plans for the region.

The Providence Planning Process

Comprehensive land use and transportation planning was initiated in the Providence region in 1961 under the direction of the Rhode Island Statewide Planning Program (RISPP). The intent was specifically to develop a comprehensive transportation and land use plan for the Providence region.

Inventories and surveys were conducted during the first stage of the planning process and again several years later in 1964. Home interview surveys were conducted in the Providence area using sample rates of 5 to 10 percent. Other surveys were also conducted to establish transit use patterns and trip characteristics of vehicles entering the region. Inventories of land use, housing, and the regional highway and transit systems were conducted as well. These data were utilized to develop trip generation, trip distribution, and traffic assignment analyses required in the travel forecasting process.

During 1970, a decision was made to update the existing origin-destination data base. This decision was based on several factors including (1) a major portion of Interstate Highway System in the region had changed travel patterns and characteristics significantly since the last survey was taken, (2) the existing data base had two base years (1961 and 1964), therefore the reliability of models developed from the data was somewhat diminished, and (3) the evolving planning philosophy focused on small area analysis rather than corridor analysis, which generally required a higher level of confidence in the model's ability to produce reliable results.

The O-D survey update involved a small sample size (overall, about 0.42 percent of the households). Interviews were conducted both by telephone and in person to obtain data of the type previously discussed. This update also included external O-D surveys and on-board transit surveys. These data, supplemented with the earlier data, were used to develop new travel pattern estimates for the region.

Planning Data Used in the Cold Mode Analysis

The same basic types of data were used for both the Pittsburgh and the Providence analyses. The first data element that will be discussed is trip distribution data. Trip distribution data were provided in the form of trip tables indicating the number of auto-driver trips generated from each analysis zone, that used a designated network link. These tables were generated using the Urban Planning System 360 battery program LINKUSE.[1] This program identifies all origin-destination pairs and the number of trip interchanges associated with each pair that have assigned travel paths that traverse a specified link, combination of links, or node. Trip distributions of this type were obtained for 24 links and nodes in Pittsburgh and 36 links and nodes in Providence. The primary purpose of these data was to identify the origin zones of all trips using each study link.

The second data element that will be discussed is travel time data. Travel time data in the form of skim trees were obtained from each planning agency. Skim trees are simply tabulations of the one-way travel time between

a zone pair over the assigned network route. A criterion used in selecting specific study links was that one end of the link had to be located at a centroid connector. This permitted the analysis of only the skim tree data that applied to the study links. In other words, it was specified that the skim tree data should indicate the travel time from specific zones centroids (those centroids located at the study link) to all other zone centroids rather than from each zone centroid in the network to all other zones. Although this provided a significant cost saving, it also introduced some error into the analyses by the fact that the travel times are from the zone located at the study link to all other zones rather than from all zones to the zone adjacent to the study link. It was assumed that the travel time from zone A to zone B is the same as the time from B to A. In most instances this assumption is valid; however, in instances where this assumption does not hold, the differences are quite small. The travel times indicated zone-to-zone travel; the interest, however, was zone-to-link travel time. This was obtained by subtracting the travel time increment associated with the zone centroid connector (adjacent to the study link) from the total zone-to-zone travel time. The travel time data described here were compiled using the Urban Planning System 360 battery program FMTSKIM[1]

Another data element used was the home interview trip record file for both regions. These are computer tapes containing data derived from the home interviews. The following list provides an example of the types of information regarding each person trip that are contained in the file for the Pittsburgh region:

- Origin trip purpose (home, work, shopping, school, etc.)
- Origin civil division (municipality)
- Destination trip purpose (home, work, shopping, school, etc.)
- Destination civil division (municipality)
- Mode of travel (auto driver, auto passenger, transit passengers, etc.)
- Time of trip (clock time at the midpoint of the trip)
- Blocks walked, origin and destination
- Type parking (curb, off street, etc.)
- Time parked (minutes)
- Origin SPRPC zone (analysis zone number)
- Destination SPRPC zone (analysis zone number)
- Home SPRPC zone (analysis zone number)
- Home civil division (municipality)

- Gravity model trip purposes (home based, work, shopping, etc.)
- Trip factor (expansion factor)
- Highway travel time (travel time in minutes)

The data contained in these files were used to determine various trip characteristics for different analysis districts (aggregations of analysis zones). For example, analyses of parking characteristics were developed from these files. An additional file - the historical record file - for each region was also obtained. These proved useful in a number of instances where link characteristics had to be identified.

The only other element of data obtained from the planning regions was general background material - base maps, network maps, traffic volume data, etc.

SUPPLEMENTARY DATA BASE

Travel Speed Analysis

One of the most critical elements in this study involved determining the time from trip-origin distributions for each study link. As indicated, the skim tree data obtained from the planning agencies provided this information. Owing to the critical nature of this data element, field tests were conducted by GCA to verify the reasonableness of the skim tree data.

Providence--

Field testing in the Providence region was conducted during the period 15 to 30 December 1976. Six arterial routes radiating from the Providence central business district (CBD) and four downtown or outlying local streets were selected for study. The so-called "floating car" technique was used to determine the travel time between designated checkpoints along each route. A total of three runs was made in each direction (inbound and outbound) on all arterial routes during each of three-time periods including the morning peak (7 a.m. to 9 a.m.), off-peak (10 a.m. to 2 p.m.) and afternoon peak (3:30 p.m. to 5:30 p.m.); runs on the four local streets were limited to the off-peak periods.

The results of the travel time runs are shown in Table 2.

As would be expected, the travel time runs for each time period yielded a range of speeds for each route (see Table 2). Several methods are available for assessing the representativeness of this type of data. The technique that was applied here is based on the assumption that sample means of travel time have a normal distribution for any study route. Using this assumption, techniques typically associated with statistical quality control were applied to derive estimates of the relative error for a desired confidence level, based primarily on the observed average range for the travel time runs and the number of observations used to estimate the average range. Tables have been

TABLE 2. TRAVEL-TIME ANALYSIS RESULTS - PROVIDENCE, RHODE ISLAND

			Measured travel speed (mph)											
			a.m. Peak period				Off peak period				p.m. Peak period			
Street	Limits	Direction	Run 1	Run 2	Run 3	Ave.	Run 1	Run 2	Run 3	Ave.	Run 1	Run 2	Run 3	Ave.
• Allens Ave.	Ocean St. - Eddy St.	Northbound	25.2	22.9	24.5	24.2	21.1	22.3	24.4	22.6	20.2	21.3	24.3	21.9
		Southbound	23.5	26.4	30.9	26.9	22.1	23.4	23.3	22.9	27.2	27.1	-	27.2
• Eddy St.	Allens Ave. - Broad St.	Northbound	24.2	22.8	22.3	23.1	21.7	19.5	16.7	19.3	24.7	23.8	-	24.2
		Southbound	20.0	20.0	22.0	20.7	16.6	10.3	14.0	13.6	9.8	17.1	18.9	15.3
• U.S. Route 6	Winter St. - Atwood Ave.	Eastbound	21.0	25.4	24.3	23.6	18.2	19.6	21.3	19.7	21.0	20.1	20.9	20.6
		Westbound	26.5	23.0	25.5	25.0	19.4	18.3	17.5	18.4	20.9	18.1	20.8	19.9
• Elmwood Ave.	Broad St. - Warwick T.L.	Northbound	19.2	24.8	24.7	22.9	18.7	22.4	25.6	22.2	23.5	20.2	-	21.9
		Southbound	23.5	24.9	21.8	23.4	21.7	24.2	21.7	22.5	14.0	20.5	-	17.3
• Broad St.	Elmwood Ave - Park St.	Northbound	20.3	19.9	18.9	19.7	19.8	19.9	17.4	19.0	19.8	20.3	-	20.1
		Southbound	26.1	20.4	21.2	22.6	19.0	22.4	19.2	20.2	20.8	21.8	-	21.3
• Smith St.	Canal St. - Allens Ave	Eastbound	22.8	17.0	19.1	19.6	15.9	20.2	16.5	17.5	18.4	18.1	18.3	18.2
		Westbound	22.0	25.2	20.9	22.7	16.8	19.3	17.2	17.8	18.9	17.7	16.4	17.7
• Washington St.	CBD/Fringe	Southbound	-	-	-	-	14.6	9.8	12.6	12.3	-	-	-	-
• Weybossett St.	CBD/Fringe	Northbound	-	-	-	-	11.6	9.6	10.8	10.9	-	-	-	-
• Dorrance St.	CBD	Eastbound	-	-	-	-	5.6	9.0	11.3	8.6	-	-	-	-
• Adelaide St.	Fringe	Eastbound	-	-	-	-	20.8	21.4	20.9	21.0	-	-	-	-
		Westbound	-	-	-	-	23.5	26.3	24.5	24.8	-	-	-	-

developed[2] indicating the relationships among the permitted error, sample size, and average range of observed travel speed. The particular table used in this study is presented, in part, as Table 3, below:

TABLE 3. MINIMUM SAMPLE SIZE REQUIREMENTS FOR TRAVEL TIME STUDIES WITH A CONFIDENCE LEVEL OF 95.0 PERCENT, PRESENTED AS THE NUMBER OF OBSERVATIONS REQUIRED*

Average range in travel speed, mph	Specified permitted error				
	± 1.0 mph	± 2.0 mph	± 3.0 mph	± 4.0 mph	± 5.0 mph
1.0	2	2	2	2	2
2.0	3	2	2	2	2
3.0	5	3	2	2	2
4.0	6	3	2	2	2
5.0	8	4	3	2	2
6.0	10	5	3	3	2
7.0	12	6	3	3	3
8.0	15	6	4	3	3
9.0	18	7	5	3	3
10.0	21	8	5	4	3
11.0	23	9	6	4	3
12.0	27	10	6	5	4
13.0	32	11	7	5	4
14.0	34	12	8	6	4
15.0	37	14	8	6	5

*Source: Reference 2.

In Table 3, the average range in travel speed can be estimated from the equation:

$$\bar{R} = \sum_{i=1}^{N-1} \frac{\left[\left(S_{i+1}\right) - \left(S_i\right)\right]}{N-1} \qquad (3)$$

where $\bar{R}$ = average range in travel speed (mph)

S_i = the measured travel speed for the ith observation

N = the number of observations made.

Application of this technique to the travel time data collected in Providence yielded the results shown in Table 4.

Typically, travel speed studies are designed to produce results that have a permitted error of about 10 percent with a confidence level of 95 percent; attempts to improve upon this level of reliability usually cannot be justified because of the level of field effort that would be required. Table 4 indicates that most, though not all, of the derived average speeds for the Providence study are within the acceptable range of $\pm$ 10 percent. Figure 10 shows the cumulative distribution of the probable error for the entire study.

As a result of the assessment described above, it was concluded that the travel time analyses provided an acceptable probable error ($\leq$ 10 percent) and would, therefore, provide a valid indication of the average travel speed for 35 of the 41 cases studied. These 35 acceptable cases, then, were used as the basis for assessing the reasonableness of the skim tree data.

Before the measured speed data presented in Table 2 were used to evaluate the network data, adjustments were made to reflect a composite average speed - that is, one that represents the average speed for both directions of travel for a 24-hour period. This was accomplished by weighting the speeds determined for each direction and time period by a factor reflecting the relative traffic volumes for the corresponding time period and direction of travel. To do this, several basic assumptions concerning the distribution of traffic were made. First, it was assumed that, on a 24-hour basis, the total volume in each direction for radial arterials is equal; hence, 50 percent of the total average daily traffic (ADT) occurs in each direction (inbound and outbound with respect to the downtown). Secondly, it was assumed that 20 percent of the total ADT on radial arterials occurs during each of the peak periods (defined as the periods from 7 a.m. to 9:30 a.m. and 3:30 p.m. to 6:00 p.m.); for a 24-hour period, then, the total volumes that occur on an arterial during the morning peak period, the evening peak period, and the off-peak period, are (0.2 x ADT), (0.2 x ADT) and 0.6 x ADT), respectively. Finally, it was assumed that a distinct directional split is associated with each of the three-time periods; during the morning peak period, 60 percent of the traffic is inbound and 40 percent outbound; during the evening peak period, 60 percent is outbound and 40 percent inbound; and during the off-peak periods the split is 50 percent in each direction. The assumed relative volumes occurring on radial arterials during the three-time periods, by direction, are indicated in Table 5.

The relative volumes shown in Table 5 were used to weight the speeds computed for each case. The resultant composite speeds for each route are presented in Table 6.

Finally, a direct comparison was made of the composite speeds shown in Table 6 and the assigned network speeds obtained from RISPP; this comparison is shown in Table 7.

TABLE 4. ASSESSMENT OF THE RELIABILITY OF THE TRAVEL TIME DATA COMPILED FOR PROVIDENCE

			a.m. Peak period				Off-peak period				p.m. Peak period			
	Street	Direction	No. of observations	Measured average speed, mph	$\bar{R}$ mph	Probable error, %	No. of observations	Measured average speed, mph	$\bar{R}$ mph	Probable error, %	No. of observations	Measured average speed, mph	$\bar{R}$ mph	Probable error, %
•	Allens Ave.	Northbound	3	24.2	1.9	±4	3	22.6	1.7	±4	3	21.9	2.1	±5
		Southbound	3	26.9	3.7	±7	3	22.9	0.7	±4	2	27.2	0.1	±4
o	Eddy St.	Northbound	3	23.1	0.9	±4	3	19.3	2.5	±8	2	24.2	0.9	±4
		Southbound	3	20.7	0.1	±4	3	13.6	5.0	±22	3	15.3	4.5	±18
o	U.S. Route 6	Eastbound	3	23.6	1.7	±4	3	19.7	1.5	±5	3	20.6	0.5	±5
		Westbound	3	25.0	3.0	±5	3	18.4	0.9	±5	3	19.9	2.8	±10
o	Elmwood Ave.	Northbound	3	22.9	2.8	±9	3	22.2	3.5	±9	2	21.9	3.2	±9
		Southbound	3	23.4	2.3	±7	3	22.5	2.5	±7	2	17.3	6.5	±17
o	Broad St.	Northbound	3	19.7	0.7	±5	3	19.0	1.3	±5	2	20.1	0.5	±5
		Southbound	3	22.6	3.3	±8	3	20.2	3.3	±10	2	21.3	1.0	±5
o	Smith St.	Eastbound	3	19.6	3.9	±10	3	17.5	4.0	±12	3	18.2	0.1	±5
		Westbound	3	22.7	3.7	±9	3	17.8	2.3	±10	3	17.7	1.3	±6
•	Washington St.	Southbound	0	-	-	-	3	12.3	3.8	±18	-	-	-	-
•	Weybossett St.	Northbound	0	-	-	-	3	10.9	1.6	±9	-	-	-	-
•	Dorrance St.	Eastbound	0	-	-	-	3	8.6	2.9	±23	-	-	-	-
o	Adelaide St.	Eastbound	0	-	-	-	3	21.0	0.6	±5	-	-	-	-
		Westbound	0	-	-	-	3	24.8	2.3	±7	-	-	-	-

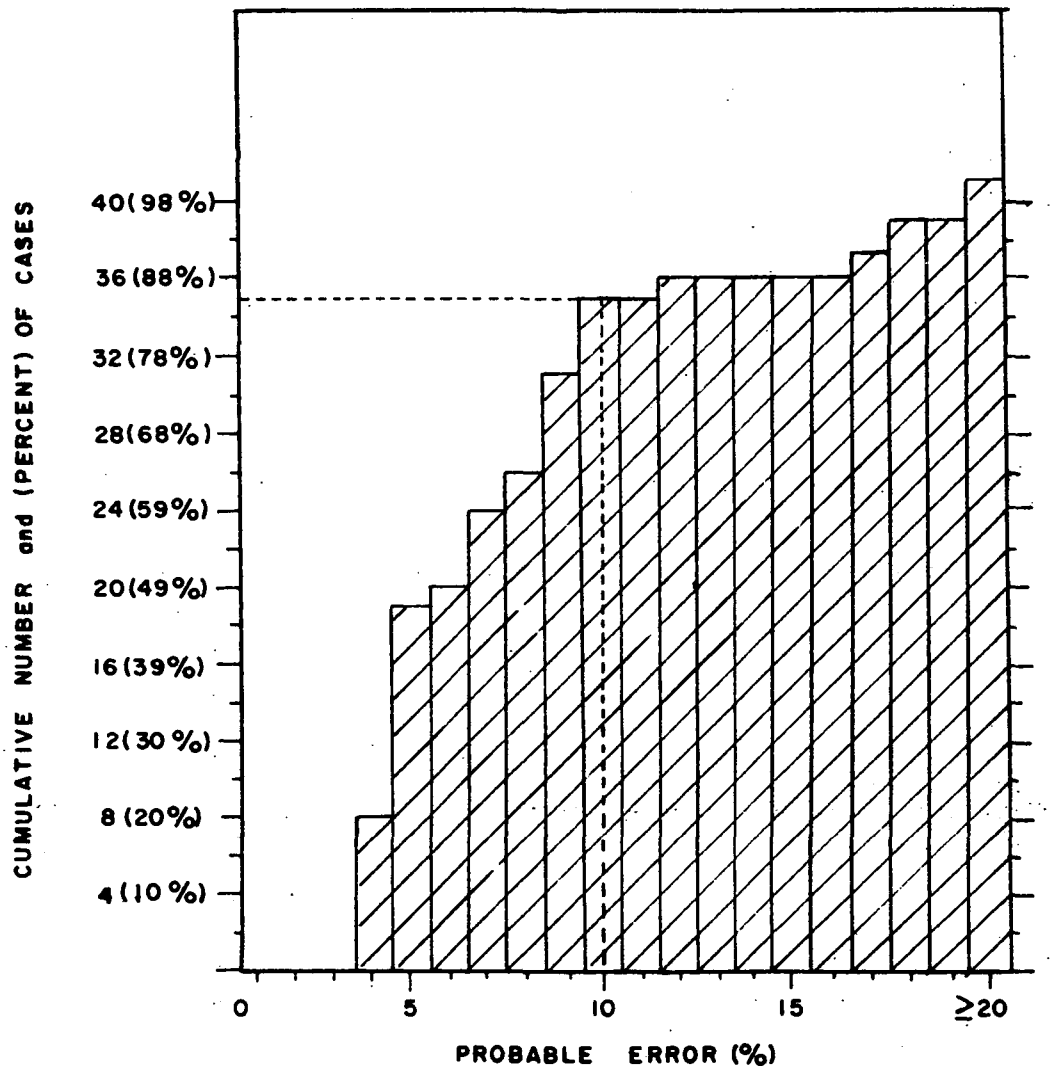

Figure 10. Cumulative distribution of the probable error for travel time runs made in Providence, Rhode Island.

TABLE 5. RELATIVE VOLUMES ON RADIAL ARTERIALS BY TIME PERIOD AND DIRECTION, SHOWN AS A PERCENTAGE OF ADT

	Relative volume - % ADT	
Period	Inbound	Outbound
a.m. Peak	12.0	8.0
p.m. Peak	8.0	12.0
Off peak	30.0	30.0

Table 7 shows fairly good agreement (good agreement being defined somewhat subjectively as being within 20 percent) between the measured and assigned speeds in all but two instances - the Webbossett Street and Dorrance Street routes. However, note too that these two routes involved distances of only 0.2 and 0.1 miles, respectively, plus the speed on each route was measured only during the off-peak periods. For these reasons it is entirely probable that the measured speeds for these two routes are not within a reasonable range of accuracy; hence, comparisons are not appropriate.

Pittsburgh--

During the week of 3 January 1977 field studies were conducted by GCA in the Pittsburgh region. These studies focused primarily on measuring travel time on the highway network, generally within the city. The techniques used for both collecting and analyzing the data were essentially identical to those used for Providence. Comparisons made as a result of the study indicated about the same degree of agreement between measured and assigned travel time as did the Providence analysis. Again, the measured and assigned travel times were closer for zone pairs separated by greater distances (say, more than 0.5 miles). Since no large differences in measured and observed values were detected, it was concluded that the assigned zone-to-zone travel times were acceptable for the study.

Parking Study

A second critical element in the cold mode analysis concerns the cold soak duration. This type of information was not available directly from any identified source in either of the two regions. Parking data were available in various formats from the trip record files, however, so that it was possible to derive the required cold soak information. The process used was essentially the same for both regions.

The first step in the process was to analyze the trip record files to determine which data elements would be relevant. The file for Pittsburgh included the following information for each auto-driver trip:

TABLE 6. COMPUTED 24-HOUR COMPOSITE AVERAGE SPEEDS FOR PROVIDENCE

Route	Direction	Average speed				
		A.M. peak period (mph)	Off-Peak period (mph)	P.M. peak period (mph)	24-Hour average directional (mph)	24-Hour composite (mph)
Allens Ave.	Northbound	24.2	22.6	21.9	22.9	23.7
	Southbound	26.9	22.9	27.2	24.6	
Eddy St.	Northbound	23.1	19.3	24.2	21.0	- +
	Southbound	20.7	13.6*	15.3*	- +	
U.S. Route 6	Eastbound	23.6	19.7	20.6	20.8	20.5
	Westbound	25.0	18.4	19.9	19.9	
Elmwood Ave.	Northbound	22.9	22.2	21.9	22.3	21.9‡
	Southbound	23.4	22.5	17.3*	21.4‡	
Broad St.	Northbound	19.7	19.0	20.1	19.3	20.1
	Southbound	22.6	20.2	21.3	20.8	
Smith St.	Eastbound	19.6	17.5	18.2	18.1	18.3
	Westbound	22.7	17.8	17.7	18.6	
Washington St.	Southbound	–	12.3*	–	- **	- **
Weybossett St.	Northbound	–	10.9	–	10.9	10.9
Dorrance St.	Eastbound	–	8.6	–	8.6	8.6
Adelaide St.	Eastbound	–	21.0	–	21.0	22.9
	Westbound	–	24.8	–	24.8	

*Probable error greater than 10 percent.

+Value not computed because probable error in data was considered too severe.

‡Value considered representative even though it was derived from data with relative error > percent.

TABLE 7. COMPARISON OF THE DERIVED AND ASSIGNED NETWORK SPEEDS FOR PROVIDENCE

Route	Total length, miles	Derived composite speed, mph	Assigned network speed, mph	Actual Difference, mph	% Difference $\left(\frac{\text{composite - assigned}}{\text{composite}} \times 100\right)$
o Allens Avenue	2.6	23.7	22.6	1.1	4.6%
o U.S. Route 6	3.8	20.5	19.5	1.0	4.9%
o Elmwood Avenue	3.6	21.9	23.3	-1.4	-6.4%
o Broad Street	3.1	20.1	18.4	1.7	-8.5%
o Smith Street	4.4	18.3	21.2	-2.9	-15.8%
o Weybossett Street	0.2	10.9	8.0	2.9	26.6%
o Dorrance Street	0.1	8.6	15.0	-6.4	-74.4%
o Adelaide Street	0.5	22.9	18.4	4.5	19.7%

- origin zone
- destination zone
- time of trip
- type of parking
- time parked

The data above provided the basis for determining the hourly distribution of trips departing from an area by the time they had been parked. This was accomplished by computing the departure time for each trip (approximated by adding the time of trip* and the time parked) and aggregating these by the time parked; e.g., the total number of trips departing a zone between, say, midnight and 1 a.m. was disaggregated into categories reflecting the amount of time that they had been parked (in 1-hour increments from less than 1 hour, to between 9 and 10 hours, and an additional increment of over 10 hours). These data were developed for 12 analysis districts. Tables were developed for each 1-hour increment of parking duration for each analysis district, indicating the number of vehicles departing by hour of the day. The processing was accomplished using a computer.

The result of this analysis was the definition of the fraction of total daily trips generated in each analysis district that occur during each hour of the day, by 1-hour increments of parking duration.

The data for Providence were processed to achieve the same result. A different technique was used, however, owing to a different trip record format.

*This was defined in the file as the mid-time (clock time) of the trip.

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SECTION 4

STUDY METHODOLOGY

GENERAL

At the beginning of the study it was hypothesized that the distributions of cold operating vehicles at a particular location on a street would be functionally related to the type of location, the orientation of the location with respect to the central business district, and the time of day. In this connection, then, analyses were conducted of diurnal traffic patterns at numerous characteristically different locations, in two separate cities. Again, the analyses were based almost entirely on data derived in connection with comprehensive planning studies conducted during the 1960's and early 1970's. The specific data elements used were described previously; the purpose of this section is to describe how these data were applied in the analyses.

SELECTION OF STUDY LINKS

The process of selecting specific links for analysis was based on the desire to consider a variety of facility-types located in different urban settings. Of primary interest were arterial streets although expressways and local streets also received attention. The intent was to analyze the cold mode characteristics of vehicles operating on (1) arterials located in the central business district (CBD), the fringe areas, mixed commercial-residential areas, and residential areas; (2) expressways at one location in each city only; and (3) local streets in one or two locations if adequate data were available. The scope of the project permitted the analysis of a total of 60 links — 24 in Pittsburgh and 36 in Providence.

ANALYTICAL PROCEDURE

The first step in the process involved analyzing the trip distribution data for each study link, which resulted in defining the number of trips generated from each analysis zone that used the study link. As indicated previously, trip distribution data, which were provided by the regional planning agencies, included tables showing the number of trips by origin zone that were assigned over a specific link or node. An example of this tabulation is shown in Table C-1 of Appendix C.

The next step was to identify the travel time from each origin zone to the study link; this was accomplished using the skim tree data (see Table C-2 in Appendix C). This identified the number of trips using the link by time-from-trip-origin; the units of time-from-trip-origin used were 2-minute

intervals beginning with 0 to 2 minutes, through 8 to 10 minutes. The result, then, was a separate tabulation for each study link showing the travel time between each analysis zone and the study link, and the number of trips from each zone that used the study link. An example of this distribution is shown in Table C-3 of Appendix C.

The next step involved determining the diurnal distribution of trip productions in each analysis district. This was accomplished by analyzing the time-of-trip distribution for each district based on the trip record file for each city. Trip productions for each analysis district were summed by the time that they occurred, using four time periods. The time periods included (1) 5 a.m. to 10 a.m., (2) 10 a.m. to 3 p.m., (3) 3 p.m. to 8 p.m., and (4) 8 p.m. to 5 a.m. For Pittsburgh, this tabulation is shown in Table C-5 of Appendix C.

Trips on each study link were then summed by the analysis district from which they originated. This distribution was applied to the data describing the diurnal distribution of trip productions, which resulted in defining the *distribution of trips originating in each analysis district as a function of the time that the trip occurred* (see Table C-7 of Appendix C).

The *distributions of travel time from trip origin to each study link* were determined from the distributions of trip origins by analysis zone for each analysis district. Table C-8 provides an example of these distributions. These distributions and the *distribution of trips originating in each analysis district as a function of the time that the trip occurred* were used to define the *distribution of trips by time from trip origin, as a function of time for each analysis district;* an example of this distribution is shown in Table C-9 of Appendix C.

The trip record file was again analyzed to derive distributions of parking duration (in 1-hour increments beginning with 0 to 1 hour, through 9 to 10 hours) as a function of the time period when the trips were generated, for each analysis district. This distribution for Pittsburgh is shown in Table C-10. This indicates, for instance, the fraction of total daily trips originating in analysis district II during the period 10 a.m. to 3 p.m., that had been parked between 6 and 7 hours prior to beginning the trip. These distributions were applied to the *distribution of link trips originating at analysis districts by time from trip origin, as a function of time,* to produce a tabulation of the *distribution of link trips by time from trip origin and by time of trip, as a function of parking duration* (see Table C-11).

This final distribution was then used in conjunction with the data provided by the Office of Mobile Source Air Pollution Control to identify the fraction of cold operating vehicles occurring on each study link during each time-period. To minimize the inherent bias in the trip distribution used in the analysis, the results (fraction of total time-period volume operating in the cold mode) for each individual link were combined to form several groups with a common element of functional category or orientation within the region. This approach provided an indication of the cold mode distribution in areas (such as the CBD) or in corridors at various distances from the CBD. A detailed example for this entire procedure is provided in Appendix C.

These final distributions were analyzed on a comparative basis to identify any apparent patterns that would provide the basis for developing general statements regarding the fraction of vehicles operating in the cold mode, at various locations within an urban area and at different times during the day.

LIMITATIONS OF THE PROCEDURE

The primary limitation in the analysis concerned the data used. In this connection, it was indicated that several basic techniques used in developing the data (for instance the trip distribution analysis and the traffic assignment process) were based largely on theoretical relationships and a synthetic highway network. Obviously, the relative error introduced into any analysis that uses these data increases as the required level of detail increases. The analyses of individual link-trip characteristics that were performed for this study required a great amount of detail, consequently the results are subject to error. Of particular concern is the fact that the analysis of cold mode operation is very sensitive to the time-from-trip-origin factor, while at the same time, the relative error in the computed time-from-trip-origin distribution is greatest in the time range of about 0 to 3 minutes. (This is crucial because the duration of the cold mode phase is only several minutes.) The reason for this is that trips can only enter the network from any zone centroid at one point only. Consequently, trips originating close to a particular point on the network (a study link for instance) tend to be overestimated. An analysis was made of the sensitivity of the study results to the distribution of trips originating very close to the study link. This was done by adding two "penalty times" (1 minute and 2-1/2 minutes) to the computed time-from-trip-origin; in other words, trips previously in the 0 to 2 minute range would now be in a range of 1 to 3 minutes. As will be shown in the following section, this added time had a very significant effect on the results.

At this point, it is not possible to dimension the accuracy of the study results. It would be possible to measure the <u>true</u> distribution of the time-from-trip-origin, however, if direct, detailed analyses were made of trip characteristics on specific links.

SECTION 5

RESULTS OF THE ANALYSES

PITTSBURGH

A total of 24 highway links in Pittsburgh were analyzed using data provided by the Southwestern Pennsylvania Regional Planning Commission (SPRPC) and information obtained directly by GCA through field studies. The specific links that were studied are listed below in Table 8 and their approximate locations within the city are shown in Figure 11.

The focus of the analyses was to identify certain characteristics of trips occurring on each study link and to relate these characteristics, in aggregate, to cold mode operating parameters. Specifically, the trip characteristics that were essential to identify were (1) the elapsed time from the trip origin to the study link, and (2) the duration of the cold soak period prior to beginning the trip. These data were related to cold mode operation based on the results of studies conducted by the U.S. Environmental Protection Agency, Office of Mobile Source Air Pollution Control.

The first result of applying the analytical process described previously was a tabulation for each analysis link showing the percentage of total volume occurring during each time period that was computed to be in the cold operating mode; these percentages are shown in Table 9. Owing to certain limitations in the basic modeling techniques used to develop the data, the results of the analysis are more meaningful if groups of links are considered rather than individual links. In this connection, each of the 24 links was categorized according to its functional classification, its location with respect to the CBD, and its setting (rural, residential, commercial, etc.); the links were then grouped into six categories based on these attributes. The links assigned to each category are listed in Table 10. The total number of vehicles computed to be operating in the cold mode within each category was determined and expressed as a percentage of total trips; these are shown in Table 11. The actual volumes of cold and stabilized vehicles are shown in Table 12.

The percentages of cold operating vehicles shown in Table 11 are in many instances much higher than what one might intuitively expect. It is noted that the travel times used in the analyses were representative of the network travel time only; there was no time increment involved that would reflect the nonnetwork operating time, which would include an initial idling period during warm-up and the access time from a parking facility to the network. If it were assumed that a 1-minute increment would be representative of this nonnetwork operating time, then the percentages shown in Table 11 would be reduced

TABLE 8. ANALYSIS LINK DESCRIPTIONS, PITTSBURGH

No.*	Link name	Limits	Type
1	Fifth Ave.	At Liberty	CBD Arterial
2	Grant Ave.	At Boulevard of the Allies	CBD Arterial
3	Seventh Ave.	At Liberty	CBD Arterial
4	Sixth Ave.	At Grant Ave.	CBD Arterial
5	Sixth Ave.	Between Wood and Smithfield Streets	CBD Arterial
6	Sixth Ave. Bridge	Between Fort Duquesne Blvd. and River Ave.	CBD Arterial
7	Smithfield St.	Between Third Ave. and Blvd. of the Allies	CBD Collector
8	Bedford Ave.	Between Washington Pl. and Grawford St.	Fringe Arterial
9	Centre Ave.	Between Washington Pl. and Grawford St.	Fringe Arterial
10	Fifth Ave.	Between Gist and Jumonville Sts.	Fringe Arterial
11	Forbes Ave.	Between Gist and Brady Sts.	Fringe Arterial
12	Baum and Centre Aves.	Between Morewood and S. Millvalle Aves.	Outer Ring Arterial
13	California Ave.	Between Yunkle and Columbus Aves.	Outer Ring Arterial
14	Centre Ave.	Between Herron Ave. and Iowa St.	Outer Ring Arterial
15	Federal St.	Between W. North Ave. and Jacksonia St.	Outer Ring Arterial
16	Fifth Ave.	Between S. Aiken Ave. and Ivy St.	Outer Ring Arterial
17	Forbes Ave.	Between Wightman St. and Murray Ave.	Outer Ring Arterial
18	Perryville Ave.	Between Marshall Ave. and Hawkins St.	Outer Ring Arterial
19	Penn-Lincoln Pkwy EB	Between Bates St. and Brady St. Bridge	Expressway
20	Penn-Lincoln Pkwy WB	Between Bates St. and Brady St. Bridge	Expressway
21	Fifth Ave.	Between S. Bellefield Ave. and S. Dithridge St.	Non-CBD Generator, Arterial
22	Forbes Ave.	Between S. Bellefield Ave. and S. Craig St.	Non-CBD Generator, Arterial
23	Carson St.	Between S. Eighteenth and S. Twentieth	Residential Collector
24	Lincoln Ave.	Between Frankston Ave. and Meadow St.	Mixed Collector

*Keyed to Figure 11.

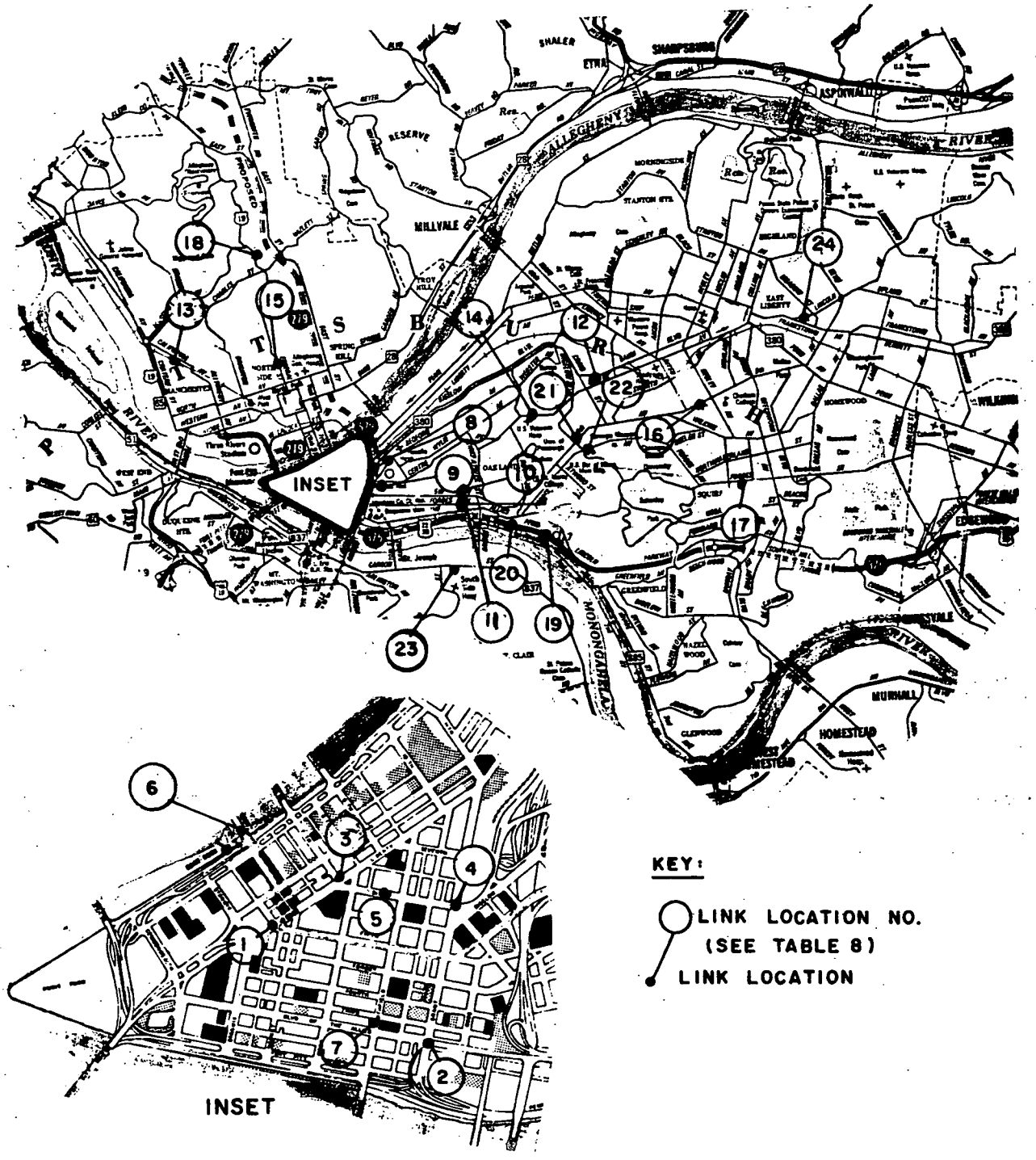


Figure 11. Study-link locations map, Pittsburgh, Pa.

TABLE 9. PERCENTAGE OF VEHICLES OPERATING IN THE COLD MODE, BY TIME PERIOD, FOR 24 LOCATIONS IN PITTSBURGH

No.*	Link	Percent of vehicles operating in cold mode by time period				
		I	II	III	IV	Total day
1	Fifth Ave.	13.0	33.3	62.2	36.4	41.5
2	Grant Ave.	8.7	19.8	33.0	34.2	25.6
3	Seventh Ave.	13.6	33.8	56.3	38.0	39.7
4	Sixth Ave.	6.5	18.2	10.2	12.5	11.8
5	Sixth Ave.	4.9	11.9	22.3	16.3	15.5
6	Sixth Ave. Bridge	9.2	27.4	31.2	28.3	25.7
7	Smithfield St.	6.7	3.7	13.4	9.5	9.0
8	Bedford Ave.	14.0	39.8	52.0	53.3	42.0
9	Centre Ave.	14.3	44.2	57.3	50.9	44.5
10	Fifth Ave.	19.8	65.7	61.8	14.3	44.2
11	Forbes Ave.	24.8	85.9	76.8	84.8	69.9
12	Baum and Centre	16.0	21.7	16.3	46.8	23.0
13	California Ave.	12.5	36.4	40.1	53.7	35.7
14	Centre Ave.	10.2	45.3	37.8	47.3	34.9
15	Federal St.	19.1	45.3	47.4	73.1	45.4
16	Fifth Ave	20.9	40.4	42.8	75.8	43.5
17	Forbes Ave.	19.5	24.6	24.7	47.0	27.7
18	Perryville Ave.	31.1	24.6	26.2	70.4	35.2
19	Penn-Lincoln Pkwy EB	4.0	4.4	8.6	12.2	7.4
20	Penn-Lincoln Pkwy WB	0.4	0.5	0.3	1.1	0.5
21	Fifth Ave.	25.6	41.5	52.5	69.6	48.7
22	Forbes Ave.	27.3	33.2	46.4	55.3	39.7
23	Carson St.	19.9	31.2	31.7	84.8	36.9
24	Lincoln Ave.	29.0	37.5	33.8	97.4	44.7

*Keyed to Figure 11.

TABLE 10. ANALYSIS LINKS BY GENERAL CATEGORY, PITTSBURGH

Classification	No.*	Links included	Description
Central Business District (CBD)	1	Fifth Avenue/Liberty Street	Includes the "Golden Triangle" bounded by the Allegheny River to the north, the Monongahela River to the south, and I-579 to the east.
	2	Grant Street/Blvd of the Allies	
	3	Seventh Street/Liberty Street	
	4	Sixth Street/Grant Street	
	5	Sixth Avenue	
	6	Sixth Street Bridge	
	7	Smithfield Street	
Fringe Arterials	8	Bedford Avenue	Includes links within about 1 mile of the CBD
	9	Centre Avenue	
	10	Fifth Avenue	
	11	Forbes Avenue	
Outer Arterials	12	Baum/Centre Avenue	Includes links greater than 1 mile from the CBD
	13	California Avenue	
	14	Centre Avenue	
	15	Federal Street	
	16	Fifth Avenue	
	17	Forbes Avenue	
	18	Perryville Avenue	
Expressway	19	Penn-Lincoln Pkwy EB	Links are about 2.5 miles east of the CBD
	20	Penn-Lincoln Pkwy WB	
Non-CBD Generators	21	Fifth Avenue	Major arterials in the university and hospital areas of Oakland
	22	Forbes Avenue	
Collectors	23	Carson Street	Serve local traffic
	24	Lincoln Avenues	

*Keyed to Figure 11.

TABLE 11. PERCENTAGE OF VEHICLES IN COLD MODE OPERATION BY TIME PERIOD AND BY LOCATION GROUP FOR PITTSBURGH

Location	Percentage of the volume operating in the cold mode during each time group				
	I*	II*	III*	IV*	Total day
Central business district	9.8	25.3	38.3	31.5	28.6
Fringe arterials	17.8	57.3	61.3	45.2	48.2
Outer arterials	17.3	34.0	32.6	58.1	34.1
Expressway inbound	0.4	0.5	0.3	1.1	0.5
Expressway outbound	4.0	4.3	8.6	12.2	7.4
Non-CBD generator	26.8	53.5	43.0	58.6	41.5
Collector streets	24.9	33.9	35.9	84.5	40.3

*Time groups.

TABLE 12. VOLUMES OF COLD AND STABILIZED VEHICLES BY TIME PERIOD AND BY LOCATION GROUP FOR PITTSBURGH

Location	Volume operating in cold and (stabilized) mode+				
	I*	II*	III*	IV*	Total day
Central business district	2,143 (19,724)	7,000 (20,668)	17,586 (28,330)	6,703 (14,576)	33,362 (83,228)
Fringe arterials	429 (1,981)	1,461 (1,089)	2,754 (1,739)	1,144 (1,387)	5,788 (6,212)
Outer arterials	3,931 (18,791)	6,869 (13,334)	12,593 (26,036)	10,746 (7,750)	34,139 (65,561)
Expressway inbound	50 (12,450)	50 (9,950)	50 (16,660)	100 (8,990)	250 (48,650)
Expressway outbound	476 (11,424)	476 (10,594)	1,744 (18,535)	1,215 (8,744)	3,911 (48,789)
Non-CBD generation	974 (2,660)	1,654 (1,438)	3,025 (4,010)	2,555 (1,805)	8,218 (11,572)
Collector streets	1,835 (5,534)	2,501 (4,877)	4,547 (8,118)	4,542 (833)	13,426 (29,874)

*Time groups.

+Total assigned volumes.

substantially; if 2.5 minutes were assumed (this might be reasonable for CBD's or areas where large, off-street parking facilities are used) the percentages would be reduced to an even greater degree. The impact of adding these time increments is shown in Tables 13 and 14.

Another significant observation concerns the distribution of trip origins by travel time from the study link. In most instances, nearly half of all trips originating within 10 minutes of the study link originate in zones that are within 2.5 minutes of the study link; this can be seen in Table 15. The point here is that the zones closest to most nonexpressway links generate a very large fraction of the total trips using (actually, assigned to) the link. However, the planning network and the traffic assignment process are such that possible trip paths are very limited in number close to the zone where the trips are generated, therefore, the trips generated from any particular zone are forced over a relatively small number of different links in the immediate vicinity of the zone, but then diffuse rapidly throughout the network as the travel time from the origin increases. The result is that a significant amount of distortion can be expected in the trip assignment process, especially during the first stages of the trip. Unfortunately, these first stages of trip assignment are the most crucial in our analysis.

A further note is that the trips represented in the analysis are auto-driver trips only. Excluded are all commercial and public transportation vehicles. The effect is that the cold mode fractions shown in Table 11 are not fractions of the total link traffic, rather it reflects about 90 percent of the total. This means that the percentages can be reduced by up to about 6 percent if it is considered that vehicles other than private autos are in the stabilized mode.

Again, a general conclusion that can be made is that the cold mode fractions shown in Table 11 are overestimated somewhat because of limitations in the traffic assignment process that tend to overload links with trips generated from nearby zones. At this point, however, one can only speculate about the degree to which this overestimating occurred.

PROVIDENCE

For Providence, a total of 36 highway links were analyzed. The data used for the analyses were obtained from the Rhode Island Statewide Planning Program (RISPP), and supplemented with field studies conducted by GCA. The links analyzed are listed in Table 16 and their locations are shown in Figure 12.

The procedure used in the analysis of the Providence data was identical to that used for Pittsburgh. The first result of applying the procedure was the tabulation of the percentages of cold operating vehicles during each of the four time groups for each study link; these are shown in Table 17.

The results are, again, more meaningful if portrayed in group form. Five groupings were defined and the individual links were aggregated into these. Table 18 identifies the categories and indicates which links are included in

TABLE 13. PERCENTAGE OF VEHICLES IN COLD MODE OPERATION WITH 1 MINUTE ADDITIONAL ACCESS TIME, PITTSBURGH, PA.

Location	Percentage of time-period volume operating in cold mode				
	I*	II*	III*	IV*	Total day
Central business district	7.1	15.2	40.8	22.3	25.2
Fringe arterials	14.3	23.0	40.5	43.8	32.1
Outer arterials	15.6	18.7	25.9	44.1	25.6
Non-CBD generator	20.7	23.7	32.9	39.1	29.9
Collector streets	20.3	17.2	25.1	71.4	29.8

*Time groups.

TABLE 14. PERCENTAGE OF VEHICLES IN COLD MODE OPERATION WITH 2.5 MINUTE ADDITIONAL ACCESS TIME, PITTSBURG, PA.

Location	Percentage of time-period volume operating in cold mode				
	I*	II*	III*	IV*	Total day
Central business district	5.4	8.9	29.2	17.4	17.8
Fringe arterials	10.4	16.0	38.4	38.2	25.5
Outer arterials	14.2	11.6	19.6	32.8	19.2
Non-CBD generator	19.2	14.9	26.4	30.9	23.8
Collector streets	10.8	10.8	18.8	57.1	21.5

*Time groups.

TABLE 15. DISTRIBUTION OF TRIPS BY TIME FROM TRIP ORIGIN - PITTSBURGH

Link No.*	Link name	Percentage of total daily link trips by time from trip origin					
		0.5 - 2.5	2.5 - 4.5	4.5 - 6.5	6.5 - 8.5	8.5 - 10.5	>10.5
1	Fifth Ave.	16.5	27.5	6.2	7.3	2.7	39.6
2	Grant Ave.	15.0	1.0	30.2	1.0	3.9	48.9
6	Sixth St. bridge	12.8	14.6	3.7	3.0	6.0	59.9
8	Bedford St.	30.5	33.5	0	6.3	7.5	22.2
9	Centre St.	21.9	25.5	9.1	14.6	0.9	28.0
13	California Ave.	2.8	0	3.2	24.7	16.9	52.2
15	Federal St.	28.4	15.8	7.3	15.7	1.0	31.8
18	Perryville Ave.	8.5	21.4	25.3	5.4	10.0	29.4
22	Forbes Ave.	34.4	12.1	18.2	11.9	4.3	19.1
23	Carson St.	28.3	2.0	4.3	8.2	8.8	48.4

*Keyed to Figure 11.

TABLE 16. ANALYSIS LINK DESCRIPTIONS, PROVIDENCE

No.*	Link name	Limits	Type
1	Atwells Ave.	At Sabin and Empire Sts.	CBD Arterial
2	Broadway	At Sabin and Empire Sts.	CBD Arterial
3	Dorrance St.	At I-195 Ramp and Dyer St.	CBD Arterial
4	Dorrance St.	Between Weybosset and Westminster Sts.	CBD Arterial
5	Dyer St.	At Fulton St.	CBD Arterial
6	Dyer St.	At Custom House St.	CBD Arterial
7	Washington St.	Between Revere and Aborn Sts.	CBD Arterial
8	W. Exchange St.	At Sabin St. and Exchange Terr.	CBD Arterial
9	Weybossett St.	Between Richmond St and Park Pl.	CBD Arterial
10	Allens Ave.	Between Public St. and I-95 Ramp	Fringe Arterial
11	Allens Ave.	Between I-95 Ramp and Oxford St.	Fringe Arterial
12	Angell St.	Between Prospect and Thayer Sts.	Fringe Arterial
13	Atwells Ave.	Between Pasquale Ave. and Knight St.	Fringe Arterial
14	Atwells Ave.	Between Valley and Culter Sts.	Fringe Arterial
15	Broadway	Between Knight and Almy Sts.	Fringe Arterial
16	Charles St.	Between Admiral and Ashburton Sts.	Fringe Arterial
17	Douglas St.	Between Camden and Chad Brown Sts.	Fringe Arterial
18	Eddy St.	Between Public St. and I-95 Ramp	Fringe Arterial
19	Elmwood St.	Between Broad and Friendship Sts.	Fringe Arterial
20	Hope St.	Between Rochambeau and Vassar Aves.	Fringe Arterial
21	N. Main St.	Between Olney and Benefit Sts.	Fringe Arterial
22	Smith St.	Between Orms and Calverley Sts.	Fringe Arterial
23	Waterman St.	Between Prospect and Thayer Sts.	Fringe Arterial
24	Allens Ave.	Between Earnest St. and I-95 Ramp	Outer Ring Arterial
25	Allens Ave.	Between Montgomery and Washington Aves.	Outer Ring Arterial
26	Atwells Ave.	Between Manton and Glenbridge Aves.	Outer Ring Arterial
27	Broad St.	Between Adelaide and Oxford Sts.	Outer Ring Arterial
28	Eddy St.	Between Earnest St. and I-95 Ramp	Outer Ring Arterial
29	Eddy St.	Between Broad St. and Washington Ave.	Outer Ring Arterial
30	Elmwood St.	Between Reservoir Ave. and Adelaide St.	Outer Ring Arterial
31	I-95 SB	Between Broad St. and Broadway	Expressway
32	I-95 NB	Between Broad St. and Washington St.	Expressway
33	Adelaide St.	Between Elmwood Ave. and Broad St.	Local Street
34	Elmgrove Ave.	Between Lloyd and President Aves.	Local Street
35	Blackstone Blvd.	Between Lloyd and President Aves.	Residential Collector
36	Kinsley Ave.	Between Eagle and Acorn Sts.	Industrial Collector

*Keyed to Figure 12.

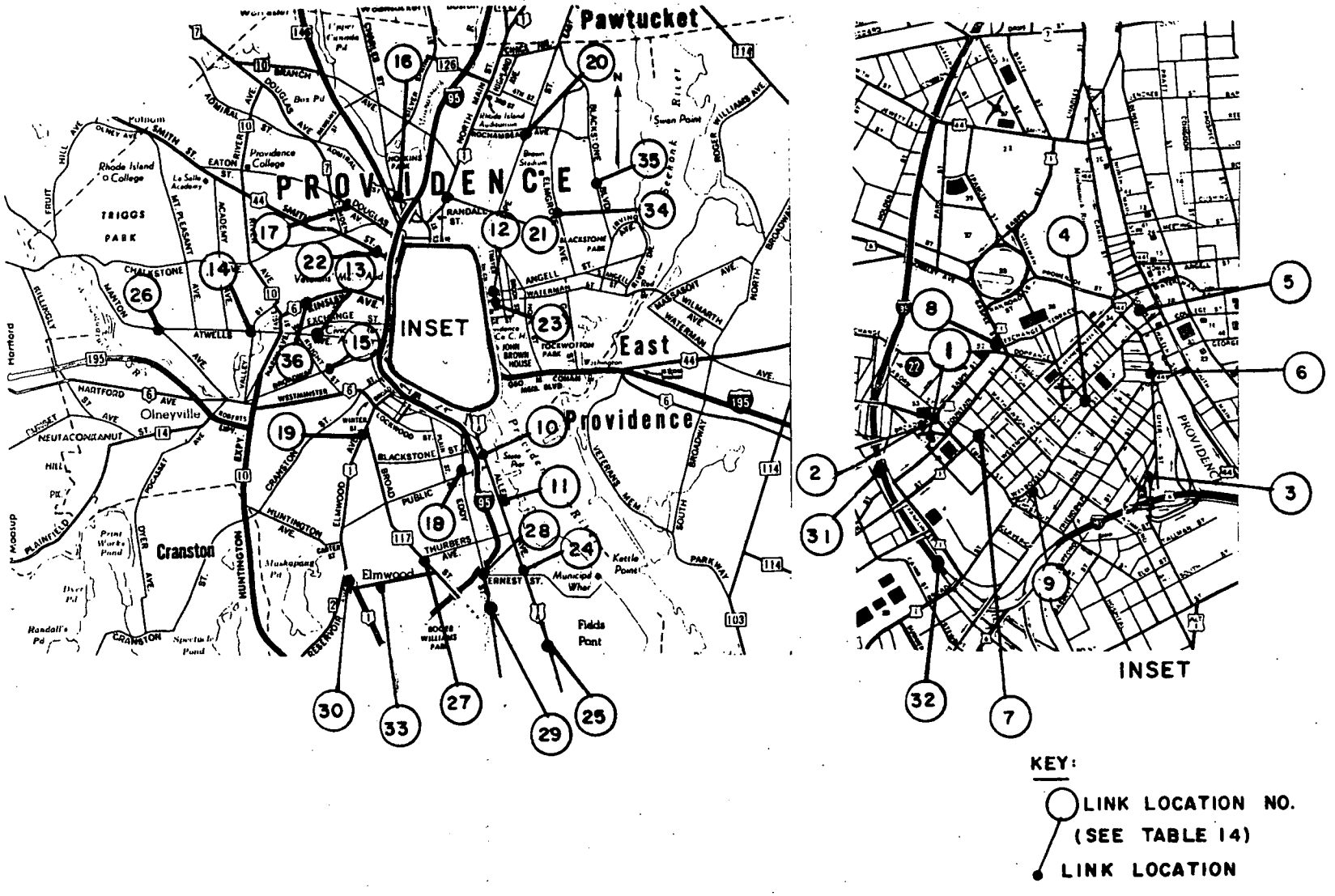


Figure 12. Study-link locations map; Providence, R.I.

TABLE 17. PERCENTAGE OF VEHICLES OPERATING IN THE COLD MODE, BY TIME PERIOD, FOR 36 LOCATIONS IN PROVIDENCE

No.*	Link	Percent of vehicles operating in cold mode by time period				
		I	II	III	IV	Total day
1	Atwells Ave.	15.8	51.3	55.3	40.0	44.7
2	Broadway	4.5	28.0	23.7	11.4	18.1
3	Dorrance St.	53.0	70.3	78.3	50.0	68.8
4	Dorrance St.	17.4	23.0	63.0	39.3	39.6
5	Dyer St.	14.1	60.8	65.9	36.0	48.5
6	Dyer St.	63.0	76.4	85.8	84.2	80.5
7	Washington St.	20.2	64.8	67.9	46.3	55.3
8	W. Exchange St.	23.6	69.3	97.3	65.3	71.1
9	Weybossett St.	18.2	39.1	54.0	28.9	39.9
10	Allens Ave.	18.0	41.7	45.6	21.2	34.4
11	Allens Ave.	9.4	34.3	47.7	21.2	31.7
12	Angell St.	6.8	29.4	49.4	33.2	33.9
13	Atwells Ave.	16.6	41.6	48.4	27.1	36.8
14	Atwells Ave.	19.0	52.2	53.7	21.8	41.1
15	Broadway	7.0	26.6	37.2	17.2	25.1
16	Charles St.	9.7	31.9	49.8	21.1	32.5
17	Douglas St.	6.6	33.8	43.7	18.9	29.4
18	Eddy St.	26.5	62.5	60.7	27.7	47.8
19	Elmwood St.	24.0	50.6	53.6	7.6	39.1
20	Hope St.	24.9	70.6	75.1	72.4	64.4
21	N. Main St.	12.5	40.2	62.3	38.7	42.9
22	Smith St.	4.7	42.2	54.4	35.1	38.7
23	Waterman St.	16.9	53.0	60.1	40.7	47.6
24	Allens Ave.	15.9	59.6	48.0	21.7	39.5
25	Allens Ave.	23.0	28.1	58.6	28.8	38.9
26	Atwells Ave.	29.5	49.3	62.9	31.9	47.8
27	Broad St.	58.8	71.8	76.7	65.8	71.2
28	Eddy St.	11.4	35.4	51.0	27.8	34.1
29	Eddy St.	29.4	63.6	61.9	32.3	50.2
30	Elmwood Ave.	27.2	26.9	65.1	34.1	42.8
31	I-95 SB	0.9	18.0	16.7	7.6	11.8
32	I-95 NB	3.2	19.9	25.5	10.9	16.7
33	Adelaide St.	25.3	43.0	61.5	38.1	47.0
34	Elmgrove Ave.	6.2	40.4	44.3	22.2	31.5
35	Blackstone Blvd.	19.8	61.8	63.7	40.5	51.6
36	Kinsley Ave.	23.6	48.7	52.5	40.0	47.3

*Keyed to Figure 12.

TABLE 18. ANALYSIS LINKS BY GENERAL CATEGORY, PROVIDENCE

Classification	No.*	Links included	Description
Central Business District (CBD)	1	Atwells Ave./Sabin and Empire Sts.	Includes the area bounded by I-95 to the west, I-195 to the south and the Providence River to the northe and east
	2	Broadway/Sabin and Empire Sts.	
	3	Dorrance St./I-195 Ramp	
	4	Dorrance St.	
	5	Dyer St./Fulton St.	
	6	Dyer St./Custom House St.	
	7	Washington St.	
	8	W. Exchange St./Sabin St.	
	9	Weybossett St.	
Fringe Arterials	10	Allens Ave.	Includes links within a ring 1 mile of the CBD
	11	Allens Ave.	
	12	Angell St.	
	13	Atwells Ave.	
	14	Atwells Ave.	
	15	Broadway	
	16	Charles St.	
	17	Douglas St.	
	18	Eddy St.	
	19	Elmwood St.	
	20	Hope St.	
	21	N. Main St.	
	22	Smith St.	
	23	Waterman St.	
Outer Arterials	24	Allens Ave.	Includes links 1 mile beyond the CBD
	25	Allens Ave.	
	26	Atwells Ave.	
	27	Broad St.	
	28	Eddy St.	
	29	Eddy St.	
	30	Elmwood St.	
Expressway	31	I-95 Southbound	Links on portions of I-95 forming CBD border
	32	I-95 Northbound	
Local/Collectors	33	Adelaide St.	Serves local traffic
	34	Elmgrove Ave.	
	35	Blackstone Blvd.	
	36	Kinsley Ave.	

*Keyed to Figure 12.

each. The individual link distributions within each category were summed and a composite cold mode distribution was developed for each group. These distributions are shown in Table 19, while Table 20 shows the actual volumes computed.

Again, the distribution of cold operating vehicles appears to be somewhat different from what one might expect. The same comments concerning the possibility of the cold mode fraction being overestimated apply to Providence as well as Pittsburgh; in this connection the time-from-trip-origin distributions for a sample of 10 locations are shown in Table 21.

In order to illustrate the sensitivity of the analysis to the time-from-trip-origin distribution, additional time increments of 1 minute and 2.5 minutes were added to the final time-from-trip-origin distributions computed previously, and new percentages of cold operating vehicles were derived. The results of adding these time increments are shown in Tables 22 and 23; the impact of relatively small time differentials is significant.

TABLE 19. PERCENTAGE OF VEHICLES IN COLD MODE OPERATION, BY TIME PERIOD AND BY LOCATION GROUP FOR PROVIDENCE

Location	Percentage of the volume during each time group operating in the cold mode				
	I*	II*	III*	IV*	Total
Central business district	20.7	58.0	67.1	41.9	53.0
Fringe arterials	12.1	37.9	48.3	23.5	34.5
Outer arterials	22.0	44.3	56.6	27.6	41.6
Expressway inbound	3.2	19.9	25.5	10.9	16.7
Expressway outbound	0.9	18.0	16.7	7.6	11.8
Local/collectors	15.1	46.2	52.8	30.7	40.8

*Time groups.

TABLE 20. VOLUMES OF COLD AND STABILIZED VEHICLES BY TIME PERIOD AND BY LOCATION GROUP FOR PROVIDENCE

Location	Volume operating in cold and (stabilized) mode+				
	I*	II*	III*	IV*	Total
Central business district	3,598 (13,766)	16,432 (11,920)	29,174 (14,319)	6,895 (9,555)	56,099 (50,217)
Fringe arterials	2,159 (7,661)	5,459 (6,861)	10,551 (8,098)	2,343 (6,143)	20,514 (28,760)
Outer arterials	2,828 (20,595)	12,159 (19,888)	22,475 (24,076)	4,931 (16,077)	42,393 (80,637)
Expressway inbound	339 (10,374)	2,036 (80,192)	4,951 (13,863)	969 (7,950)	8,095 (40,378)
Expressway outbound	58 (6,347)	1,101 (5,015)	1,855 (9,275)	406 (4,927)	3,420 (25,564)
Local/collectors	631 (3,553)	2,820 (3,290)	4,719 (4,220)	1,039 (2,346)	9,209 (13,373)

*Time groups.

+Total assigned volumes.

TABLE 21. DISTRIBUTION OF TRIPS BY TIME-FROM-TRIP-ORIGIN - PROVIDENCE, R.I.

Link No.*	Link name	Percentage of total daily link trips by time from trip origin					
		0.5-2.5	2.5-4.5	4.5-6.5	6.5-8.5	8.5-10.5	>10.5
2	Broadway	10.5	6.0	13.0	6.1	8.0	56.4
7	Washington St.	45.4	15.9	2.8	5.9	4.9	25.1
9	Weybossett St.	25.2	9.2	30.0	12.0	5.9	17.7
12	Angell St.	9.8	26.7	24.2	18.5	12.5	8.3
16	Charles St.	16.9	18.4	14.2	10.4	5.8	34.3
22	Smith St.	14.9	32.9	15.8	9.7	6.6	20.1
25	Allens Ave.	31.5	9.6	5.7	12.2	9.9	31.1
28	Eddy St.	43.0	5.9	6.8	14.1	8.0	22.2
30	Elmwood St.	28.9	21.2	11.3	5.2	4.5	28.9
36	Kinsley Ave.	25.7	29.4	23.5	9.8	5.1	6.5

*Keyed to Figure 12.

TABLE 22. PERCENTAGE OF VEHICLES IN COLD MODE OPERATION WITH 1 MINUTE ADDITIONAL ACCESS TIME - PROVIDENCE, R.I.

Location	Percentage of time period volume operating in cold mode				
	I*	II*	III*	IV*	Total
Central business district	11.7	41.0	51.6	32.5	39.0
Fringe arterials	6.4	23.2	34.6	15.6	23.8
Outer arterials	12.8	25.6	43.0	19.7	28.8
Local/collectors	7.9	32.7	38.9	19.6	28.2

*Time groups.

TABLE 23. PERCENTAGE OF VEHICLES IN COLD MODE OPERATION WITH 2.5 MINUTES ADDITIONAL ACCESS TIME - PROVIDENCE, R.I.

Location	Percentage of time period volume operating in cold mode				
	I*	II*	III*	IV*	Total
Central business district	1.0	18.2	35.8	20.8	23.1
Fringe arterials	1.0	10.8	19.5	8.1	11.8
Outer arterials	2.4	11.2	27.7	10.7	15.6
Local/collectors	1.8	13.4	22.2	9.4	14.6

*Time groups.

SECTION 6

CONCLUSIONS OF THE STUDY

GENERALIZATION REGARDING COLD MODE DISTRIBUTION

Obviously, one would hope that the distributions identified by this type of analysis would exhibit definite patterns that would provide a basis for developing general statements regarding cold mode operations. Unfortunately, patterns of this nature are not evident at this point.

Comparisons of several combinations of cold mode distributions were made using an analogical approach. First, direct comparisons were made of the distributions for similar locations in both cities (see Tables 11 and 19), by both time group and for the fraction of the total daily trips. Also, the relative percentages of cold operating vehicles were considered for each time grouping and location category in both cities but, again, the cold mode fractions do not appear to display consistent patterns. Perhaps a valid conclusion is that there may not necessarily be similarities in the cold mode distributions from city to city, or at least between Pittsburgh and Providence. Factors such as the density and distribution of parking facilities within a city would have an extremely strong influence on the eventual distribution of cold operating vehicles on the street network, as would the relationship between volume demand and capacity on the street network. Parameters such as these would not be expected to correlate closely among different cities; for that matter, they would not necessarily correlate positively among different areas of a particular city.

Further comparisons were made among locations within each city. The specific intent was to determine whether or not patterns could be detected on a basis other than the type (CBD, Fringe, etc.) of location. For both cities the distribution at various points along major radial corridors is shown in Tables 24 and 25.

These tables again do not indicate the types of distributions that one might expect. For instance, it might be expected that the fraction of cold operating vehicles would be greater at locations further from the CBD in the morning (especially along arterials serving residential areas) and, conversely, they would be greater closer to the CBD in the afternoon. These types of patterns appear to a limited degree within the three corridors in Pittsburgh, but not in Providence (see Tables 24 and 25).

TABLE 24. PERCENTAGE OF VEHICLES IN COLD MODE OPERATION BY DISTANCE FROM CENTRAL BUSINESS DISTRICT FOR TWO CORRIDORS IN PROVIDENCE, R.I.

No.*	Link name	Distance from CBD, miles	Percent of vehicles operating in cold mode by time period				
			I	II	III	IV	Total day
1	Atwells Ave	0.0	15.8	51.3	55.3	40.0	44.7
13	Atwells Ave	0.7	16.6	41.6	48.4	27.1	36.8
14	Atwells Ave	1.3	19.0	52.2	53.7	21.8	41.1
26	Atwells Ave	2.2	29.5	49.3	62.9	31.9	47.8
11 18	Allens Ave Eddy St	0.9	15.8	44.6	52.6	23.6	37.7
24 28	Allens Ave Eddy St	1.6	15.2	55.6	48.5	21.9	38.6
25 29	Allens Ave Eddy St.	2.4	24.6	36.5	59.3	29.6	41.6

*Keyed to Figure 12.

TABLE 25. PERCENTAGE OF VEHICLES IN COLD MODE OPERATION BY DISTANCE FROM CENTRAL BUSINESS DISTRICT FOR THREE CORRIDORS IN PITTSBURGH, PA

No.*	Link name	Distance from CBD, miles	Percent of vehicles operating in cold mode by time period				
			I	II	III	IV	Total day
6	Sixth Ave Bridge	0.3	9.2	27.4	31.2	28.3	25.7
15	Federal St	1.1	19.1	45.3	47.4	73.1	45.4
18	Perryville Ave	2.3	31.1	24.6	26.2	70.4	35.2
8 9	Bedford Ave Centre Ave	0.4	14.2	43.2	56.2	51.5	43.9
14	Centre Ave	2.1	10.2	45.3	37.8	47.3	34.9
12	Baum & Centre Ave	3.1	16.0	21.7	16.3	46.8	23.0
10 11	Fifth Ave Forbes Ave	1.1	21.6	72.8	67.1	39.0	53.2
21 22	Fifth Ave Forbes Ave	2.8	27.0	35.0	43.1	58.9	41.7
16 17	Fifth Ave Forbes Ave	3.9	20.3	33.6	42.5	69.7	36.6

*Keyed to Figure 11.

CONCLUSIONS

The analyses performed indicate that strong patterns in cold mode distribution do not necessarily exist from city to city; in fact, it appears that trends do not exist on a citywide basis, either. Tables 11 and 19 do show that relatively large fractions of arterial traffic may be in the cold mode during the late morning, afternoon, and early evening hours. In addition, the fraction of cold operating vehicles on expressways is relatively small compared with other types of facilities.

At this point it is appropriate to provide recommendations regarding values reflecting the percentage of cold operating vehicles for different time periods and at several types of urban locations. Obviously, these recommendations are subjective to a large degree, and are based on a relatively limited study. The percentages of cold operating vehicles presented here then, are intended to provide guidance in selecting values to use in a particular instance, rather than providing absolute values.

Table 26 provides suggested values to be used in accounting for cold mode operation. Included are ranges of cold mode percentages for 10 types of roadway facilities by time period for three separate "cases." The three "cases" reflect the observed effect of adding small time increments (i.e., 1 minute and 2.5 minutes) to the time-from-trip-origin distribution. Case I is based on use of the time-from-trip-origin distribution computed originally while Case II and Case III are based on adding a 1-minute and a 2.5-minute increment, respectively, to the original time-from-trip-origin distribution.

In using the information provided in Table 26, a certain amount of subjective judgment is required. The user must consider carefully the specific location or area under analysis and judge which of the three cases is appropriate. A suggested criterion for making this decision is the nature of the area being considered; for the very densely developed portions of an urban area that are characterized by congested traffic and generally low travel speeds, Case III, which reflects slow traffic movement, would be appropriate. For less densely developed portions of an urban area where traffic movement is not severely impeded, either Case I or II would be appropriate. The specific suggestion, then, is that the user select either Case I, II, or III based on the <u>relative</u> level of traffic congestion and impedance within the particular urban area.

Further, it is suggested that the propensity be toward selecting the higher values within the ranges specified in Table 26 when the maximum 1-hour percentage of cold operating vehicles is required. Also, the nature of the specific location being analyzed should be assessed when selecting a particular value from Table 26. For instance, if the location is an intersection located in the vicinity of several major parking facilities, a higher value would be appropriate. Conversely, if the location is a collector street, for instance, downstream from a busy off-ramp from an expressway, lower levels would be appropriate.

TABLE 26. SUGGESTED RANGES OF VALUES OF THE PERCENTAGE OF VEHICLES OPERATING IN THE COLD MODE FOR VARIOUS CONDITIONS OF TIME AND LOCATION

Case*	General location	Morning peak hours, %	Midday off-peak hours, %	Evening peak hours, %	Evening and early morning off-peak hours, %	Total day %
I	CBD	10 - 20	20 - 50	40 - 70	25 - 50	25 - 55
	Fringe areas	10 - 20	25 - 60	40 - 65	20 - 45	25 - 50
	Outer arterials	15 - 25	30 - 50	30 - 60	25 - 60	30 - 40
	Local/collector streets	10 - 20	35 - 50	35 - 55	20 - 70	30 - 45
	Expressways:					
	Within core area and fringes: inbound+	3 - 5	15 - 20	20 - 30	10 - 15	15 - 20
	Within core area and fringes: outbound+	1 - 3	15 - 20	15 - 20	5 - 10	10 - 15
	Outer portion of urban area: inbound+	3 - 5	2 - 4	2 - 4	4 - 6	3 - 5
	Outer portion of urban area: outbound+	3 - 5	2 - 4	15 - 20	10 - 15	10 - 15
	Special generators outside the CBD	25 - 40	30 - 50	45 - 60	50 - 65	40 - 60
II	CBD	5 - 15	15 - 45	30 - 50	20 - 35	20 - 40
	Fringe aereas	5 - 15	20 - 25	30 - 45	15 - 45	20 - 35
	Outer arterials	10 - 20	15 - 25	20 - 45	15 - 45	20 - 30
	Local/collector streets	5 - 20	15 - 35	25 - 40	20 - 70	25 - 30
	Expressways:					
	Within core area and fringes: inbound+	2 - 4	10 - 20	15 - 25	10 - 15	10 - 20
	Within core area and fringes: outbound+	1 - 3	10 - 20	10 - 20	5 - 10	10 - 15
	Outer portion of urban area: inbound+	2 - 4	2 - 4	2 - 4	3 - 5	3 - 5
	Outer portion of urban area: outbound+	2 - 4	2 - 4	10 - 20	10 - 15	10 - 15
	Special generators outside the CBD	15 - 25	20 - 25	30 - 35	35 - 40	25 - 35
III	CBD	1 - 6	5 - 20	25 - 40	15 - 25	15 - 25
	Fringe areas	1 - 15	10 - 20	15 - 40	10 - 40	10 - 30
	Outer arterials	5 - 15	10 - 15	15 - 30	10 - 35	15 - 20
	Local/collector streets	5 - 15	10 - 15	15 - 25	10 - 60	10 - 25
	Expressways:					
	Within core area and fringes: inbound+	1 - 3	10 - 15	10 - 20	10 - 15	10 - 15
	Within core area and fringes: outbound+	1 - 3	10 - 15	10 - 15	5 - 10	10 - 15
	Outer portion of urban area: inbound+	1 - 3	1 - 3	1 - 3	2 - 4	2 - 4
	Outer portion of urban area: outbound+	1 - 3	1 - 3	10 - 15	10 - 15	10 - 15
	Special generators outside the CBD	15 - 20	10 - 20	20 - 30	25 - 35	20 - 30

*Case I - no access time added; Case II - 1-minute additional access time; Case III - 2.5-minute additional access time.

+With respect to the CBD.

RECOMMENDATIONS FOR FURTHER STUDY

In view of the several deficiencies and inadequacies of existing data, it is recommended that studies be undertaken to obtain and analyze data specific to a number of urban locations to provide an indication of the reasonableness of the results obtained here.

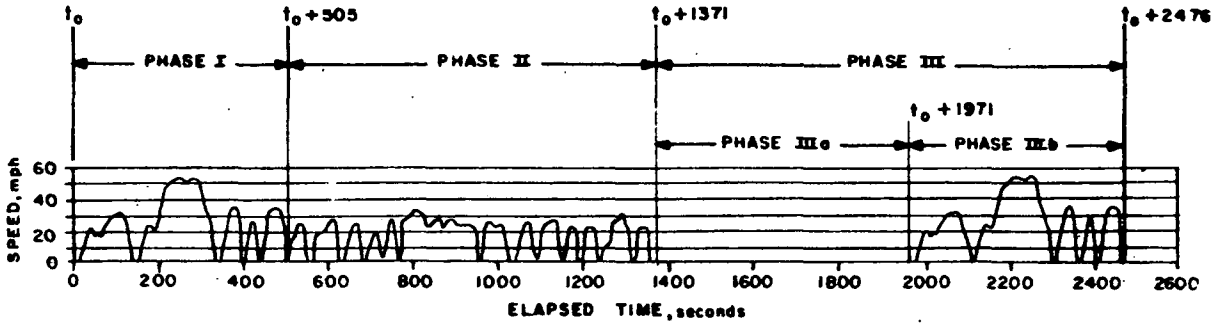
APPENDIX A

FEDERAL TEST PROCEDURE

A methodology has been developed that provides the basis for analyzing the emission characteristics of motor vehicles in a comprehensive and consistent manner. This methodology, referred to as the Federal Test Procedure (FTP), establishes the standard for conducting tests of automotive emission characteristics, which are used as the basis for certifying that a particular type of vehicle meets the appropriate federal emission standards. The FTP prescribes in detail the entire procedure for the conduct of dynamic testing of either production or prototype vehicles powered by combustion engines

The FTP involves determination of mass emissions of carbon monoxide, hydrocarbons, oxides of nitrogen, and carbon dioxide produced by a test vehicle during operation through a standard driving schedule. Testing is performed on stationary vehicles using a dynamometer to simulate actual highway driving. The driving schedule, referred to as the EPA Urban Dynamometer Driving Schedule, consists of three phases - cold transient, hot stabilized, and hot transient. Each phase is comprised of a specific series of acceleration, deceleration, cruise, and idle events; the duration and rates of acceleration, deceleration, and cruise, and the duration of idle events are specified by the Dynamometer Driving Schedule. Figure A-1 provides both a trace of the instantaneous speed as a function of elapsed time, and a description of the events associated with each cycle.

The test procedure begins with an initial vehicle soak at ambient temperatures in the range of 68°F to 86°F, for a period of between 12 and 36 hours. Upon completion of the initial soak period, the vehicle is moved (not under its own power, however) onto a calibrated dynamometer. The vehicle is then instrumented and all emission collection apparatus are installed and connected to the sampling system. Exhaust emission testing begins when the vehicle is started, and continues through the three phases of the Dynamometer Driving Schedule. The sampling system is designed to collect exhaust samples and analyze pollutant concentrations for each phase of the test on a separate basis. The sample obtained for the first phase (cold transient) is referred to as Bag 1 emissions. This sample represents the first 505 seconds (3.598 miles) that the vehicle is operated and includes five cycles of acceleration and deceleration from a stopped position, plus five idle events. It is of interest to note that the 505 seconds associated with cold transient emissions reflects a convenient point (when the vehicle is idling) at which the sampling device can be switched from Bag 1 to Bag 2, rather than reflecting some absolute function between cold mode emissions and operating time.



SUMMARY OF EVENTS

Time, sec	Event
t_0	Start engine, begin idle*.
t_{0+20}	Begin first driving cycle; maximum speed during first cycle is 32.4 mph.
t_{0+125}	End first driving cycle, begin idle period.
t_{0+163}	End idle period, begin second driving cycle; maximum speed during second cycle is 56.7 mph.
t_{0+333}	End second driving cycle, begin idle.
t_{0+346}	End idle, begin third driving cycle; maximum speed during third cycle is 36.5 mph.
t_{0+397}	End third driving cycle, begin idle.
t_{0+403}	End idle, begin fourth driving cycle's maximum speed during fourth cycle is 30.1 mph.
t_{0+429}	End fourth driving cycle, begin idle.
t_{0+447}	End idle, begin fifth driving cycle, maximum speed during fifth cycle is 35.5 mph.
t_{0+505}	End fifth driving cycle, begin idle.
t_{0+510}	End idle, begin sixth driving cycle, maximum speed during sixth cycle is 26.8 mph.
t_{0+552}	End sixth driving cycle, begin idle.
t_{0+568}	End idle, begin seventh driving cycle, maximum speed during seventh cycle is 27.0 mph.
t_{0+620}	End seventh driving cycle, begin idle.
t_{0+645}	End idle, begin eighth driving cycle, maximum speed during eigth cycle is 26.5 mph.
t_{0+680}	End eighth driving cycle, begin idle.

Figure A-1. Summary of the EPA Urban Dynamometer Driving Schedule, used in the Federal Test Procedure.

Time, sec	Event
t_{0+694}	End idle, begin ninth driving cycle, maximum speed during ninth cycle is 23.5 mph.
t_{0+727}	End ninth driving cycle, speed is 0 mph, begin tenth driving cycle, maximum speed during ninth cycle is 28.6 mph.
t_{0+767}	End tenth driving cycle, speed is 0 mph, begin eleventh driving cycle, maximum speed during eleventh cycle is 34.3 mph.
t_{0+957}	End eleventh driving cycle, begin idle.
t_{0+959}	End idle, begin twelfth driving cycle, maximum speed during twelfth cycle is 28.5 mph.
t_{0+1023}	End twelfth driving cycle, begin idle.
t_{0+1052}	End idle, begin thirteenth driving cycle, maximum speed during thirteenth cycle is 28.0 mph.
t_{0+1100}	End thirteenth driving cycle, speed is 0 mph, begin fourteenth driving cycle, maximum speed during fourteenth cycle is 27.0 mph.
t_{0+1153}	End fourteenth driving cycle, begin idle.
t_{0+1168}	End idle, begin fifteenth driving cycle; maximum speed during fifteenth cycle is 23.5 mph.
t_{0+1187}	End fifteenth driving cycle, begin idle.
t_{0+1196}	End idle, begin sixteenth driving cycle, maximum speed during sixteenth cycle is 21.8 mph.
t_{0+1244}	End sixteenth driving cycle, begin idle.
t_{0+1251}	End idle, begin seventeenth driving cycle, maximum speed during s-venteenth cycle is 29.1 mph.
t_{0+1313}	End seventeenth driving cycle, begin idle.
t_{0+1337}	End idle, begin eighteenth driving cycle, maximum speed during eighteenth cycle is 22.0 mph.
t_{0+1367}	End eighteenth driving cycle, begin idle.
t_{0+1371}	End idle, shut engine off.
t_{0+1971}	Restart engine, repeat idle cycles and driving cycles for the period t_0 through t_{0+505}.
t_{0+2476}	End driving cycle, speed is 0 mph, end test.

*Idle in this context implies that the vehicle is stopped and the clutch disengaged (if standard transmission) or the transmission is in the "drive" position (if automatic).

Figure A-1 (continued). Summary of the EPA Urban Dynamometer Driving Schedule, used in the Federal Test Procedure.

The second phase emissions are referred to as Bag 2 emissions representing hot stabilized operation. This sample reflects emissions generated during the subsequent 866 seconds (3.902 miles) of the Driving Schedule. At the end of the second phase (at $t_o + 1371$ - see Figure A-1) the engine is shut down and remains off for 10 minutes. After this 10 minute hot soak period, the engine is restarted and the vehicle is operated through the remainder of the Driving Schedule, which duplicates the first five cycles that comprise the first phase. The emissions collected during this phase are referred to as Bag 3 emissions.

The weighted mass emissions from vehicles tested are computed from the equation:

$$Y_{wm} = 0.43 \left(Y_{ct} + Y_s\right) / \left(D_{ct} + D_s\right) + 0.57 \left(Y_{ht} + Y_s\right) / \left(D_{ht} + D_s\right) \quad \text{(A-1)}$$

where Y_{wm} = weighted mass emissions of each pollutant (i.e., HC, CO, NO_x, or CO_2) in grams per mile;

Y_{ct} = mass emissions as calculated from the cold transient phase of the test, in grams per test phase;

Y_{ht} = mass emissions as calculated from the hot transient phase of the test, in grams per test phase;

Y_s = mass emissions as calculated from the hot stabilized phase of the test, in grams per test phase;

D_{ct} = measured driving distance during the cold transient phase, in miles;

D_{ht} = measured driving distance during the hot transient phase, in miles;

D_s = measured driving distance during the hot stabilized phase, in miles.

It can be seen from equation (A-1) that the weighted mass emissions (Y_{wm}) reflect the weighted average emission rate during two identical 7.5 mile trips (Phase I plus Phase II, and Phase IIIb plus Phase II as shown in Figure A-1). The implication is that the hot stabilized emission characteristics are identical for both trips. Since the driving cycles in Phases I and IIIb are identical, equation (A-1) can be simplified to:

$$Y_{wm} = \left[0.43 \left(Y_{ct} + Y_s\right) + 0.57 \left(Y_{ht} + Y_s\right) \right] / D_t \quad \text{(A-2)}$$

and

$$Y_{wm} = \left(0.43\ Y_{ct} + 0.57\ Y_{ht} + Y_s\right) / D_t \quad \text{(A-3)}$$

where $D_t = D_{ht} + D_s = D_{ct} + D_s$.

The Federal Test Procedure covers many areas of vehicle testing including vehicle preconditioning, test data recording procedures, fuel specifications, instrumentation required, conduct of instrumentation and apparatus calibration, emission computations, testing procedures, etc. For details regarding these areas of the FTP, the reader should consult reference 1.

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APPENDIX B

OVERVIEW OF THE COMPREHENSIVE PLANNING PROCESS

INTRODUCTION

To fully understand the procedures used in this study, it is necessary to have a general understanding of the comprehensive planning process since data developed for and used in the comprehensive planning process were used extensively in the analysis of cold mode operation. The following provides an overview of the planning process in general terms, which will satisfy the requirement stated above. It is strongly recommended, however, that the reader who is totally unfamiliar with the techniques used in the comprehensive planning process refers to a more detailed treatise of the various techniques used in order to fully undestand the implications of applying this type of data in the analysis described in the main body of this report.

BACKGROUND

The Federal-Aid Highway Act of 1944 first provided Federal-aid funds on a regular basis for use in urban areas. These funding programs included provisions for conducting transportation planning activities as well as for designing and implementing specific projects. The Federal-Aid Highway Act of 1962, however, required that programs for Federal-aid highway projects approved subsequent to 1 July 1965, in urban areas with populations greater than 50,000, must be based on a continuing, comprehensive, and cooperative transportation planning process. The planning process that evolved from this concept is known as the 3-C planning process.

Several basic features of the 3-C process are important to consider. First, the continuing nature of the process focuses on developing and continuously evaluating both short- and long-range highway and transportation plans that are soundly conceived to meet the objectives and basic requirements of the state and the urban communities. The comprehensive nature of the process requires that (1) economic, demographic, and land-use parameters be included in the planning activities, (2) that forecasts be made of future demands for all transportation modes, both private and public, for the movement of both persons and goods; (3) that the process include consideration of terminal and transfer facilities, and traffic control systems; and (4) that the entire area within which the forces of development are interrelated, and which is expected to be urbanized within the forecast period, be included. To satisfy this requirement the planning process must characterize several specific elements for the present (with respect to the time when the planning procedure is implemented) condition; the characterization include inventorying and analyzing:

- the economic factors that affect regional development
- population
- land-use patterns
- transportation facilities (including mass transportation)
- terminal and transfer facilities (goods movement)
- traffic control devices and systems
- zoning ordinances, subdivision regulations, building codes, etc.
- financial resources
- social and community-value factors

and more recently:

- air and water quality

Finally, the cooperative aspect ensures that the final product of the process reflects the various needs and desires of all segments of the population, and accounts for the plans and policies of all relevant local, state, and federal agencies.

To define the primary objective of the comprehensive planning process, one could say that it is a mechanism for (1) identifying both the short- and long-range regional transportation requirements, (2) defining various methods for satisfying these requirements, and (3) evaluating alternative transportation and land-use scenarios in order to optimize future regional growth patterns.

Several organizational structures have been used to carry out the comprehensive planning process. Among the most widely used are:

- Centralized state staff generally drawn from the State's Department of Transportation;
- Semi-independent organizations established as an ad hoc joint effort and responsive to a multiagency board;
- Council of Governments comprised of elected or appointed representatives of communities within the region;
- Regional Planning Commission; and
- Contract study organizations such as private consulting firms retained by a state or regional agency holding overall responsibility for the planning effort.

The organization responsible for conducting the planning effort generally receives input from several committees. These include technical committees, policy committees, and citizens advisory groups. These committees provide guidance

on administrative matters, set technical objectives and standards, and generally serve to ensure that the planning effort is conducted in accordance with the needs and desires of the region. Generally, a study director orchestrates the entire process.

Obviously, there are wide differences in the scope of planning projects from city to city. The size of study areas ranges from less than a few hundred square miles to several thousand square miles. The cost of conducting these studies is directly proportional to the size (in terms of population and land area) of the area being studied. It has been indicated that the costs associated with conducting a comprehensive transportation planning study are in the range of $1.00 to $1.50 per capita.[1] The nature of these studies is such that the duration of the study period may be 2 to 3 years or longer.

A discussion of every aspect of the comprehensive planning process is clearly beyond the scope of this report. Detailed discussions of the entire process can be found in several texts and reference material (for instance, References 1 through 4). The discussion here is limited to only the specific portions of the planning process that relate to the highway transportation system, specifically, as it concerns the movement of persons within a region.

TRAVEL FORECASTING

One of the most important concepts in the transportation planning process is travel forecasting. Travel forecasting is the process from which detailed descriptions of regional travel activity are developed. Urban travel patterns are a function of several observable and quantifiable elements, viz:

- Land-use patterns including location and intensity
- Social and economic factors particular to the area
- The availability of various types of transportation facilities in the area.

Travel forecsting, then, actually is a process that derives relationships between regional travel patterns and the aggregate of the interrelationships that exist among the three elements listed above.

The general process of travel forecasting consists of four phases. First, inventories are conducted in order to define economic activity, population, land use, travel patterns, transportation facilities, etc. for the region. In the second phase, the inventory data are analyzed and the relationships between travel patterns and the socioeconomic, land use, and transportation facility characteristics are defined. The third phase involves redefining the regional travel patterns based on various scenarios of future economic, social, land use, and transportation facility characteristics. Finally, the fourth phase provides for the evaluation of alternative transportation systems and land use plans based on the forecasted travel patterns defined in the third phase. Each of the phases associated with travel forecasting warrants additional discussion.

Transportation Inventories and Analyses

Inventories--

Various inventories provide the foundation for the entire planning process. Inventories are conducted to define characteristics that generally relate to:

- land use
- population
- economic factors
- transportation facilities
- travel patterns
- legislation (laws, bylaws, ordinances)
- financial resources
- environmental aspects

Many of the analyses and inventorying tasks are conducted at a subregional level. Planning regions are generally divided into analysis zones, which can range in size from a fraction of a square mile, to areas that encompass entire townships. Certain inventories and analyses are conducted at levels that include several individual analysis zones; these larger areas are referred to as analysis districts.

For the purposes of this discussion, the most important inventories are those that concern transportation facilities and travel patterns. Inventories of regional transportation facilities include physical highway inventories, highway use and operating inventories, and mass transit inventories. Physical inventories of the regional highway network are conducted in order to define certain functional and physical characteristics of each roadway in the network. Functional characteristics include the type of service that a roadway provides. Several general categories are typically used to describe the functional classification of each street in the network; examples of these categories include:

- principal arterial system streets
- major arterial system streets
- minor arterial system streets
- collector system streets
- local streets

Additional categories may be used to designate each section according to its location within the region in terms of being in the central business district, in the urbanized portion of the region, in a rural area, or others.

Other portions of the physical highway inventory identify features of each roadway section that affect capacity. Included are elements such as the

number of lanes, lane width, lane use, intersectional traffic control, speed and and parking regulations, etc.

Travel time or speed data are also included in the inventorying process. Studies are usually conducted on portions of the highway network to determine speed characteristics during both peak and off-peak travel periods.

Data regarding regional transit systems are included in the inventory. The data required for a transit inventory must provide good definition of a number of aspects including:

- Service area
  - routes and type of service
  - locations of transfer points, terminals, etc.
  - nature of the areas through which the routes pass
  - potential new service areas
- System data
  - route mileage
  - physical resources (number and condition of transit vehicles and facilities)
  - franchise limitations or restrictions
  - fare structure
  - organizational structure and financial condition of transit companies
  - methods of financing
- Revenue data
  - summaries of annual, average, weekday, and average Saturday or Sunday revenue for each route
  - revenue per vehicle-mile for each route
- Cost data
  - salaries, facility operating costs, vehicle operating and replacement costs, etc.
- Operating characteristics
  - annual and average weekday vehicle-miles and vehicle-hours of operation
  - route data including streets utilized, hours of operation, average headways, etc.

- Passenger volumes
  - annual and average weekday user volumes by system and route
  - locations of maximum activity (loadings and unloadings)
  - counts at terminals and major loading points, etc.

Obviously, the transportation facilities inventories are quite extensive. The items described above are generally the types that are included in the regional inventory. It is possible that the inventory for a specific region would contain additional elements as well.

Transportation Analyses--

The second major portion of the regional inventory concerns identifying travel patterns. The interest is in identifying the number of trips that occur between all pairs of analysis zones (internal-internal trips), between a point located outside the region and each analysis zone (external or internal-external trips), and between points located outside the region but where a portion of the trip occurs within the region (external-external trips); the modal distribution of these trips; and the travel path taken. The primary method used to compile these data is to conduct origin-destination surveys throughout the region.

Four types of origin-destination (O-D) surveys are used to determine regional vehicle and person travel; viz:

- Home interview surveys
- Truck and taxi surveys
- Cordon line surveys*
- On-board surveys of transit vehicles

Home interview surveys provide a measure of the travel undertaken by residents of the region. It is generally agreed that these trips account for between 80 and 90 percent of the total number of trips that occur within an urban area. Sampling techniques are used in the conduct of the home interview surveys. The overall sampling rate is a function of the population of the area being analyzed. General guidelines indicate that a sample rate of about 12 percent should be used in urban areas with populations in the range of 50,000 to 150,000 while a sample rate of about 4 percent would be adequate in areas where the population exceeds 1 million.[2] The basic unit used in the selection of a sample is the housing unit. Specific housing units are selected at random from each analysis zone and interviews are conducted through personal visits or by telephone.

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*Cordon line surveys involve determining travel characteristics of persons entering an area defined by a cordon line around the area. Studies are made at the cordon line and can include vehicle counts, classification counts, interviews, etc.

The data obtained using the home interview technique generally include information regarding (1) the number of persons by age and sex occupying the dwelling, (2) family income, (3) vehicle ownership, (4) various physical characteristics of the dwelling, (5) employment categories of household members, and (6) trip characteristics. Trip characteristics include a record of every trip made during a specified day by each individual (usually over 5 years old) in the household, indicating the exact points of origin and destination, the mode used, time that the trip began and ended, purpose, parking characteristics (if appropriate), and others.

The second type of O-D survey characterizes the movement of trucks and taxis through the region. Interviews are conducted at truck terminals and taxi dispatch points to determine the routes and frequency of truck service, and the extent of the demand for taxi service.

Cordon line surveys are conducted on the major highways radiating from the study region. Interview stations are established along these highways at the edge of the study region. Information on trip origins and destinations, purpose, frequency, vehicle occupancy, etc., is obtained for trips crossing the cordon line. Several techniques are used to obtain the data including direct interviews, distributing mail-back questionnaires, and mailing questionnaires to motorists observed passing the survey station using their license plate number for identification. The sampling rate used in these studies ranges from about 25 percent for conducting direct interviews, to 80 or 90 percent for distributing questionnaires.

On-board surveys are conducted to identify the travel patterns of transit patrons or airline passengers. Data are obtained regarding the trip origin and destination, waiting time at the bus stop or terminal, modes used to get to the bus stop or terminal and to get from the bus stop or terminal to the final destination, frequency of travel, reason for using the bus (or for flying), etc.

The data samples obtained from the travel pattern inventory are expanded based on the actual usable sample size obtained and the expanded data is transcribed onto a trip record file (usually on a computer readable medium). The expanded data, then, represents regional travel patterns at the analysis zone level. An important process that is undertaken at this point is to evaluate the travel data obtained. Several techniques can be used to assess the quality of the travel data. The most basic test involves comparing expanded dwelling unit data such as total population or number of vehicles available, to similar information found in other independent sources. This particular test merely indicates whether or not the relatively easily obtained dwelling unit data have been collected and expanded correctly; it does not necessarily indicate whether or not the trip data are acceptable. Other tests do provide this indication. The most widely used test is the screenline comparison. A screenline is an imaginary line dividing the study area into two parts. Manual classification counts are taken on all roadways intercepted by the screenline. These counts are compared to the number of trips having an origin and destination on different sides of the screenline as determined by the expanded interview data. Comparisons made in this fashion on an hourly basis provide a good check of the accuracy and completeness of the expanded

trip data. If the comparison shows that the number of screenline crossings from the expanded trip data are at least 85 to 90 percent of the total ground count crossings, the trip data are considered adequate.* Where the expanded trips are less than about 85 percent of the ground count trips, adjustments must be made to account for the underreporting. Several methods are suggested in the literature for deriving adjustment factors. These generally involve determining where the underreporting error is likely to occur and using this determination as the basis for adjusting trips. For instance, the number of peak-hour trips may compare favorably, therefore the off-peak hours could be adjusted. Also, only internal trips are adjusted owing to the much higher probability that external trips are more fully-reported since much larger sample rates are used to define external trip patterns.+

Once the analyst is satisfied that the trip data are adequate, trip tables are generated. These trip tables show the number of trip interchanges that occur between all analysis zone pairs. Numerous tables can be generated to show any particular type of trip pattern. For instance, separate tables could be generated showing total person trips, auto-driver trips only, auto-driver work trips only, etc. These tables are usually computer generated.

Other inventories are also conducted during the first phase of the travel forecasting process. These inventories are concerned with defining the land-use and population characteristics of each analysis zone (which, by the way, is typically comprised of a standard unit of area used by the U.S. Bureau of Census, such as a census tract or enumeration district). Other inventories that are required concern the economic factors and financial resources of the region, and laws and ordinances regulating land use. These inventories will not be discussed in detail here, but are mentioned for completeness.

The first phase, then, of the travel forecasting process involves defining the existing nature of travel in the region. It is interesting to note that about half of the total cost of a comprehensive study is reflected in this first phase.[5]

Regional Transportation Analysis

Trip Generation Analysis--

The second phase of the travel forecasting process focuses on analyzing the data developed in the first phase in order to define and quantify the functional relationships that exist between travel and socioeconomic characteristics. The first of several specific analyses that are undertaken as part of this phase is trip generation analysis. Trip generation analysis attempts to identify causal relationships between the number and types of trips

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*Apparently, underreporting is the dominant problem in the survey process.

+As was indicated previously, external trip characteristics are identified from cordon line studies where sampling rates are generally 20 to 25 percent whereas internal trip data is obtained from home interviews using sampling rates of 2 to 10 percent.

generated in an area such as an analysis zone, and certain features of that zone that relate to its population, land use, employment, and general social and economic nature. The general process used is to develop correlations between observed or measured trip-making and the socioeconomic, demographic, and land use features of the area. These correlations are made using mathematical techniques such as regression or factor analysis with either single or multivariate approaches. The outcome of the analysis is an equation that expresses the intensity of trips generated from a zone as a function of a set of variables such as land use, employment, etc. The significance of this analysis is that it provides a means of assessing the impact of changes in, say, land use of a zone in terms of travel activity; this capability is essential in travel forecasting.

Trip generation analyses identify these functional relationships for various types of trips (such as truck trips, auto-driver trips) and by trip purpose. In separate but related analyses, relationships are derived that define the probable modal split between transit and private auto trips. The discussion to this point has merely skimmed the surface of the topic of trip generation analysis. Detailed discussions of the topic can be found in the literature (see References 1, 2, 3, 4, 6, and 7, for instance).

Trip Distribution Analyses--

The second type of analysis undertaken concerns trip distribution. Trip distribution analyses focus on defining and quantifying the relationships that determine how trips generated in one zone are distributed to other zones in the region. Two general types of trip distribution models have received much use. The first type uses growth factor techniques to project future trip distribution patterns. The most widely used method of this type is the Frater Growth-Factor Method. This method was developed using the basic premise that the distribution of future year trips generated from a zone is proportional to the distribution pattern identified in the base year travel surveys, modified by both a growth factor for the zone pair being considered, and an adjustment factor for the relative attractiveness of other competing zones. This technique is used primarily for estimating future external trips or for interurban trip interchanges in small areas.

A second type of procedure referred to is the Gravity Model, which has been the most widely-used model in trip distribution analysis work. This model provides a totally synthetic approach to the problem of trip distribution. The concept is that zone-to-zone interchanges are directly proportional to the total trip production at the origin and the total trip attraction at the destination, and inversely proportional to some function of the spatial separation of the two zones. In this relationship, the spatial separation factor provides a friction factor that reflects the relative travel time between any zone pair. This process does not utilize observed (base year) trip distribution data directly; hence, it is entirely a synthetic process. Since it is a synthetic model, calibration is required. In the calibration process the factor describing the spatial separation is adjusted until several criteria are met regarding agreement between observed and simulated trip-length frequency distributions and the need for satisfying a trip-end

constraint equation that basically states that the total number of trips attracted to a zone must be equal to the number of trips generated from the zone.

Several other models have been developed and used successfully. Two of these are the Intervening Opportunities Model and the Competing Opportunities Model. These are also synthetic in the sense that the distributions derived are based entirely on mathematical relationships.

Traffic Assignment--

The third element involves a process for synthesizing the interzonal trip movements over the regional highway network. This process, known as traffic assignment modeling, involves the computer selection of the minimum impedance path between a zone pair; the trips that occur between the zones are assigned to the roadway comprising the minimum impedance path. A basic requirement is that the regional highway network be described in a format suitable for computer processing. The first step in the traffic assignment process, then, involves selecting and coding the network to be used. All streets and highways in the region cannot be included in the network. An important consideration in the process, then, is the selection of streets that will be included. The principal criterion for selecting the network is judgment. It is important that a balance be achieved between having too few or too many streets in the network. Generally, all streets and roadways that carry substantial volumes (obviously, this is a relative term; substantial volume might be 5,000 vehicles per day in a large city, while in a small city it might imply 1,000 vehicles per day) and have functional classifications of collector or higher; local streets are generally not included in the network. The basic network is described in terms of nodes and links. A node is an intersection of two or more network roadways, the intersection of a network roadway and a State or municipal boundary, or an arbitrary location along a network street that serves to limit distances between nodes. Each node is assigned a number for identification. The roadway section between nodes is referred to as a link. All interzonal trip activity is assumed to occur from a single point in each analysis zone. This point is the zone centroid which theoretically is the center of the trip generating activity for the zone. Zone centroids are connected to the street network by a centroid connector, which actually is a synthetic street link. All centroids are assigned an identification number.

The next procedure involves describing the operating parameters of the network. Data obtained during the first phase is used to describe the physical and operational aspects of each link in the network in terms of functional classification, travel speed, capacity, etc. At each intersection on the network, turn penalties and prohibitions are defined. Turn penalties reflect the additional impedance to traffic flow that occurs at intersections, and also reflects the relative impedance for each possible movement (for instance, higher impedance would be reflected for left turns than for through movements at most intersections). A sample network map is shown in Figure B-1.

The link data and intersection data are coded using a standard format and transcribed onto a medium such as a computer tape. The entire file describing all elements of the network is called the Historical Record file.

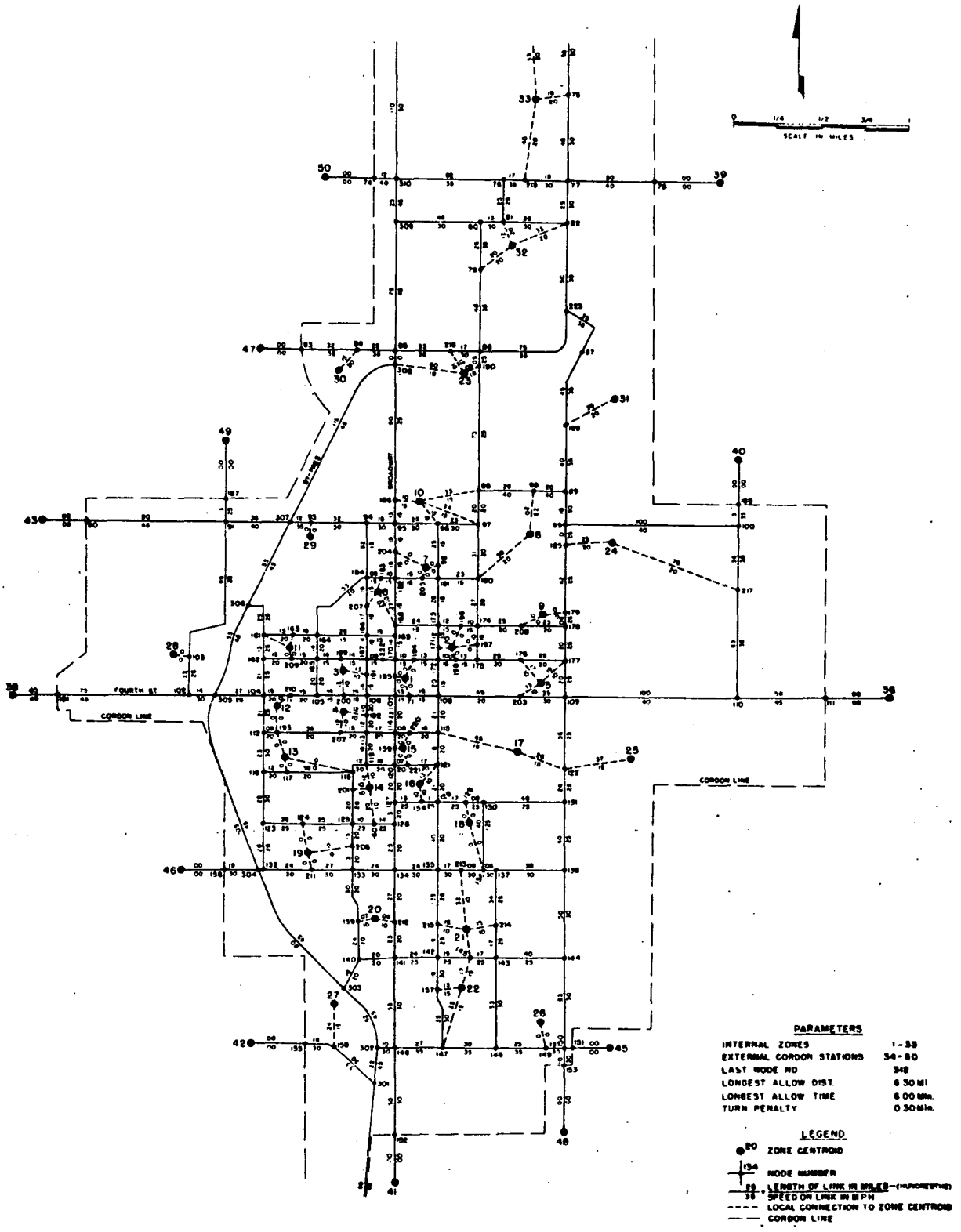

Figure B-1. Sample network map (Source: Reference 2).

The actual assignment process is accomplished using a standard computer program that uses the historical record and the trip distribution results as input. The program computes the minimum impedance path between each zone pair As the assignment process takes place, the number of trips assigned to each link is accumulated in storage. The primary output of the assignment process is a listing of the assigned volume for each link. A satisfactory assignement is one where the total assigned volume within a corridor approximates the total measured volume within the corridor. Calibration of the assignment model is undertaken by adjusting the impedance factors (travel speed and turn penalties) on various links. Usually, several iterations are required to obtain satisfactory results.

Several types of assignment models are used. The most straightforward of these is the all-or-nothing model where all trips from an origin zone to a specific destination zone are assigned to one travel path only. A much more sophisticated technique is capacity restraint. This is an iterative process whereby the accumulated volumes on each link are continually compared with the links capacity. As the assigned volume increases the impedance factor is increased at a predetermined rate based on the ratio of the volume to capacity.

Analyzing Future Scenarios (Forecast)--

The third phase of the travel forecasting process involves forecsting changes in regional population, employment, land-use, etc. based on perceived trends and alternative development scenarios for the region. The impact on travel demand at the analysis zone level is defined using the relationships derived in the trip generation analyses conducted during the second phase. The impact on trip generation for all zones in the region is analyzed and regional trip distribution characteristics are redefined, again using the procedures in Phase II. The highway network is updated to reflect expected new facilities that will be available by the forecast year, and traffic assignment modeling is conducted. Assignment modeling using forecast year travel and the base year network is also conducted to identify where new facilities are needed.

Systems Analysis--

This phase involves additional analysis of the transportation system to determine specific requirements to meet the forecast year travel demands. Alternative scenarios of highway and transit improvements (or changes) are considered. An outline of the elements involved in the urban travel forecasting process is provided in Figure B-2.

An important tool used in large scale planning is a battery of standard computer programs developed by the Federal Highway Administration. This battery of programs, referred to as the Urban Planning System 360 battery, provides the capability for performing an extremely wide range of analyses using the basic data inputs described in the Phase II portion, above. Included are basic programs for building files, performing trip generation and trip distribution, and utility programs for performing many types of special analyses. A complete description of the UPS 360 battery is provided in Reference 2.

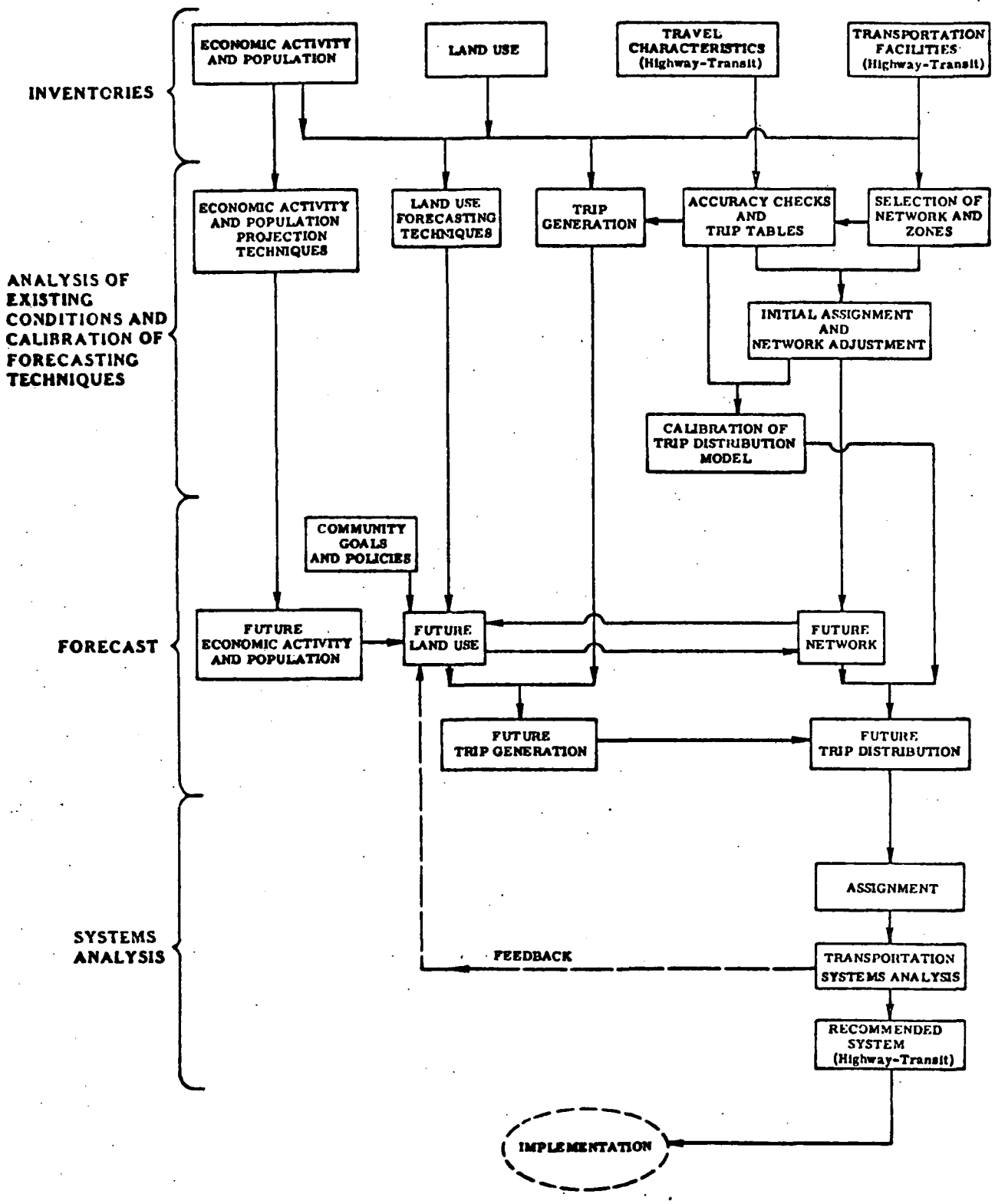

Figure B-2. General perspective of the urban travel forecasting process (Source: Reference 2).

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APPENDIX C

EXAMPLE OF THE METHOD USED TO IDENTIFY THE PERCENTAGE OF VEHICLES OPERATING IN THE COLD MODE

Presented here is an example of the computations required to determine the percentage of vehicles operating in the cold mode for any study link, The example shows the computations for a link located on Forbes Avenue in Pittsburgh; this link is identified as location 17 on the Study Link Locations Map shown in Figure 11.

The first step in the analysis is to identify the origin-destination distributions for all trips using the link. This is accomplished through the use of the LINKUSE computer program (described in Appendix B) and the trip generation, trip distribution, and traffic assignment data for the region. This step was accomplished by the Southwestern Pennsylvania Regional Planning Commission (SPRPC). The result is a computer printout showing the number of trips entering and leaving each analyses zone that used the designated study link. Table C-1 shows this printout for the study link.

The next step involves identifying the travel times from all zones to the study link. The FMTSKIM computer program, which generated a printout for each zone showing the travel time to all other zones, was utilized. The printout for zone 039 (see Table C-2), which is adjacent to the study link, was used for the example study link. The travel times shown in Table C-2 represent travel on (1) a centroid connector between the origin zone and the street network, (2) the various highway links, and (3) a centroid connector between the street network and the destination zone. For the purposes of this analysis, the desired travel time is from each analysis zone to the study link, therefore, to use the skimtree data, the travel time from the study link to the destination zone had to be subtracted from the total zone-to-zone travel time. Since a criterion for selecting study links was that one end-point of the link had to be located at a centroid connector, travel times from all zones to the study link could be determined by subtracting the travel time for the adjacent zone centroid connector from the total travel time between the connected zone and all other zones. Travel times on links and centroid connectors were determined from the Historical Record File.

At the time that these computations were being made, detailed information regarding the relationship between the cold soak duration and the cold mode operating time was not available. Therefore, it was estimated that the upper boundary for the time that a vehicle would be operating in the cold mode would be 10 minutes. From this point, then, two groups of vehicle trips were considered - trips originating within 10 minutes travel time from the study link,

and trips originating further than 10 minutes away from the study link; trips in the first category were studied in detail while trips in the second category were considered in general terms.

The next step in analyzing the example study link was to identify the analysis zones that were within 10 minutes travel time from the study link, and to determine the number of trips generated by these zones that were routed over the study link. A tabulation of the zones and number of trips is presented in Table C-3; these were developed from Tables C-1 and C-2.

The detailed analysis of trips with origins within 10 minutes of the study link focused on identifying various trip characteristics from the Trip Record File, described in Section 3. This file provided information such as trip origin zone, time parked, and the (clock) time that the trip began. Aggregations of these types of data were made for groups of zones, referred to as analysis districts. These aggregations provided the basis for defining several critical attributes of trips occurring on the study links as will be demonstrated. The aggregations were made for groups of analysis zones rather than individual analysis zones primarily because the accuracy of the data did not warrant analyses at a level as fine as the zone level. The analysis districts were established by combining zones that provide similar land-use functions; for instance, 11 individual analysis zones comprising the Pittsburgh central business district were combined to form one analysis district. In this manner, a total of 12 analysis districts were defined by combining 138 analysis zones in and surrounding the City of Pittsburgh; the individual analysis zones included in each district are listed in Table C-4.

An important objective of the project was to identify the diurnal patterns of vehicles operating in the cold mode. In this connection, four time groupings were selected, viz.:

- Group I - 0500 to 1000 hours
- Group II - 1000 to 1500 hours
- Group III - 1500 to 2000 hours
- Group IV - 2000 to 0500 hours

Using these time groupings, the Trip Record File was computer-sorted to determine the fractional distribution of the trips generated in each analysis district by time group; the result of this is shown in Table C-5.

Based on the data provided in Tables C-3 and C-4, a table was constructed showing the distribution of trips originating within 10 minutes of the study link by the origin (analysis district). This distribution is shown in Table C-6.

Using the data provided in Tables C-5 and C-6, a determination was made of the fraction of trips (originating within 10 minutes of the study link) generated in each analysis district that occurred during each time group; these fractions are shown in Table C-7.

Tables C-3 and C-4 were used to develop a table showing the fraction of total link trips originating in each analysis district as a function of the travel time from the origin zone to the study link; these fractions are shown in Table C-8.

The data in Tables C-7 and C-8 were used to develop Table C-9, which shows the fraction of trips (originating within 10 minutes of the study link) by analysis district, by time group, as a function of the time from trip origin.

The next step involved analyzing the parking characteristics of each analysis district. This was accomplished utilizing the trip record file. A computer-sorting routine was developed that identified the parking duration distribution for each analysis district as a function of the time group during which the trip began. This distribution is shown in Table C-10.

Tables C-9 (column C) and C-10 were then used to develop Table C-11, which shows the distribution of trips (originating within 10 minutes of the study link) by time from trip origin, and by time group, as a function of the parking duration. Development of this table completed the characterization of link trips that was necessary to identify the percentages of cold operating vehicles for each time group.

Data provided by the U.S. Environmental Protection Agency,Office of Mobile Sources were used to define a functional relationship between cold mode operation and cold soak duration and operating time. Table C-12 provides a summary of this relationship; indicated in Table C-12 is the duration (in minutes) of the cold operating cycle as a function of the cold soak duration (in hours) for ambient temperatures of $75^{o}F$ and $20^{o}F$.

Tables C-11 and C-12 provided the data required to identify the cold mode percentages during each time group for the study link. Table C-12 shows, for example, that the duration of the cold operating cycle is at least 2.4 (say 2.5) minutes regardless of the cold soak duration; therefore, all vehicles that are within the first 2.5 minutes of operation are in the cold mode. From Table C-11, then, all trips that are in the 0.5 to 2.5 minute range of the Time From Trip Origin column, are in the cold mode. For other ranges of Time from Trip Origin, the fraction of cold operating vehicles is found by interpolation. As an example, consider the 2.5 to 4.5 minute range. Here it is first assumed that the mid-point time (3.5 minutes) will adequately represent the trips in this group. Therefore, from Table C-12 it is indicated that (at $75^{o}F$) the cold operating duration of 3.5 minutes occurs when the cold soak duration is almost 1.5 hours; hence, all trips that are within the range of 2.5 to 4.5 minutes from their origin are assumed to be operating in the cold mode if the cold soak duration is 1.5 hours or more. The results of applying this technique to the Forbes Avenue study link are shown in line A of Table C-13; lines A through F provide an overall summary of the analysis of the link.

TABLE C-1. NUMBER OF TRIPS TRAVERSING ANALYSIS LINK, FORBES AVE. NODE 03901 TO NODE 04106

TRIP END SUMMARY FOR TRIPS MEETING SELECTED LINK CRITERIA FOR TABGRP 4

ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS
1	5	--	5	2	52	1	53	3	42	1	43	4	98	56	154
5	23	--	23	6	55	1	56	7	197	80	277	8	--	49	49
9	73	23	96	10	77	71	148	11	70	146	216	12	--	5	5
13	--	--	--	14	65	64	129	15	--	--	--	16	31	4	35
17	3	73	76	18	91	31	122	19	--	--	--	20	4	5	9
21	2	43	45	22	2	3	5	23	63	27	90	24	31	30	61
25	108	137	245	26	34	29	63	27	106	175	281	28	1092	2286	3378
29	38	78	116	30	269	290	559	31	172	146	318	32	378	208	586
33	192	290	482	34	6	3	9	35	--	--	--	36	--	--	--
37	227	165	392	38	65	131	196	39	1302	1258	2560	40	964	995	1959
41	231	266	497	42	36	35	71	43	--	--	--	44	--	--	--
45	72	33	105	46	--	--	--	47	5	5	10	48	5	6	11
49	1	--	1	50	--	--	--	51	--	1	1	52	--	5	5
53	--	51	51	54	--	81	81	55	--	33	33	56	212	301	513
57	--	76	76	58	154	165	319	59	--	--	--	60	579	104	683
61	--	--	--	62	386	439	825	63	508	1018	1526	64	--	--	--
65	--	--	--	66	--	--	--	67	78	72	150	68	18	6	24
69	285	242	527	70	77	71	148	71	85	428	513	72	114	101	215
73	25	7	32	74	8	5	13	75	3	14	17	76	2	66	68
77	1	13	14	78	1	3	4	79	1	24	25	80	22	--	22
81	--	--	--	82	--	--	--	83	--	--	--	84	29	29	58
85	47	47	94	86	1	--	1	87	--	--	--	88	--	--	--
89	2	8	10	90	26	26	52	91	2	2	4	92	1	2	3
93	--	--	--	94	6	3	9	95	2	2	4	96	11	3	14
97	1	1	2	98	50	68	118	99	11	10	21	100	2	1	3
101	27	1	28	102	5	5	10	103	24	24	48	104	1	--	1
105	27	62	89	106	3	23	26	107	44	27	71	108	2	1	3
109	2	1	3	110	2	1	3	111	44	22	66	112	3	42	45
113	1	--	1	114	67	1	68	115	25	22	47	116	1	--	1
117	1	--	1	118	--	28	28	119	1	--	1	120	23	1	24
121	1	--	1	122	--	--	--	123	1	--	1	124	--	--	--
125	1	--	1	126	3	--	3	127	2	--	2	128	1	1	2
129	1	--	1	130	--	1	1	131	--	1	1	132	--	--	--
133	--	1	1	134	--	--	--	135	--	1	1	136	--	1	1
137	--	--	--	138	69	29	98	139	49	4	53	140	--	--	--
141	7	--	7	142	--	--	--	143	--	--	--	144	57	54	111
145	236	172	408	146	272	278	550	147	28	55	83	148	104	117	221
149	53	60	113	150	2	29	31	151	56	49	105	152	68	27	95
153	7	1	8	154	7	41	48	155	80	2	82	156	84	--	84
157	3	--	3	158	--	--	--	159	3	1	4	160	6	1	7
161	30	26	56	162	23	--	23	163	53	23	76	164	61	1	62
165	5	1	6	166	33	1	34	167	5	1	6	168	61	37	98
169	93	93	186	170	5	3	8	171	31	2	33	172	16	13	29
173	67	31	98	174	14	49	63	175	67	6	73	176	58	24	82
177	30	1	31	178	9	2	11	179	9	1	10	180	73	44	117
181	71	1	72	182	83	41	124	183	4	1	5	184	32	1	33
185	81	1	82	186	27	22	49	187	4	1	5	188	29	1	30
189	2	--	2	190	4	1	5	191	4	1	5	192	3	--	3
193	6	31	37	194	4	1	5	195	2	1	3	196	57	26	83

TABLE C-1 (continued). NUMBER OF TRIPS TRAVERSING ANALYSIS LINK, FORBES AVE. NODE 03901 TO NODE 04106

TRIP END SUMMARY FOR TRIPS MEETING SELECTED LINK CRITERIA FOR TABGRP 4

ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS
197	3	--	3	198	4	1	5	199	1	--	1	200	3	1	4
201	--	--	--	202	2	--	2	203	4	1	5	204	3	1	4
205	6	2	8	206	78	1	79	207	--	--	--	208	4	1	5
209	5	1	6	210	--	--	--	211	--	--	--	212	--	--	--
213	--	--	--	214	--	--	--	215	3	--	3	216	2	1	3
217	--	--	--	218	--	--	--	219	27	1	28	220	--	--	--
221	--	--	--	222	--	--	--	223	1	--	1	224	--	--	--
225	--	--	--	226	--	--	--	227	--	--	--	228	--	--	--
229	--	--	--	230	--	--	--	231	5	5	10	232	--	--	--
233	--	--	--	234	4	4	8	235	--	--	--	236	3	29	32
237	--	--	--	238	--	--	--	239	--	--	--	240	34	33	67
241	--	--	--	242	--	--	--	243	1	--	1	244	--	--	--
245	--	--	--	246	--	--	--	247	--	--	--	248	--	--	--
249	--	--	--	250	1	1	2	251	23	24	47	252	--	--	--
253	--	--	--	254	--	--	--	255	--	--	--	256	--	--	--
257	--	--	--	258	--	--	--	259	--	--	--	260	--	--	--
261	--	--	--	262	--	--	--	263	--	--	--	264	1	--	1
265	--	--	--	266	--	--	--	267	37	--	37	268	--	--	--
269	--	--	--	270	--	--	--	271	--	--	--	272	--	--	--
273	--	--	--	274	--	--	--	275	--	--	--	276	--	--	--
277	--	--	--	278	--	--	--	279	--	--	--	280	--	--	--
281	--	--	--	282	--	--	--	283	--	--	--	284	--	--	--
285	--	--	--	286	--	--	--	287	--	--	--	288	3	11	14
289	3	2	5	290	15	3	18	291	2	1	3	292	1	23	24
293	65	23	88	294	23	1	24	295	1	1	2	296	4	1	5
297	--	--	--	298	4	1	5	299	2	--	2	300	23	1	24
301	--	4	4	302	--	--	--	303	--	--	--	304	22	22	44
305	2	--	2	306	--	41	41	307	1	--	1	308	--	--	--
309	--	--	--	310	--	1	1	311	--	--	--	312	1	--	1
313	--	1	1	314	--	--	--	315	--	--	--	316	3	3	6
317	3	2	5	318	22	1	23	319	--	1	1	320	1	1	2
321	2	1	3	322	--	1	1	323	24	24	48	324	1	1	2
325	2	--	2	326	--	--	--	327	2	1	3	328	--	1	1
329	2	2	4	330	2	1	3	331	1	2	3	332	1	--	1
333	1	1	2	334	22	--	22	335	--	--	--	336	--	2	2
337	1	1	2	338	14	32	46	339	1	1	2	340	--	--	--
341	--	3	3	342	1	--	1	343	1	2	3	344	53	14	67
345	3	3	6	346	1	2	3	347	1	--	1	348	34	23	57
349	--	1	1	350	3	2	5	351	2	1	3	352	1	--	1
353	--	--	--	354	1	1	2	355	2	2	4	356	--	1	1
357	--	--	--	358	--	--	--	359	--	--	--	360	1	1	2
361	--	--	--	362	1	2	3	363	1	--	1	364	1	1	2
365	--	--	--	366	1	2	3	367	1	--	1	368	--	--	--
369	1	1	2	370	--	--	--	371	1	1	2	372	1	--	1
373	--	--	--	374	--	--	--	375	29	--	29	376	1	1	2
377	--	1	1	378	--	--	--	379	--	--	--	380	--	--	--
381	--	--	--	382	--	--	--	383	--	1	1	384	--	--	--
385	--	--	--	386	--	--	--	387	--	--	--	388	--	--	--
389	--	--	--	390	1	--	1	391	1	--	1	392	--	--	--

TABLE C-1 (continued). NUMBER OF TRIPS TRAVERSING ANALYSIS LINK, FORBES AVE. NODE 03901 TO NODE 04106

TRIP END SUMMARY FOR TRIPS MEETING SELECTED LINK CRITERIA FOR TABGRP 4

ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS
393	1	1	2	394	3	3	6	395	--	--	--	396	11	24	35
397	1	1	2	398	22	22	44	399	2	2	4	400	1	--	1
401	2	2	4	402	3	25	28	403	5	5	10	404	--	--	--
405	--	--	--	406	1	--	1	407	--	1	1	408	1	1	2
409	--	--	--	410	--	--	--	411	--	--	--	412	--	--	--
413	--	--	--	414	--	--	--	415	--	--	--	416	--	--	--
417	--	1	1	418	--	--	--	419	4	1	5	420	27	28	55
421	26	28	54	422	2	1	3	423	1	1	2	424	1	1	2
425	2	1	3	426	--	--	--	427	--	--	--	428	37	25	62
429	1	--	1	430	--	1	1	431	3	1	4	432	--	--	--
433	--	1	1	434	1	--	1	435	--	--	--	436	--	1	1
437	1	--	1	438	--	--	--	439	--	--	--	440	--	--	--
441	--	--	--	442	--	1	1	443	1	--	1	444	1	--	1
445	1	--	1	446	1	1	2	447	--	--	--	448	--	--	--
449	--	--	--	450	--	--	--	451	--	--	--	452	--	--	--
453	1	--	1	454	--	--	--	455	--	--	--	456	1	--	1
457	--	--	--	458	--	--	--	459	--	--	--	460	--	--	--
461	--	1	1	462	--	--	--	463	--	--	--	464	--	--	--
465	--	--	--	466	--	--	--	467	--	--	--	468	--	1	1
469	--	--	--	470	--	--	--	471	--	--	--	472	--	--	--
473	--	--	--	474	--	--	--	475	--	--	--	476	--	--	--
477	--	--	--	478	--	--	--	479	--	--	--	480	--	--	--
481	--	--	--	482	--	--	--	483	--	--	--	484	1	1	2
485	--	--	--	486	--	--	--	487	--	--	--	488	--	--	--
489	--	--	--	490	--	--	--	491	--	--	--	492	--	--	--
493	--	--	--	494	--	--	--	495	--	--	--	496	--	--	--
497	--	--	--	498	--	--	--	499	--	--	--	500	--	--	--
501	--	--	--	502	--	--	--	503	--	--	--	504	--	--	--
505	--	--	--	506	--	--	--	507	--	--	--	508	1	1	2
509	--	--	--	510	--	--	--	511	--	--	--	512	--	--	--
513	--	--	--	514	--	--	--	515	--	--	--	516	--	--	--
517	--	--	--	518	--	--	--	519	--	--	--	520	--	--	--
521	--	--	--	522	1	--	1	523	--	--	--	524	--	--	--
525	--	--	--	526	3	--	3	527	--	--	--	528	--	--	--
529	1	--	1	530	--	--	--	531	--	--	--	532	--	--	--
533	--	--	--	534	--	--	--	535	--	--	--	536	--	--	--
537	--	1	1	538	--	--	--	539	--	--	--	540	--	--	--
541	--	--	--	542	--	--	--	543	--	--	--	544	--	--	--
545	--	--	--	546	--	--	--	547	--	--	--	548	--	--	--
549	--	--	--	550	--	--	--	551	--	--	--	552	--	--	--
553	--	--	--	554	--	--	--	555	--	--	--	556	1	--	1
557	1	--	1	558	2	1	3	559	1	--	1	560	--	--	--
561	1	--	1	562	2	--	2	563	1	1	2	564	--	--	--
565	--	--	--	566	--	--	--	567	--	1	1	568	--	--	--
569	--	--	--	570	--	--	--	571	--	--	--	572	--	--	--
573	--	--	--	574	--	--	--	575	--	--	--	576	1	--	1
577	1	--	1	578	--	--	--	579	1	--	1	580	1	--	1
581	1	--	1	582	2	1	3	583	--	--	--	584	--	--	--
585	--	--	--	586	--	--	--	587	--	--	--	588	--	--	--

TABLE C-1 (continued). NUMBER OF TRIPS TRAVERSING ANALYSIS LINK, FORBES AVE. NODE 03901 TO NODE 04106

TRIP END SUMMARY FOR TRIPS MEETING SELECTED LINK CRITERIA FOR TABGRP 4

ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS
589	--	--	--	590	1	--	1	591	--	--	--	592	--	--	--
593	--	--	--	594	--	--	--	595	--	--	--	596	--	--	--
597	--	--	--	598	--	--	--	599	--	--	--	600	--	--	--
601	1	--	1	602	--	--	--	603	1	--	1	604	2	--	2
605	--	--	--	606	--	--	--	607	--	--	--	608	--	--	--
609	--	--	--	610	--	--	--	611	--	--	--	612	--	--	--
613	--	--	--	614	--	--	--	615	1	--	1	616	--	--	--
617	2	--	2	618	--	--	--	619	2	1	3	620	2	--	2
621	--	--	--	622	--	--	--	623	1	--	1	624	--	--	--
625	--	1	1	626	1	--	1	627	1	--	1	628	2	--	2
629	2	1	3	630	1	--	1	631	1	--	1	632	--	--	--
633	--	--	--	634	20	--	20	635	1	--	1	636	--	--	--
637	--	1	1	638	1	--	1	639	--	--	--	640	--	--	--
641	1	--	1	642	2	--	2	643	--	--	--	644	1	--	1
645	--	--	--	646	3	--	3	647	1	1	2	648	--	--	--
649	1	--	1	650	2	--	2	651	1	--	1	652	--	--	--
653	1	1	2	654	1	--	1	655	2	--	2	656	1	1	2
657	1	--	1	658	1	--	1	659	2	--	2	660	--	--	--
661	1	1	2	662	1	--	1	663	--	--	--	664	1	--	1
665	22	--	22	666	1	--	1	667	1	1	2	668	2	--	2
669	--	--	--	670	1	--	1	671	--	--	--	672	1	1	2
673	24	--	24	674	--	--	--	675	2	--	2	676	2	--	2
677	1	1	2	678	1	--	1	679	--	--	--	680	2	--	2
681	2	1	3	682	3	1	4	683	1	--	1	684	3	--	3
685	2	1	3	686	1	--	1	687	3	1	4	688	26	--	26
689	28	1	29	690	4	1	5	691	3	1	4	692	3	--	3
693	3	1	4	694	25	--	25	695	25	1	26	696	2	23	25
697	3	1	4	698	5	1	6	699	27	24	51	700	1	--	1
701	2	1	3	702	2	--	2	703	23	--	23	704	1	--	1
705	2	1	3	706	1	--	1	707	2	--	2	708	2	1	3
709	2	--	2	710	2	1	3	711	1	--	1	712	2	--	2
713	2	1	3	714	1	--	1	715	--	--	--	716	1	1	2
717	--	--	--	718	1	--	1	719	29	--	29	720	1	--	1
721	2	1	3	722	--	--	--	723	--	--	--	724	1	--	1
725	1	--	1	726	1	--	1	727	1	1	2	728	2	--	2
729	4	1	5	730	2	--	2	731	3	1	4	732	7	1	8
733	26	23	49	734	2	1	3	735	1	--	1	736	1	--	1
737	2	1	3	738	2	--	2	739	2	--	2	740	1	1	2
741	--	--	--	742	1	--	1	743	--	--	--	744	--	--	--
745	--	--	--	746	--	--	--	747	--	--	--	748	--	--	--
749	--	--	--	750	1	--	1	751	--	--	--	752	2	23	25
753	1	1	2	754	--	--	--	755	--	--	--	756	--	--	--
757	--	--	--	758	--	--	--	759	--	--	--	760	--	--	--
761	--	--	--	762	--	--	--	763	--	1	1	764	--	--	--
765	--	--	--	766	--	--	--	767	--	--	--	768	--	--	--
769	--	--	--	770	--	--	--	771	--	--	--	772	--	--	--
773	--	--	--	774	--	--	--	775	--	--	--	776	--	--	--
777	--	--	--	778	--	--	--	779	--	--	--	780	--	--	--
781	--	--	--	782	--	--	--	783	--	--	--	784	--	--	--

TABLE C-1 (continued). NUMBER OF TRIPS TRAVERSING ANALYSIS LINK, FORBES AVE. NODE 03901 TO NODE 04106

TRIP END SUMMARY FOR TRIPS MEETING SELECTED LINK CRITERIA FOR TABGRP 4

ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS
785	--	--	--	786	--	--	--	787	--	--	--	788	1	--	1
789	--	--	--	790	--	--	--	791	--	--	--	792	1	2	3
793	--	--	--	794	41	40	81	795	--	--	--	796	--	--	--
797	--	--	--	798	1	9	10	799	--	--	--	800	1	--	1
801	1	--	1	802	--	--	--	803	--	--	--	804	1	--	1
805	1	1	2	806	--	--	--	807	--	--	--	808	--	--	--
809	1	1	2	810	--	--	--	811	--	--	--	812	--	--	--
813	--	1	1	814	2	--	2	815	--	--	--	816	--	--	--
817	2	--	2	818	--	--	--	819	23	1	24	620	--	--	--
821	1	1	2	822	--	1	1	823	--	--	--	824	--	--	--
825	--	--	--	826	--	--	--	827	--	--	--	828	--	--	--
829	--	--	--	830	--	--	--	831	--	--	--	832	--	--	--
833	--	--	--	834	--	--	--	835	--	--	--	836	--	--	--
837	--	--	--	838	--	--	--	839	1	--	1	840	--	--	--
841	--	--	--	842	--	--	--	843	22	--	22	844	--	--	--
845	1	--	1	846	--	--	--	847	--	--	--	848	25	1	26
849	1	--	1	850	--	2	2	851	--	15	15	852	--	--	--
853	1	--	1	854	2	1	3	855	2	1	3	856	1	--	1
857	1	--	1	858	--	--	--	859	1	--	1	860	--	3	3
861	1	1	2	862	--	--	--	863	--	--	--	864	1	1	2
865	--	--	--	866	--	--	--	867	--	--	--	868	1	--	1
869	1	--	1	870	--	--	--	871	--	1	1	872	--	1	1
873	1	1	2	874	10	9	19	875	--	--	--	876	--	--	--
877	--	1	1	878	1	--	1	879	--	--	--	880	--	--	--
881	--	9	9	882	--	--	--	883	--	--	--	884	--	--	--
885	--	--	--	886	--	--	--	887	--	--	--	888	--	--	--
889	--	--	--	890	--	--	--	891	--	--	--	892	--	--	--
893	--	--	--	894	--	--	--	895	--	--	--	896	--	--	--
897	--	--	--	898	--	--	--	899	--	--	--	900	1	--	1
901	--	--	--	902	--	--	--	903	1	--	1	904	--	--	--
905	--	--	--	906	--	--	--	907	--	--	--	908	--	--	--
909	--	--	--	910	--	--	--	911	--	1	1	912	--	1	1
913	--	--	--	914	1	--	1	915	--	1	1	916	1	--	1
917	1	--	1	918	--	--	--	919	--	--	--	920	--	--	--
921	--	--	--	922	--	--	--	923	--	--	--	924	--	--	--
925	--	--	--	926	--	--	--	927	1	--	1	928	--	--	--
929	--	--	--	930	--	--	--	931	--	--	--	932	--	--	--
933	--	--	--	934	1	1	2	935	--	--	--	936	--	--	--
937	--	--	--	938	--	--	--	939	--	--	--	940	--	--	--
941	--	--	--	942	--	--	--	943	--	--	--	944	--	--	--
945	--	--	--	946	--	--	--	947	--	--	--	948	--	--	--
949	--	--	--	950	--	--	--	951	--	--	--	952	--	--	--
953	--	--	--	954	--	--	--	955	--	--	--	956	--	--	--
957	--	--	--	958	--	--	--	959	1	--	1	960	--	--	--
961	--	--	--	962	--	--	--	963	--	--	--	964	--	--	--
965	--	--	--	966	--	--	--	967	2	2	4	968	--	--	--
969	--	--	--	970	--	--	--	971	1	6	7	972	--	--	--
973	--	--	--	974	17	1	18	975	12	26	38	976	49	3	52
977	1	--	1	978	--	--	--	979	11	7	16	980	--	--	--

TABLE C-1 (continued). NUMBER OF TRIPS TRAVERSING ANALYSIS LINK, FORBES AVE. NODE 03901 TO NODE 04106

1972 NETWORK - SELECT LINK - FOR GCA LINKUSE 03/15/77 18.54.23 PAGE 32

TRIP END SUMMARY FOR TRIPS MEETING SELECTED LINK CRITERIA FOR TABGRP 4

ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS	ZONE	TRIPS OUT	TRIPS IN	TRIP ENDS
981	51	3	54	982	--	--	--	983	16	3	19	984	—	—	—
985	7	12	19	986	27	21	48								
TOTALS	13354	13354	26708												

TABLE C-2. TRAVEL TIMES FROM PITTSBURGH ZONES TO ZONE 039
(FORBES AVE. LINK 03901 TO 04106)

1972 TRAVEL AND TERMINAL TIMES FOR SELECTED ZONES
03/15/77

TABLE 1 FROM ZONE 39 CONTINUED

ZONE	00	1	2	3	4	5	6	7	8	9
10	13	11	12	18	18	12	10	10	8	11
20	16	15	16	13	9	8	7	7	6	6
30	6	7	5	7	11	13	10	5	3	—
40	4	2	6	5	8	10	11	12	16	13
50	15	13	14	13	11	9	8	8	9	6
60	6	4	5	3	3	4	10	5	6	7
70	10	9	11	12	11	13	12	12	17	16
80	20	21	20	19	19	20	22	18	21	20
90	22	25	24	26	16	17	18	20	18	21
100	21	23	22	22	19	22	23	24	27	17
110	14	18	18	20	18	19	20	22	21	23
120	23	26	26	26	26	18	19	20	22	21
130	23	24	23	26	27	26	17	18	21	27
140	31	25	21	17	14	7	7	10	10	12
150	12	14	16	16	20	22	25	33	41	32
160	27	24	25	27	22	20	21	23	9	9
170	10	12	13	16	15	13	14	14	14	16
180	16	16	23	21	22	20	19	23	20	19
190	19	20	22	19	19	21	26	27	23	25
200	29	24	25	25	23	26	25	28	26	27
210	24	26	25	29	31	33	33	34	37	38
220	44	42	43	44	14	10	13	11	14	14
230	15	15	18	17	17	19	20	22	21	20
240	20	24	25	21	28	27	32	31	32	33
250	25	27	29	28	28	25	22	23	22	17
260	22	24	28	31	30	31	34	35	33	30
270	26	25	24	26	25	26	28	34	35	36
280	31	30	29	31	36	36	36	37	20	19
290	23	26	25	21	25	33	30	29	28	26
300	24	27	30	29	31	31	36	33	34	35
310	35	33	37	39	38	39	24	23	22	25
320	28	32	27	26	25	25	29	27	28	31
330	31	35	39	38	35	40	43	38	43	34
340	36	34	29	26	24	23	30	31	31	32
350	35	38	38	35	35	38	37	43	43	44
360	27	29	28	30	30	31	30	31	34	31
370	34	37	37	34	42	38	39	41	43	49
380	42	40	41	41	43	45	47	39	41	52
390	52	47	48	22	21	22	20	22	26	26
400	25	27	28	31	31	35	35	29	30	34
410	39	34	44	47	46	43	40	42	38	21
420	19	24	24	24	22	23	27	27	28	29
430	30	30	38	32	31	33	39	41	35	42
440	42	32	33	36	37	40	47	42	45	47
450	50	49	53	53	59	55	52	50	56	54
460	48	41	45	45	45	49	53	56	49	57
470	63	61	56	69	70	66	64	58	66	60
480	56	49	53	52	50	57	57	65	59	61
490	65	58	62	69	72	76	72	72	71	65
500	66	57	61	63	61	59	65	63	60	60
510	59	61	63	58	65	64	67	71	69	76
520	74	79	78	78	74	70	67	72	70	66

Note: Times shown are minutes.

TABLE C-2 (continued). TRAVEL TIMES FROM PITTSBURGH ZONES TO ZONE 039 (FORBES AVE. LINK 03901 TO 04106)

1972 TRAVEL AND TERMINAL TIMES FOR SELECTED ZONES
03/15/77

TABLE 1 FROM ZONE 39 CONTINUED

ZONE	00	1	2	3	4	5	6	7	8	9
530	70	77	72	75	74	83	85	87	81	80
540	80	80	86	91	98	89	90	86	81	86
550	86	90	91	97	96	102	55	50	48	55
560	63	65	56	52	56	64	60	62	70	58
570	65	75	79	78	74	80	72	69	82	75
580	76	89	96	88	81	75	81	79	78	79
590	82	88	87	84	82	82	95	95	97	97
600	85	101	116	104	92	105	106	56	55	55
610	53	47	49	52	54	61	50	52	56	64
620	64	61	54	57	58	60	62	60	67	74
630	80	81	81	74	71	74	65	63	60	62
640	57	59	57	56	53	53	54	50	51	53
650	50	49	48	47	41	40	38	40	42	47
660	46	47	48	50	46	45	44	46	50	54
670	48	43	42	45	43	41	41	40	40	38
680	38	36	42	47	49	43	46	35	33	29
690	32	31	32	35	28	26	29	32	26	30
700	33	35	38	40	34	37	42	45	44	44
710	48	56	64	64	57	60	63	63	60	58
720	60	59	87	86	87	54	53	51	47	35
730	32	30	25	33	35	41	43	36	44	38
740	43	40	37	40	39	41	41	43	44	48
750	47	55	50	51	53	56	79	75	72	64
760	60	63	64	71	77	69	70	74	77	67
770	65	64	67	69	72	68	64	64	59	59
780	57	59	62	59	48	52	59	56	61	59
790	55	52	52	56	55	56	54	56	55	54
800	54	58	60	57	56	55	61	66	72	75
810	15	69	64	56	52	52	51	49	48	48
820	47	47	46	44	48	55	48	47	47	51
830	51	53	50	49	40	42	36	45	40	42
840	44	50	43	46	43	51	48	57	56	61
850	56	47	50	46	50	46	43	40	38	42
860	46	51	58	54	48	55	55	49	46	51
870	49	48	52	53	51	55	53	45	47	52
880	50	54	55	58	57	52	51	55	56	62
890	57	58	67	69	64	68	65	61	63	65
900	69	71	68	68	72	74	58	60	60	58
910	54	56	59	64	55	60	59	64	61	64
920	71	67	69	70	74	82	73	68	64	56
930	69	58	59	62	60	65	69	71	74	75
940	76	74	73	77	72	75	77	74	69	78
950	82	80	87	81	80	78	72	76	79	78
960	76	75	69	69	59	48	53	22	17	85
970	91	77	79	88	65	87	83	91	89	91
980	108	92	131	127	93	71	72			

Note: Times shown are minutes.

TABLE C-3. RECORD OF TRAVEL TIME AND NUMBER OF TRIPS FROM ALL ZONES TO ANALYSIS LINK, FORBES AVENUE (NODE 03901 TO 04106)

Analysis zone number	Travel time, minutes	Number of trips	Fraction of total trips
16	10	31	
17	10	3	
18	8	91	
24	9	31	
25	8	108	
26	7	34	
27	7	106	
28	6	1092	
29	6	38	
30	6	269	
31	7	172	
32	5	378	
33	7	192	
36	10	0	
37	5	227	
38	3	65	
39	2	1302	
40	4	964	
41	2	231	
42	6	36	
43	5	0	
44	8	0	
45	10	72	
55	9	0	
56	8	212	
57	8	0	
58	9	154	
59	6	0	
60	6	579	
61	4	0	
62	5	386	
63	3	508	
64	3	0	
65	4	0	
66	10	0	
67	5	78	
68	6	18	
69	7	285	
70	10	77	
71	9	85	
145	7	236	
146	7	272	
147	10	28	
148	10	104	
168	9	61	
169	9	93	
170	10	5	
225	10	0	
Subtotal		8623	0.646
All other zones	>10	4731	0.354
Total		13,354	1.000

TABLE C-4. ASSIGNMENT OF PITTSBURGH ANALYSIS ZONES TO ANALYSIS DISTRICTS

Analysis district	Analysis zones
I	001, 002, 003, 004, 005, 006, 007, 008, 009, 010, 968
II	011, 012, 015, 016, 017, 018, 019
III	013, 014, 020, 021, 125, 128
IV	022, 023, 024, 025, 026, 027, 028, 029, 040
V	031, 034, 035
VI	030, 032, 033, 036, 037, 038, 039, 064, 065, 067, 146, 148, 168, 169, 170
VII	041, 042, 043, 044, 045, 055, 056, 057, 058, 059, 060, 061, 062, 063, 068, 069, 070, 071, 074, 145, 147
VIII	046, 047, 049, 050, 051, 052, 053, 054, 072, 073, 136
IX	075, 076, 077, 078, 079, 080, 083, 084, 085, 086, 089, 094, 095, 096, 097, 098, 104, 106, 289
X	109, 110, 111, 112, 113, 114, 115, 116, 117, 126, 127, 129, 130, 131, 132, 133
XI	118, 119, 120, 121, 122, 123, 124, 134, 135
XII	343, 344, 345, 360, 361, 362, 363, 366, 393, 399, 967

TABLE C-5. DISTRIBUTION OF DAILY TRIPS OCCURRING BY TIME PERIOD FOR PITTSBURGH ANALYSIS DISTRICTS*

Analysis district	Time period				
	I†	II**	III††	IV§	Total
I	0.064	0.235	0.543	0.158	1.000
II	0.072	0.281	0.402	0.245	1.000
III	0.105	0.211	0.505	0.179	1.000
IV	0.086	0.232	0.387	0.295	1.000
V	0.106	0.140	0.458	0.296	1.000
VI	0.157	0.222	0.321	0.300	1.000
VII	0.120	0.229	0.357	0.294	1.000
VIII	0.157	0.200	0.330	0.313	1.000
IX	0.120	0.199	0.332	0.349	1.000
X	0.082	0.245	0.409	0.264	1.000
XI	0.155	0.213	0.280	0.352	1.000
XII	0.116	0.231	0.351	0.302	1.000

* Derived from Trip Record File.

† Time period I: 0500 to 1000 hours.

** Time period II: 1000 to 1500 hours.

†† Time period III: 1500 to 2000 hours.

§ Time period IV: 2000 to 0500 hours.

TABLE C-6. DISTRIBUTION OF TRIPS ORIGINATING WITHIN 10 MINUTES OF THE STUDY LINK, BY ORIGIN (ANALYSIS DISTRICT); FORBES AVENUE LINK (NODE 03901 TO 04106)

Analysis district	Number of trips	Fraction of total
I	0	0.000
II	125	0.009
III	0	0.000
IV	2373	0.178
V	172	0.012
VI	3046	0.228
VII	2907	0.218
VIII	0	0.000
IX	0	0.000
X	0	0.000
XI	0	0.000
XII	0	0.000
Total	8623	0.646

TABLE C-7. DISTRIBUTION OF TRIPS ORIGINATING WITHIN 10 MINUTES OF THE STUDY LINK BY ORIGIN ANALYSIS DISTRICT AS A FUNCTION OF TIME GROUP, FORBES AVENUE LINK (NODE 03901 TO 04106)

Time group	Origin district	(Fraction of trips generated from district by time group (from Table C-5))	x	(Fraction of link trips generated from origin district (from Table C-6))	=	Fraction of total link trips originating within 10 minutes of study link by analysis district and time group
I	II	0.072		0.009		0.001
	IV	0.086		0.178		0.015
	V	0.106		0.012		0.001
	VI	0.157		0.228		0.036
	VII	0.120		0.218		0.026
				Σ = 0.646		0.079
II	II	0.281		0.009		0.003
	IV	0.232		0.178		0.041
	V	0.140		0.012		0.002
	VI	0.222		0.228		0.051
	VII	0.229		0.218		0.050
				Σ = 0.646		Σ = 0.167
III	II	0.402		0.009		0.004
	IV	0.387		0.178		0.069
	V	0.458		0.012		0.006
	VI	0.321		0.228		0.073
	VII	0.357		0.218		0.078
				Σ = 0.646		Σ = 0.230
IV	II	0.245		0.009		0.002
	IV	0.295		0.178		0.052
	V	0.296		0.012		0.004
	VI	0.300		0.228		0.068
	VII	0.294		0.218		0.064
				Σ = 0.646		Σ = 0.190
						ΣΣ = 0.646

TABLE C-8. FRACTION OF TRIPS ORIGINATING IN EACH ANALYSIS DISTRICT AS A FUNCTION OF THE TRAVEL TIME FROM ORIGIN TO STUDY LINK, FORBES AVENUE LINK (NODE 03901 TO 04106)

Analysis district	Travel time — analysis zone to study link	Number of trips	Fraction of subtotal
II	0.5 - 2.5	0	0.000
	2.5 - 4.5	0	0.000
	4.5 - 6.5	0	0.000
	6.5 - 8.5	91	0.728
	8.5 - 10.5	34	0.272
Subtotal		125	1.000
IV	0.5 - 2.5	0	0.000
	2.5 - 4.5	964	0.406
	4.5 - 6.5	1130	0.476
	6.5 - 8.5	248	0.105
	8.5 - 10.5	31	0.013
Subtotal		2373	1.000
V	0.5 - 2.5	0	0.000
	2.5 - 4.5	0	0.000
	4.5 - 6.5	0	0.000
	6.5 - 8.5	172	1.000
	8.5 - 10.5	0	0.000
Subtotal		172	1.000
VI	0.5 - 2.5	1302	0.427
	2.5 - 4.5	65	0.021
	4.5 - 6.5	952	0.313
	6.5 - 8.5	464	0.152
	8.5 - 10.5	263	0.086
Subtotal		3046	1.000
VII	0.5 - 2.5	231	0.079
	2.5 - 4.5	508	0.175
	4.5 - 6.5	1019	0.351
	6.5 - 8.5	733	0.252
	8.5 - 10.5	416	0.143
Subtotal		2907	1.000

TABLE C-9. DISTRIBUTION OF LINK TRIPS ORIGINATING AT ANALYSIS ZONES BY TIME FROM TRIP ORIGIN - FORBES AVENUE LINK (NODE 03901 - 04106)

Time period	Origin analysis district	Column A: Distribution of total daily link trips during time periods originating from analysis district*	Column B: Time from trip origin distribution for link trips originating at analysis district+					Column C: Distribution of link trips originating at analysis zone by time from trip origin‡				
			0.5 to 2.5	2.5 to 4.5	4.5 to 6.5	6.5 to 8.5	8.5 to 10.5	0.5 to 2.5	2.5 to 4.5	4.5 to 6.5	6.5 to 8.5	8.5 to 10.5
I	II	0.001	–	–	–	0.728	0.272	–	–	–	0.001	–
	IV	0.015	–	0.406	0.476	0.105	0.013	–	0.006	0.007	0.002	–
	V	0.001	–	–	–	1.000	–	–	–	–	0.001	–
	VI	0.036	0.427	0.021	0.312	0.152	0.087	0.016	0.001	0.011	0.005	0.003
	VII	0.026	0.079	0.175	0.351	0.252	0.143	0.002	0.005	0.009	0.006	0.004
II	II	0.003	–	–	–	0.728	0.272	–	–	–	0.002	0.001
	IV	0.041	–	0.406	0.476	0.105	0.013	–	0.016	0.020	0.004	0.001
	V	0.002	–	–	–	1.000	–	–	–	–	0.002	–
	VI	0.051	0.427	0.021	0.312	0.152	0.087	0.022	0.001	0.016	0.008	0.004
	VII	0.050	0.079	0.175	0.351	0.252	0.143	0.004	0.009	0.017	0.013	0.007
III	II	0.004	–	–	–	0.728	0.272	–	–	–	0.003	0.001
	IV	0.069	–	0.406	0.476	0.105	0.013	–	0.028	0.033	0.007	0.001
	V	0.006	–	–	–	1.000	–	–	–	–	0.006	–
	VI	0.073	0.427	0.021	0.312	0.152	0.087	0.031	0.001	0.023	0.011	0.007
	VII	0.078	0.079	0.175	0.351	0.252	0.143	0.006	0.014	0.027	0.020	0.011
IV	II	0.002	–	–	–	0.728	0.272	–	–	–	0.002	–
	IV	0.052	–	0.406	0.476	0.105	0.013	–	0.021	0.025	0.005	0.001
	V	0.004	–	–	–	1.000	–	–	–	–	0.004	–
	VI	0.068	0.427	0.021	0.312	0.152	0.087	0.029	0.001	0.021	0.010	0.007
	VII	0.064	0.079	0.175	0.351	0.252	0.143	0.005	0.011	0.022	0.016	0.010

*From Table C-7.

+From Table C-8.

‡Column C = (Column A) x (Column B).

TABLE C-10. PARKING DURATION DISTRIBUTION FOR PITTSBURGH

Analysis district	Time period	Parking duration distribution, hours									
		<1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9
I	I	0.423	0.094	0.031	0.016	0.016	0.016	0.016	0.016	0.250	0.125
	II	0.306	0.226	0.119	0.157	0.064	0.034	0.034	0.013	0.030	0.017
	III	0.109	0.057	0.057	0.040	0.028	0.029	0.031	0.063	0.322	0.263
	IV	0.177	0.114	0.133	0.089	0.063	0.082	0.038	0.020	0.095	0.190
II	I	0.417	0.056	0.014	0.014	0.014	0.014	0.028	0.014	0.014	0.417
	II	0.530	0.174	0.068	0.050	0.032	0.046	0.014	0.004	0.021	0.060
	III	0.259	0.090	0.085	0.057	0.022	0.015	0.047	0.057	0.209	0.159
	IV	0.155	0.159	0.180	0.106	0.078	0.020	0.065	0.045	0.024	0.167
III	I	0.314	0.059	0.029	0.029	0.000	0.000	0.000	0.067	0.171	0.295
	II	0.332	0.100	0.062	0.043	0.038	0.033	0.038	0.028	0.242	0.085
	III	0.095	0.024	0.038	0.030	0.032	0.014	0.010	0.016	0.396	0.347
	IV	0.179	0.067	0.028	0.022	0.050	0.022	0.017	0.056	0.246	0.313
IV	I	0.314	0.070	0.012	0.012	0.012	0.012	0.012	0.047	0.058	0.453
	II	0.310	0.216	0.121	0.112	0.047	0.043	0.009	0.009	0.039	0.095
	III	0.220	0.098	0.121	0.070	0.034	0.016	0.026	0.070	0.238	0.109
	IV	0.163	0.115	0.217	0.156	0.071	0.037	0.041	0.031	0.041	0.129
V	I	0.189	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.292	0.472
	II	0.500	0.179	0.000	0.000	0.057	0.000	0.000	0.000	0.264	0.000
	III	0.087	0.017	0.000	0.000	0.017	0.000	0.000	0.035	0.635	0.207
	IV	0.166	0.017	0.017	0.034	0.105	0.051	0.027	0.034	0.483	0.068
VI	I	0.140	0.025	0.006	0.006	0.000	0.000	0.070	0.025	0.057	0.669
	II	0.158	0.171	0.054	0.041	0.032	0.005	0.014	0.005	0.023	0.140
	III	0.411	0.193	0.093	0.037	0.034	0.016	0.019	0.031	0.078	0.087
	IV	0.187	0.120	0.120	0.067	0.047	0.053	0.037	0.053	0.040	0.277
VII	I	0.300	0.017	0.008	0.008	0.000	0.008	0.008	0.017	0.083	0.550
	II	0.489	0.192	0.061	0.048	0.044	0.026	0.009	0.009	0.017	0.105
	III	0.308	0.154	0.070	0.056	0.039	0.014	0.017	0.028	0.165	0.148
	IV	0.163	0.122	0.112	0.085	0.061	0.048	0.054	0.037	0.061	0.255
VIII	I	0.178	0.032	0.000	0.000	0.000	0.013	0.013	0.032	0.089	0.643
	II	0.485	0.130	0.075	0.055	0.030	0.020	0.005	0.015	0.010	0.175
	III	0.288	0.173	0.091	0.045	0.039	0.021	0.027	0.027	0.130	0.158
	IV	0.176	0.073	0.089	0.093	0.054	0.038	0.038	0.029	0.058	0.351
IX	I	0.233	0.025	0.025	0.017	0.017	0.008	0.017	0.008	0.117	0.533
	II	0.563	0.151	0.045	0.035	0.040	0.015	0.005	0.000	0.050	0.095
	III	0.292	0.099	0.075	0.042	0.024	0.009	0.021	0.030	0.253	0.154
	IV	0.149	0.092	0.089	0.069	0.069	0.052	0.046	0.052	0.080	0.304
X	I	0.256	0.073	0.012	0.012	0.012	0.012	0.012	0.037	0.049	0.524
	II	0.449	0.229	0.073	0.045	0.045	0.020	0.016	0.029	0.020	0.073
	III	0.225	0.103	0.071	0.042	0.015	0.017	0.022	0.046	0.284	0.176
	IV	0.167	0.133	0.076	0.095	0.049	0.042	0.042	0.030	0.106	0.261
XI	I	0.103	0.019	0.000	0.000	0.000	0.019	0.019	0.045	0.090	0.703
	II	0.596	0.080	0.056	0.019	0.019	0.000	0.009	0.005	0.005	0.211
	III	0.389	0.175	0.136	0.046	0.025	0.007	0.007	0.039	0.107	0.079
	IV	0.165	0.108	0.102	0.082	0.043	0.085	0.043	0.026	0.034	0.313
XII	I	0.181	0.034	0.009	0.000	0.009	0.000	0.017	0.017	0.078	0.655
	II	0.472	0.152	0.074	0.030	0.043	0.026	0.004	0.009	0.048	0.143
	III	0.365	0.165	0.077	0.048	0.031	0.014	0.017	0.020	0.160	0.103
	IV	0.172	0.142	0.103	0.063	0.043	0.043	0.043	0.053	0.070	0.268

TABLE C-11. DISTRIBUTION OF TOTAL LINK TRIPS BY COLD SOAK DURATION FOR TRIPS WITHIN 10.5 MINUTES OF STUDY LINK

Time group	Time from trip origin	Analysis district	Distribution of total link trips*	Distribution of total link trips by cold soak duration, hours									
				<1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9
I	0.5 to 2.5	VI	0.016	0.002	–	–	–	–	–	0.001	–	0.001	0.011
		VII	0.002	0.001	–	–	–	–	–	–	–	–	0.001
	2.5 to 4.5	IV	0.006	0.002	–	–	–	–	–	–	–	–	0.003
		VI	0.001	–	–	–	–	–	–	–	–	–	0.001
		VII	0.005	0.002	–	–	–	–	–	–	–	–	0.003
	4.5 to 6.5	IV	0.007	0.002	–	–	–	–	–	–	–	–	0.003
		VI	0.011	0.002	–	–	–	–	–	0.001	–	0.001	0.007
		VII	0.009	0.003	–	–	–	–	–	–	–	0.001	0.005
	6.5 to 8.5	II	0.001	–	–	–	–	–	–	–	–	–	–
		IV	0.002	0.001	–	–	–	–	–	–	–	–	0.001
		V	0.001	–	–	–	–	–	–	–	–	–	0.001
		VI	0.005	0.001	–	–	–	–	–	–	–	–	0.003
		VII	0.006	0.002	–	–	–	–	–	–	–	–	0.003
	8.5 to 10.5	VI	0.003	–	–	–	–	–	–	–	–	–	0.002
		VII	0.004	0.001	–	–	–	–	–	–	–	–	0.002
II	0.5 to 2.5	VI	0.022	0.003	0.004	0.001	0.001	0.001	–	–	–	0.001	0.003
		VII	0.004	0.002	0.001	–	–	–	–	–	–	–	–
	2.5 to 4.5	IV	0.016	0.005	0.003	0.002	0.002	0.001	0.001	–	–	0.001	0.002
		VI	0.001	–	–	–	–	–	–	–	–	–	–
		VII	0.009	0.004	0.002	0.001	–	–	–	–	–	–	0.001
	4.5 to 6.5	IV	0.020	0.004	0.006	0.002	0.002	0.001	0.001	–	–	0.001	0.002
		VI	0.016	0.003	0.003	0.001	0.001	0.001	–	–	–	–	0.002
		VII	0.017	0.008	0.003	0.001	0.001	0.001	–	–	–	–	0.002
	6.5 to 8.5	II	0.002	0.001	–	–	–	–	–	–	–	–	–
		IV	0.004	0.001	0.001	–	–	–	–	–	–	–	–
		V	0.002	0.001	–	–	–	–	–	–	–	0.001	–
		VI	0.008	0.001	0.001	–	–	–	–	–	–	–	0.001
		VII	0.013	0.006	0.002	0.001	0.001	0.001	–	–	–	–	0.001
	8.5 to 10.5	II	0.006	0.003	0.001	–	–	–	–	–	–	–	–
		IV	0.001	–	–	–	–	–	–	–	–	–	–
		VI	0.004	0.001	0.001	–	–	–	–	–	–	–	0.001
		VII	0.007	0.003	0.001	–	–	–	–	–	–	–	0.001
III	0.5 to 2.5	VI	0.031	0.013	0.006	0.003	0.001	0.001	–	–	0.001	0.002	0.003
		VII	0.006	0.002	0.001	–	–	–	–	–	–	0.001	0.001
	2.5 to 4.5	IV	0.028	0.006	0.003	0.003	0.002	0.001	–	0.001	0.002	0.007	0.003
		VI	0.001	–	–	–	–	–	–	–	–	–	–
		VII	0.014	0.004	0.002	0.001	0.001	0.001	–	–	–	0.002	0.002
	4.5 to 6.5	IV	0.033	0.007	0.003	0.004	0.002	0.001	0.001	0.001	0.002	0.008	0.004
		VI	0.023	0.009	0.004	0.002	0.001	0.001	–	–	0.001	0.002	0.002
		VII	0.027	0.008	0.004	0.002	0.002	0.001	–	–	0.001	0.004	0.004
	6.5 to 8.5	II	0.003	0.001	–	–	–	–	–	–	–	0.001	–
		IV	0.007	0.002	0.001	0.001	–	–	–	–	–	0.002	0.001
		V	0.006	0.001	–	–	–	–	–	–	–	0.004	0.001
		VI	0.011	0.005	0.002	0.001	–	–	–	–	–	0.001	0.001
		VII	0.020	0.006	0.003	0.001	0.001	0.001	–	–	0.001	0.003	0.003
	8.5 to 10.5	II	0.001	–	–	–	–	–	–	–	–	–	–
		IV	0.001	–	–	–	–	–	–	–	–	–	–
		VI	0.007	0.003	0.001	0.001	–	–	–	–	–	0.001	0.001
		VII	0.011	0.003	0.002	0.001	0.001	–	–	–	–	0.002	0.002
IV	0.5 to 2.5	VI	0.029	0.005	0.003	0.003	0.002	0.001	0.002	0.001	0.002	0.001	0.008
		VII	0.005	0.001	0.001	0.001	–	–	–	–	–	–	0.001
	2.5 to 4.5	IV	0.021	0.003	0.002	0.005	0.003	0.001	0.001	0.001	0.001	0.001	0.003
		VI	0.001	–	–	–	–	–	–	–	–	–	–
		VII	0.011	0.002	0.001	0.001	0.001	0.001	0.001	0.001	–	0.001	0.003
	4.5 to 6.5	IV	0.025	0.004	0.003	0.005	0.004	0.002	0.001	0.001	0.001	0.001	0.003
		VI	0.021	0.004	0.003	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.006
		VII	0.022	0.004	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.006
	6.5 to 8.5	II	0.002	–	–	–	–	–	–	–	–	–	–
		IV	0.005	0.001	0.001	0.001	0.001	–	–	–	–	–	0.001
		V	0.004	0.001	–	–	–	–	–	–	–	0.002	–
		VI	0.010	0.002	0.001	0.001	0.001	–	0.001	–	0.001	–	0.003
		VII	0.016	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.004
	8.5 to 10.5	IV	0.001	–	–	–	–	–	–	–	–	–	–
		VI	0.007	0.001	0.001	0.001	–	–	–	–	–	–	0.002
		VII	0.010	0.002	0.001	0.001	0.001	0.001	–	0.001	–	0.001	0.003

*Recorded from Table C-9.

TABLE C-12. COLD MODE CYCLE LENGTH (IN MINUTES) AS A FUNCTION OF COLD SOAK DURATION (IN HOURS) FOR AMBIENT TEMPERATURES OF 75°F AND 20°F*

Ambient temperature	Cold soak period (mid-point), hours									
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5
75°F	2.4	3.6	4.3	4.9	5.3	5.8	6.1	6.4	6.7	7.0
20°F	3.3	4.4	5.0	5.4	5.8	6.1	6.4	6.8	7.0	7.2

TABLE C-13. SUMMARY OF THE COLD MODE ANALYSIS FOR THE FORBES AVENUE STUDY LINK (NODES 03901 TO 04106)

	Time period				
	I	II	III	IV	Total
A. Cold mode operation as a fraction of daily link trips.	0.004	0.050	0.096	0.088	0.278
B. Stabilized mode operation as a fraction of daily link trips.	0.181	0.153	0.290	0.098	0.722
C. Total - distribution of daily vehicle operation.	0.225	0.203	0.386	0.186	1.000
D. Number of vehicles in cold mode operation per time period.	590	670	1286	1180	3,726
E. Total number of link trips per time period.	3018	2724	5209	2509	13,460
F. Percent of vehicles operating in cold mode by time period.	19.5	29.6	24.7	47.0	27.7

GLOSSARY

Analysis District: A geographic area defined by a group of two or more analysis zones (see below).

Analysis Zone: A subdivision of a study or survey area that comprises the smallest geographic area for which data are aggregated and basic analyses are made.

Arterial Street: A major street or highway that provides regional service for through traffic; arterials generally have at-grade intersections and provide access to abutting land development.

Centroid: A point within an analysis zone or district that is assumed to represent the center of trip generation and attraction activity; all travel to and from the zone or district is assumed to occur through the centroid.

Centroid Connector: A synthetic roadway link connecting a zone centroid to the actual highway network. Generally, up to four connectors may be used to connect a zone centroid to the highway network.

Cold Mode Operation: The initial stage of vehicle operation when engine and coolant temperatures have not stabilized and usually the choke is in use. Cold mode operation is characterized by very high emission rates of carbon monoxide and hydrocarbons relative to stabilized operation.

Collector Street: A street that collects or distributes traffic between higher type arterial streets and either less important local streets or destinations. The functions of traffic movement and access to abbuting properties are equally important for collector streets.

Cordon Line: An imaginary line enclosing a study area along which external interviews are conducted.

Federal Test Procedure: A detailed procedure prescribed by the U.S. Environmental Protection Agency for certifying the performance of motor vehicles with regard to compliance with federal emission regulations. (Also, see Appendix A of this report.)

Forecasting: The process of estimating future values of land-use, socioeconomic, and trip-making variables within an area based on observed (measured) values for a base year case.

Link: A section of highway designated by nodes at each end-point.

Modal Split: The distribution of total person trips by mode of travel.

Mode of Travel: Means of travel such as auto driver, auto passenger, transit passenger, walk, etc.

Network: A system of links and nodes describing a highway system.

Node: A designated point on a street or highway that delineates the end-point of a street or highway link.

Skim Trees: Computer-generated listing of the travel time between zone pairs reflecting the assigned travel path between each zone pair.

Terminal and Transfer Facilities: Refers to trucking or railroad terminals. These facilities are included in studies of goods movement within a region.

Traffic Assignment: The process of determining probable travel paths over the highway network between analysis zones. The assignment process is based on the assumption that trips between zone pairs will occur over the path (combination of links) that minimizes travel time.

Trip Distribution: A general term describing the ultimate distribution of trips between each zone and all other zones, both internal and external with respect to the study area. Analytical techniques employed in determining trip distribution generally include defining trip production and attraction characteristics for each zone based on land-use patterns so that relationships between the relative attracting power of all zones for trips generated in each zone.

Trip Generation: A general term describing the analysis of numerous characteristics of an area (e.g., an analysis zone) to define the relationships that exist between the area's trip-making characteristics, and parameters such as land-use, socioeconomic structure, demographics, etc. within the area.

Turn Penalties: A feature of the traffic assignment process that accounts for delays typically experienced in making turning movements at intersections by adding an increment of time (i.e., a penalty) for each turn in an assigned routing. Generally, left-turn (across traffic) penalties are more severe than right-turn penalties.

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16. ABSTRACT Estimates of the percentages of vehicles operating in less than the stabilized condition (i.e., cold mode) have been made for 60 locations in the Pittsburgh and Providence regions. These estimates were derived using detailed regional travel data for both regions.

Accurate knowledge of the percentages of vehicles operating in the cold mode at a particular study location is a key factor in estimating carbon monoxide emissions. That carbon monoxide emission rates are severely affected by operation in the pre-stabilized condition has been well documented through numerous laboratory studies. While these laboratory studies have served to characterize carbon monoxide emissions from cold operating vehicles with respect to variables such as ambient temperatures and cold soak duration, the study being reported here examines specific traffic streams to identify the actual percentages of vehicles that are operating in the cold mode.

Cold start percentages are presented for the morning commuter hours, the mid-day period, the evening commuter hours, and the evening and early morning off-peak period for each of the 60 traffic streams analyzed. Results indicate that the percentage of cold operating vehicles is highly variable both among locations within an urban area, and during different time periods at any specific location. It is also indicated that the actual percentages of vehicles operating in the cold mode may be somewhat different from the percentages assumed in the Federal Test Procedure.

17. KEY WORDS AND DOCUMENT ANALYSIS

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