ROADWAY USAGE PATTERNS: URBAN CASE STUDIES

FINAL REPORT

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TABLE OF CONTENTS

1. Introduction 1
   - 1.1 Study Background 1
   - 1.2 Study Objectives 1
   - 1.3 Report Organization 2

2. Literature Review 3
   - 2.1 Introduction 3
   - 2.2 *Statistical Analysis of Continuous Traffic Counter Data* 3
   - 2.3 *Quantifying Congestion* 5
   - 2.4 *Traffic Data Collection and Analysis: Methods and Procedures* 5
   - 2.5 *Development of A Statewide Traffic Counting Program Based on HPMS* 6
   - 2.6 *Guide To Urban Traffic Volume Counting* 7
   - 2.7 *Speed Determination Models For The Highway Performance Monitoring System* 8
   - 2.8 *An Analysis of Urban Area Travel By Time of Day* 8

3. Study Approach 10
   - 3.1 Data Sources 10
   - 3.2 Data Characteristics 11
   - 3.3 Analysis Methodology 14

4. Analysis Results 27
   - 4.1 Initial Temporal Distributions 27
   - 4.2 Identification of Congestion 28
   - 4.3 Final Temporal Distributions 31
   - 4.4 AADT/C vs. V/C Relationships 35
   - 4.5 Revised HPMS Speed Determination Models 44
   - 4.6 Changes in Temporal Distributions Over Time 46

5. Congestion Monitoring Practices 82
   - 5.1 Use of Freeway Surveillance System Data 82
   - 5.2 Options for National Congestion Monitoring 83

6. Summary and Recommendations 98
   - 6.1 Project Summary 98
   - 6.2 Recommendations 99

Appendix A: Survey of States to Collect ATR Location Inventory Data

Appendix B: Urban ATR Dataset Development

Appendix C: State and Local Data Collection: Freeway Surveillance and Arterial Signal Control Systems

Appendix D: Traffic and Physical Characteristics of the Urban ATR Sites Used in the Analysis

Appendix E: Orlando Temporal Distributions

Appendix F: Seattle Temporal Distributions

Appendix G: Lexington Temporal Distributions

Appendix H: Simultaneous Speed/Volume Plots Over Time for Orlando

Appendix I: AADT/C vs. V/C Tables Produced From Urban ATR data

Appendix J: Volume-Density Plots

Appendix K: Speed-Volume Curves

1. INTRODUCTION

1.1 Study Background

The transportation profession -- and the highway profession in particular -- has long suffered from inadequate data on which to base policy and programming decisions. One of the data shortcomings has been the lack of realistic urban travel patterns on which to base models of highway performance, a topic of great interest to the Volpe National Transportation Systems Center (VNTSC) and the Federal Highway Administration (FHWA). The most immediate need is to enhance the urban usage patterns imbedded in the Highway Performance Monitoring System (HPMS) simulation models. These models (the HPMS Analytical Process and the Highway Economic Requirements System {HERS}) are used by FHWA to study the relationships between alternative investment strategies on highway performance and to estimate future highway needs. One of the key underpinnings of these models is the distribution of daily traffic at various congestion levels, as imbedded in the tables of AADT/C versus V/C[1]. These tables are used to predict the congestion patterns of facilities, a central determinant of highway performance (as measured by user costs) in urban areas.

In addition to the needs of HPMS, this work will have several spinoff applications to other areas of concern to VNTSC and FHWA:

- congestion and its effects on vehicle speeds are vital to the air quality planning process;
- relationships developed for this project will aid other research into the nature of congestion as well as the development of congestion management systems; and
- the highway planning process will profit from new insights into such things as how K- and D-factors vary and the phenomenon of peak spreading which occurs when roadways become heavily congested.

1.2 Study Objectives

The study pursued five objectives. The first objective was the development of a study data base. This effort provided the basis the current work and lessons in the data base assembly can be applied to future similar endeavors. Previous work by Science Applications International Corporation (SAIC) and Cambridge Systematics Incorporated (CSI) revealed weaknesses in existing FHWA data for congestion monitoring purposes.[2] Further, many state and local agencies are now undertaking data collection activities for their own uses, and these data can be adapted to the needs of the project. Therefore, the need for quality data that are capable of measuring congestion was tantamount to the success of the project.

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[1]"AADT/C" is the annual average daily traffic to capacity ratio and "V/C" is the volume to capacity ratio. Throughout the remainder of this report, the capacity in the "AADT/C" term is the two-way capacity of the roadway while capacity in the "V/C" term is the traditional one-way capacity.

[2]Cohen, Harry and Richard Margiotta, *Statistical Analysis of Continuous Traffic Counter Data, Task 2 Report, Study of Congestion Patterns*, prepared for VNTSC and FHWA, September 15, 1992.

Second, the study provided a general understanding of congestion. This understanding should included techniques for defining and measuring congestion as well as estimating its duration and extent on a national basis.

Third, two specific products were developed by analyzing the data that were collected: (1) revised AADT/C vs. V/C relationships and (2) temporal distributions of traffic. Both of these products are to be used by the HPMS simulation models. Both of these products were also prepared as part of the *Statistical Analysis* study. However, the expanded and improved data base allowed these to be re-estimated with a greater level of confidence.

Fourth, the study revised the congestion term in the HPMS speed determination models previously developed for FHWA.[1] These models relied on assumed temporal distributions of traffic (from the *Statistical Analysis* study) in order to assess the full effect of congestion. Since these distributions changed as a result of the current work, it was felt that the speed models should also be updated.

Finally, the study outlined options for monitoring congestion on a continuing and national basis. These options are based on the experience gained during the study.

1.3 Report Organization

Much of the technical information uncovered during the research has been placed in Appendices to aid readability of the report. The remaining chapters of the report are:

- Chapter 2 -- Literature Review
- Chapter 3 -- Study Approach
- Chapter 4 -- Analysis Results
- Chapter 5 -- Congestion Monitoring Practices
- Chapter 6 -- Summary and Recommendations

[1]Margiotta, Richard et. al., *Speed Determination Models for the Highway Performance Monitoring System, Final Report*, October 31, 1993.

2. LITERATURE REVIEW

2.1 Introduction

A concurrent study sponsored by NCHRP is looking at the problem of quantifying congestion[1]. As part of that study, a large review of the literature on congestion was undertaken. As a result, the Project Team did not feel that a duplicate review of congestion literature would be warranted. (A review of the NCHRP project is provided in this Chapter.) Therefore, the literature review presented here focuses on previous efforts to develop temporal distributions.

2.2 *Statistical Analysis of Continuous Traffic Counter Data*[2]

This project was recently completed by members of the Project Team. Task 2 of this project was concerned with developing AADT/C vs. V/C relationships for urban facilities for the HPMS simulation models in the same way that the current study will. However, the current study is much larger in scope and encompasses supplemental data collection, whereas the effort in the original study was limited to working with the data provided by FHWA. Particularly relevant to the current work are the following points from the *Statistical Analysis* study.

Because no supplemental data collection was specified, the analysis had to match automatic traffic recorder (ATR) locations with HPMS sections to obtain the necessary variables (e.g., number of lanes, urban area size, and capacity). This process revealed that although many ATR locations had HPMS Sample Numbers coded, exact matches could not be obtained (indicating a data entry problem with the ATR data). This is the reason that only 189 sites were available for study. (143 sites had two years worth of data, yielding a total of 331 combinations of site and year).

The main finding from preliminary work that examined temporal distributions was: *although individual sites show substantial variation in their daily traffic use patterns, patterns for categories based on broad physical and operating characteristics could not be distinguished.* When the sites are grouped by characteristics usually used to classify facilities, the variation was substantially reduced, although those factors that somehow measure the intensity of facility use during peak periods did show minor variations. (The characteristics that showed the most distinction was the empirically-derived K*D factor.) The differences, where they exist, are on the order of 1.0 to 1.5 percent of AADT in an hour at the most and they manifest themselves in the morning peak and at midday; the afternoon peak showed almost no variation with the different classifications tried. Furthermore, weekend and holiday traffic distributions were found to be virtually indistinguishable regardless of the classification used.

Based on the above finding, the study concluded that no reason exists to differentiate urban facilities, therefore, a single table of AADT/C vs. V/C was produced from the data. (An equation was also developed to avoid table lookup.)

The notion that all urban facilities operate similarly from a traffic standpoint is at first counterintuitive -- one would expect some differences to exist. (In fact, minor differences were noted but the SAIC Team felt that these would have little practical difference within the context of the HPMS simulation models.)

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[1] *Quantifying Congestion*, NCHRP Project 7-13. Interim report dated October 1992.

[2] Cohen, Harry and Richard Margiotta, "Task 2 Final Report: Study of Congestion Patterns", prepared for VNTSC and FHWA, September 30, 1992.

Based on the data at hand, this conclusion is supported. However, the SAIC Team was compelled to make several recommendations.

- Better ways of defining how facilities are used might yield traffic patterns that are different. The variables used to classify the sites in the *Statistical Analysis* study could not detect practical differences in traffic patterns. However, in general, variables related to the intensity of facility use showed minor differences. It might be that better methods to measure this feature would yield differences in traffic patterns. Possible ways to define facilities for this purpose would include some combination of orientation within the urban area, the degree to which long distance travel uses the facility, and the nature of local commuting (e.g., suburb-to-CBD vs. suburb-to-suburb).

- The number of HPMS sample segments where ATRs exist should be increased. Increased information on traffic variation on HPMS segments will be quite useful to FHWA in the future, both in supporting the HPMS simulation models and congestion management. Two ways exist for enriching the sample. First, early work on this project revealed that although some ATR locations had HPMS Sample Numbers coded, they could not be matched. States should be encouraged to check the coding of this data. Second, additional equipment could be installed on urban HPMS sections. This equipment would benefit not only FHWA but state and local agencies who would use it in their congestion management activities.

- More consideration should be given to collecting K and D factors on HPMS segments. Accurate K and D factors are extremely important in HPMS and other planning efforts since they define peak period congestion. The inception of Congestion Management Systems further increases the need for traffic data in general and K and D factors in specific. The study showed that the ATR-derived K*D factor produced the most distinction in traffic patterns. It also showed only a weak relationship between the ATR-derived K*D factor and those reported by the states in HPMS. Where ATR and HPMS sections coincide, states should be encouraged to use the ATR data to develop K and D factors. Further, a special study might be undertaken to investigate how states develop their K and D factors; our observation is that some states use class-wide averages for HPMS. Also, this study would further explore FHWA's ATR data to produce default values for the HPMS K and D factors. Finally, the phenomenon of peak spreading under congested conditions and how capacity improvements affect K and D could be explored, and the relationships could be imbedded in the HPMS simulation models.

- Likewise, the capacity of urban HPMS sections should be scrutinized closely. The study found several locations where hourly volumes routinely exceed coded capacity by a considerable amount. Three possible explanations exist: (1) the capacity is incorrectly reported by the states; (2) the ATR equipment occasionally reports faulty data; and (3) capacity is actually variable from day-to-day. FHWA may want to consider checking HPMS urban capacity submittals by using other HPMS variables to calculate capacity, if they are not already doing so. (Although the full range of information needed to calculate capacity is not present, large discrepancies could be detected.) Also, the possible variable nature of capacity could be explored further by analyzing the ATR data strictly for this purpose.

- Further research on the nature of congestion could yield additional benefits. We observed some striking patterns in the coefficient of variation for traffic in different hours of the day. Specifically, coefficients of variation for peak periods were found to be higher than those for mid-day periods. These patterns, we believe, result from the fact that the consequences of incidents such as accidents, stalled vehicles, and work zones are greatly magnified during the

peak period. For example, a four-lane facility could suffer a lane loss during mid-day without affecting traffic volume since there is ample capacity at that time of day; however, a lane loss during the peak period would significantly reduce observed volume. These patterns, if confirmed, could be very useful in measuring congestion and understanding its impacts on the traveling public.

2.3 *Quantifying Congestion*[1]

The first phase of this study undertook a large review of the literature on congestion as well as surveys of state DOTs and local agencies to ascertain how these groups measure congestion. The study found that an array of different measurements have been developed by researchers to study congestion, but that in practice the most prevalent techniques were based on the *Highway Capacity Manual (HCM)* methods (e.g., level of service, V/C ratio). The study then formulated a definition of congestion as "... travel time or delay in excess of that normally occurring under light or free-flow traffic conditions". After review of the past studies, practice, and using their definition as a base, the researchers recommended that the direct measure of congestion be travel rate, as measured in minutes per mile. In addition to meeting technical criteria -- such as the ability to be analyzed statistically -- this unit has the advantage of being easily understood by a wide variety of audiences (e.g., the public and policymakers). The study then recognized the problems with collecting data of this type, its scarce use by practitioners, and its difficulty in being applied to future conditions. To circumvent these problems, the researchers recommend that surrogate factors be used to derive estimates of travel rate. As a preliminary step, the researchers state that they will explore a method that incorporates two factors: "traffic per effective lane divided by percent green time" and signal density to produce travel rate estimates[2]. Based on its preliminary findings and its implications for state and local congestion management systems, the Project Team feels that it is extremely important to track the progress of and coordinate with this study. Further, data collection efforts for both studies can be combined, producing data at lower collection costs.

2.4 *Traffic Data Collection and Analysis: Methods and Procedures*[3]

This study found that the state of the art of highway traffic data collection and analysis is solidly based on experience and statistical analyses conducted over the past 50 years, with advances in electronic and other technology employed as they became economically feasible. The main findings of the study are:

- Telemetry, inductance loops, and solid-state recording devices are generally reliable and are gaining acceptance for obtaining, recording, and transmitting traffic volume, vehicle classification, vehicle speed, and weight data.

- For coverage counts, air tubes with nonrecording mechanical accumulators remain the favored device by a wide margin because of their low cost compared to other available equipment.

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[1]Texas Transportation Institute *et al*, "Interim Report: Quantifying Congestion", NCHRP Project 7-13, October 1992.

[2]This approach is nearly identical to the approach taken by the SAIC Team as part of the *HPMS Speed Determination Modeling* project where the NETSIM simulation model was applied to develop relationships between speeds, fuel consumption, and emissions as a function of traffic, signal, and highway conditions.

[3]French, Alexander and David Solomon, "Traffic Data Collection and Analysis: Methods and Procedures", NCHRP Synthesis of Practice 132, December, 1986.

- Requirements for monitoring compliance with the national 55-mph speed limit have resulted in development of equipment capable of continuous automatic vehicle classification (AVC) of vehicles where classification is based on axle arrangement.

- Weigh-in-motion (WIM) capabilities are continually improving and now provide reliable continuous vehicle weight and classification data. Recent improvements in results from instrumentation on existing bridges hold promise for extensive unobserved road section sampling at reasonable cost. AVI (Automated Vehicle Identification), using pavement sensors, transponders on the vehicle, and roadside units that read the transponder, may provide sufficient advantage to both truck operators and government to make feasible the automated monitoring of vehicle speeds, origin-destination (O&D), travel time, distance traveled, and, in combination with WIM, the automated billing of fees including weight-distance tax.

- Manual classification counting continues to be essential for planning and design data, such as vehicle and driver attributes, turning movements, occupancy, seat belt use, etc., that are not obtained by existing automated data-collection systems. Manual procedures have advantages for infrequently counted locations where installation of automated equipment is uneconomical.

- Continued development of automated procedures, using infrared, video, and pattern recognition technology has the potential for automated identification and classification beyond the capability of the human eye.

- The HPMS continues to improve its value in meeting federal data needs. It has improved statistical efficiency of providing data for federal policy analysis.

- Continuing efforts to develop an integrated, efficient transportation data system are needed to keep pace with the rapid advances in data acquisition technology.

Unfortunately, this study offers little guidance for the current work as congestion monitoring was not a point that was covered.

2.5 *Development of A Statewide Traffic Counting Program Based on HPMS*[1]

This study entailed:

- a review of federal and state traffic data needs;

- a description of a recommended traffic monitoring program designed to meet those needs in a cost effective manner;

- a sampling plan for collecting data with a given statistical precision;

- a series of default values for use in the sampling plan statistical equations;

- alternative sampling plans for estimating volumes on local roads;

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[1]Hallenbeck, M.E. and L.A. Bowman, "Development of a Statewide Traffic Counting Program Based on the Highway Performance Monitoring System", FHWA Contract No. DTFH61-82-C-00099, March, 1984.

- a review of available traffic counting, classification, and weighing equipment currently on the market, and

- five case studies implementing the proposed program for states chosen by FHWA.

The study found that the HPMS program offers states a convenient structure with the potential to redirect their traffic counting programs. The HPMS sample provides a basic set of traffic count locations for which geometric, operational, and traffic volume data will be available on a continuing basis. By using statistical sampling concepts that complement the HPMS, states can potentially increase overall traffic monitoring program efficiency through the development of coordinated data collection processes including traffic volume data, vehicle classification data, and truck weight data.

The report recommended a methodology for developing a statewide traffic monitoring program based on the objectives of reducing costs and producing estimates with known precision. The program uses statistical sampling (based on the HPMS) wherever possible to reduce costs and provide statistically defensible data. It also provides cost effective solutions to data collection problems that cannot be addressed viably with statistical counting procedures. The recommended statewide traffic data collection program is divided into three major parts:

- the Continuous Element, consisting of continuous traffic counters (ATRS);

- the HPMS Element, consisting of statistically representative statewide samples of volume, vehicle classification, and truck weight data; and

- the Special Data Collection Element, consisting of site-specific traffic measurements and other data necessary to fulfill state needs not met by the other elements.

Again, there appears to be no direct relevance to the current project, except perhaps the recommendation that HPMS be used as the focal point for data collection efforts.

2.6 *Guide To Urban Traffic Volume Counting*[1]

This manual provides guidelines for urbanized areas to develop, implement and manage traffic counting programs, and offers insight into the importance of integrating these programs into a single plan so that the needs of the individual agencies are satisfied. It stresses the importance of coordination, and suggests methods of organizing such a plan so that traffic counts and sampling are performed in a cost efficient manner. Volume counting efforts are many times geared to a specific need, but with coordination and cooperation between agencies, a much more complete data base can be achieved.

The manual discusses the various steps which must be considered while developing an integrated traffic counting plan. After determining the objectives, such as types of volume counts needed, the required level of precision, and the related costs, decisions need to be made concerning the data collection. Various methods of determining the count locations are also discussed. The authors stress the importance of stratification so that vehicle miles of travel (VMT) can be estimated for different regions and for different functional classes.

Finally, detailed statistical sampling procedures are proposed for studies concerning regional needs as

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[1]Ferlis, R.A., L.A. Bowman, and B.T. Cima, "Guide To Urban Traffic Volume Counting", FHWA Contract No. DOT-FH-11-9249, February, 1980.

well as studies focusing on a certain location. The emphasis is placed on sound methods of determining the appropriate sample size and then the actual selection of the sample locations.

2.7 *Speed Determination Models For The Highway Performance Monitoring System*[1]

As part of this report the researchers made initial contacts with several states to determine if they had the capability for collecting vehicle speed data from automated equipment. (Most of the newer ATR equipment can also collect vehicle classification or speed data.) The basic information gathered involved the capabilities of the ATR equipment utilized by the states to collect speed data and the ability of the state to provide this information to the study team in a usable format. Table 2-1 summarizes the results of the contacts made.

TABLE 2-1

SUMMARY OF STATE CONTACTS FOR SPEED DATA

	ID	IN	MI	MN	NM	NY	PA	TN	WA
# Perm ATR Sta.	115	59	n/a	161	96	60	60	30	80
Speed @ ATR?	Y	N	Y	Y	Y	N	Y	Y	Y
Data Available?	Y	?	Y	Y	Y	Y	Y	Y	Y

Note: All States can provide speed data from portable short count stations (generally at locations mandated by FHWA for speed limit compliance).

Of these nine states, five were found to be the most promising candidates for supplying detailed speed data at their ATR sites: Idaho, Minnesota, New Mexico, Pennsylvania, and Washington.

2.8 *An Analysis of Urban Area Travel By Time of Day*[2]

This report presents the results of research performed for the Federal Highway Administration by Peat, Marwick, Mitchell, and Company. In urban transportation planning and design, it is important to recognize the distribution of travel by time of day. As travel demand varies throughout the day, system performance in terms such as speed, travel time costs, and vehicle operating costs varies. This should be recognized in estimating transportation service and in performing an economic evaluation of alternative courses of action. In addition, the variation in travel by time of day significantly affects the capacity requirements of transportation facilities and is therefore important in design.

[1]Margiotta, Richard *et al*, "Speed Determination Models for the Highway Performance Monitoring System", FHWA Contract No. DTFH61-92-R-00022, October 31, 1993.

[2]Tittemore, Lawrence H. *et al*, "An Analysis of Urban Area Travel By Time of Day", prepared for FHWA, Report No. FH-11-7519, January 1972.

In Phase A of the research, the distribution of travel by time of day was analyzed using travel data for eight cities ranging in size from 100,000 to 3,500,000 population. The report includes: (1) summaries of the basic travel statistics including trips by mode and purpose, trip length, trip time, and average auto occupancy; (2) summaries of trips in motion by mode and trip purpose; (3) time of day distributions for vehicular travel data by vehicle type and trip purpose; (4) the development of graphical models for use in predicting the distribution of total vehicular travel by time of day; and (5) an analysis of the variation in auto occupancy by trip purpose and time of day.

The Phase B analysis was based on traffic count data from seven cities. Hourly distributions of travel and directional splits were presented by facility type, location within the study area, and orientation with respect to the center of the study area (e.g., radial arterials in the suburbs). In total, data for 27 cells were presented for each city. The "K" (percent of average daily traffic in the peak hour) and "D" (percentage of peak hour traffic in the peak direction) design parameters were also presented for the 27 cells.

With regard to the current research, this study provides an historical reference since it compiled temporal distributions over a range of facilities. Its usefulness -- other than comparing current distributions to historical ones -- is extremely limited.

3. STUDY APPROACH

3.1 Data Sources

Introduction

Two basic types of information were needed for the study:

- Traffic Data. At the absolute minimum resolution, these data are hourly traffic volume counts. Greater levels of refinement include volume data collected more frequently (e.g., 5- or 15-minute intervals) as well as traffic flow measurements. Ideally, traffic flow measurements should be measured speed data that corresponds to the volume data. In lieu of direct speed measurements, occupancy (the percent of time that loop detectors are "occupied" by vehicles over a time period) can be used to estimate both density and speed, although this conversion relies on several simplifying assumptions.[1]

- Inventory Data. Essential data items on each highway location studied include those items which define its basic physical characteristics, most notably capacity. At a minimum, the number of lanes is required to provide capacity estimates. The next tier would include the actual capacity for freeways as calculated with the *Highway Capacity Manual*, typical or average percent green times for signalized arterials, and the highway's land use setting (central business district {CBD}, suburban, etc). The next level of refinement would be the capacities of signalized intersections on the segment of interest and/or the arterial level of service. Finally, under the most ideal situation, the location and capacity of bottlenecks along the segment would be specified. (For signalized arterials, bottlenecks are usually specific intersections. However, bottlenecks could also include lane drops and interchanges for freeways; these would have to be identified separately.)

FHWA ATR Data Base

As part of their traffic monitoring programs, states operate ATRs for a variety of purposes including the development of adjustment factors for expanding short-duration traffic counts and the estimation of K- and D-factors. In addition, the states report data from these devices to FHWA on a monthly basis. The primary use of the data by FHWA is the production of the *Traffic Volume Trends* report which tracks monthly changes in travel. Of the roughly 4,000 ATRs nationwide, approximately 1,000 are located in urban areas. Because these urban ATRs are spread throughout the country and the data are readily available from FHWA, they became the foundation for performing the study. Even though the ATR locations have **not** been selected as a representative statistical sample, they still provide a wide range of underlying conditions.

Previous work on the *Statistical Analysis* study showed that while the traffic variability from site-to-site was very high, no systematic differences between alternative categories could be found (with the 189 sites examined). This result implies that a large sample is required if differences are to be detected. The 189 sample size was restricted due to the need to match ATR with HPMS segments to obtain the required inventory data. A major part of this study was to expand on the usable ATR sample by collecting inventory information from the states via a mailback survey. (A full description of this

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[1]For example: Dailey, Daniel J., Mark P. Haselorn, and Nancy l. Nihan, *Improved Estimates of Travel Time From Real-Time Inductance Loop Sensors*, Washington State Transportation Center, Report No. WA-RD-292.1, April 1993.

process appears in Appendix A.)

ATR data were available for 1991 and 1992. These sites were then matched against 1992 HPMS data and the data from the state surveys, resulting in a total of 713 urban stations for which at least some inventory data were available. (545 of these sites had both years of data present.) Of these 713 sites, capacities were able to be developed for 579 sites. (Incomplete data from the state surveys precluded capacity development for all sites.) This more than tripled the sample size used in the *Statistical Analysis* study. The raw data were subjected to range of error checks. (A full description of the urban ATR dataset development process, including editing, appears in Appendix B.) In addition to those listed in Appendix B -- which were automated checks -- several manual edits were also performed on the capacities from the state surveys and 1992 HPMS data by two methods:

- sites with abnormally high or low AADT/C values were checked; and
- sites where the median hourly volume was greater than the capacity were checked.

Based on a review of these data, several capacities were recoded based on either increasing the number of lanes present or on the hourly volume distribution (values close to the 99th percentile volume were assigned in this case).

Freeway Surveillance and Arterial Signal Control System Data
An extensive effort was made to contact state and local agencies to obtain data from freeway surveillance (e.g., ramp metering) and central signal control systems. Traffic surveillance and control systems routinely collect data describing the characteristics of the traffic stream. These data are used primarily to monitor travel conditions and to implement traffic control strategies to improve flow characteristics. In addition, however, these data also represent a potential source of information for use in transportation research. Therefore, the Project Team undertook a search for metropolitan locations currently collecting traffic data on a routine basis as part of a traffic surveillance and control system to supplement the ATR data base for this project. A complete description how the Project Team went about this task is given in Appendix C.

In the end, data were available for freeways in three cities and signal control systems in one city (Table 3-1). As of the date of this report, data from several additional sources was pending including freeway data from I-880 in Oakland, CA and the Chicago area as well as signal control data from Little Rock, AR. Although these data were unavailable for analysis, they will be processed and added to the final data base at a later date if they are eventually supplied.

3.2 Data Characteristics

Figure 3-1, Table 3-2, and Table 3-3 display some of the basic characteristics of the urban ATR dataset used in the analysis. Appendix D contains detailed traffic and physical characteristics of individual ATR locations.

- The data cover the full range of functional classes. About 37 percent of the ATRs selected were on urban Interstates and about 26 percent were on principal arterials.
- Based on the AADT/C ranges, the majority of ATR locations should be relatively uncongested. Our previous work indicates that congestion usually starts to appear at an AADT/C level around 10, therefore, about 15 percent of the urban Interstates and principal arterials in the dataset should experience some level of congestion.

Table 3-1. Sources of Freeway and Arterial Traffic Data

Location	Type	System Extent	No. Days	No. Stations	Data Available				Comments
					Volume	Occupancy	Speed	By Lane	
I-4, Orlando, Florida	Freeway	10.99 miles	29	25	5 min	x	x	x	
I-5, Seattle, Washington	Freeway	5.31 miles	72	13	5 min	x			Number of lane change frequently along freeway
I-25, Denver, Colorado	Freeway	9.5 miles	88	12	5 min	x	x	x	5:00 am - 10:00 am and 2:00 pm - 7:00 pm only
Lexington, Kentucky	Arterial	Citywide	21	18	15 min	x			

- The ATRs on urban Interstates show a wide range of number of lanes with most being four or six lanes. The arterials tend to be four lanes and the collectors and local streets tend to be two lanes.

- The average AADT on freeways is about 68,000 vehicles per day (vpd) while it is around 19,000 vpd for nonfreeways. However, the distribution of AADTs is widely spread for both facility types: the 90th percentile for freeways is 133,812 vpd and 39,735 for nonfreeways.

- A wide geographic spread of sites is evident. All regions of the country are represented, and the states include those that are predominantly rural (e.g., Iowa) and predominantly urban (e.g., New Jersey).

- The frequency table showing facility type (freeway vs. nonfreeway) by three AADT/C ranges is of special note. These were the categories that were eventually used to distinguish among temporal distributions. Since a large number of nonfreeways did not have capacities available, about 36 percent of these type of sites were not included in the final temporal distribution analysis. Freeway coverage, however, was extensive. In both cases, the proportion of sites expected to have significant congestion (i.e., those above AADT/C of 11.0) was 4-5 percent.

- The average K- and D-factors, as calculated from the raw ATR data, exhibit a downward trend as AADT/C increases. This trend -- also referred to as peak spreading -- is a phenomenon of congestion that has been reported in many past studies; as facilities become congested, the traffic "peaks" become less pronounced and traffic spreads out more in time. Also, the directionality of congested facilities trends to be more balanced.

The relationship between AADT/C and V/C is approximately linear, with a better correlation below a V/C level of 1.0 (Figure 3-2). A simple regression of this data yields the equation:

$$AADT/C = -0.162 + (8.96 * V/C) \qquad \{R^2 = 0.84\}.$$

Based on this equation, one would expect a V/C level of 1.0 (i.e., congestion) to occur at approximately AADT/C = 8.8.

Table 3-4 shows the traffic characteristics of data from Orlando, Seattle, and Lexington. Note that no capacity information was available for Seattle; the section of Interstate-5 that was covered underwent major reconstruction since the data were collected (Fall 1991), and the number of lanes on each section changed significantly. (The Seattle data were still used to produce temporal distributions and to gauge the hourly volume effects of congestion, however.) AADT information was not provided with the Denver data and AADTs could not be computed since only hours surrounding the morning and afternoon peaks were provided. The covered sections of Interstate 25 in Denver were either six or eight lane cross-sections. HPMS data for 1992 were reviewed for possible insight but could not be exactly matched to the Denver station locations. However, based on 1992 HPMS information, the capacity of three lane sections on I-25 in Denver is 6,170 vehicles per hour (vph) and 8,275 vph for four lane sections.[1] Also, the HPMS data showed that the AADT on the six lane sections ranged between 130,000 and 164,000 vpd while it ranged from 151,000 to 189,000 on the eight lane sections. Using the AADT midpoints, the AADT/C for the six lane sections would be roughly 12.0 and 10.5 for the eight lane sections,

[1]The coded HPMS capacities were increased by 10 percent to account for the new maximum service flow rate of 2,200 vehicles per hour per lane.

indicating that substantial congestion should exist. Because of the lack of 24 hours of data from Denver, it was not used in the temporal distribution analysis. However, since it is a congested corridor, it was helpful in analyzing congestion effects such as speed, density, and volume changes during congestion (see Chapter 4). Since the Lexington data covered highway segments scattered around the city (rather than in specific corridors like the freeway data), both AADT and AADT/C showed the greatest variability from site to site.

3.3 Analysis Methodology

Figure 3-3 summarizes the approach taken to analyzing the data and producing the required products. The ATR data are the foundation of the research. Inventory data for urban ATR sites were derived from both the 1992 HPMS data and the independent state survey; capacity information from both of these sources were cross-checked. The ATR data were then used to produce temporal distributions for various categories of traffic and inventory conditions (e.g., functional class). The freeway surveillance and arterial signal control data were used in several ways:

- they provided valuable information on the temporal distributions of known congested locations for comparison against the ATRs;
- they allowed the development of rudimentary algorithms to detect congestion from hourly ATR volume data;
- they form the basis of the congestion research data base delivered as part of this project;
- they furnished detailed insights into the nature of congestion (e.g., speed/volume plots) that helped in the formulation of congestion monitoring options; and
- they provided additional data for the high AADT/C range in the production of the final temporal distributions (see Chapter 4).

Once the temporal distributions were selected, the AADT/C vs. V/C tables and equations were produced. The temporal distributions were then used to recalibrate the congestion term in the HPMS speed models.

Figure 3-1. Basic Characteristics of the Urban ATR Sites

FUNCTIONAL CLASS / Frequency / Row Pct	AADT/C: .	LE 3.0	3.01 -- 5.00	5.01 -- 7.00	7.01 - - 9.00	9.01 -- 11.00	11.01-- 13.00	GT 13.0	Total
URBAN INTERSTATE	2 0.77	34 13.03	55 21.07	66 25.29	59 22.61	32 12.26	8 3.07	5 1.92	261
URBAN FREEWAY	4 4.30	26 27.96	20 21.51	21 22.58	13 13.98	8 8.60	1 1.08	0 0.00	93
URBAN PRINCIPAL ARTERIAL	45 24.59	13 7.10	25 13.66	40 21.86	27 14.75	18 9.84	14 7.65	1 0.55	183
URBAN MINOR ARTERIAL	43 38.74	22 19.82	23 20.72	15 13.51	5 4.50	1 0.90	2 1.80	0 0.00	111
URBAN COLLECTOR	27 55.10	14 28.57	4 8.16	3 6.12	1 2.04	0 0.00	0 0.00	0 0.00	49
URBAN LOCAL	13 81.25	0 0.00	1 6.25	2 12.50	0 0.00	0 0.00	0 0.00	0 0.00	16
Total	134	109	128	147	105	59	25	6	713

FUNCTIONAL CLASS / Frequency / Row Pct	AADT RANGE: 0 -- 20000	20001-- 40000	40001-- 70000	70001-- 100000	100000+	Total
URBAN INTERSTATE	21 8.05	44 16.86	70 26.82	51 19.54	75 28.74	261
URBAN FREEWAY	19 20.43	23 24.73	31 33.33	11 11.83	9 9.68	93
URBAN PRINCIPAL ARTERIAL	68 37.16	83 45.36	26 14.21	5 2.73	1 0.55	183
URBAN MINOR ARTERIAL	86 77.48	23 20.72	1 0.90	1 0.90	0 0.00	111
URBAN COLLECTOR	44 89.80	5 10.20	0 0.00	0 0.00	0 0.00	49
URBAN LOCAL	13 81.25	3 18.75	0 0.00	0 0.00	0 0.00	16
Total	251	181	128	68	85	713

Figure 3-1 (Continued)

FUNCTIONAL CLASS	NUMBER OF LANES						
Frequency Row Pct	.	2/3 LANES	4/5 LANES	6 LANES	8 LANES	10+ LANES	Total
URBAN INTERSTATE	3 1.15	0 0.00	101 38.70	105 40.23	42 16.09	10 3.83	261
URBAN FREEWAY	4 4.30	3 3.23	57 61.29	28 30.11	0 0.00	1 1.08	93
URBAN PRINCIPAL ARTERIAL	2 1.09	34 18.58	117 63.93	29 15.85	1 0.55	0 0.00	183
URBAN MINOR ARTERIAL	1 0.90	53 47.75	46 41.44	11 9.91	0 0.00	0 0.00	111
URBAN COLLECTOR	0 0.00	40 81.63	9 18.37	0 0.00	0 0.00	0 0.00	49
URBAN LOCAL	0 0.00	10 62.50	5 31.25	1 6.25	0 0.00	0 0.00	16
Total	8	142	335	174	43	11	713

Figure 3-1 (Continued)

STATE	FUNCTIONAL CLASS						
Frequency Col Pct	INTER-STATE	FREEWAY	PRINC. ARTERIAL	MINOR ARTERIAL	COLLECT-OR	LOCAL	Total
ALABAMA	4 1.53	0 0.00	18 9.84	7 6.31	4 8.16	0 0.00	33
ARIZONA	1 0.38	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	1
ARKANSAS	4 1.53	2 2.15	3 1.64	2 1.80	0 0.00	0 0.00	11
CALIFORNIA	1 0.38	4 4.30	0 0.00	0 0.00	0 0.00	0 0.00	5
COLORADO	6 2.30	4 4.30	3 1.64	1 0.90	1 2.04	0 0.00	15
CONNECTICUT	10 3.83	4 4.30	6 3.28	1 0.90	0 0.00	0 0.00	21
GEORGIA	11 4.21	1 1.08	8 4.37	8 7.21	6 12.24	4 25.00	38
IDAHO	10 3.83	0 0.00	10 5.46	9 8.11	3 6.12	0 0.00	32
ILLINOIS	0 0.00	0 0.00	1 0.55	0 0.00	0 0.00	0 0.00	1
INDIANA	0 0.00	2 2.15	3 1.64	2 1.80	0 0.00	0 0.00	7
IOWA	2 0.77	0 0.00	10 5.46	3 2.70	1 2.04	2 12.50	18
KANSAS	0 0.00	0 0.00	2 1.09	3 2.70	1 2.04	0 0.00	6
KENTUCKY	2 0.77	0 0.00	1 0.55	2 1.80	1 2.04	0 0.00	6
Total (Continued)	261	93	183	111	49	16	713

Figure 3-1 (Continued)

STATE	FUNCTIONAL CLASS						
Frequency Col Pct	INTER-STATE	FREEWAY	PRINC. ARTERIAL	MINOR ARTERIAL	COLLECT-OR	LOCAL	Total
MAINE	0 0.00	2 2.15	1 0.55	2 1.80	1 2.04	0 0.00	6
MASSACHUSETTS	13 4.98	5 5.38	3 1.64	8 7.21	0 0.00	0 0.00	29
MICHIGAN	17 6.51	4 4.30	2 1.09	1 0.90	0 0.00	3 18.75	27
MINNESOTA	22 8.43	5 5.38	9 4.92	15 13.51	12 24.49	7 43.75	70
MISSOURI	17 6.51	8 8.60	5 2.73	0 0.00	0 0.00	0 0.00	30
MONTANA	0 0.00	0 0.00	0 0.00	1 0.90	0 0.00	0 0.00	1
NEBRASKA	4 1.53	0 0.00	5 2.73	1 0.90	1 2.04	0 0.00	11
NEVADA	3 1.15	1 1.08	5 2.73	3 2.70	0 0.00	0 0.00	12
NEW HAMPSHIRE	6 2.30	2 2.15	5 2.73	1 0.90	0 0.00	0 0.00	14
NEW JERSEY	5 1.92	3 3.23	13 7.10	5 4.50	3 6.12	0 0.00	29
NEW MEXICO	1 0.38	8 8.60	1 0.55	7 6.31	3 6.12	0 0.00	20
NEW YORK	6 2.30	3 3.23	16 8.74	5 4.50	0 0.00	0 0.00	30
NORTH CAROLINA	0 0.00	3 3.23	4 2.19	0 0.00	0 0.00	0 0.00	7
Total (Continued)	261	93	183	111	49	16	713

Figure 3-1 (Continued)

STATE	FUNCTIONAL CLASS						
Frequency Col Pct	INTER-STATE	FREEWAY	PRINC. ARTERIAL	MINOR ARTERIAL	COLLECT-OR	LOCAL	Total
OHIO	14 5.36	2 2.15	6 3.28	2 1.80	3 6.12	0 0.00	27
OKLAHOMA	4 1.53	1 1.08	2 1.09	1 0.90	0 0.00	0 0.00	8
OREGON	13 4.98	2 2.15	3 1.64	1 0.90	0 0.00	0 0.00	19
PENNSYLVANIA	7 2.68	1 1.08	7 3.83	2 1.80	4 8.16	0 0.00	21
RHODE ISLAND	0 0.00	1 1.08	2 1.09	1 0.90	1 2.04	0 0.00	5
SOUTH CAROLINA	1 0.38	1 1.08	4 2.19	1 0.90	1 2.04	0 0.00	8
SOUTH DAKOTA	3 1.15	0 0.00	0 0.00	1 0.90	2 4.08	0 0.00	6
TEXAS	31 11.88	11 11.83	0 0.00	0 0.00	0 0.00	0 0.00	42
UTAH	13 4.98	1 1.08	12 6.56	5 4.50	0 0.00	0 0.00	31
VERMONT	2 0.77	2 2.15	1 0.55	1 0.90	0 0.00	0 0.00	6
WASHINGTON	9 3.45	5 5.38	1 0.55	1 0.90	0 0.00	0 0.00	16
WISCONSIN	19 7.28	5 5.38	11 6.01	8 7.21	1 2.04	0 0.00	44
Total	261	93	183	111	49	16	713

Figure 3-1 (Continued)

URBAN LOCATION FUNCTIONAL CLASS

Frequency Col Pct	INTER-STATE	FREEWAY	PRINC. ARTERIAL	MINOR ARTERIAL	COLLECT-OR	LOCAL	Total
N/A	38 14.56	20 21.51	9 4.92	6 5.41	0 0.00	0 0.00	73
CBD	25 9.58	10 10.75	25 13.66	13 11.71	4 8.16	0 0.00	77
COMMERCIAL/HI DENSITY	56 21.46	16 17.20	33 18.03	19 17.12	4 8.16	5 31.25	133
COMMERCIAL/LO DENSITY	99 37.93	35 37.63	61 33.33	31 27.93	10 20.41	1 6.25	237
RESIDENT/HI DENSITY	20 7.66	6 6.45	28 15.30	33 29.73	27 55.10	10 62.50	124
RESIDENT/LO DENSITY	23 8.81	6 6.45	27 14.75	9 8.11	4 8.16	0 0.00	69
Total	261	93	183	111	49	16	713

FACILITY TYPE AADT/C

Frequency Row Pct	.	LE 7.00	7.01--11.00	GT 11.0	Total
FREEWAY	6 1.69	222 62.71	112 31.64	14 3.95	354
NONFREEWAY	128 35.65	162 45.13	52 14.48	17 4.74	359
Total	134	384	164	31	713

Figure 3-2. Relationship between AADT/C and V/C

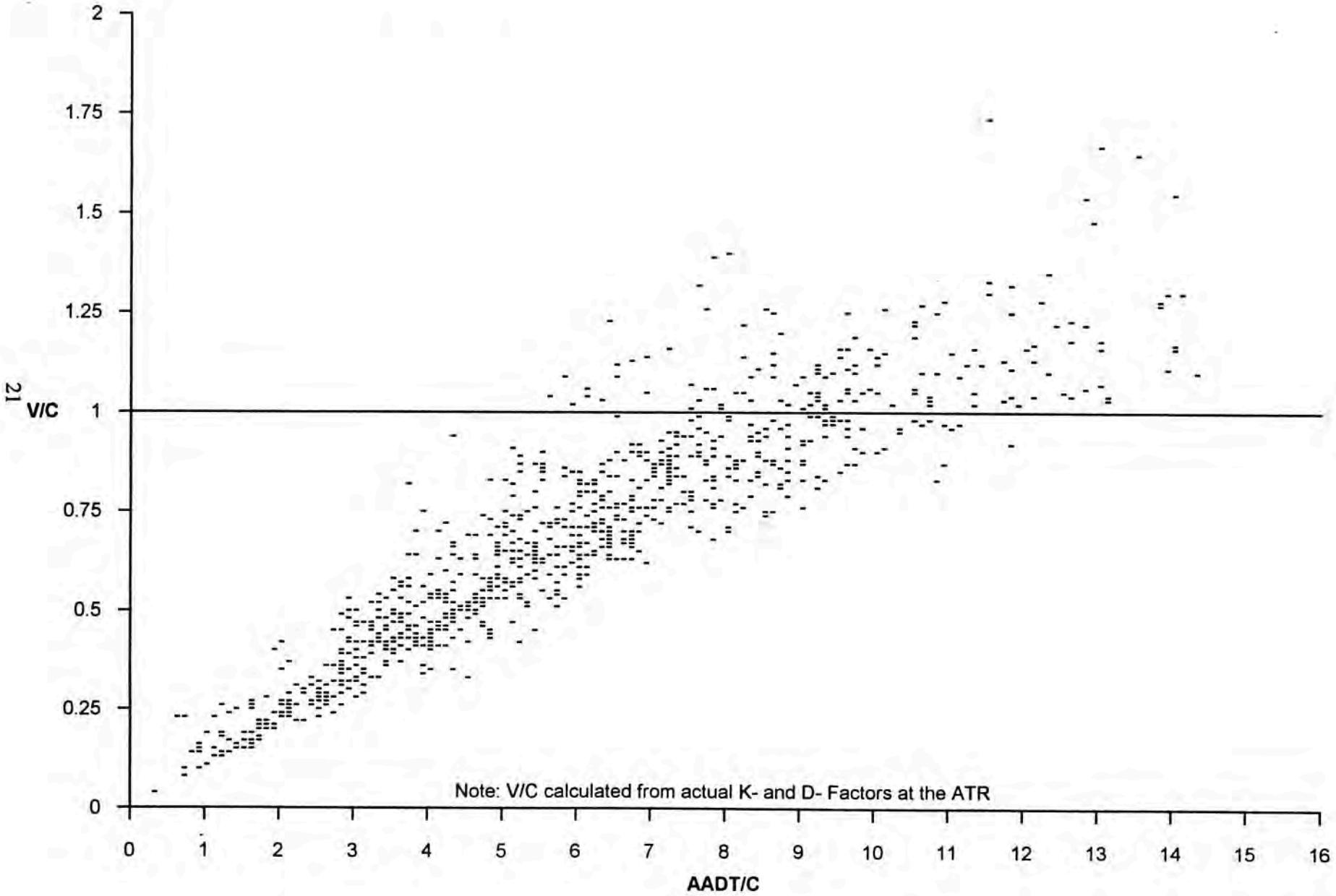


Table 3-2. Distributions for Traffic Variables in the Urban ATR Dataset

DISTRIBUTIONS FOR K-FACTOR

FACILITY TYPE	MEAN	CV[1]	Percentiles P10	P25	P50	P75	P90	P95	P99
FREEWAY	0.1006	11.301	0.0863	0.0932	0.0996	0.1072	0.1151	0.1207	0.1313
NONFREEWAY	0.1058	17.872	0.0908	0.0959	0.1021	0.1131	0.1222	0.1319	0.1721

DISTRIBUTIONS FOR D-FACTOR (BI-DIRECTIONAL REPORTING)

FACILITY TYPE	MEAN	CV[1]	Percentiles P10	P25	P50	P75	P90	P95	P99
FREEWAY	0.5885	11.614	0.5140	0.5333	0.5725	0.6331	0.6795	0.7213	0.7877
NONFREEWAY	0.5770	11.292	0.5119	0.5268	0.5613	0.6131	0.6620	0.7026	0.8249

DISTRIBUTIONS FOR AADT

FACILITY TYPE	MEAN	CV[1]	Percentiles P10	P25	P50	P75	P90	P95	P99
FREEWAY	68,153	64.742	17,914	34,791	57,055	97,157	133,812	152,817	180,898
NONFREEWAY	19,449	82.532	3,440	7,502	16,493	26,443	39,735	46,414	77,374

DISTRIBUTIONS FOR AADT/C

FACILITY TYPE	MEAN	CV[1]	Percentiles P10	P25	P50	P75	P90	P95	P99
FREEWAY	6.1	47.0	2.4	3.9	5.9	8.0	9.8	10.8	13.5
NONFREEWAY	5.7	55.2	1.5	3.5	5.6	7.7	10.0	11.8	13.0

[1]Coefficient of variation: the standard deviation divided by the mean and expressed as a percent.

Table 3-3. K-Factor, D-Factor, and K * D by Facility Type and AADT/C Range

FUNCTIONAL CLASS: FREEWAY

	K-FACTOR		D-FACTOR		K * D	
	MEAN	CV	MEAN	CV	MEAN	CV
AADT/C						
LE 7.0	0.1040	9.99	0.5957	12.03	0.0621	18.47
7.01--11.00	0.0954	8.97	0.5777	9.85	0.0554	14.68
GT 11.0	0.0854	13.04	0.5498	9.17	0.0470	16.53

FUNCTIONAL CLASS: NONFREEWAY

	K-FACTOR		D-FACTOR		K * D	
	MEAN	CV	MEAN	CV	MEAN	CV
AADT/C						
LE 7.0	0.1093	17.91	0.5864	11.65	0.0639	25.75
7.01--11.00	0.0991	10.09	0.5676	9.67	0.0556	14.09
GT 11.0	0.0898	8.30	0.5524	8.60	0.0490	13.04

Note: CV is the coefficient of variation, the standard deviation divided by the mean and expressed as a percent.

Table 3-4. Characteristics of Freeway and Arterial Systems Used in the Analysis

CITY: ORLANDO

	AADT	AADT/C
STATION		
1	109,000	7.9
2	136,300	9.9
3	129,100	9.4
4	122,400	8.9
5	155,500	11.3
6	166,100	12.0
7	141,100	10.2
8	158,700	11.5
9	161,600	11.7
11	152,100	11.0
12	142,300	10.3
13	130,600	9.5
14	164,000	11.9
15	177,000	12.8
16	168,000	12.2
17	167,600	12.1
18	149,200	10.8
19	136,400	9.9
20	139,200	10.1
21	150,400	10.9
22	160,100	11.6
23	122,600	8.9
24	110,100	8.0
25	126,400	9.2
AVERAGE	144,800	10.5

Table 3-4 (Continued)

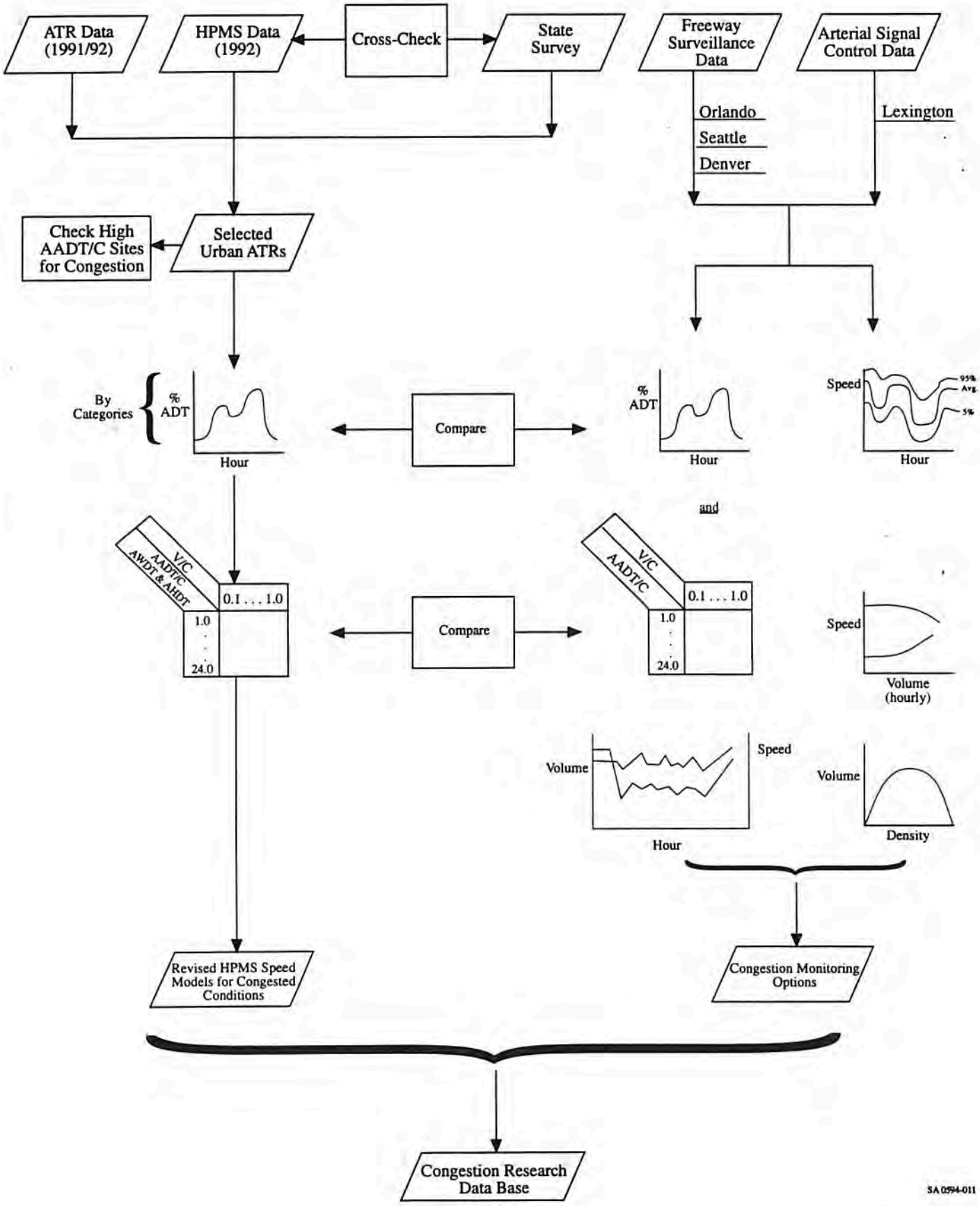
CITY: LEXINGTON

STATION	AADT	AADT/C
1	32,500	8.5
2	35,800	5.0
3	43,500	9.4
4	42,900	5.9
5	35,800	7.1
6	36,700	15.1
7	35,400	9.2
8	48,700	9.4
9	40,000	11.8
10	40,000	11.8
11	33,100	8.6
12	37,000	7.8
13	37,000	5.7
14	38,000	8.2
15	38,000	8.2
16	25,800	3.6
17	33,300	5.8
18	18,300	5.8
AVERAGE	36,211	8.2

CITY: SEATTLE

STATION	AADT	AADT/C
1	147,092	.
2	126,540	.
3	131,271	.
4	164,746	.
5	154,730	.
6	135,729	.
7	166,213	.
8	131,581	.
9	145,588	.
10	167,414	.
11	173,313	.
12	177,998	.
13	166,029	.
AVERAGE	152,942	.

Figure 3-3. Overview of Analysis Methodology



4. ANALYSIS RESULTS

4.1 Initial Temporal Distributions

A variety of different classifications was used in an attempt to distinguish temporal distributions among facility types for weekday nonholidays for the urban ATRs (Figures 4-1 to 4-7). The data were plotted for individual directions where each direction corresponded to either a morning (AM) or afternoon (PM) peak-orientation. In other words, for each ATR site, each direction was assigned either the AM peak direction or the PM peak direction depending on where the average highest hourly volume appeared. (One way to visualize this concept is to think of the AM direction as the inbound direction on a facility connecting a suburb with its CBD.) The reason for defining the directions in this way is that the temporal distributions ultimate use is for providing inputs to the simulation model for estimating speeds. Some observations on these plots follow.

- The temporal distributions of facilities vary by functional class (Figure 4-1). In the AM direction, freeways have a higher morning peak and experience relatively lower midday traffic than arterials and collectors. In the PM direction, freeways experience a different morning peak and less midday traffic than the other classes, but the afternoon peaking characteristics are nearly the same as arterials and collectors. The same trends appear when arterials and collectors are grouped into a single category (nonfreeways; Figure 4-2).

- As was found in the *Statistical Analysis* study, the K*D factor (i.e., the product of K- and D-factors) produces strong differences in temporal distributions (Figure 4-3). Although HPMS sections include K- and D-factors, these may not reflect the true situation at the segment since most HPMS segments do not have an ATR from which to compute these values. Further, for HPMS submittals, some states may be coding the K- and D-factors as statewide averages. This limits the use of the K*D factor for HPMS, although it may be of use in other studies.

- Urban location or setting shows only slight differences in temporal distributions (Figure 4-4). CBD locations have less pronounced peaking than the other categories defined.

- Facilities with six or more lanes show a stronger morning peak in the AM direction and less midday traffic than either two or four lane facilities (Figure 4-5). As with functional class, the afternoon peak in the PM direction is roughly the same for all three lane categories, the same result as for functional class. In fact, number of lanes and functional class are highly correlated (Figure 3-1) so this result is to be expected.

- Three different AADT/C ranges were defined: (1) less than or equal to 7.0, to identify facilities that do not normally experience recurring congestion; 7.1 to 11.0, for facilities that experience recurring congestion some of the time; and greater than 11.0, for facilities that are routinely congested (Figure 4-6). In the AM direction, the highest AADT/C category shows a more spread out peak than the other two categories, which are practically identical. The PM direction shows substantial differences at both the afternoon and morning peaks. In the morning, the highest AADT/C category shows the highest peak followed by the middle and low categories. In the afternoon, the reverse is true. This pattern is indicative of peak spreading in that traffic on the highest AADT/C facilities is more spread out during the day over both directions. Less congested facilities show a greater tendency to concentrate traffic by both time of day and direction.

- Figure 4-7 was an attempt to distinguish between freeways and nonfreeways by urban location. Only very slight differences are apparent for freeways. For nonfreeways, the least intensive land use (residential) shows the strongest peaking characteristics. High density commercial land use shows the highest midday use while facilities in the CBD show generally the greatest peak spreading patterns.

Weekend/holiday distributions were also prepared (Figures 4-8 to 4-11). Only slight differences were found based on the categories available. Nonfreeways showed a greater amount of midday travel than freeways (Figure 4-9). High density commercial land uses showed the greatest proportion of midday travel and CBDs the smallest proportion, an indication of the trend toward suburbanization of retail activities.

4.2 Identification of Congestion

The phenomenon of peak spreading was examined further with the ATR data (Figure 4-12). As a measure of peak spreading, the 99th percentile hourly volume divided by the AADT (V99/AADT) of the site was used. (For a site with all days of the year counted, the 99th percentile corresponds to the 88th highest hour in a year (i.e., 0.01 * 365 * 24 = 88). Lower than expected values of V99/AADT suggest that peak period volumes are constrained by capacity and that some peak spreading is occurring. The analysis indicates that as AADT/C increases, the peaking of traffic becomes less pronounced, which is corroborated by the temporal distributions of the different AADT/C levels. Analysis of covariance was used to discern differences in functional classes, urban locations, and number of lanes. In all cases, once AADT/C was taken into account, these other classifiers became insignificant.

Extensive plotting of the data from Orlando, Seattle, and Lexington was also performed (Appendices E, F, and G, respectively). All stations from Orlando and Seattle were combined and compared to the ATR distribution for freeways with AADT/C values greater than 11.0 (Figure 4-13). In the AM direction, Orlando and the ATRs show a close correspondence; Seattle shows more spreading. The same is true for the PM direction, although the volumes during the afternoon peak show some divergence. Further examination of the plots reveal two interesting trends: (1) the early peaking for both Orlando and Seattle for hour ending at 4:00 pm and (2) the "notch" evident for Seattle in the AM direction for the hour ending at 5:00 pm. These patterns are even more apparent for individual sites (see Orlando stations 6 and 7 for the PM direction in Appendix E and Seattle stations 5 and 6 for the AM direction in Appendix F). It was hypothesized that these patterns might be indicative of congestion (queuing) since observed volumes would drop under congested conditions. Close examination of five minute speed data for Orlando (for example, Appendix H) and occupancy data for Seattle verified that this was indeed the case. Both of these corridors experience recurring congestion routinely and it is reflected in their temporal distributions. For the purpose of producing the AADT/C vs. V/C tables, congested hours had to be detected by a means other than taking the observed V/C ratio since under congestion it would appear to be less than 1.0. Therefore, several algorithms were developed and applied to the ATR data to detect congested hours; in the later AADT/C vs. V/C table development, these were assigned a V/C greater than 1.0. The algorithms determine that an hour is congested if:

- a "notch" appears in an hour **and** the previous hour's volume is 92.5 percent of capacity **and** the drop between hours is greater than or equal to two percent (notches are detected for 8:00 am, 9:00 am and 4:00 to 6:00 pm); or

- the afternoon peak occurs at 4:00 pm **and** the 4:00 pm volume is 92.5 percent of capacity **and** the drop between 4:00 pm and 5:00 pm is greater than or equal to two percent.

Based on these criteria, only a relatively small number of hours were detected as congested from the

ATRs on freeway sections (Table 4-1). This is not to say that congestion does not occur at the ATR sites since short periods of congestion (say up to 30 minutes) may go undetected because flow has a chance to recover. Still, the total number of hours identified as congested was minuscule compared to the total number of hours of data present in the ATR freeway data (roughly 17 million if directionality is accounted for).

Table 4-1. Number of Congested Hours Detected in the Urban ATR Dataset (Freeways)

Criterion	No. Hours
Notch at 8:00 am	116
Notch at 9:00 am	207
Notch at 4:00 pm	151
Notch at 5:00 pm	671
Notch at 6:00 pm	416
Peak at 4:00 pm	1,305
TOTAL	2,866

The Orlando data with its five-minute speed and volume data represented an opportunity to assess the effect of congestion on the observed temporal distributions. As previously stated, the "notches" or the early peak represent congestion but the observed volumes at these times do not reflect the demand; the observed V/C ratio is less than 1.0 but the demand V/C ratio is greater than 1.0. Two methods were explored to adjust the observed volumes to demand volumes, neither of which proved satisfactory but may be worth pursing with a more intensive effort in the future.

The first method attempts to reassign the times that volumes appear at stations based on calculating the congestion delay along a segment. For example, consider a situation where: (1) 400 vehicles are observed at Station 6 at 9:30 am, (2) station-to-station distances are as shown in Table 4-2, and (3) observed speeds at upstream stations are as follows:

- Station 1: 51 mph
- Station 2: 38 mph
- Station 3: 33 mph
- Station 4: 20 mph
- Station 5: 25 mph
- Station 6: 28 mph

For this situation, the time when the 400 vehicles would have passed Station 6, had there been no congestion might be estimated as shown in Table 4-2.

Table 4-2. Example Distances and Speeds for Reassigning Congested Volumes

Section	Distance (miles)	Average Speed (mph)[1]	Free-Flow Speed (mph)	Cong. Delay (hours)[2]
1-2	0.6	43.55	57	0.003251
2-3	0.5	35.32	57	0.005383
3-4	0.7	24.91	57	0.015825
4-5	0.4	22.22	57	0.010982
5-6	0.4	26.42	57	0.008125
Total	2.6			0.043567

In this example, the total congestion delay is 0.044 hours or 2.6 minutes, so it is assumed that the 400 vehicles would have passed Station 6 2.6 minutes before 9:30 am had there been no congestion on the highway mainline.

The key assumptions made in this procedure are as follows:

- Speeds change slowly over time (since we are using the speeds observed at 9:30 a.m. to estimate the speeds experienced by vehicles upstream of Station 6)
- On-ramp and off-ramp volumes are small relative to mainline volumes (since we are using delays experienced on the mainline sections for all vehicles passing Station 6). To the extent that volumes at ramps are significant, the actual delays will probably be less than the delays calculated above.

When this procedure was instituted, the results showed only minor shifting of the times that volumes passed a point. Although the procedure may have merit, further testing was dropped.

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[1]This would be calculated as the average of the observed speeds at the upstream (S_u) and downstream (S_d) ends of the section. Ideally, harmonic averaging should be used:

$$\text{Ave. Speed} = 2/(1S_d + 1/S_u)$$

although the speeds are probably close enough that there would not be much difference between a simple average and a harmonic average.

[2]Congestion delay (in hours) is calculated as:

$$CD = (1/Sa - 1/Sf)\ (d)$$

where Sa is average speed, Sf is free-flow speed, and d is distance in miles.

The second method basically adds volume to the congested time period and subtracts this volume from a time period after the queue has started to recover. The steps in the process are as follows.

- Identify the onset of congestion by tracking volumes and speeds. When speed and volume drop abruptly, especially after volume has gotten close to capacity, congestion has occurred.

- Estimate the "demand" V/C as a function of speed using a link delay function. Several of these functions appear in the literature, including the so-called Bureau of Public Roads (BPR) function typically used in urban traffic assignment or one of its many variants:

  $$\text{speed} = \text{free flow speed}/((1 + (0.15 * (V/C)^4)); \text{ therefore,}$$

  $$V/C = \{(((\text{free flow speed}/\text{speed}) - 1)/0.15\}^{1/4}.$$

- The volume for the congested time period is then estimated by multiplying V/C by the section's capacity.

- The difference in the calculated volume and the observed volume is then subtracted from a time period after queue recovery has begun. Queue recovery is identified when both speed and volume increase from some minimum value. (See Appendix H for a graphical depiction of queue formation and recovery from speed and volume data.)

Several problems surfaced in applying this approach. First, a single queue rarely forms and dissipates. Several perturbations usually exist in traffic flow that would make it difficult to assess when queue recovery begins and queue formation ends (see Appendix H). Second, even if the first problem could be handled, the procedure is sensitive to the hour selected from which traffic is subtracted. Theoretically, this subtraction occurs under the assumption that without the queue, the volume in this later time period would be less than what is observed with the queue present. However, selecting this point proved to be difficult.

Since so few hours from the ATRs were identified as being congested from the ATR dataset, the above procedures were not explored further since it was felt that there would be little effect on the results. However, future research may want to consider these procedures further.

4.3 Final Temporal Distributions

Based on the initial temporal distributions, two categories were selected to distinguish weekday temporal distributions: freeway/nonfreeway and the three AADT/C ranges. For weekends, only freeway/nonfreeway was selected. Because of the sparseness of data in the high AADT/C range (greater than 11.0), one site each from Orlando, Seattle, and Lexington was added to the dataset (Station 15 for Orlando; Stations 3 and 22 for Seattle; and Stations 15 and 16 for Lexington.[1] The resulting distributions are shown in Figures 4-14 to 4-16. (The data used in producing the plots appear in Tables 4-3 and 4-4.) For both freeways and nonfreeways, the effect of peak spreading on the high AADT/C sites is apparent in the lower peak in the morning for the AM direction, as well as the higher morning peak and lower afternoon peaks in the PM direction. General differences also exist between facility types in that nonfreeways experience a larger share of their travel during midday and the morning peaks are less pronounced both in the AM and PM orientations.

[1]Stations for Seattle and Lexington were coded as one-way directions.

Table 4-3. Final Weekday Temporal Distributions

TYPE OF FACILITY: FREEWAY

	AADT/C					
	LE 7.0		7.1 -- 11.0		GT 11.0	
	PEAK DIRECTION		PEAK DIRECTION		PEAK DIRECTION	
	AM	PM	AM	PM	AM	PM
	PCT. OF DAILY VOL.	PCT. OF DAILY VOL.	PCT. OF DAILY VOL.	PCT. OF DAILY VOL.	PCT. OF DAILY VOL.	PCT. OF DAILY VOL.
HOUR						
1	0.42	0.58	0.44	0.57	0.47	0.54
2	0.27	0.33	0.27	0.34	0.27	0.32
3	0.23	0.25	0.22	0.26	0.20	0.24
4	0.23	0.22	0.21	0.21	0.18	0.18
5	0.38	0.29	0.36	0.28	0.31	0.25
6	1.17	0.68	1.12	0.69	1.06	0.72
7	3.26	1.75	3.16	1.90	2.86	2.18
8	4.83	2.90	4.59	3.05	3.90	3.27
9	3.56	2.57	3.80	2.76	3.66	3.04
10	2.58	2.24	2.75	2.30	2.94	2.53
11	2.46	2.33	2.50	2.34	2.68	2.49
12	2.56	2.56	2.61	2.61	2.73	2.69
13	2.65	2.71	2.68	2.75	2.75	2.78
14	2.70	2.77	2.75	2.81	2.82	2.86
15	2.93	3.12	2.93	3.15	2.97	3.15
16	3.26	4.01	3.21	3.87	3.21	3.60
17	3.47	4.81	3.38	4.43	3.28	3.82
18	3.42	4.85	3.32	4.39	3.29	3.77
19	2.66	3.23	2.66	3.20	2.82	3.22
20	1.95	2.23	1.97	2.25	2.12	2.36
21	1.54	1.78	1.54	1.79	1.62	1.86
22	1.40	1.63	1.44	1.69	1.54	1.74
23	1.14	1.30	1.19	1.39	1.27	1.46
24	0.79	0.98	0.83	1.05	0.89	1.07
TOTAL	49.87	50.13	49.92	50.08	49.84	50.16

Note: One High AADT/C Site From Seattle, Orlando, and Lexington Added

Table 4-3. (Continued)

TYPE OF FACILITY: NONFREEWAY

	AADT/C					
	LE 7.0		7.1 -- 11.0		GT 11.0	
	PEAK DIRECTION		PEAK DIRECTION		PEAK DIRECTION	
	AM	PM	AM	PM	AM	PM
	PCT. OF DAILY VOL.	PCT. OF DAILY VOL.	PCT. OF DAILY VOL.	PCT. OF DAILY VOL.	PCT. OF DAILY VOL.	PCT. OF DAILY VOL.
HOUR						
1	0.34	0.47	0.37	0.47	0.41	0.49
2	0.21	0.28	0.23	0.27	0.24	0.28
3	0.15	0.18	0.17	0.18	0.18	0.20
4	0.14	0.14	0.16	0.15	0.17	0.18
5	0.24	0.18	0.28	0.20	0.33	0.27
6	0.74	0.42	0.81	0.48	1.03	0.67
7	2.23	1.19	2.35	1.27	2.55	1.72
8	4.11	2.28	3.85	2.39	3.57	2.79
9	3.45	2.33	3.42	2.39	3.09	2.78
10	2.64	2.29	2.69	2.31	2.58	2.47
11	2.64	2.56	2.65	2.54	2.62	2.57
12	2.90	3.02	2.90	2.98	2.83	2.89
13	3.20	3.35	3.17	3.30	3.04	3.13
14	3.14	3.24	3.14	3.22	3.06	3.13
15	3.18	3.44	3.16	3.37	3.21	3.34
16	3.40	4.13	3.35	3.93	3.41	3.78
17	3.46	4.78	3.49	4.49	3.47	3.92
18	3.31	4.83	3.45	4.55	3.39	3.86
19	2.68	3.23	2.75	3.31	2.82	3.12
20	2.14	2.41	2.18	2.53	2.28	2.53
21	1.73	1.97	1.75	2.07	1.83	2.09
22	1.49	1.71	1.50	1.77	1.55	1.80
23	1.10	1.26	1.11	1.25	1.22	1.29
24	0.74	0.94	0.75	0.90	0.83	0.97
TOTAL	49.36	50.64	49.67	50.33	49.71	50.29

Note: One High AADT/C Site From Seattle, Orlando, and Lexington Added

Table 4-4. Final Weekend/Holiday Temporal Distributions

	TYPE OF FACILITY:	
	FREEWAY	NONFREEWAY
	PCT. OF	PCT. OF
	DAILY VOL.	DAILY VOL.
HOUR		
1	2.16	2.01
2	1.45	1.36
3	1.06	0.90
4	0.69	0.57
5	0.63	0.50
6	1.02	0.79
7	1.98	1.55
8	2.87	2.43
9	3.70	3.42
10	4.69	4.72
11	5.66	5.92
12	6.45	6.85
13	7.06	7.64
14	7.06	7.63
15	7.09	7.62
16	7.19	7.60
17	7.19	7.40
18	6.90	6.87
19	6.22	6.04
20	5.15	5.09
21	4.24	4.22
22	3.77	3.66
23	3.27	2.96
24	2.50	2.26
TOTAL	100.00	100.00

Note: One High AADT/C Site From Seattle, Orlando, and Lexington Added

4.4 AADT/C vs. V/C Relationships

AADT/C, AWDT/C, and AHDT/C vs. V/C distributions were prepared from the ATR data (Tables 4-5 to 4-7). Because of the relatively small number of ATR sites in relation to the 1.0 increments of AADT/C specified in the contract, AADT/C ranges were defined instead. (The full complement of AADT/C ranges appears in Appendix I). Even with this restriction, one minor anomaly appeared: for nonfreeways, the 11.01 to 13.00 AADT/C category shows a higher percentage of vehicles operating under congestion than the greater than 13.0 category. (We feel this is a sample size problem.) To rectify this problem, these two categories were combined for nonfreeways only. Orlando data was used for comparison for freeways (Table 4-8). Results show that the Orlando sites and the ATR sites are roughly similar in their V/C distributions by AADT/C range.

For ease of use within the HPMS simulation models, a curve fitting exercise was undertaken to provide the AADT/C vs. V/C data in equation form. For a facility where the AADT/C ratio is known, the probability distribution of V/AADT can be used to determine the percentage of traffic experiencing a given volume-to-capacity ratio. This is done by converting the volume-to-capacity ratio into an equivalent value of V/AADT through division by AADT/C. For example, on a facility with an AADT/C of 8.0, a volume-to-capacity ratio of 0.6 is equivalent to a V/AADT ratio of 0.075 (i.e., 0.6 / 8.0).

ATR traffic volume distributions compiled as part of this study were used to estimate the following cumulative distribution functions for freeways and non-freeways:

$$P_{fwy}(u) = 225.8\ u^2 - 1{,}259\ u^3 - 2{,}809\ u^4 + 20{,}610\ u^5 \quad \text{for } 0 <= u <= 0.117$$

$$P_{fwy}(u) = 1.0 \quad \text{for } u > 0.117$$

$$P_{nfwy}(u) = 194.0\ u^2 - 845.1\ u^3 - 4{,}276\ u^4 + 21{,}486\ u^5 \quad \text{for } 0 <= u <= 0.136$$

$$P_{nfwy}(u) = 1.0 \quad \text{for } u > 0.136$$

where:

- u is volume divided by annual average daily traffic (V/AADT)
- $P_{fwy}(u)$ is the fraction of vehicles experiencing a V/AADT ratio less than u on freeways
- $P_{nfwy}(u)$ is the fraction of vehicles experiencing a V/AADT ratio less than u on non-freeways

Table 4-9 shows the results of applying this procedure. For future reference, the relationship between AWDT, AHDT, and AADT from the urban ATR dataset is given in Table 4-10. These factors may be used to convert AADTs to AWDTs and AHDTs.

Table 4-5. AADT/C vs. V/C Distribution from Urban ATR Sites

FACILITY TYPE = FREEWAY

AADT/C	V/C												
Frequency Row Pct	0.00 -- 0.10	0.11 -- 0.20	0.21 -- 0.30	0.31 -- 0.41	0.41 -- 0.50	0.51 -- 0.60	0.61 -- 0.70	0.71 -- 0.80	0.81 -- 0.90	0.91 -- 0.94	0.95 -- 0.97	0.98+	Total
LE 3.0	1.674E8 28.50	2.854E8 48.57	1.047E8 17.82	2.158E7 3.67	6227266 1.06	1987290 0.34	204513 0.03	19110 0.00	4870 0.00	2450 0.00	5121 0.00	9479 0.00	5.875E8
3.01--5.00	1.567E8 8.66	4.081E8 22.56	6.236E8 34.48	3.112E8 17.21	1.422E8 7.86	9.607E7 5.31	4.338E7 2.40	1.974E7 1.09	7122672 0.39	377424 0.02	144907 0.01	110625 0.01	1.809E9
5.01--7.00	1.733E8 5.27	3.3E8 10.04	6.542E8 19.90	8.491E8 25.83	5.506E8 16.75	3.11E8 9.46	1.897E8 5.77	1.258E8 3.83	5.878E7 1.79	9840893 0.30	7045714 0.21	2.811E7 0.86	3.287E9
7.01--9.00	1.287E8 3.50	1.989E8 5.41	3.512E8 9.55	5.629E8 15.30	8.278E8 22.50	6.416E8 17.44	3.5E8 9.51	2.537E8 6.90	1.678E8 4.56	3.625E7 0.99	2.674E7 0.73	1.334E8 3.63	3.679E9
9.01--11.00	6.037E7 2.51	9.155E7 3.80	1.356E8 5.63	2.075E8 8.62	2.965E8 12.32	4.442E8 18.45	3.926E8 16.31	2.612E8 10.85	1.837E8 7.63	4.904E7 2.04	4.246E7 1.76	2.427E8 10.08	2.407E9
11.01--13.00	1.691E7 2.10	2.446E7 3.03	2.943E7 3.65	4.517E7 5.60	6.468E7 8.02	9.984E7 12.37	1.317E8 16.32	1.314E8 16.29	1.095E8 13.57	2.771E7 3.43	2.474E7 3.07	1.013E8 12.56	8.069E8
GT 13.00	8211952 1.56	1.173E7 2.22	1.436E7 2.72	1.811E7 3.43	2.61E7 4.95	3.147E7 5.96	4.248E7 8.05	8.082E7 15.32	8.459E7 16.03	2.32E7 4.40	2.128E7 4.03	1.653E8 31.33	5.276E8
Total	7.115E8	1.35E9	1.913E9	2.016E9	1.914E9	1.626E9	1.15E9	8.727E8	6.115E8	1.464E8	1.224E8	6.709E8	1.31E10

CELL ENTRIES ARE THE NUMBER AND PERCENT OF VEHICLES IN EACH V/C RANGE
INCLUDES REASSIGNMENT OF CONGESTED HOURS (FREEWAYS ONLY)

Table 4-5 (Continued)

FACILITY TYPE = NONFREEWAY

AADT/C V/C

Frequency Row Pct	0.00 -- 0.10	0.11 -- 0.20	0.21 -- 0.30	0.31 -- 0.41	0.41 -- 0.50	0.51 -- 0.60	0.61 -- 0.70	0.71 -- 0.80	0.81 -- 0.90	0.91 -- 0.94	0.95 -- 0.97	0.98+	Total
LE 3.0	4.655E7 32.82	6.13E7 43.22	2.03E7 14.31	7559204 5.33	4006717 2.82	1560180 1.10	422289 0.30	32941 0.02	20175 0.01	2429 0.00	2487 0.00	82393 0.06	1.418E8
3.01--5.00	3.962E7 8.39	9.716E7 20.58	1.516E8 32.12	8.366E7 17.72	4.539E7 9.62	2.236E7 4.74	1.252E7 2.65	7369174 1.56	5287283 1.12	928563 0.20	619646 0.13	5549845 1.18	4.721E8
5.01--7.00	3.168E7 4.78	5.323E7 8.03	9.544E7 14.40	1.446E8 21.82	1.289E8 19.45	7.981E7 12.04	4.061E7 6.13	3.198E7 4.82	2.095E7 3.16	4722969 0.71	3779977 0.57	2.706E7 4.08	6.628E8
7.01--9.00	1.735E7 3.27	2.678E7 5.04	4.085E7 7.69	6.109E7 11.50	9.583E7 18.04	9.909E7 18.65	7.002E7 13.18	3.969E7 7.47	2.361E7 4.44	5037248 0.95	3810698 0.72	4.816E7 9.06	5.313E8
9.01--11.00	8719521 2.70	1.248E7 3.87	1.688E7 5.24	2.484E7 7.71	3.978E7 12.34	5.414E7 16.80	5.525E7 17.14	4.031E7 12.50	2.785E7 8.64	5425107 1.68	4572401 1.42	3.211E7 9.96	3.224E8
11.01--13.00	5669193 1.92	7633119 2.59	1.02E7 3.45	1.359E7 4.60	1.665E7 5.64	2.23E7 7.56	3.251E7 11.01	4.704E7 15.94	4.214E7 14.28	1.111E7 3.76	9493566 3.22	7.686E7 26.04	2.952E8
GT 13.00	639809 1.83	990072 2.83	1067133 3.05	1302941 3.72	1822952 5.21	2618330 7.48	3249153 9.28	6163204 17.61	6496837 18.56	2389601 6.83	1627204 4.65	6637935 18.96	3.501E7
Total	1.502E8	2.596E8	3.364E8	3.367E8	3.324E8	2.819E8	2.146E8	1.726E8	1.263E8	2.961E7	2.391E7	1.965E8	2.461E9

CELL ENTRIES ARE THE NUMBER AND PERCENT OF VEHICLES IN EACH V/C RANGE
INCLUDES REASSIGNMENT OF CONGESTED HOURS (FREEWAYS ONLY)

Table 4-6. AWDT/C vs. V/C Distribution from Urban ATR Sites

FACILITY TYPE = FREEWAY

AWDT_C	V/C												
Frequency Row Pct	0.00 -- 0.10	0.11 -- 0.20	0.21 -- 0.30	0.31 -- 0.41	0.41 -- 0.50	0.51 -- 0.60	0.61 -- 0.70	0.71 -- 0.80	0.81 -- 0.90	0.91 -- 0.94	0.95 -- 0.97	0.98+	Total
LE 3.0	1.382E8 33.56	1.946E8 47.28	6.247E7 15.17	1.137E7 2.76	3128648 0.76	1676928 0.41	168544 0.04	12494 0.00	4870 0.00	2450 0.00	5121 0.00	9479 0.00	4.117E8
3.01--5.00	1.543E8 10.05	4.256E8 27.70	5.085E8 33.10	2.308E8 15.02	1.032E8 6.71	6.345E7 4.13	2.809E7 1.83	1.552E7 1.01	6410533 0.42	381244 0.02	144907 0.01	100757 0.01	1.537E9
5.01--7.00	1.532E8 5.89	3.128E8 12.03	6.579E8 25.30	6.645E8 25.55	3.433E8 13.20	2.093E8 8.05	1.279E8 4.92	7.316E7 2.81	3.239E7 1.25	5848132 0.22	4507988 0.17	1.561E7 0.60	2.6E9
7.01--9.00	1.366E8 3.97	2.237E8 6.51	3.913E8 11.38	6.693E8 19.47	7.963E8 23.17	4.877E8 14.19	2.651E8 7.71	2.004E8 5.83	1.297E8 3.77	2.524E7 0.73	1.828E7 0.53	9.352E7 2.72	3.437E9
9.01--11.00	8.325E7 2.90	1.228E8 4.27	2.031E8 7.07	3.036E8 10.57	4.845E8 16.86	5.769E8 20.08	3.724E8 12.96	2.339E8 8.14	1.621E8 5.64	4.143E7 1.44	3.663E7 1.27	2.526E8 8.79	2.873E9
11.01--13.00	3.143E7 2.25	4.981E7 3.56	6.502E7 4.65	1.035E8 7.41	1.337E8 9.56	2.294E8 16.42	2.785E8 19.93	2.148E8 15.37	1.368E8 9.79	3.581E7 2.56	2.852E7 2.04	9.018E7 6.45	1.398E9
GT 13.00	1.451E7 1.71	2.083E7 2.46	2.483E7 2.93	3.252E7 3.83	5.002E7 5.89	5.775E7 6.81	7.797E7 9.19	1.349E8 15.90	1.441E8 16.99	3.77E7 4.44	3.433E7 4.05	2.19E8 25.81	8.485E8
Total	7.115E8	1.35E9	1.913E9	2.016E9	1.914E9	1.626E9	1.15E9	8.727E8	6.115E8	1.464E8	1.224E8	6.709E8	1.31E10

CELL ENTRIES ARE THE NUMBER AND PERCENT OF VEHICLES IN EACH V/C RANGE
INCLUDES REASSIGNMENT OF CONGESTED HOURS (FREEWAYS ONLY)

Table 4-6. (Continued)

FACILITY TYPE = NONFREEWAY

AWDT_C V/C

Frequency Row Pct	0.00 -- 0.10	0.11 -- 0.20	0.21 -- 0.30	0.31 -- 0.41	0.41 -- 0.50	0.51 -- 0.60	0.61 -- 0.70	0.71 -- 0.80	0.81 -- 0.90	0.91 -- 0.94	0.95 -- 0.97	0.98+	Total
LE 3.0	4.066E7 41.00	4.303E7 43.39	1.126E7 11.36	2438337 2.46	1135143 1.14	493685 0.50	127056 0.13	5731 0.01	4598 0.00	0 0.00	0 0.00	7779 0.01	9.917E7
3.01--5.00	3.987E7 9.50	1.047E8 24.94	1.431E8 34.08	7.153E7 17.04	3.317E7 7.90	1.368E7 3.26	5411046 1.29	3647160 0.87	1954710 0.47	199988 0.05	147778 0.04	2377967 0.57	4.198E8
5.01--7.00	3.029E7 5.19	5.265E7 9.01	9.446E7 16.17	1.322E8 22.64	1.062E8 18.18	6.336E7 10.85	3.639E7 6.23	2.759E7 4.72	1.757E7 3.01	3604039 0.62	2728790 0.47	1.704E7 2.92	5.841E8
7.01--9.00	1.888E7 3.63	2.991E7 5.75	4.774E7 9.18	7.28E7 14.01	1.035E8 19.91	8.872E7 17.07	5.316E7 10.23	3.324E7 6.39	2.027E7 3.90	4789206 0.92	3951748 0.76	4.285E7 8.24	5.198E8
9.01--11.00	1.161E7 2.84	1.691E7 4.14	2.356E7 5.77	3.588E7 8.78	6.082E7 14.88	7.765E7 19.00	6.795E7 16.63	3.992E7 9.77	2.368E7 5.80	4714161 1.15	3908323 0.96	4.208E7 10.30	4.087E8
11.01--13.00	5667282 2.24	7906513 3.13	1.058E7 4.19	1.489E7 5.89	1.807E7 7.15	2.518E7 9.97	3.4E7 13.45	3.727E7 14.75	3.391E7 13.42	7637748 3.02	6050745 2.39	5.155E7 20.40	2.527E8
GT 13.00	3259730 1.85	4469223 2.53	5685965 3.22	6930044 3.93	9503735 5.39	1.28E7 7.25	1.754E7 9.95	3.091E7 17.52	2.896E7 16.42	8666144 4.91	7118595 4.04	4.056E7 22.99	1.764E8
Total	1.502E8	2.596E8	3.364E8	3.367E8	3.324E8	2.819E8	2.146E8	1.726E8	1.263E8	2.961E7	2.391E7	1.965E8	2.461E9

CELL ENTRIES ARE THE NUMBER AND PERCENT OF VEHICLES IN EACH V/C RANGE
INCLUDES REASSIGNMENT OF CONGESTED HOURS (FREEWAYS ONLY)

Table 4-7. AHDT/C vs. V/C Distribution from Urban ATR Sites

FACILITY TYPE = FREEWAY

AHDT_C	V/C												
Frequency Row Pct	0.00 -- 0.10	0.11 -- 0.20	0.21 -- 0.30	0.31 -- 0.41	0.41 -- 0.50	0.51 -- 0.60	0.61 -- 0.70	0.71 -- 0.80	0.81 -- 0.90	0.91 -- 0.94	0.95 -- 0.97	0.98+	Total
LE 3.0	2.037E8 22.18	3.974E8 43.27	2.142E8 23.32	6.276E7 6.83	2.606E7 2.84	9229558 1.01	3240845 0.35	1536140 0.17	182639 0.02	53013 0.01	16625 0.00	9479 0.00	9.184E8
3.01--5.00	2.217E8 6.64	5.014E8 15.02	9.249E8 27.72	7.044E8 21.11	3.907E8 11.71	2.617E8 7.84	1.559E8 4.67	9.446E7 2.83	4.785E7 1.43	9428970 0.28	6547150 0.20	1.826E7 0.55	3.337E9
5.01--7.00	1.844E8 4.06	3.001E8 6.61	5.572E8 12.27	9.113E8 20.07	9.787E8 21.56	6.766E8 14.90	3.887E8 8.56	2.589E8 5.70	1.567E8 3.45	2.932E7 0.65	2.139E7 0.47	7.705E7 1.70	4.54E9
7.01--9.00	7.814E7 2.64	1.109E8 3.75	1.71E8 5.79	2.667E8 9.02	4.127E8 13.97	5.185E8 17.55	4.097E8 13.86	3.143E8 10.63	2.234E8 7.56	6.142E7 2.08	5.095E7 1.72	3.375E8 11.42	2.955E9
9.01--11.00	1.954E7 1.89	3.336E7 3.22	3.766E7 3.63	6.061E7 5.85	8.975E7 8.66	1.392E8 13.44	1.65E8 15.92	1.575E8 15.19	1.358E8 13.11	3.364E7 3.25	3.11E7 3.00	1.332E8 12.85	1.036E9
11.01--13.00	4146174 1.31	7055243 2.22	8175042 2.58	9943239 3.13	1.606E7 5.06	2.101E7 6.62	2.748E7 8.66	4.612E7 14.53	4.753E7 14.97	1.255E7 3.95	1.242E7 3.91	1.049E8 33.06	3.174E8
Total	7.115E8	1.35E9	1.913E9	2.016E9	1.914E9	1.626E9	1.15E9	8.727E8	6.115E8	1.464E8	1.224E8	6.709E8	1.31E10

CELL ENTRIES ARE THE NUMBER AND PERCENT OF VEHICLES IN EACH V/C RANGE
INCLUDES REASSIGNMENT OF CONGESTED HOURS (FREEWAYS ONLY)

Table 4-7. (Continued)

FACILITY TYPE = NONFREEWAY

AHDT_C V/C

Frequency Row Pct	0.00 -- 0.10	0.11 -- 0.20	0.21 -- 0.30	0.31 -- 0.41	0.41 -- 0.50	0.51 -- 0.60	0.61 -- 0.70	0.71 -- 0.80	0.81 -- 0.90	0.91 -- 0.94	0.95 -- 0.97	0.98+	Total
LE 3.0	6.464E7 20.24	1.069E8 33.49	7.863E7 24.62	3.218E7 10.08	1.883E7 5.90	9426115 2.95	4631266 1.45	2479755 0.78	408442 0.13	86225 0.03	55921 0.02	1015519 0.32	3.193E8
3.01--5.00	3.541E7 6.35	7.409E7 13.28	1.35E8 24.19	1.201E8 21.52	7.598E7 13.62	4.283E7 7.68	2.397E7 4.30	1.753E7 3.14	1.446E7 2.59	2942036 0.53	2051498 0.37	1.365E7 2.45	5.58E8
5.01--7.00	2.728E7 4.00	4.604E7 6.76	7.757E7 11.38	1.181E8 17.32	1.348E8 19.78	9.853E7 14.46	5.658E7 8.30	3.774E7 5.54	2.384E7 3.50	5935697 0.87	4746759 0.70	5.032E7 7.38	6.814E8
7.01--9.00	1.615E7 2.89	2.322E7 4.15	3.324E7 5.94	5.098E7 9.12	8.24E7 14.74	1.03E8 18.43	9.229E7 16.51	5.93E7 10.61	3.821E7 6.83	7291809 1.30	5916571 1.06	4.71E7 8.42	5.591E8
9.01--11.00	4835919 1.99	6616845 2.72	8675954 3.57	1.138E7 4.68	1.483E7 6.10	2.029E7 8.34	2.652E7 10.91	3.475E7 14.29	3.128E7 12.86	7989047 3.29	6656578 2.74	6.936E7 28.52	2.432E8
11.01--13.00	1794902 1.93	2536302 2.73	3042421 3.28	3725136 4.01	5288205 5.70	7415743 7.99	1.019E7 10.98	2.02E7 21.76	1.734E7 18.68	5065422 5.46	4110922 4.43	1.211E7 13.05	9.283E7
GT 13.00	120630 1.79	146810 2.18	204810 3.05	281950 4.19	248140 3.69	355640 5.29	390600 5.81	583610 8.68	812780 12.09	301050 4.48	367730 5.47	2909309 43.27	6723059
Total	1.502E8	2.596E8	3.364E8	3.367E8	3.324E8	2.819E8	2.146E8	1.726E8	1.263E8	2.961E7	2.391E7	1.965E8	2.461E9

CELL ENTRIES ARE THE NUMBER AND PERCENT OF VEHICLES IN EACH V/C RANGE
INCLUDES REASSIGNMENT OF CONGESTED HOURS (FREEWAYS ONLY)

Table 4-8. AADT/C vs. V/C for Orlando

AADT/C	V/C												
Frequency Row Pct	0.00 -- 0.10	0.11 -- 0.20	0.21 -- 0.30	0.31 -- 0.41	0.41 -- 0.50	0.51 -- 0.60	0.61 -- 0.70	0.71 -- 0.80	0.81 -- 0.90	0.91 -- 0.94	0.95 -- 0.97	0.98+	Total
9.01--11.00	522722 2.49	560701 2.67	1016536 4.83	1402816 6.67	2059303 9.79	3969136 18.88	4269057 20.30	3035227 14.44	1702366 8.10	385089 1.83	219877 1.05	1883498 8.96	2.103E7
11.01--13.00	703154 2.03	813647 2.35	1016053 2.93	1696041 4.89	2070658 5.97	3028677 8.73	5706651 16.45	6569632 18.94	4417058 12.73	1242577 3.58	740103 2.13	6686223 19.27	3.469E7
GT 13.00	578643 1.66	755301 2.16	690024 1.98	1194374 3.42	1858160 5.33	1779179 5.10	2324250 6.66	4697125 13.46	6675222 19.13	2207942 6.33	1324912 3.80	1.081E7 30.97	3.489E7
Total	1804519	2129649	2722613	4293231	5988121	8776992	1.23E7	1.43E7	1.279E7	3835608	2284892	1.938E7	9.061E7

Table 4-9. AADT/C vs. V/C from Applying the Equations

Freeways

	V/C											
AADT/C	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.975	1
0.5	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.5	0.602	0.398	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.5	0.276	0.477	0.247	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3.5	0.153	0.332	0.325	0.183	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4.5	0.097	0.231	0.274	0.237	0.143	0.018	0.000	0.000	0.000	0.000	0.000	0.000
5.5	0.067	0.168	0.218	0.221	0.183	0.117	0.027	0.000	0.000	0.000	0.000	0.000
6.5	0.049	0.126	0.174	0.191	0.181	0.148	0.099	0.033	0.000	0.000	0.000	0.000
7.5	0.037	0.098	0.140	0.162	0.165	0.151	0.123	0.086	0.038	0.000	0.000	0.000
8.5	0.029	0.079	0.115	0.137	0.146	0.143	0.128	0.105	0.076	0.026	0.010	0.006
9.5	0.024	0.064	0.096	0.117	0.128	0.131	0.125	0.111	0.092	0.037	0.016	0.060
10.5	0.019	0.054	0.081	0.100	0.113	0.118	0.117	0.110	0.098	0.043	0.020	0.128
11.5	0.016	0.045	0.069	0.087	0.099	0.106	0.108	0.105	0.098	0.045	0.021	0.199
12.5	0.014	0.039	0.059	0.076	0.088	0.096	0.099	0.099	0.095	0.045	0.022	0.268
13.5	0.012	0.033	0.052	0.067	0.078	0.086	0.091	0.092	0.091	0.044	0.021	0.332
14.5	0.010	0.029	0.046	0.059	0.070	0.078	0.083	0.086	0.086	0.042	0.021	0.391

Nonfreeways

	V/C											
AADT/C	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.975	1
0.5	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.5	0.556	0.444	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.5	0.248	0.457	0.277	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3.5	0.136	0.307	0.319	0.200	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4.5	0.086	0.211	0.260	0.236	0.157	0.052	0.000	0.000	0.000	0.000	0.000	0.000
5.5	0.059	0.151	0.203	0.213	0.185	0.128	0.058	0.004	0.000	0.000	0.000	0.000
6.5	0.043	0.113	0.160	0.180	0.176	0.151	0.109	0.058	0.011	0.000	0.000	0.000
7.5	0.032	0.088	0.128	0.151	0.157	0.149	0.126	0.094	0.057	0.014	0.003	0.001
8.5	0.025	0.070	0.104	0.127	0.138	0.138	0.128	0.109	0.083	0.031	0.013	0.036
9.5	0.020	0.057	0.086	0.107	0.120	0.124	0.121	0.111	0.095	0.040	0.018	0.099
10.5	0.017	0.047	0.072	0.091	0.104	0.111	0.112	0.108	0.098	0.044	0.021	0.173
11.5	0.014	0.040	0.061	0.079	0.091	0.099	0.103	0.102	0.097	0.045	0.022	0.247
12.5	0.012	0.034	0.053	0.068	0.080	0.089	0.093	0.095	0.093	0.044	0.022	0.317
13.5	0.010	0.029	0.046	0.060	0.071	0.079	0.085	0.087	0.087	0.043	0.021	0.380
14.5	0.009	0.026	0.040	0.053	0.063	0.071	0.077	0.081	0.082	0.041	0.020	0.437

Note: Values in the table are the percent of vehicles in each V/C range. Rows add to 100 percent.

Table 4-10. Conversion Factors for AADT, AWDT, and AHDT

Facility Type	No. of Station-Years	AWDT/AADT	AHDT/AADT
Freeway	623	1.07644	0.83597
Nonfreeway	630	1.07391	0.84259

4.5 Revised HPMS Speed Determination Models

The primary use of the temporal distributions and the AADT/C vs. V/C relationships by FHWA is as part of the speed estimation procedure in the HPMS simulation models. The historical approach is to first estimate the percent of time a facility operates in various V/C ranges and then to estimate speeds for each of the ranges. The approach taken in the *HPMS Speed Determination Models* project was to combine these steps. In other words, the temporal distributions are imbedded within the speed models in that the distributions were used to produce inputs to a simplified simulation model which in turn produced speed estimates as a function of AADT/C.[1] In doing so, the full effects of congestion are incorporated since the simplified simulation model produced hour-by-hour speed estimates. Curves were then fit to the simulation model results to produce a direct method for estimating speeds without table look-ups.

The temporal distributions developed by this research are different than those used in the *HPMS Speed Determination Models* project. The new distributions are based on much more data and are felt to be more reliable. Their most attractive attribute is that they account for peak spreading since AADT/C is used as a discriminator. Therefore, the congestion terms (D_{cong}) of the previously developed speed models were re-estimated using the procedure described above.

Freeways

$$D_{cong} = 0.0797\ x + 0.00385\ x^2 \qquad \text{for } x <= 8$$

$$D_{cong} = 12.1 - 2.95\ x + 0.193\ x^2 \qquad \text{for } x > 8 \text{ and } x <= 12$$

$$D_{cong} = 19.6 - 5.36\ x + 0.342\ x^2 \qquad \text{for } x > 12$$

where:

- D_{cong} is average congestion delay in hours per 1,000 vehicle miles
- x is the AADT/C ratio for the segment

[1]The simplified simulation model was calibrated with the FRESIM and NETSIM microscopic simulation models as part of the *HPMS Speed Determination Models* project. A full description of the procedure is given in Appendix K of that project's Final Report.

Urban Signalized Arterials

$$D_{cong} = (1 - e^{-n/24.4}) (68.7 + 17.7 x)$$

for $x <= 7$ and $n < 16$

$$D_{cong} = (1 - e^{-n/24.4}) (192.6 + 14.4 (x - 7) - 1.16 (x-7)^2) + 0.160 (x-7)^2$$

for $7 < x <= 18$ and $n < 16$

where

D_{cong} is average congestion delay in hours per 1,000 vehicle miles

x is AADT/C

n is the number of traffic signals per mile

Urban Arterials with Unsignalized Intersections

$$D_{cong} = n (1.90 + 0.067 s_{ff} + 0.103 x + 0.0145 x^2)$$

for $x <= 6$ and $n < 10$

$$D_{cong} = n (3.04 + 0.067 s_{ff} - 0.029 (x-6)^2) + 0.354 (x-6)^2$$

for $6 < x < 15$ and $n < 10$

where

- D_{cong} is average delay in hours per 1,000 vehicle miles
- x is AADT/C
- n is the number of stop signs per mile
- s_{ff} is free-flow speed in miles per hour

The structure of these new relationships are essentially the same as before, but the coefficients have changed. The net effect of these changes is to reduce the estimate of congestion delay over what the previous speed determination models predicted (Figure 4-17). The reduction is due to the incorporation of peak spreading into the temporal distributions that serve as inputs to the simulation model.

A test was run to check the new speed models against actual speed data from Orlando. For each day of data at each station, the harmonic average daily speeds were calculated along with ADT (24 hour volume). ADT/C was then used as a surrogate for AADT/C and the speed models were applied using this number. For each day, the observed and predicted speeds were calculated and the percent error noted. The results are as follows (Table 4-11).

Table 4-11. Distribution of Error Rates for Test of HPMS Speed Models vs. Orlando Data

No. of	((Predicted - Observed)/Observed) * 100							
Station-Days	Mean	Std	P10	P25	P50	P75	P90	P95
647	1.1	10.4	-10.9	-6.3	0.6	6.5	14.1	20.1

The average and median errors are very small (1.1 and 0.6 percent, respectively), but the data show very large variations. Given the wide variation in day-to-day traffic patterns, this is to be expected. The fact that the speed models on average produce a small error is encouraging for HPMS purposes.

Application of the simplified simulation model on an hourly basis yields the first predicted congested hour (V/C greater than 1.0) at an AADT/C of approximately 11.[1] This is much higher than the regression equation reported in Section 3.2 (AADT/C = 8.8). However, that equation as based on estimating the peak V/C from K- and D-factors which are based on the 30th highest hour concept. Also, as AADT/C increased, the scatter in the data became greater (i.e., the coefficients of the equation are based primarily on the large number of observations at the low end of the AADT/C and V/C ranges.) By comparison, the temporal distributions are based on the **average** hourly volumes. While the 30th highest hour may be appropriate for design purposes, for estimating congestion on an annual basis it will probably overstate congestion. Still, the implications for HPMS of using the new speed relationships are notable. As shown in Table 4-12, the congestion threshold has a substantial impact on estimating on HPMS sections. For urban Interstates, if the cutoff is AADT/C = 11, then about 10 percent of the sections would be predicted to experience congestion. If the cutoff is lowered to 9, then the number of sections doubles to 20 percent.

4.6 Changes in Temporal Distribution Patterns Over Time

A comparison of daily traffic volume distributions for Seattle, WA and Boston, MA highlights the relationship between population growth and traffic congestion. Data collection in 1972 along with data collected for this study serve as the basis for this comparison.[2] Figure 4-18 portrays the 1972 hourly distribution of freeway traffic in Boston, MA for a freeway segment located in the Central City serving traffic demand in a radial direction from the Central Business District. Three AADT/C groups are shown in this figure based on the 1991-92 ATR data collected for this study: less than 7.0, 7.1 to 11.0, and greater than 11.0. Generally speaking, the higher the value of AADT/C, the more congestion a roadway is experiencing .

The 1972 hourly distribution of traffic for Boston, MA has the general shape of the three hourly distributions developed from the 1991-92 data. The distributions are characterized by two peak periods

[1]The simulation model includes a feature for randomly selecting volumes so that AADT/C levels less than 11 have a chance of experiencing congestion and some levels greater than 11 might not on a particular day. This feature was added as a "smoothing agent" so that the resulting curves would not be a step function and they would account for variations in daily traffic.

[2] Peat, Marwick, Mitchell & Co., An Analysis of Urban Area Travel by Time of Day. Federal Highway Administration: Washington, D.C., January 1972.

Table 4-12. AADT/C Distributions in the 1992 HPMS Data (Number of Segments)

Functional Class	AADT/C							
Frequency Row Pct Col Pct	LE 3.0	3.01-- 5.00	5.01-- 7.00	7.01-- 9.00	9.01-- 11.00	11.01-- 13.00	GT 13.00	Total
URBAN INTERSTATE	1333 16.72 3.61	2000 25.08 12.73	1861 23.34 19.25	1176 14.75 21.56	779 9.77 24.98	459 5.76 28.60	365 4.58 28.19	7973
URBAN FREEWAY	1498 30.45 4.06	1227 24.94 7.81	874 17.76 9.04	607 12.34 11.13	349 7.09 11.19	214 4.35 13.33	151 3.07 11.66	4920
URBAN PRINCIPAL ARTERIAL	7881 37.12 21.36	5742 27.05 36.54	3557 16.75 36.80	2043 9.62 37.45	1089 5.13 34.93	517 2.44 32.21	402 1.89 31.04	21231
URBAN MINOR ARTERIAL	11314 54.63 30.66	4484 21.65 28.53	2447 11.81 25.31	1180 5.70 21.63	695 3.36 22.29	310 1.50 19.31	282 1.36 21.78	20712
URBAN COLLECTOR	14870 78.61 40.30	2262 11.96 14.39	928 4.91 9.60	449 2.37 8.23	206 1.09 6.61	105 0.56 6.54	95 0.50 7.34	18915
Total	36896	15715	9667	5455	3118	1605	1295	73751

one during the afternoon commute and one during the morning commute. The afternoon peak is slightly higher than the morning peak and a mid-day downturn of traffic is observed between the two peak periods. Peak-spreading is occurring during the afternoon period for all three distributions which suggests the presence of congestion.

Figure 4-19 shows the 1972 hourly distribution for a similar freeway segment in Seattle, WA along with the three AADT/C distributions developed from the 1991-92 data. The 1972 hourly distribution for Seattle, WA is much different than the AADT/C distributions. The 1972 distribution contains two very sharp peaks during the morning and afternoon peak commute periods and a very pronounced drop of traffic during the mid-day period. The absence of peak-spreading for the 1972 distribution suggests that the freeway segment was probably not experiencing long periods of congestion throughout the day.

The differences in the Seattle, WA and Boston, MA distributions when compared against the hourly travel distributions for this study may be explained by the magnitude of population and congestion in each city twenty years ago. In 1972, the Boston, MA roadway system may have already been experiencing significant congestion which led to peak-spreading. The 1991-92 urban freeway data suggest that peak-spreading is now occurring on may urban freeways throughout the nation. Therefore, the travel patterns observed in Boston, MA in 1972 may be thought of as an indicator of future travel patterns in the nation as congestion becomes more widespread as a result of increased population and job growth.

In 1972, the Seattle, WA metropolitan area was much different than today. Significant population and job growth has occurred over the past 20 years. In 1972, Seattle, WA was not as congested therefore, peak-spreading was not occurring to the magnitude it was observed in Boston, MA. Figure 4-20 supports this conclusion. This figure contains the hourly distribution for two freeway segments in Seattle, WA recorded in 1972. In addition, this figure contains a distribution based on the average of all count locations contained in the 1991 Seattle Freeway Surveillance data collected for this study. The peak spreading of traffic as a result of increased congestion over the last 20 years is very obvious in this figure.

Figure 4-1. Comparison of Functional Classes: Hourly Distribution of Travel Weekday - AM Direction

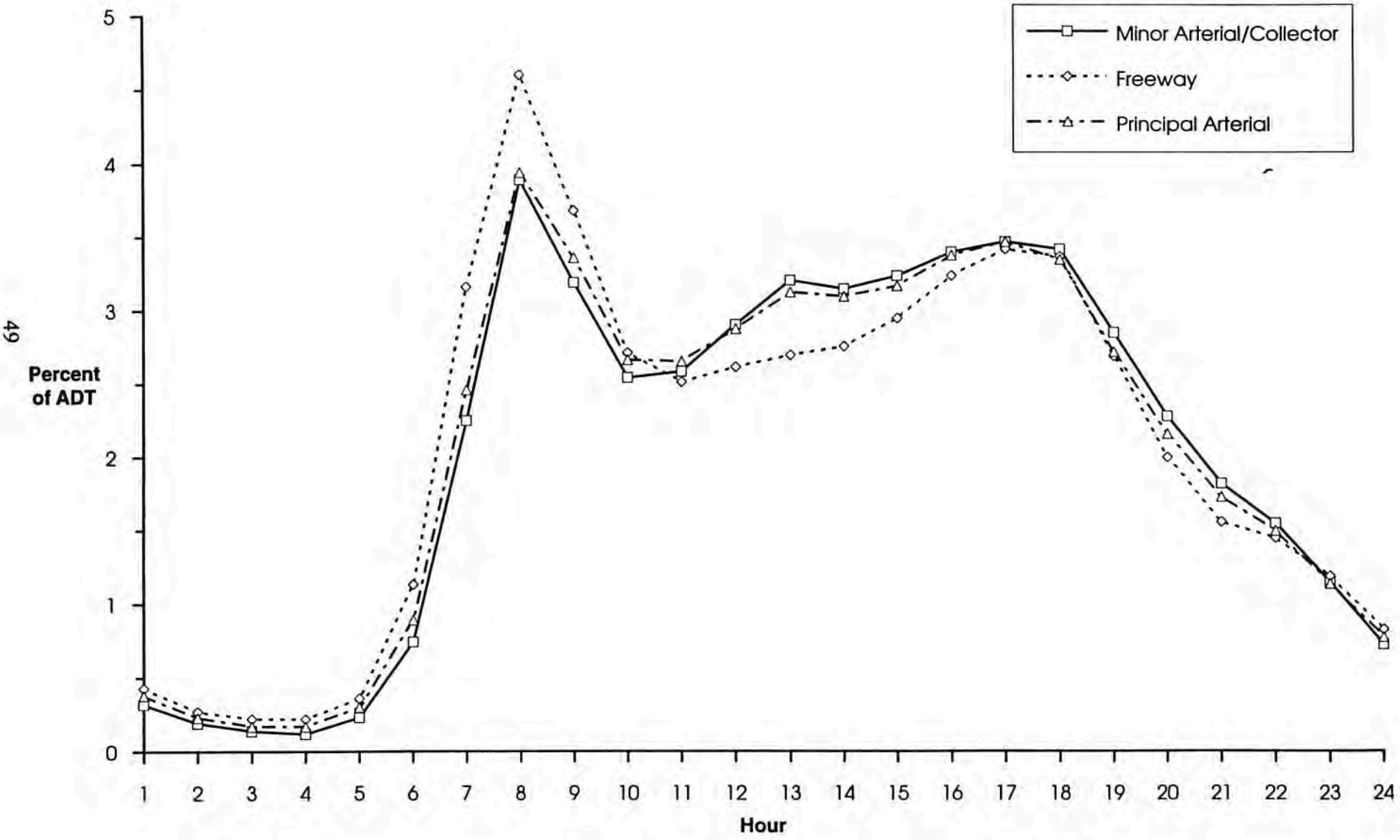


Figure 4-1 (continued). Comparison of Functional Classes: Hourly Distribution of Travel Weekday - PM Direction

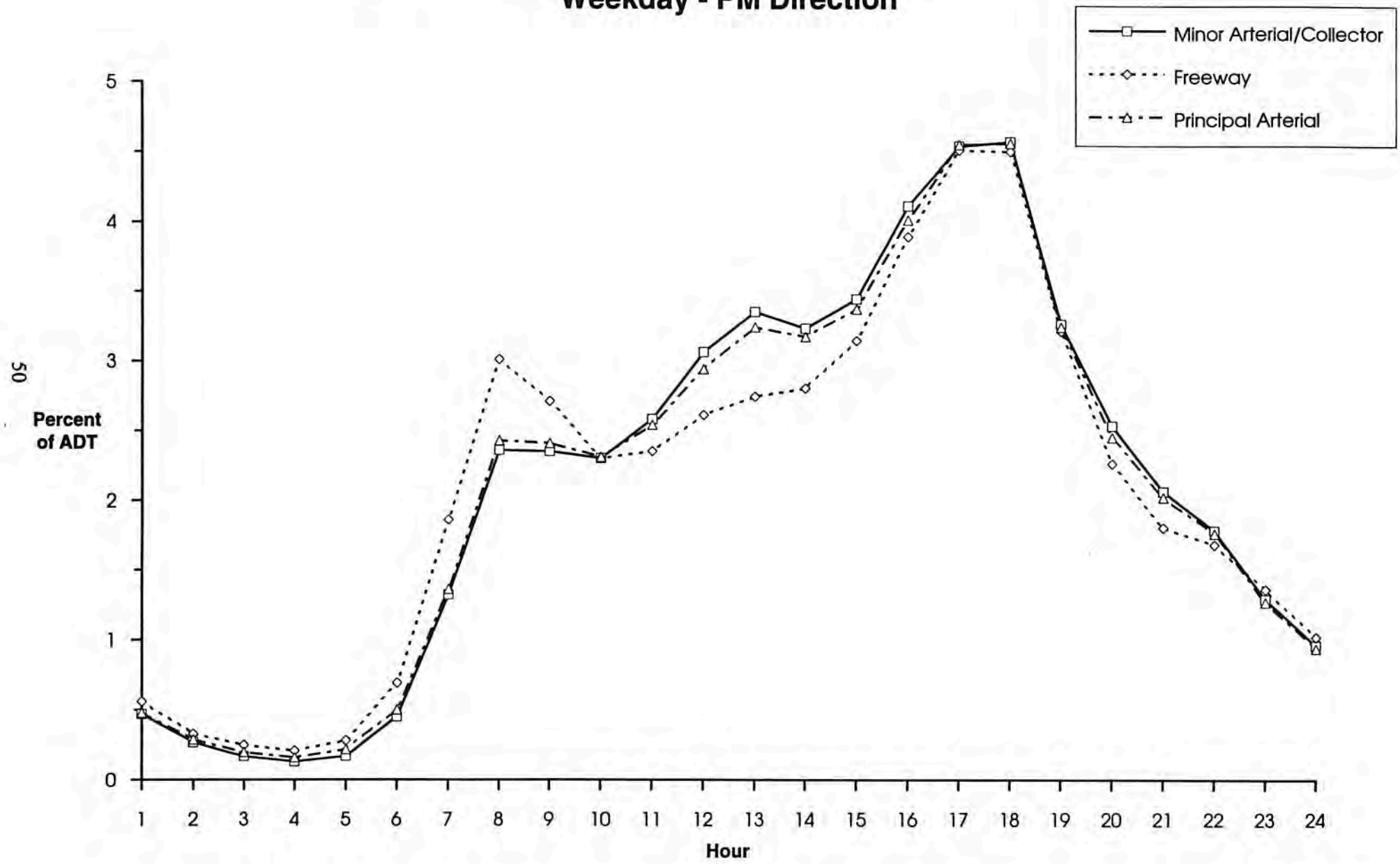


Figure 4-2. Comparison of Highway Types: Hourly Distribution of Travel Weekday - AM Direction

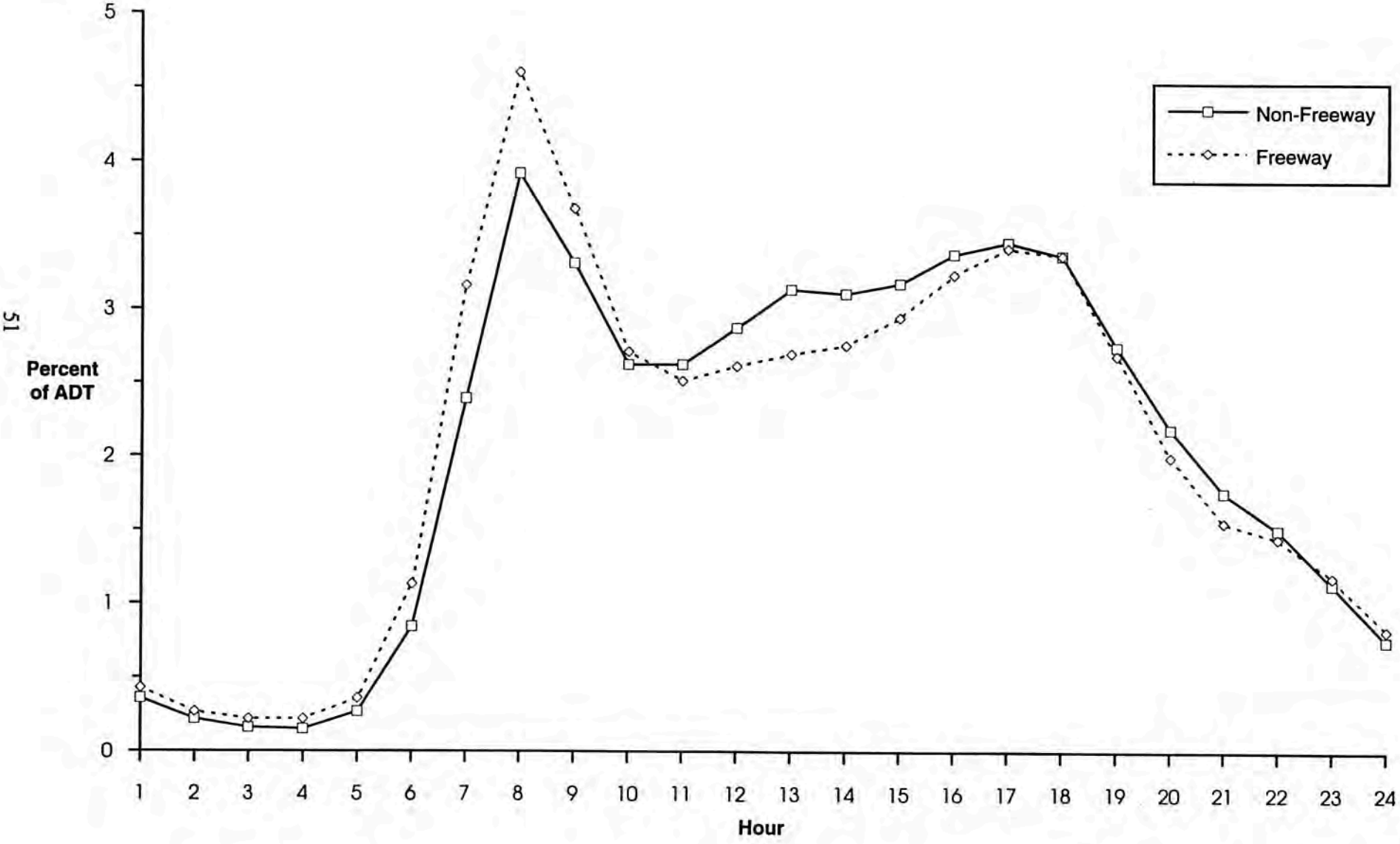


**Figure 4-2 (continued). Comparison of Highway Types:
Hourly Distribution of Travel
Weekday - PM Direction**

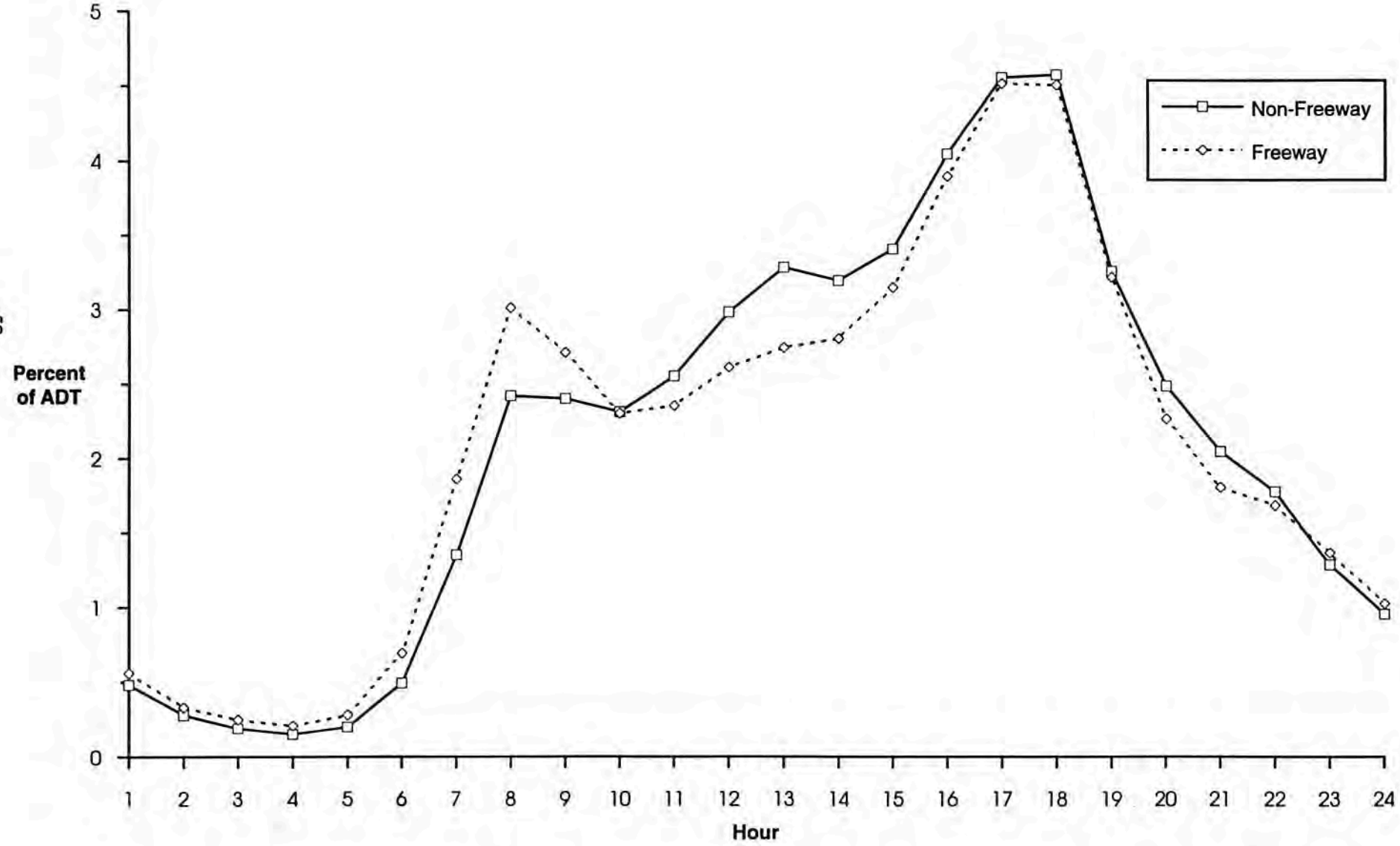


Figure 4-3. Comparison of ATR K*D: Hourly Distribution of Travel Weekday - AM Direction

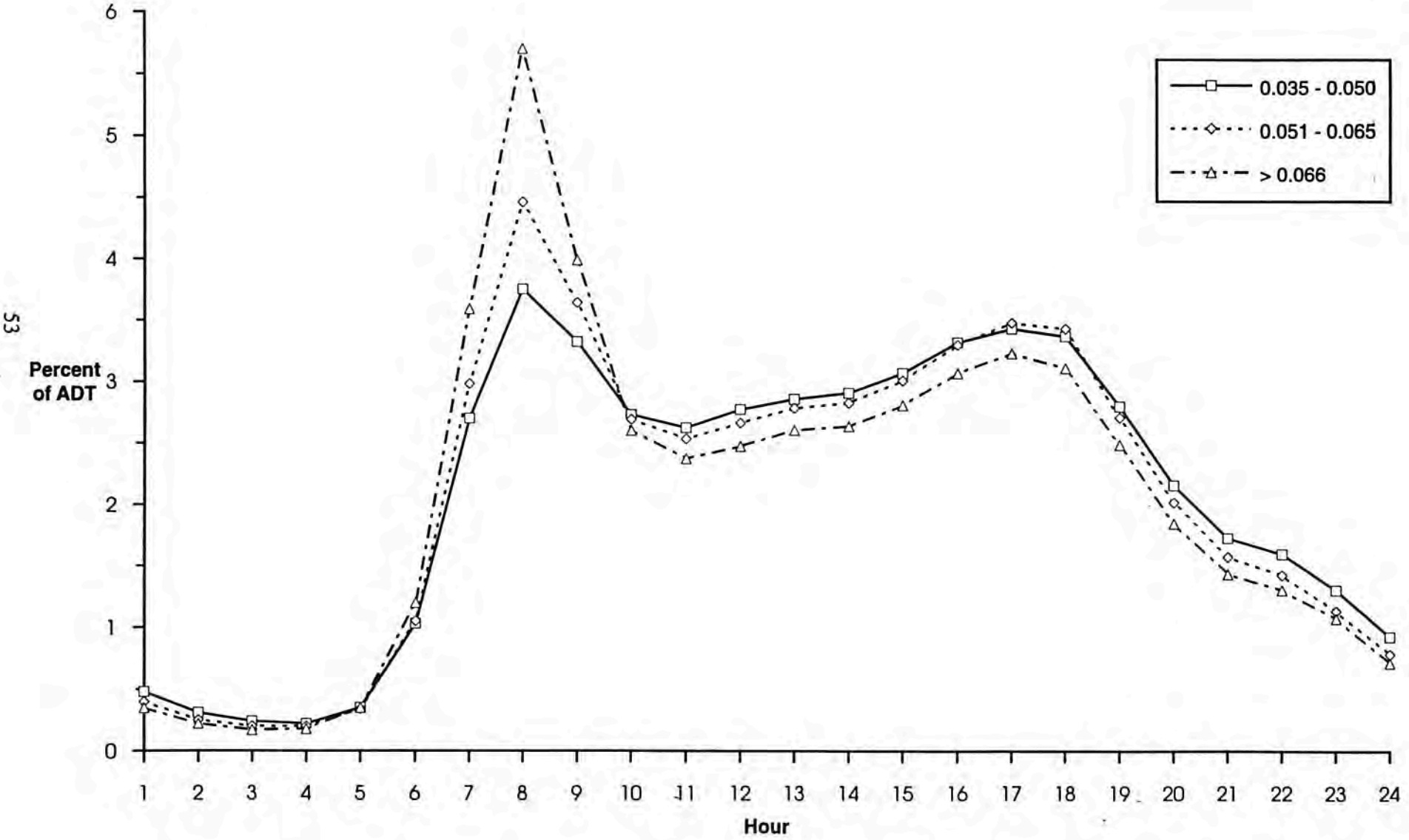


Figure 4-3 (continued). Comparison of ATR K*D:
Hourly Distribution of Travel
Weekday - PM Direction

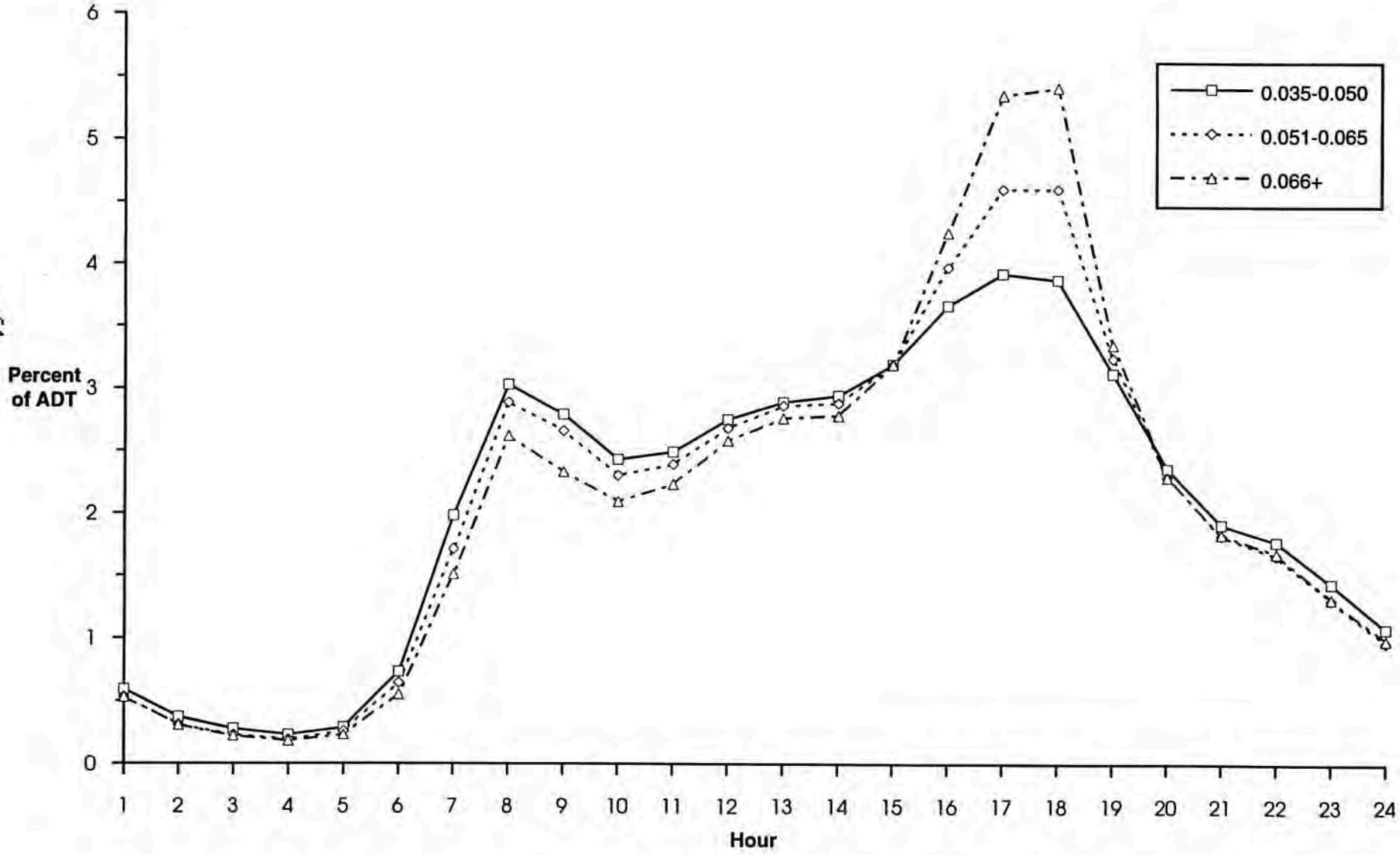


Figure 4-4. Comparison of Urban Locations: Hourly Distribution of Travel Weekday - AM Direction

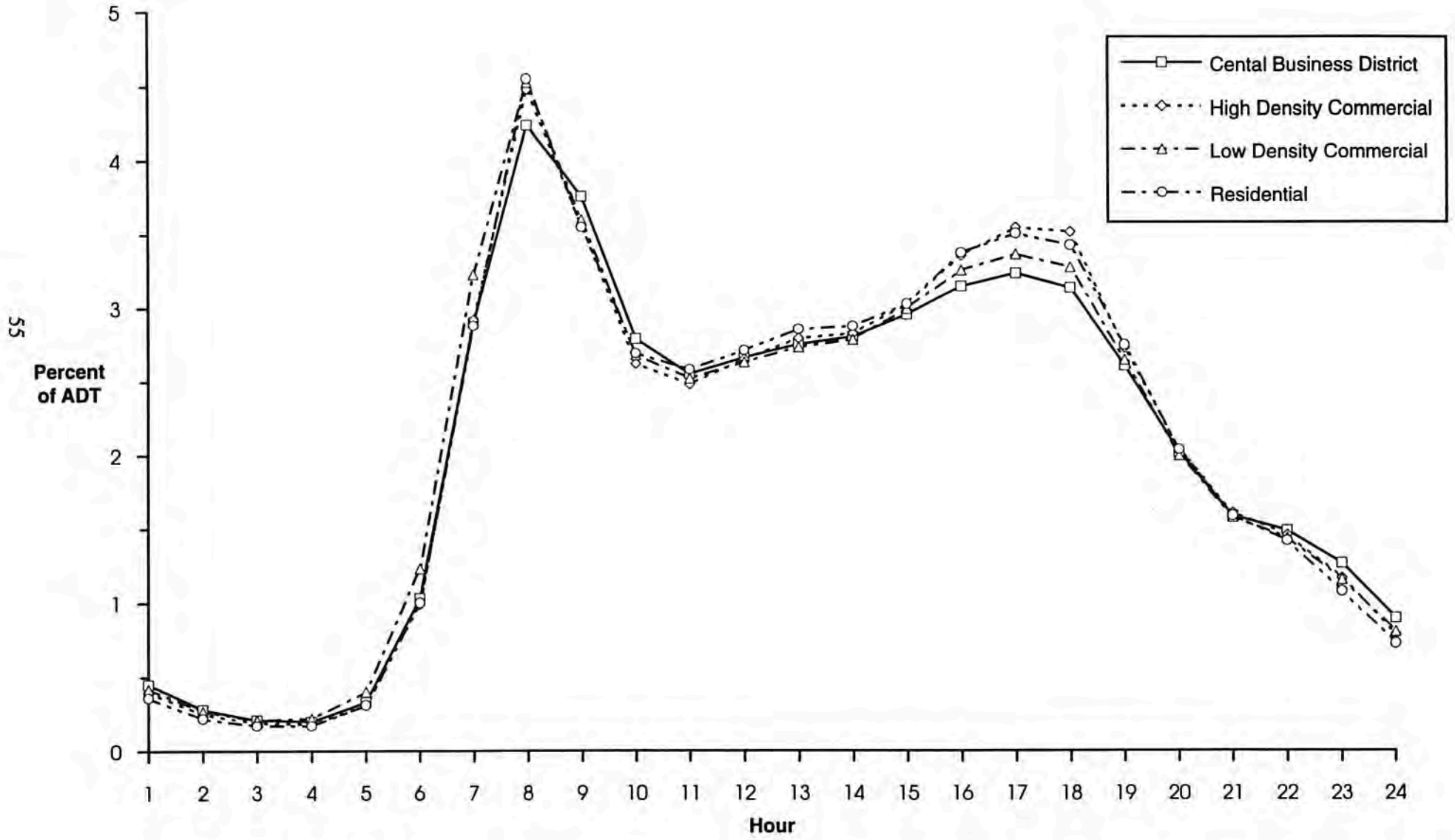


Figure 4-4 (continued). Comparison of Urban Locations:
Hourly Distribution of Travel
Weekday - PM Direction

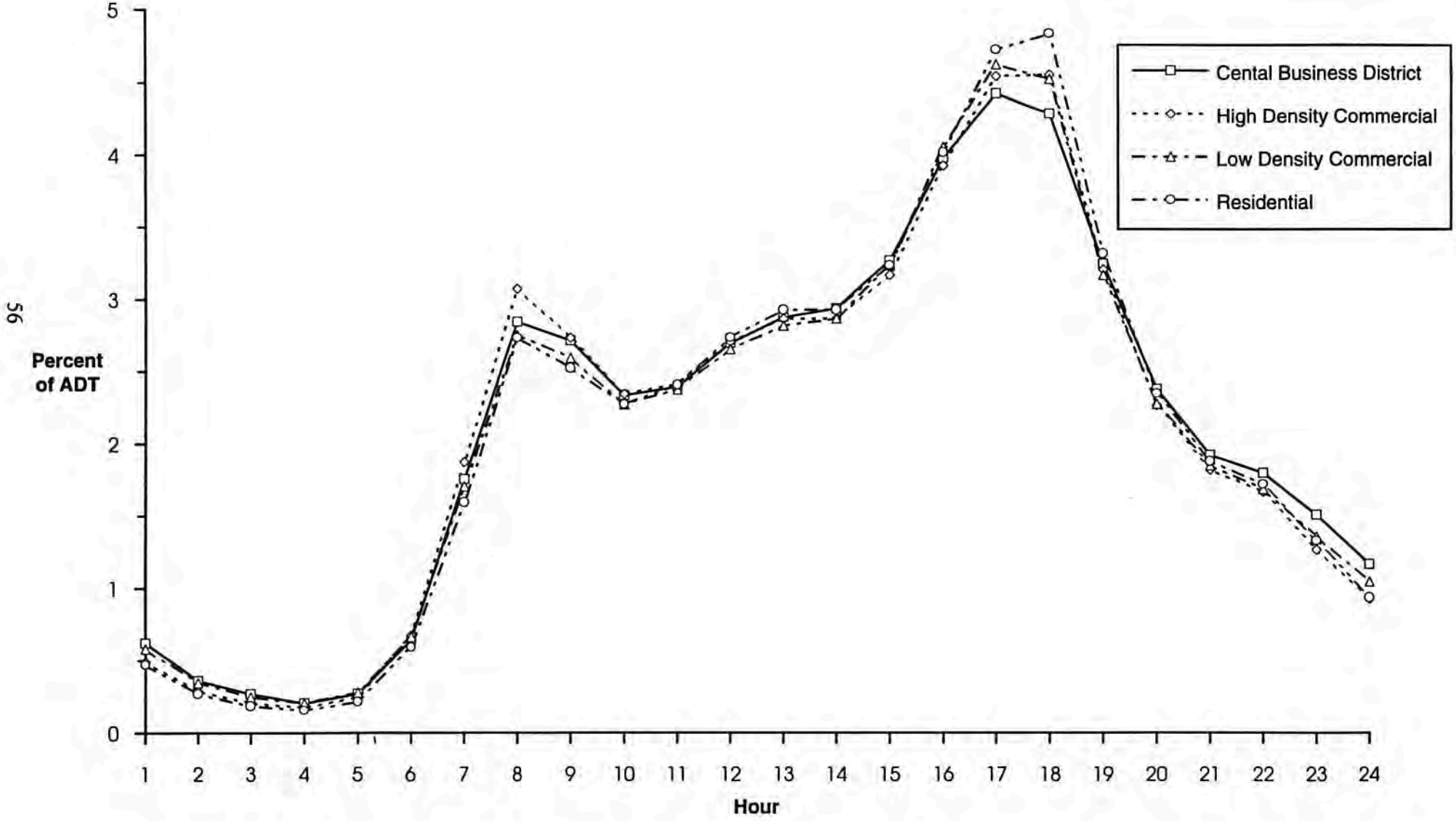


Figure 4-5. Comparison of Number of Lanes: Hourly Distribution of Travel Weekday - AM Direction

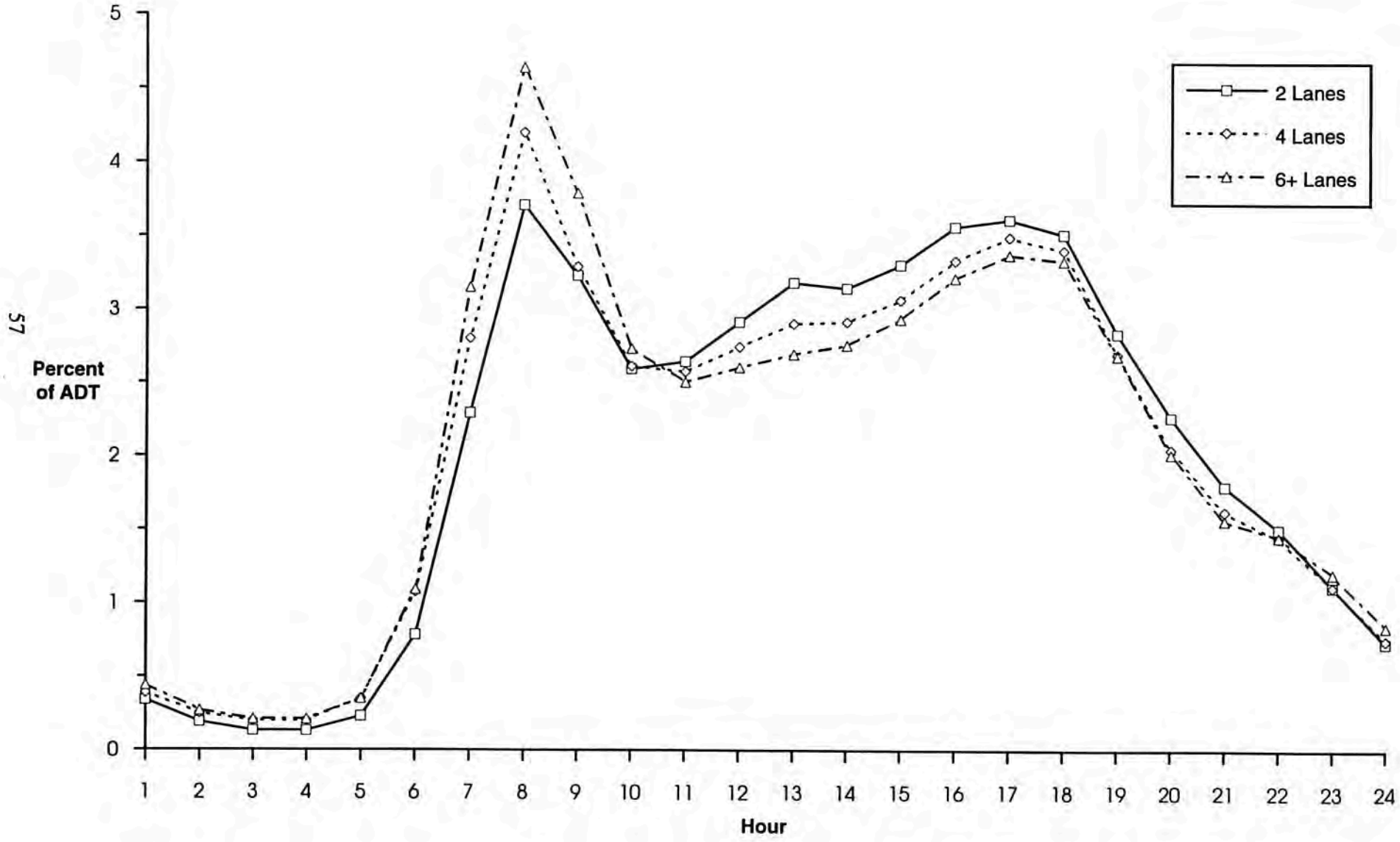


**Figure 4-5 (continued). Comparison of Number of Lanes:
Hourly Distribution of Travel
Weekday - PM Direction**

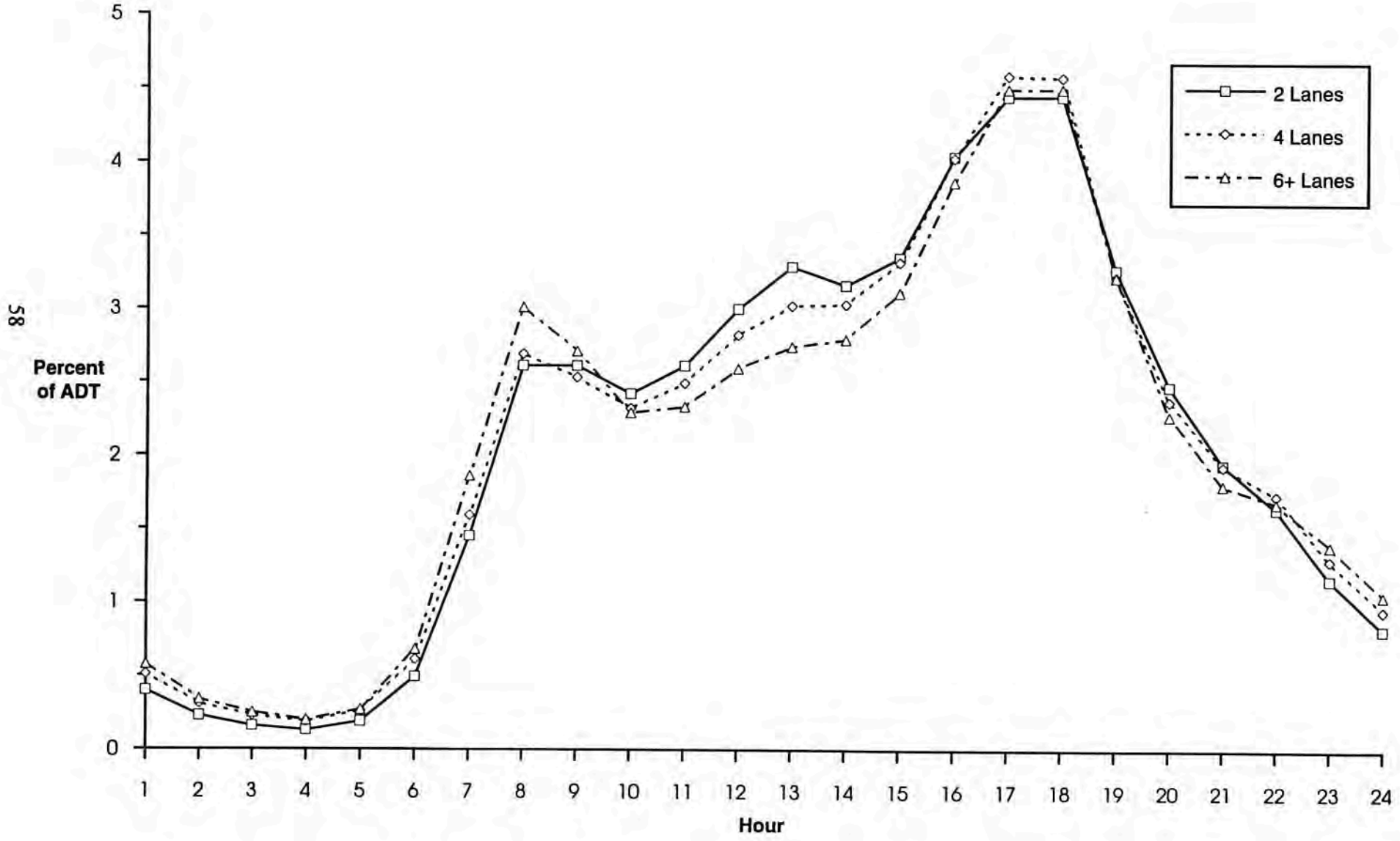


**Figure 4-6. Comparison of AADT/C:
Hourly Distribution of Travel
Weekday - AM Direction**

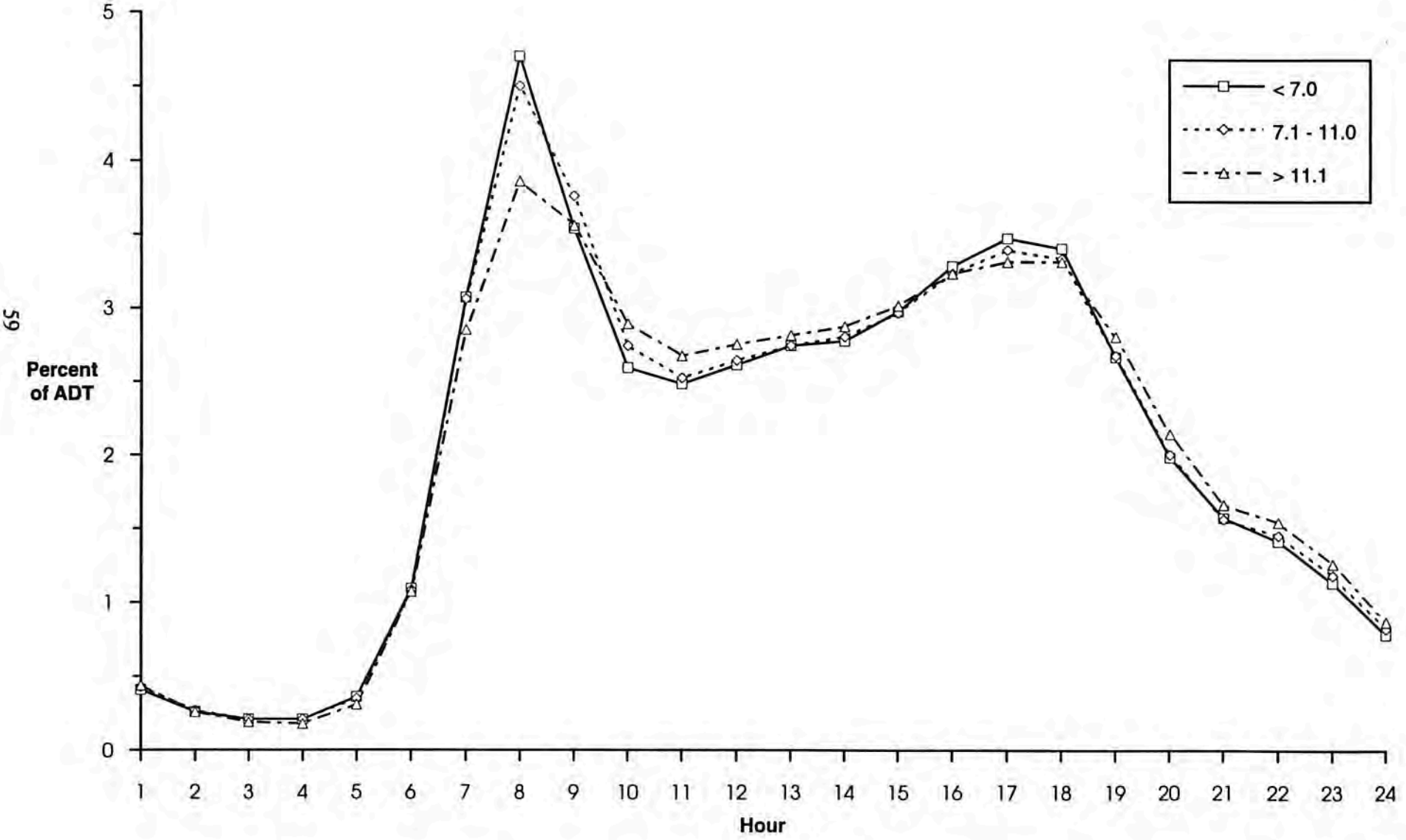


Figure 4-6 (continued). Comparison of AADT/C: Hourly Distribution of Travel Weekday - PM Direction

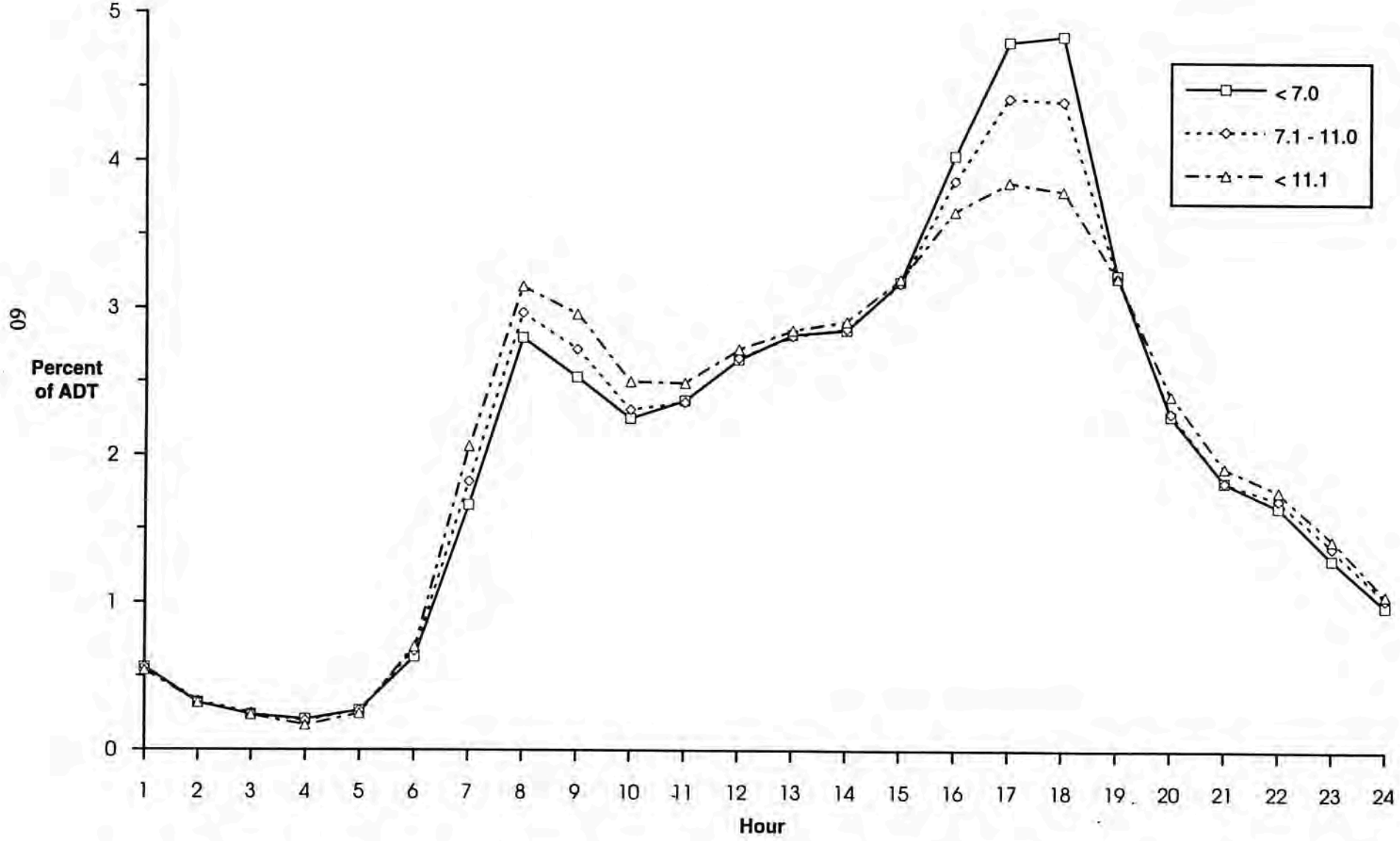


Figure 4-7. Comparison of Urban Location Hourly Distribution of Travel Weekday - AM Direction - Freeway

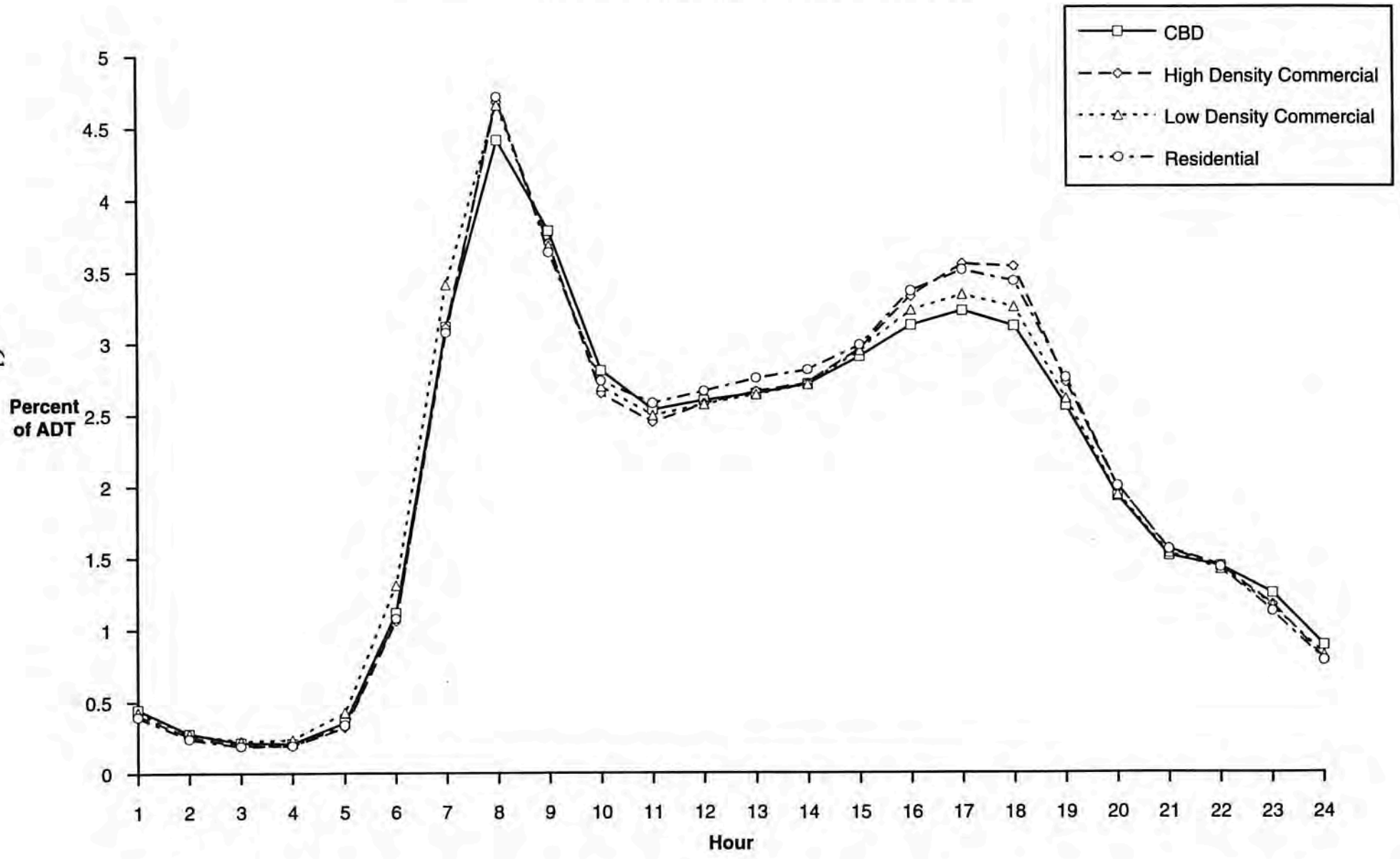


Figure 4-7 (continued). Comparison of Urban Location Hourly Distribution of Travel Weekday - PM Direction - Freeway

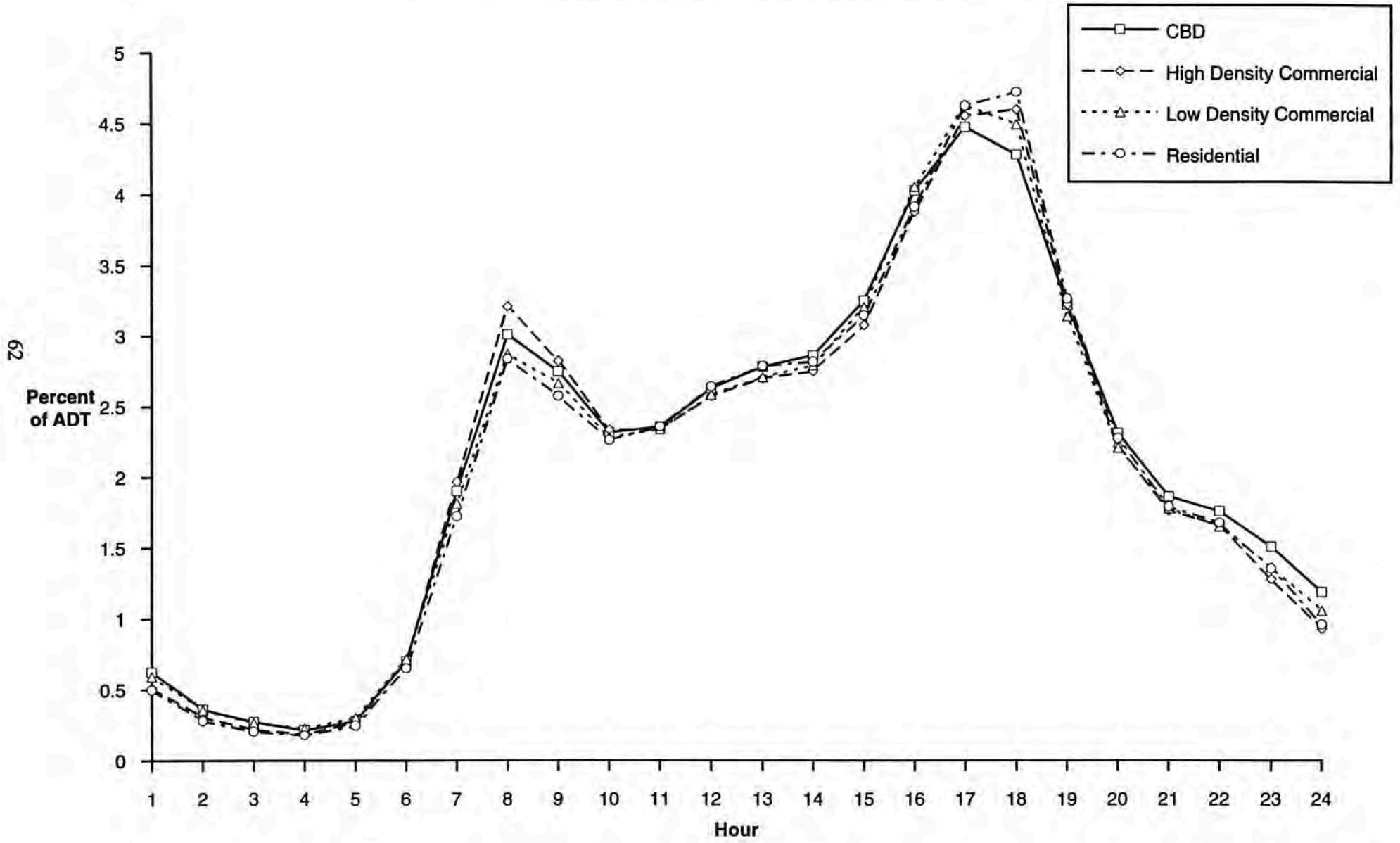


Figure 4-7 (continued). Comparison of Urban Location Hourly Distribution of Travel Weekday - AM Direction - Non-Freeway

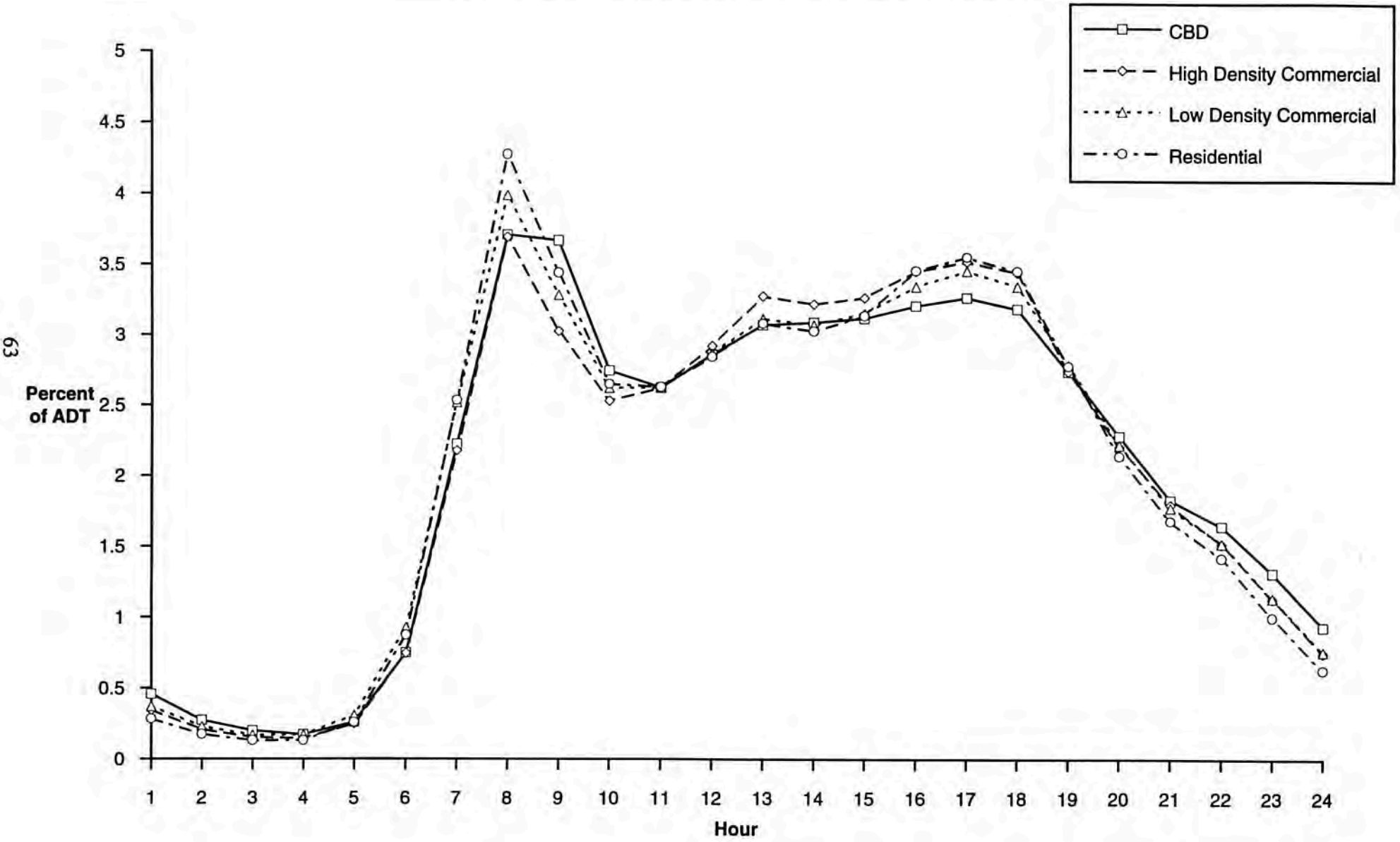


Figure 4-7 (continued). Comparison of Urban Location
Hourly Distribution of Travel
Weekday - PM Direction - Non-Freeway

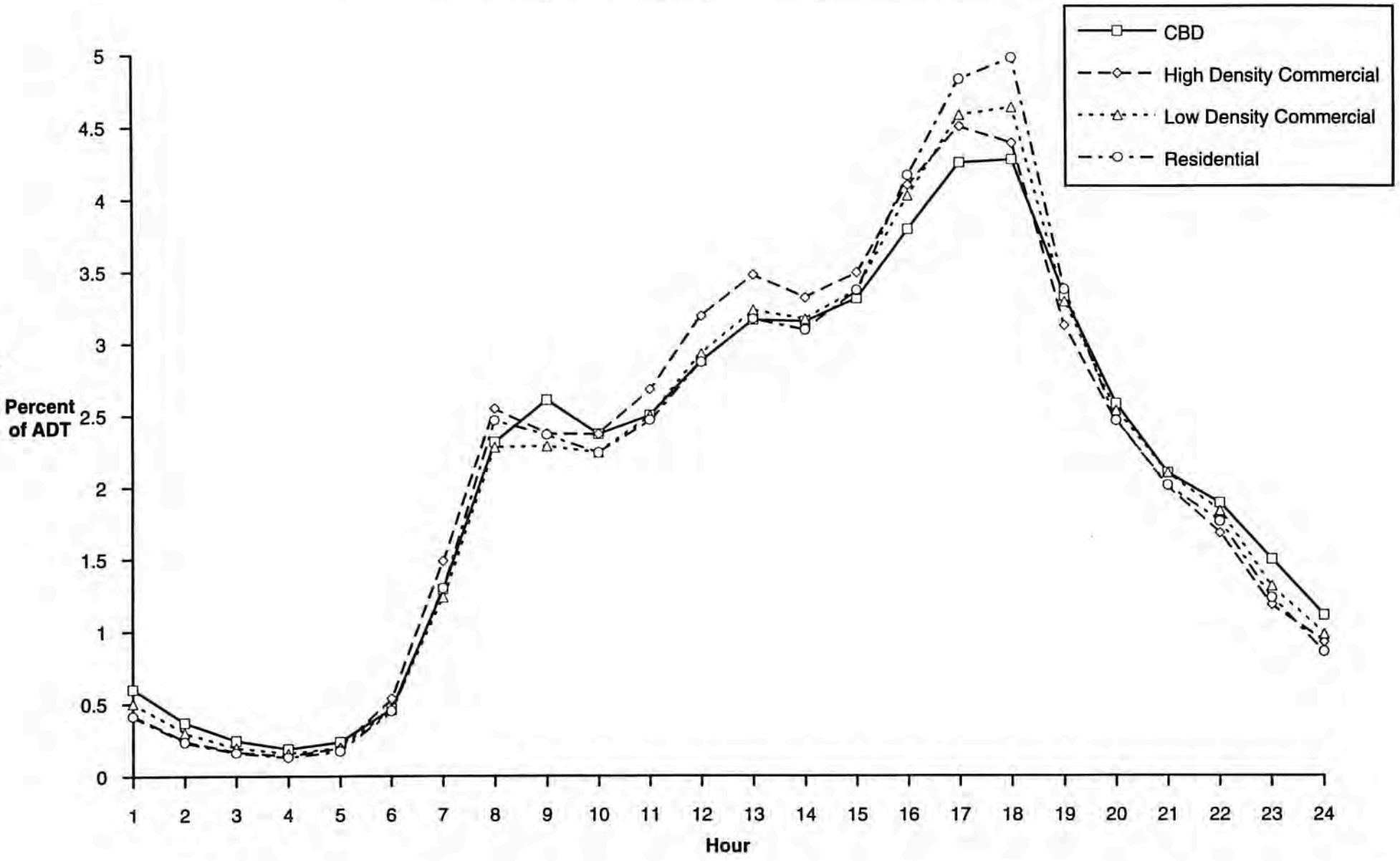


Figure 4-8. Comparison of Functional Classes: Hourly Distribution of Travel Weekends and Holidays

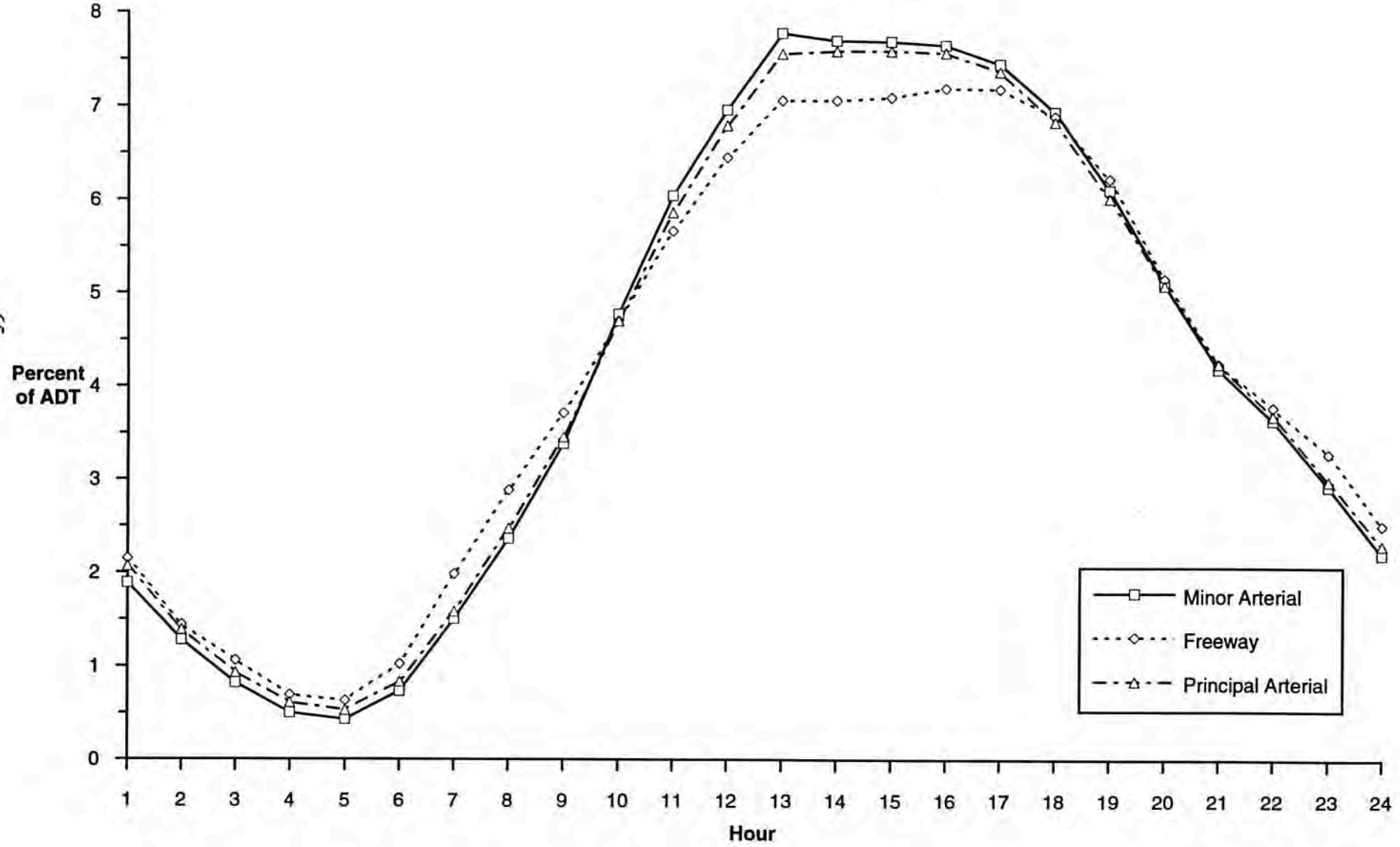


Figure 4-9. Comparison of Functional Classes: Hourly Distribution of Travel Weekends and Holidays

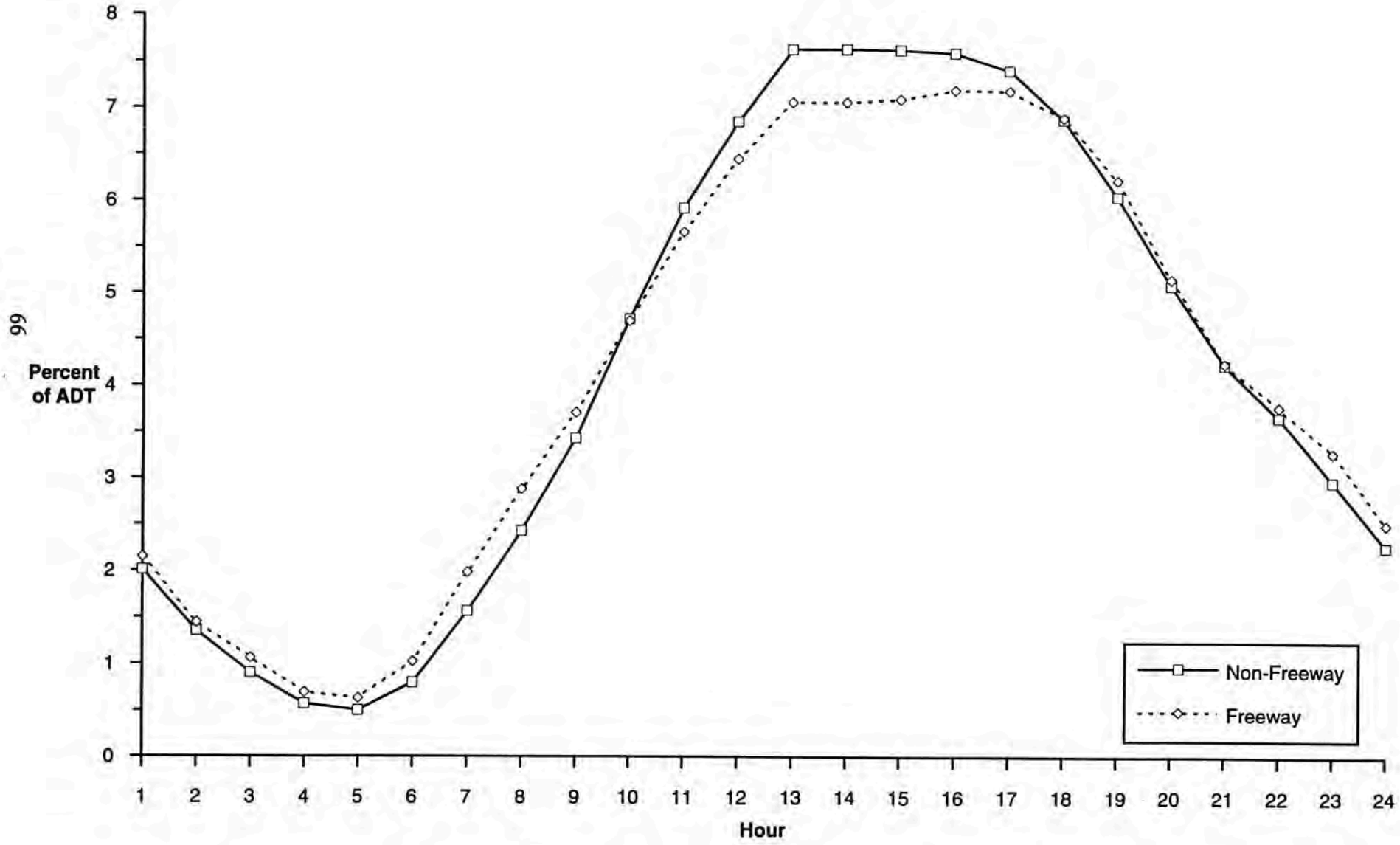


Figure 4-10. Comparison of Urban Locations: Hourly Distribution of Travel Weekends and Holidays

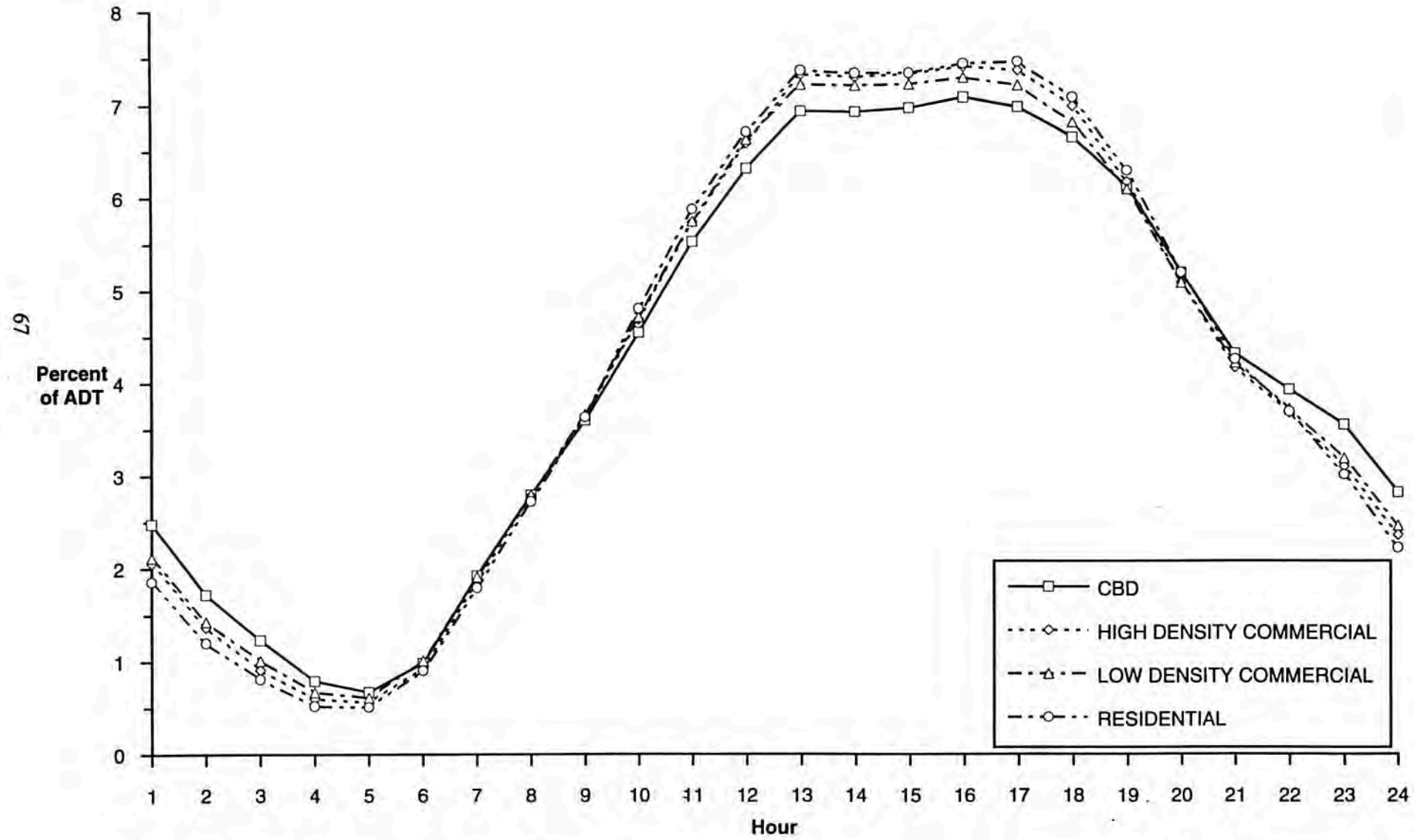


Figure 4-11. Comparison of Urban Location: Hourly Distribution of Travel Weekends and Holidays - Freeway

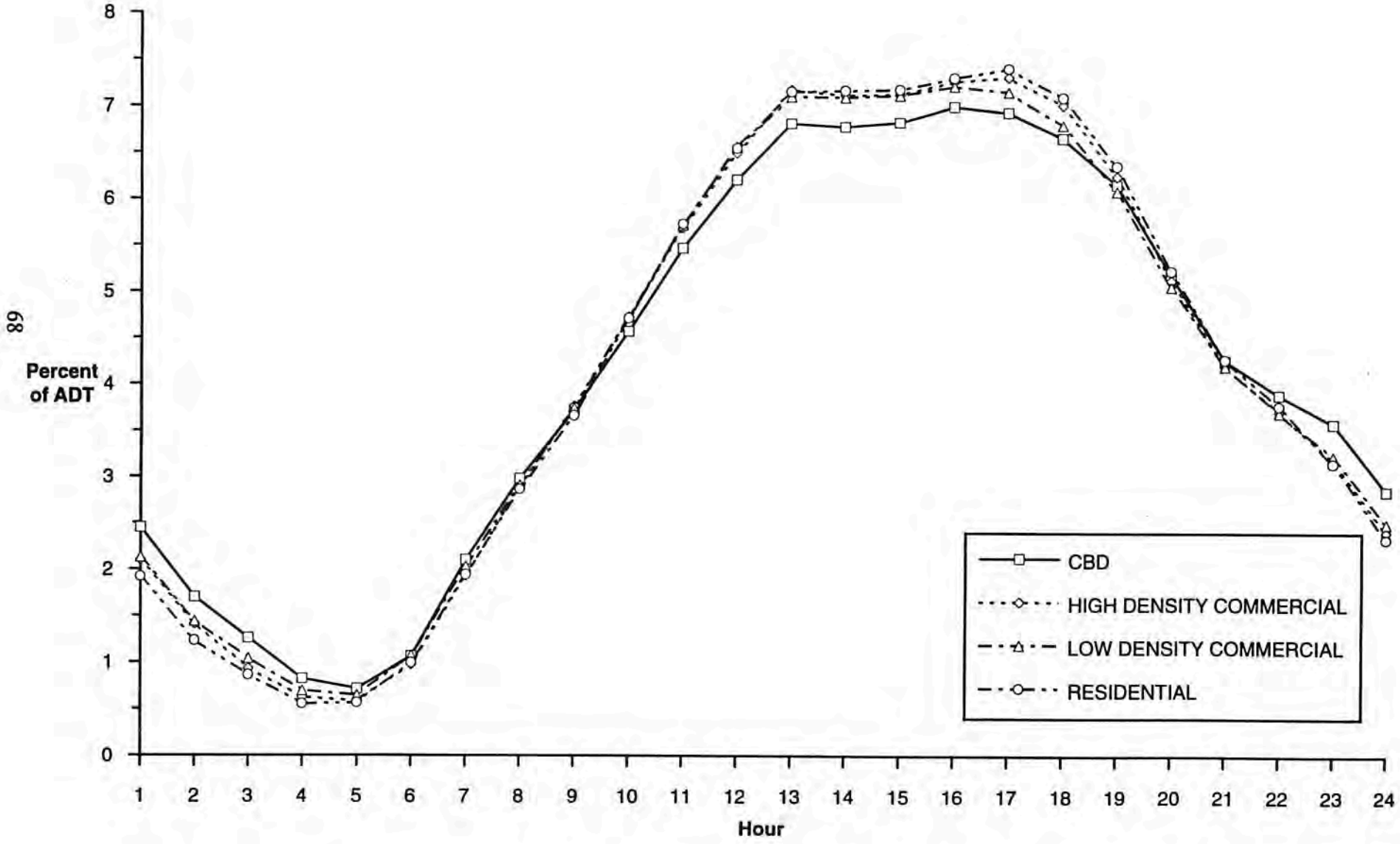


Figure 4-11 (continued). Comparison of Urban Location: Hourly Distribution of Travel Weekends and Holidays - Non-Freeway

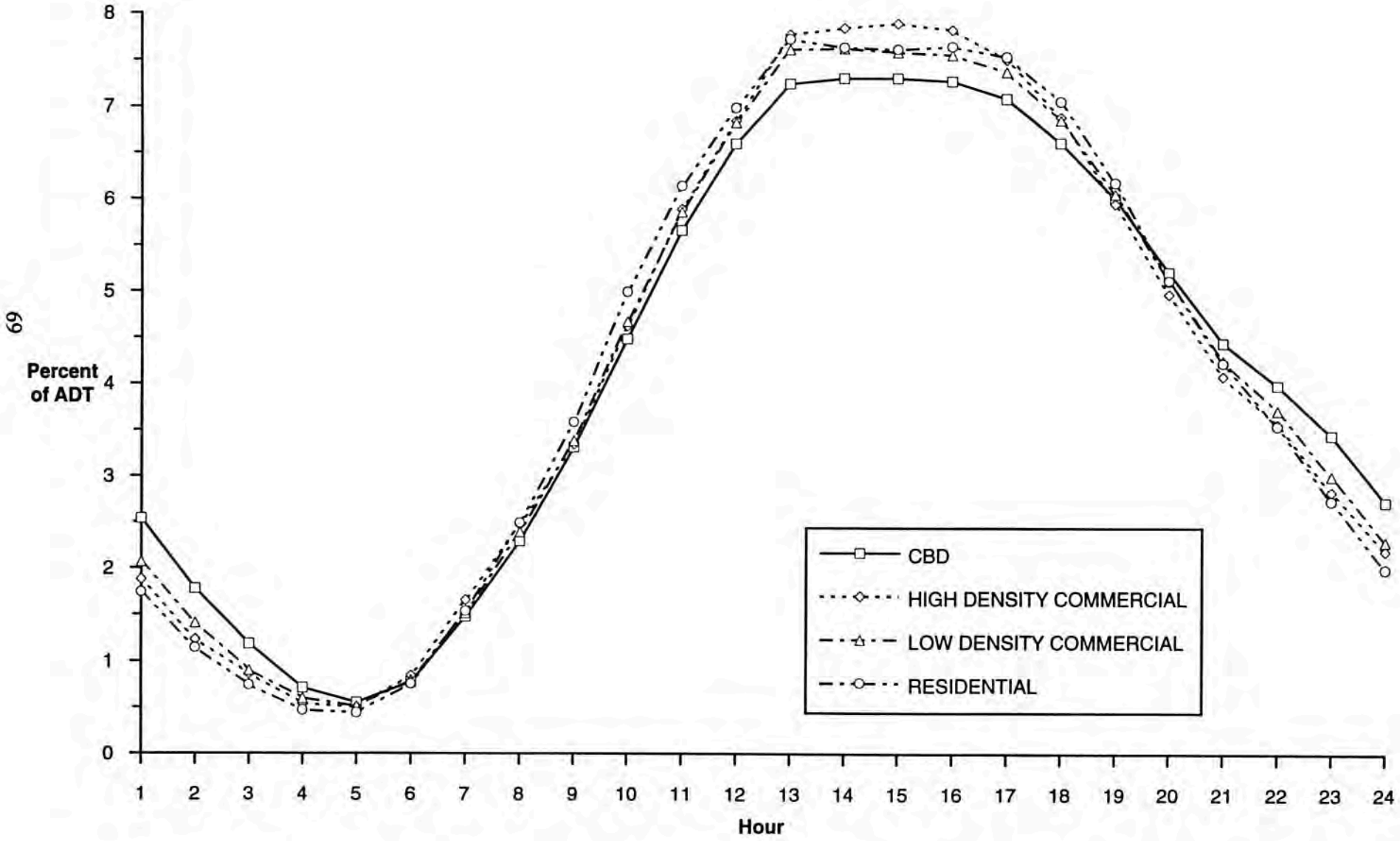


Figure 4-12. Effect of AADT/C on Peak Spreading

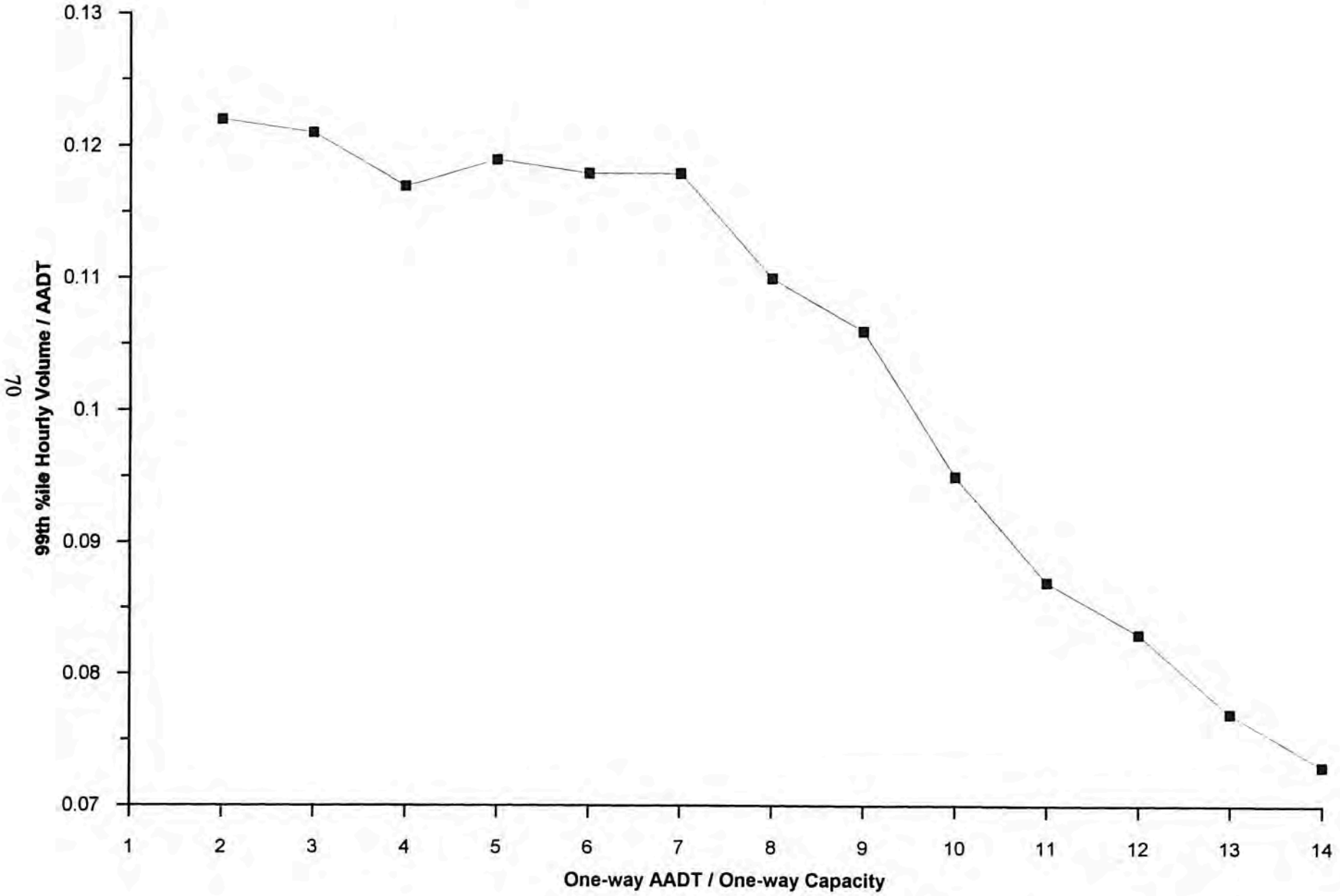


Figure 4-13. Seattle and Orlando Compared to High AADT/C ATR Sites
Hourly Distribution of Travel
AM Direction

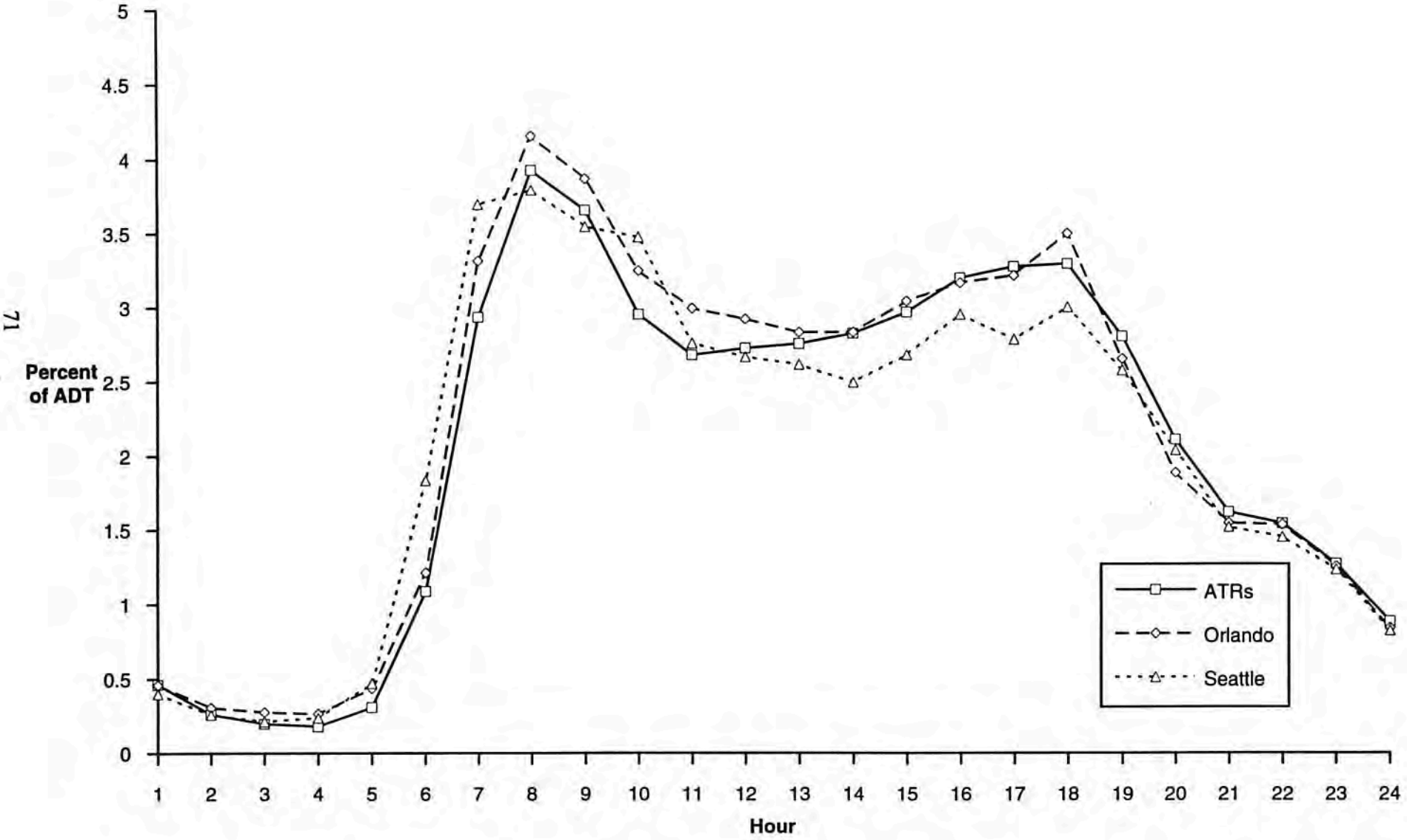


Figure 4-13 (continued). Seattle and Orlando Compared to High AADT/C ATR Sites Hourly Distribution of Travel PM Direction

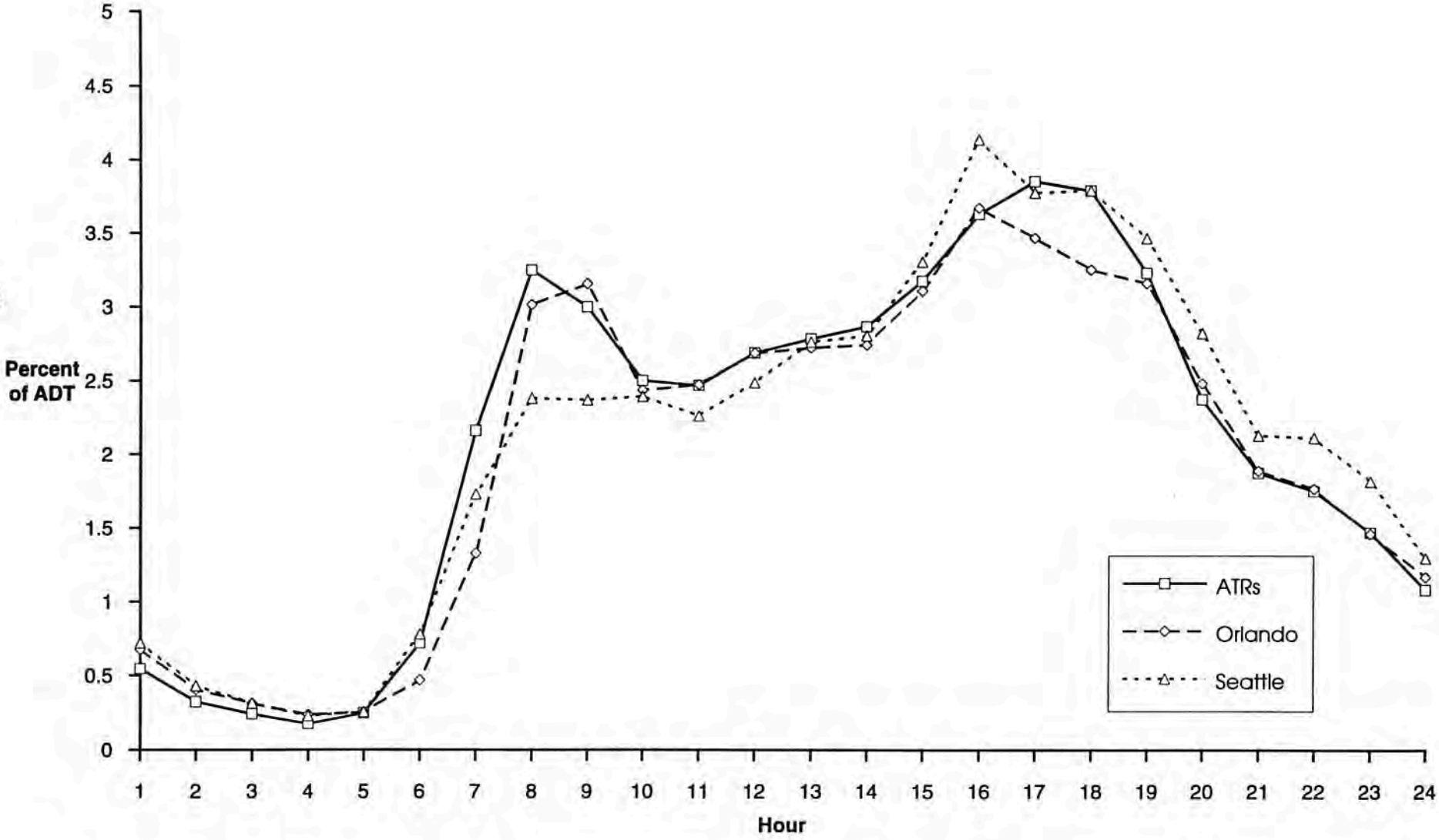


Figure 4-14. Final Weekday Hourly Distribution of Travel Freeway AM Direction

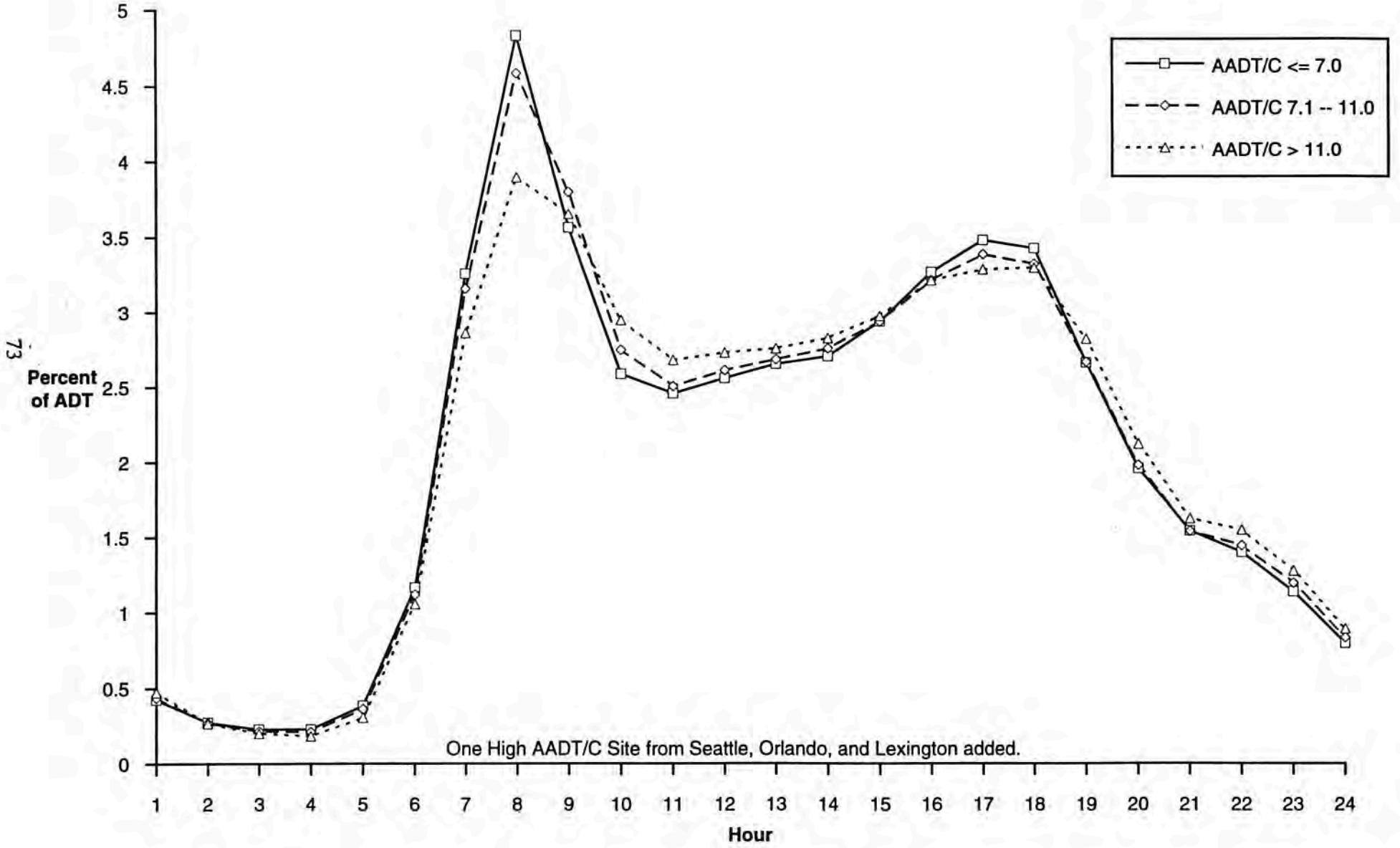


Figure 4-14 (continued). Final Weekday Hourly Distribution of Travel Freeway PM Direction

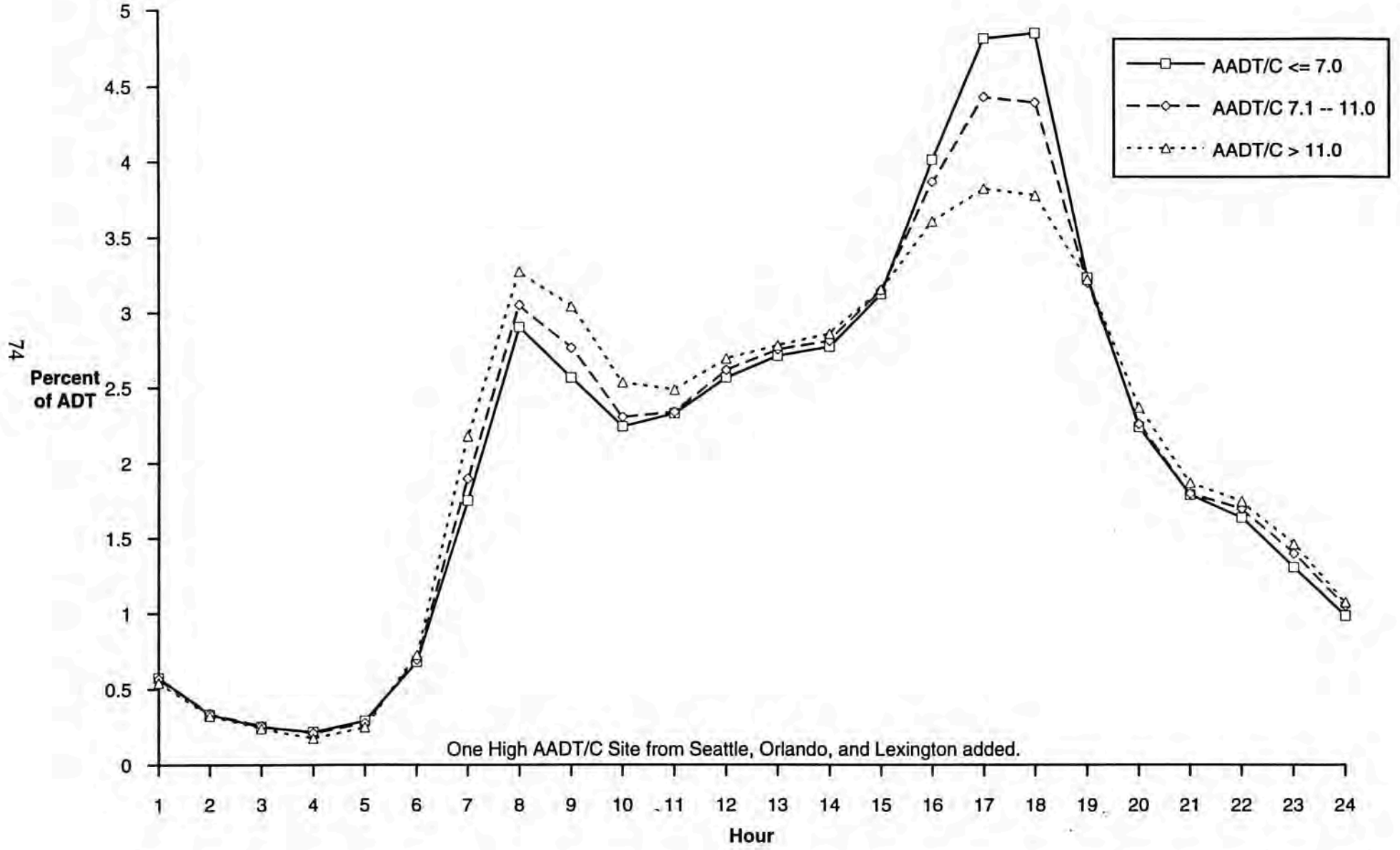


Figure 4-15. Final Weekday Hourly Distribution of Travel Non-Freeway AM Direction

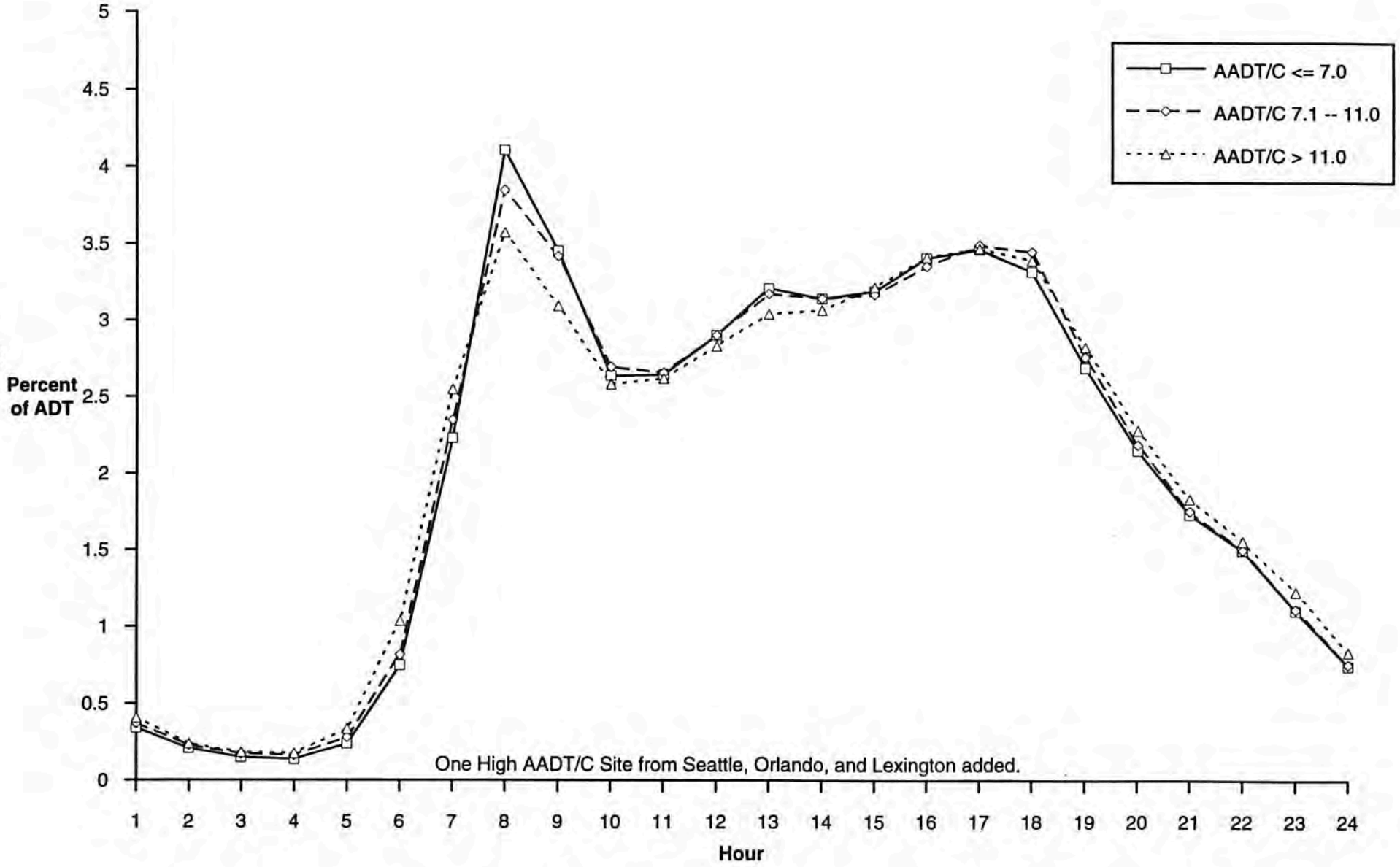


Figure 4-15 (continued). Final Weekday Hourly Distribution of Travel Non-Freeway PM Direction

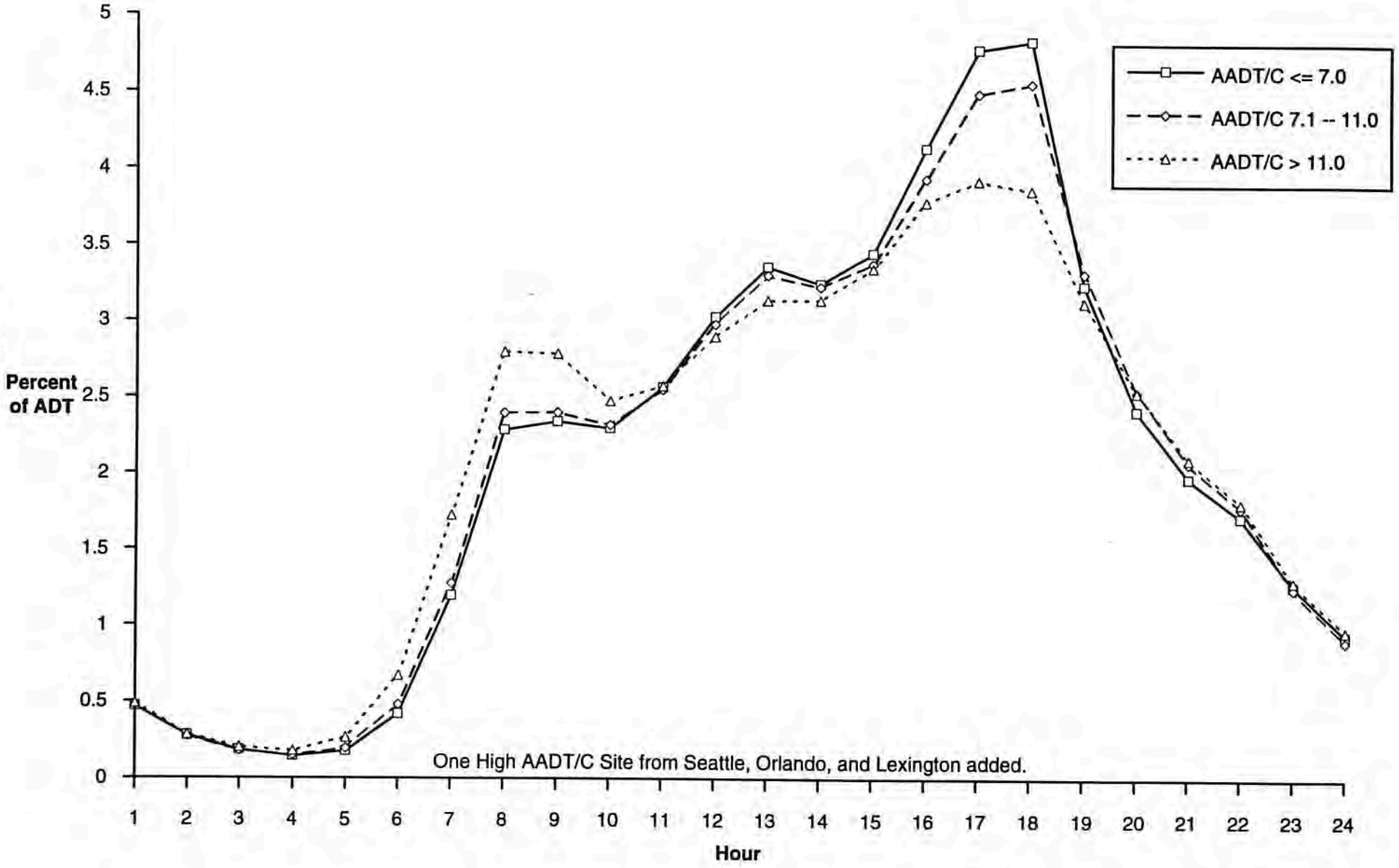


Figure 4-16. Final Weekend and Holiday Hourly Distribution of Travel

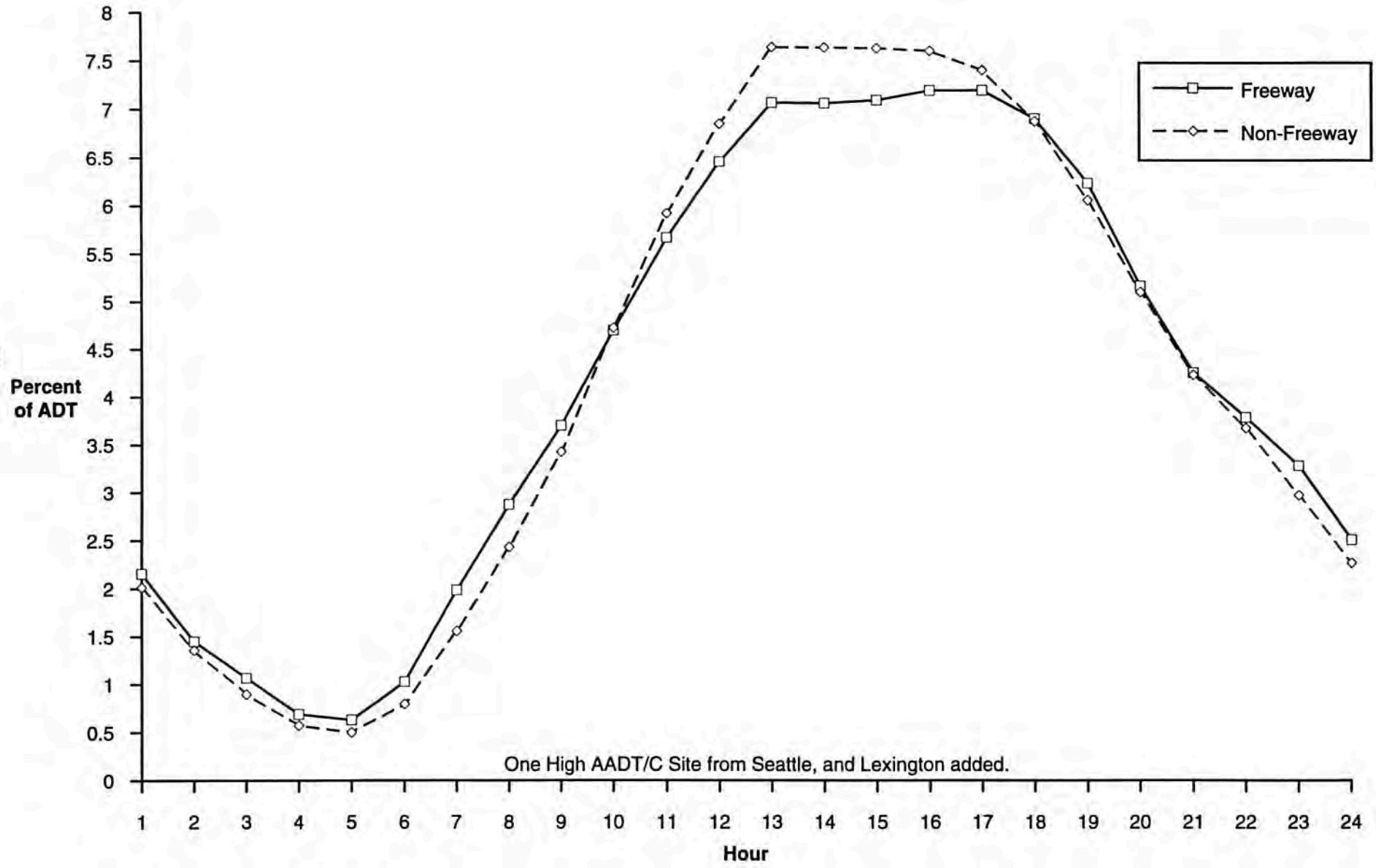


Figure 4-17. Delay Due to Congestion
HPMS Speed Determination Models (Freeways)

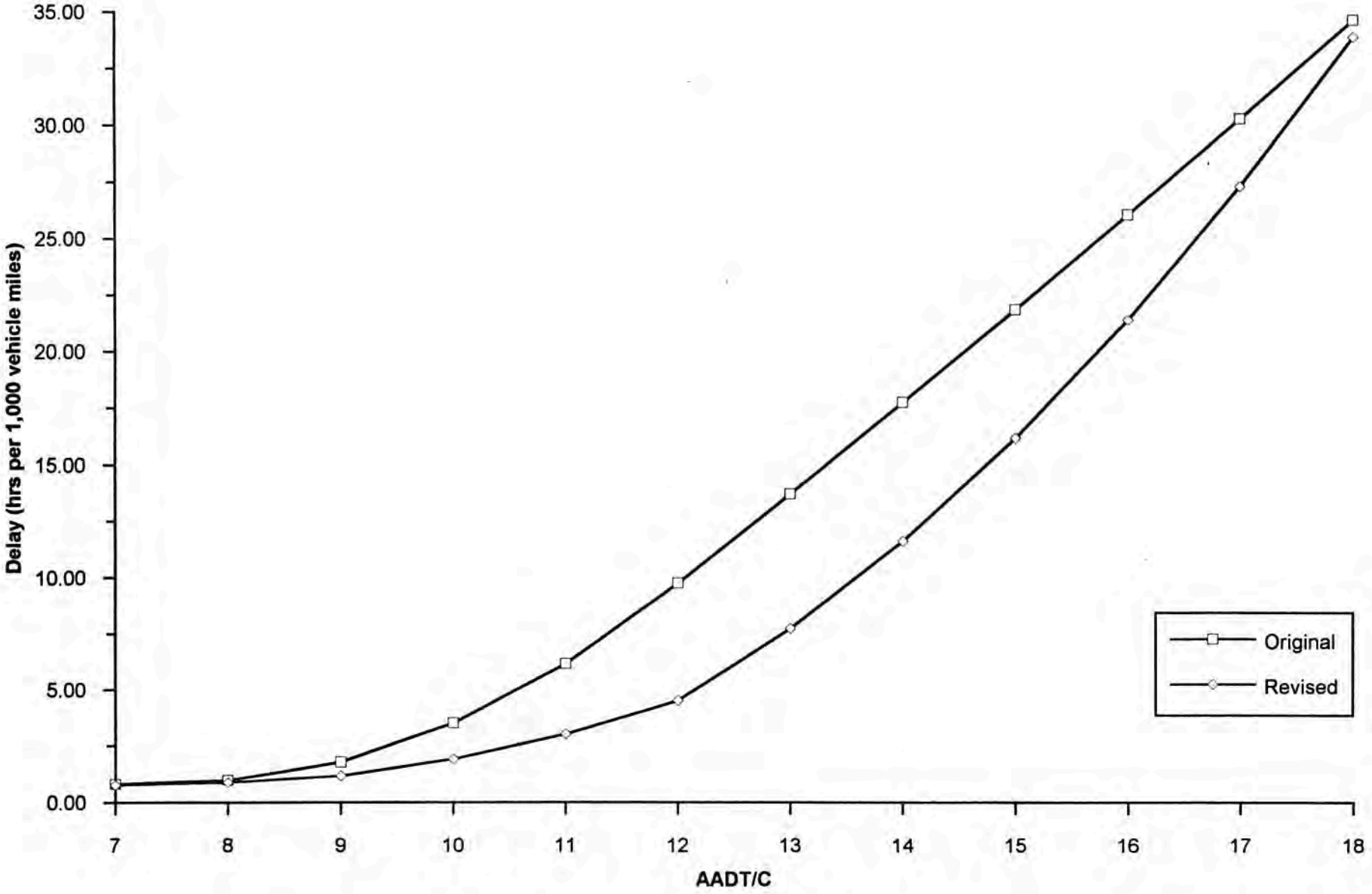


Figure 4-18. Historical Comparisons Hourly Distribution of Travel Freeways

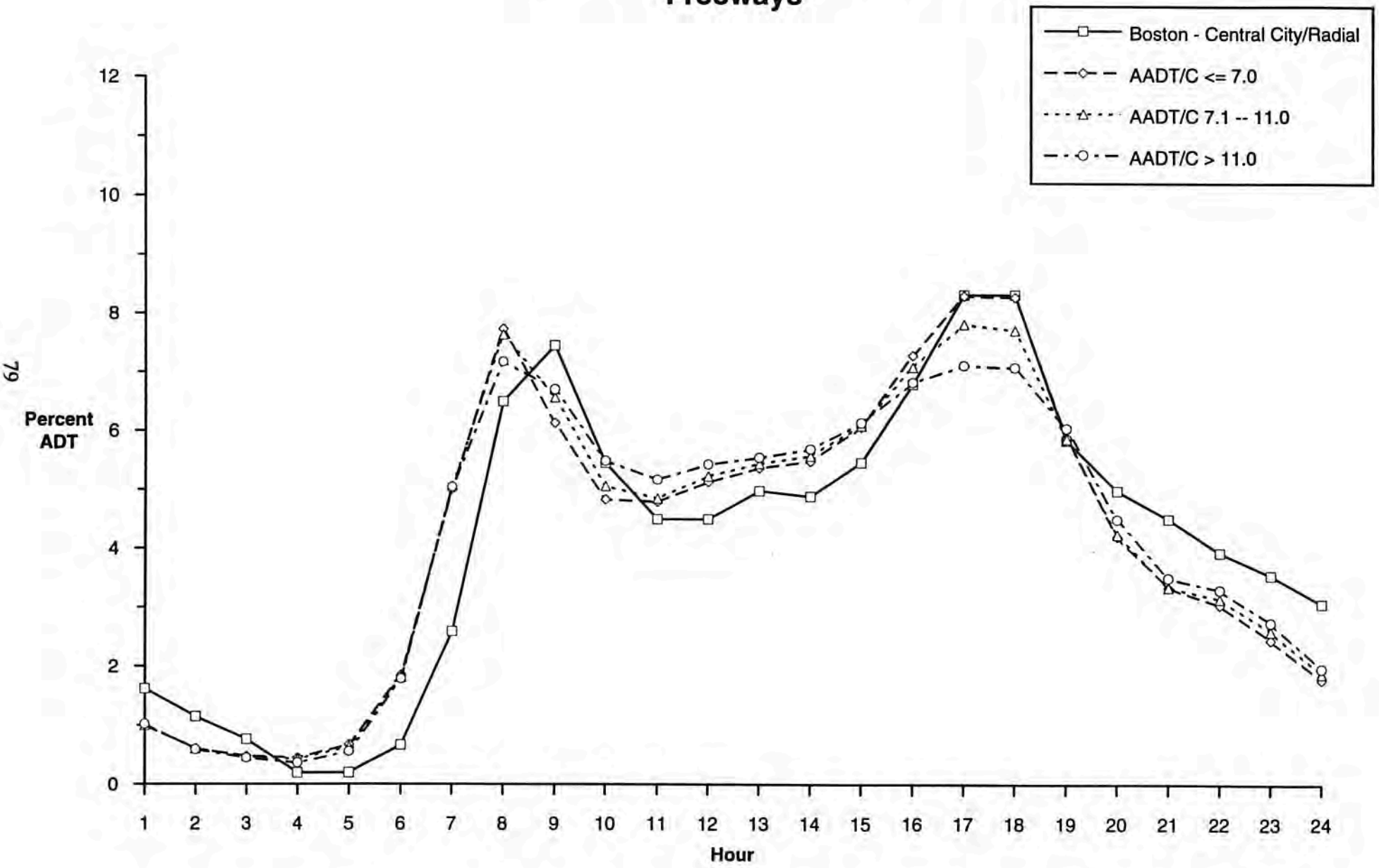


Figure 4-19. Historical Comparisons Hourly Distribution of Travel Freeways

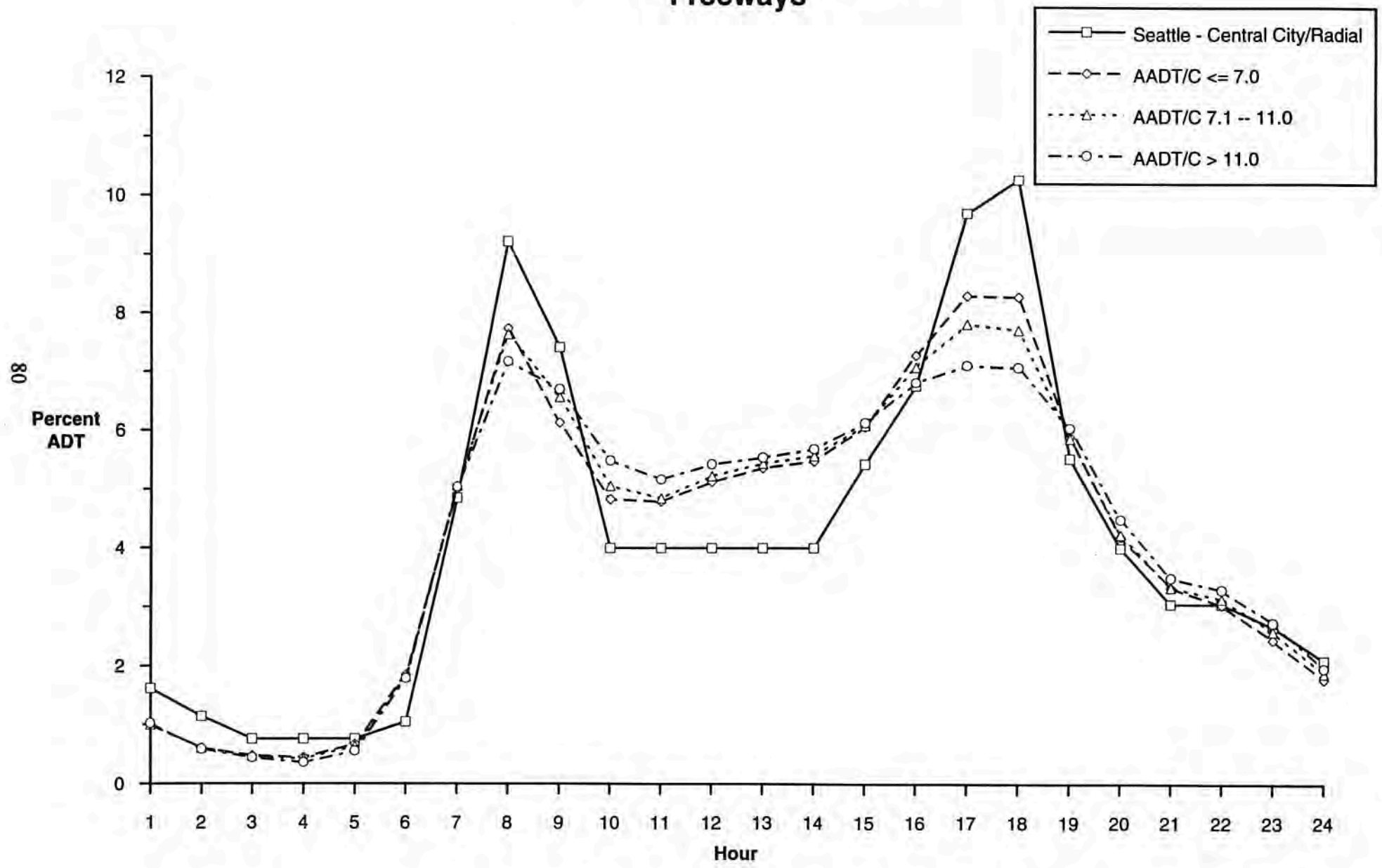
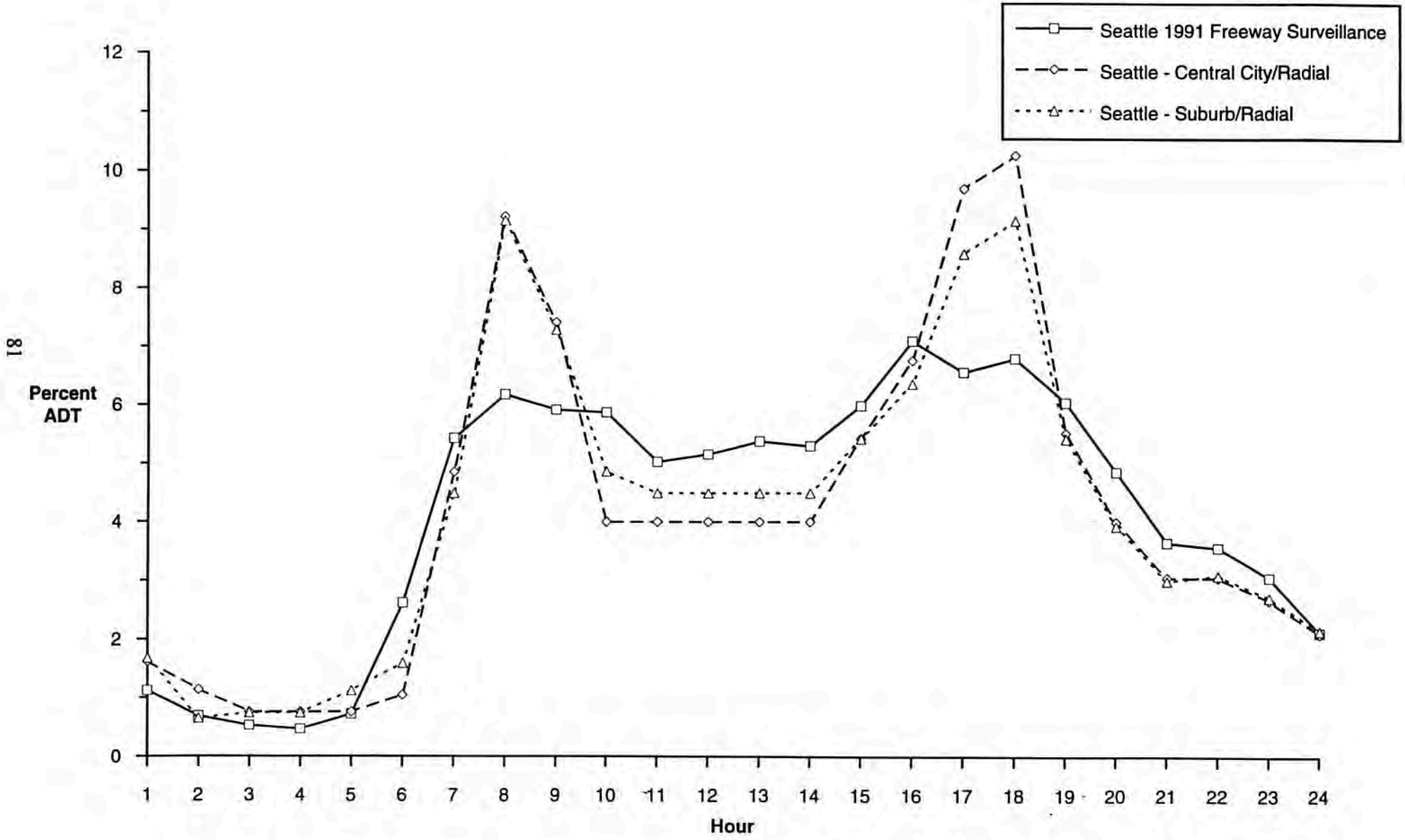


Figure 4-20. Historical Comparisons - Seattle
Hourly Distribution of Travel
Freeways



5. CONGESTION MONITORING PRACTICES

5.1 Use of Freeway Surveillance System Data

The research undertaken here found freeway surveillance data extremely useful in portraying congestion. The freeway systems used had very detailed data: five-minute volume counts, occupancies (which can be converted to densities), and sometimes speeds for points approximately every one-half mile along a freeway section. Unfortunately, arterial system data are far less useful since the so-called "system" detectors are located at midblock and can detect only extraordinarily long queues formed upstream at signalized intersections.

Freeway system data allow the identification of queues (or slow speeds) over both space and time. Simultaneous plots of speed and volume, such as those shown in Appendix H, can be very valuable in tracking daily speeds and showing the drop in capacity once traffic flow has broken down. Freeway system data can also be used to produce more traditional relationships such as volume-density plots (Appendix J) and speed-volume plots (Appendix K). These latter plots can be used to estimate the capacity of individual highway sections, although it would be important to observe the percentage of trucks in the traffic stream for each point on the plot if a rigorous capacity is desired.

In addition to these depictions of traffic conditions using freeway system data, we have found that three dimensional plots of highway location, time, and speed can be effective in visualizing congestion. Figures 5-1 through 5-5 show these contour plots for selected afternoon peak periods in Orlando. In addition to conveying a sense of the extent and duration of congestion, these plots are useful in other ways. If it is assumed that these patterns are representative of this section of Interstate 4, then:

- days earlier in the week appear to suffer less congestion than days later in the week; and
- the Stations between 5 and 15 are the trouble spots, particularly between 4:30 and 6:00 pm.

With the requirement for states and large Metropolitan Planning Organizations to develop a congestion management system (CMS), accurate techniques for monitoring congestion take on a great importance: monitoring existing and predicting future conditions is really the foundation of a CMS. A standard measure of congestion is yet to be identified, although it now appears that NCHRP Project 7-13 will recommend the use of a travel time based measure, the *delay rate* or the relative delay rate (R):

$$R = \frac{t_1 - t_2}{t_2}$$

where:

R	= relative delay rate
$t_1 - t_2$	= delay rate (minutes per mile)
t_1	= actual travel rate (minutes per mile)
t_2	= free flow travel rate (minutes per mile).

The delay rate may either be measured by the floating car method or inferred from surrogate measures (e.g., the HPMS speed models developed in this report). If freeway system data are available, presumably they should be used over any surrogate measures. However, a fundamental difference exists between travel rates as collected by floating cars (or "probe vehicles") and the section by section speed data from freeway systems. The floating car method captures traffic conditions as the vehicle passes

through the system but the freeway speed data exists only for fixed points in time and space. Therefore, some method should be available to transform freeway system data into travel rate data. As part of this project, a simple simulation model was created to do so. This model sends a probe vehicle into the system every five minutes and uses the freeway speed data to move each vehicle through the system. The model was applied to Orlando data for the afternoon peak period (4:00 to 6:00 pm); the results appear in Table 5-1. Since a probe vehicle was engaged every five minutes, each day's results are the average of 36 vehicles for the two-hour period. For each day, the relative travel rate (R) is calculated; the relationship between R and the space mean speed is shown in Figure 5-6. A curvilinear relationship is to be expected since space mean speed is the reciprocal of travel rate, but the curve will shift depending on the free flow speed.

A more dramatic representation of the probe vehicles appears in Figures 5-7 through 5-11. As with Table 5-1, large day-to-day variations in congestion are apparent. Moreover, the estimate of congestion within a day is dependent on the start time of the probe vehicle. Based on these plots, the probe vehicles should be engaged between 5:15 and 5:30 pm to capture the maximum amount of congestion; earlier starts would generally lead to lesser estimates of congestion level. These results have obvious implications for localities measuring congestion with the floating car method: congestion estimates are sensitive to day of the week and start time of the probe vehicle.

5.2 Options for National Congestion Monitoring

Because of the problems with detecting congestion from hourly volume data alone, ATR data are not sufficient for national congestion monitoring. Our research developed some simple algorithms to detect congestion from hourly ATR data, but their application distinguished only a small number of potentially congested hours. Further, current ATRs tend to be located on relatively uncongested facilities (see Chapter 3). Therefore, the use of ATRs in their current form to monitor congestion is limited to providing basic relationships such as the temporal distributions developed in this research.

Although we have presented a method for converting freeway surveillance system data into travel rate data, the problems with collecting and managing data from enough cities to be statistically representative is probably insurmountable. Further, we were unable to develop a method for using arterial signal control data to measure congestion directly. Finally, given the problems we encountered in obtaining data from cities and states, it is not in VNTSC's and FHWA's interest to pursue collecting data from these systems on an ongoing basis. For research purposes, we believe it is feasible to expand on the data set created as part of this project. We found that a few localities were able to supply data for short periods of time (up to three months) without much trouble. However, collecting ample data from enough systems to be representative of the entire country is clearly an insurmountable task. Also, at this point in time, the existence of such systems in an area indicate that congestion is a severe problem (e.g., freeway ramp metering would not be installed if congestion was not prevalent). Therefore, even if a representative sample was created, until the existence of such systems are ubiquitous there would be a tendency to overestimate congestion at the national level. These facts leave three basic options for national congestion monitoring.

Option 1: Revamp the ATR System

Hourly volume data are insufficient to allow detection of congestion. However, data collected at shorter time intervals (at most 15 minute and ideally five minute intervals) would offer the chance to detect congestion, especially if speed data can be provided along with the volume data. Much of the new ATR equipment being installed by the states has the capability of providing speed (and vehicle classification data) along with volume data. If speed data were available, then congestion could be detected by viewing the simultaneous speed-volume over time plots (Appendix H). If speed data were unavailable,

then detection algorithms will have to be developed for use with the volume data; this research provides a few simple algorithms as a starting point. The main problem with this option is the burden it places on the states. Another problem is the representativeness of the ATRs -- they have not been located as a result of statistical sampling.

Option 2: Synthesize Congestion Estimates from HPMS Data and Models

The HPMS speed determination models, as revised in this report with the new temporal distributions, offer a means by which congestion may be estimated with limited knowledge about a particular highway segment's characteristics. For freeways, all the models require is the free flow speed and the AADT/C; arterials also require the number of signals per mile. The models then produce estimates of speed based on these characteristics, with the temporal distributions produced by this research imbedded in the models. However, it must be emphasized that the HPMS speed models cover recurring congestion only; the effects of incidents (nonrecurring congestion) are not modeled. The temporal distributions developed by this research are based primarily on ATR data -- no attempt was made to isolate incidents (it would have been impossible). Both the ATR and the freeway surveillance data should have incidents imbedded in them. However, the effect of incidents on the temporal distributions is unknown. We were unable to identify many congested hours from the ATR data, indicating that peak period incidents probably are not represented well in the ATR data. Also, the handful of simultaneous speed-volume plots in Appendix H indicate that at least for the afternoon peak period, congestion is initiated as a recurring event. (Note how the volumes almost uniformly build to capacity, closely followed by a drop in both speed and volume.) Although some incidents probably occur during this time, which may explain why some days are worse than others, separating them out was beyond the scope of this research. Based on these facts, it should be assumed that the temporal distributions -- and the HPMS speed models -- do not incorporate the effects of incidents on congestion. Incidents are an extremely important contributor to urban congestion and it has been estimated that 40 to 70 percent of all congestion is incident-related.[1] This necessitates further examination of incidents on speeds within the HPMS modeling framework.

If the incident issue is eventually addressed, relying on the HPMS data and models to monitor national congestion requires that states accurately code the AADT and capacity variables in their annual submittal. These variables should be rigorously cross-checked and validated. Another action that would increase data veracity would be the use of freeway surveillance and arterial signal control systems to collect AADT data on HPMS sections where they coincide; continuous counts would be vastly preferable to AADT estimation from short counts.

Option 3: Integration of State CMSs

The Intermodal Surface Transportation Assistance Act (ISTEA) requires states and the larger cities to develop CMSs. The monitoring portion of state CMSs could be annually submitted to a single Federal system. The system should be constructed in such a way as to minimize the burden on the states, which should not be great since they will be developing CMSs for their own purposes and the monitoring data will be a fraction of the entire CMS. As state CMSs are only now being formulated, it is not possible to provide more precise guidance on how the national system would work. However, it appears to us that integration of state CMSs is a cost-effective way to provide VNTSC and FHWA with congestion monitoring data. Some issues of which to be aware so that the integration can proceed smoothly include:

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[1]L. R. Grenzeback, W. R. Reilly, P. O. Roberts, and J. R. Stowers; "Urban Freeway Gridlock Study: Reducing the Impacts of Large Trucks on Peak- Period Urban Freeway Congestion;" paper prepared for Transportation Research Board; 69th Annual Meeting; January 1990.

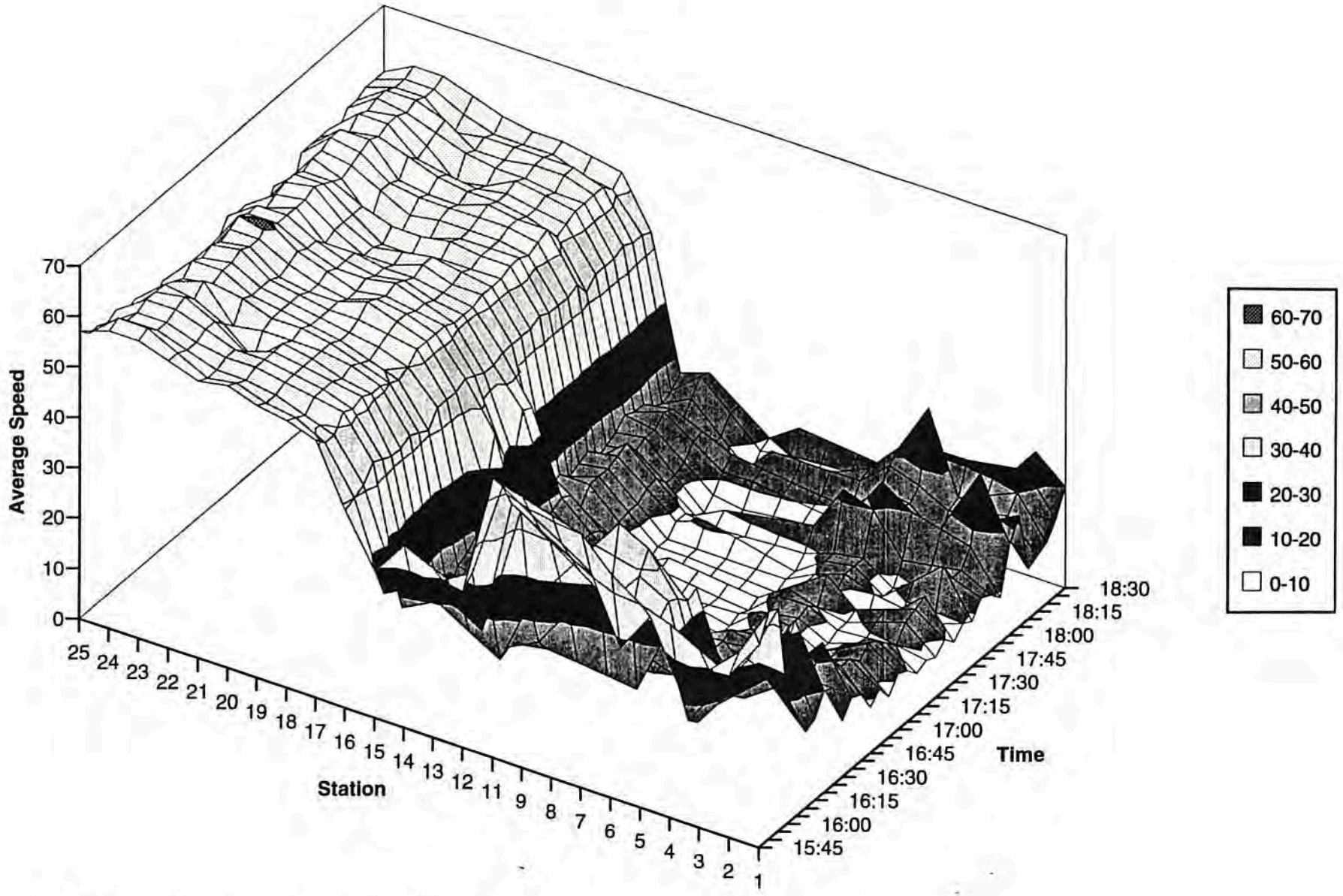
- Ensuring some degree of commonality in the congestion measurements used by states. This includes not only common definitions but data collection, management, and processing techniques as well.

- Providing submittal software (similar to HPMS) so states can easily transmit the data.

Table 5-1. Results of Applying the Travel Rate Simulation Model to Orlando Data

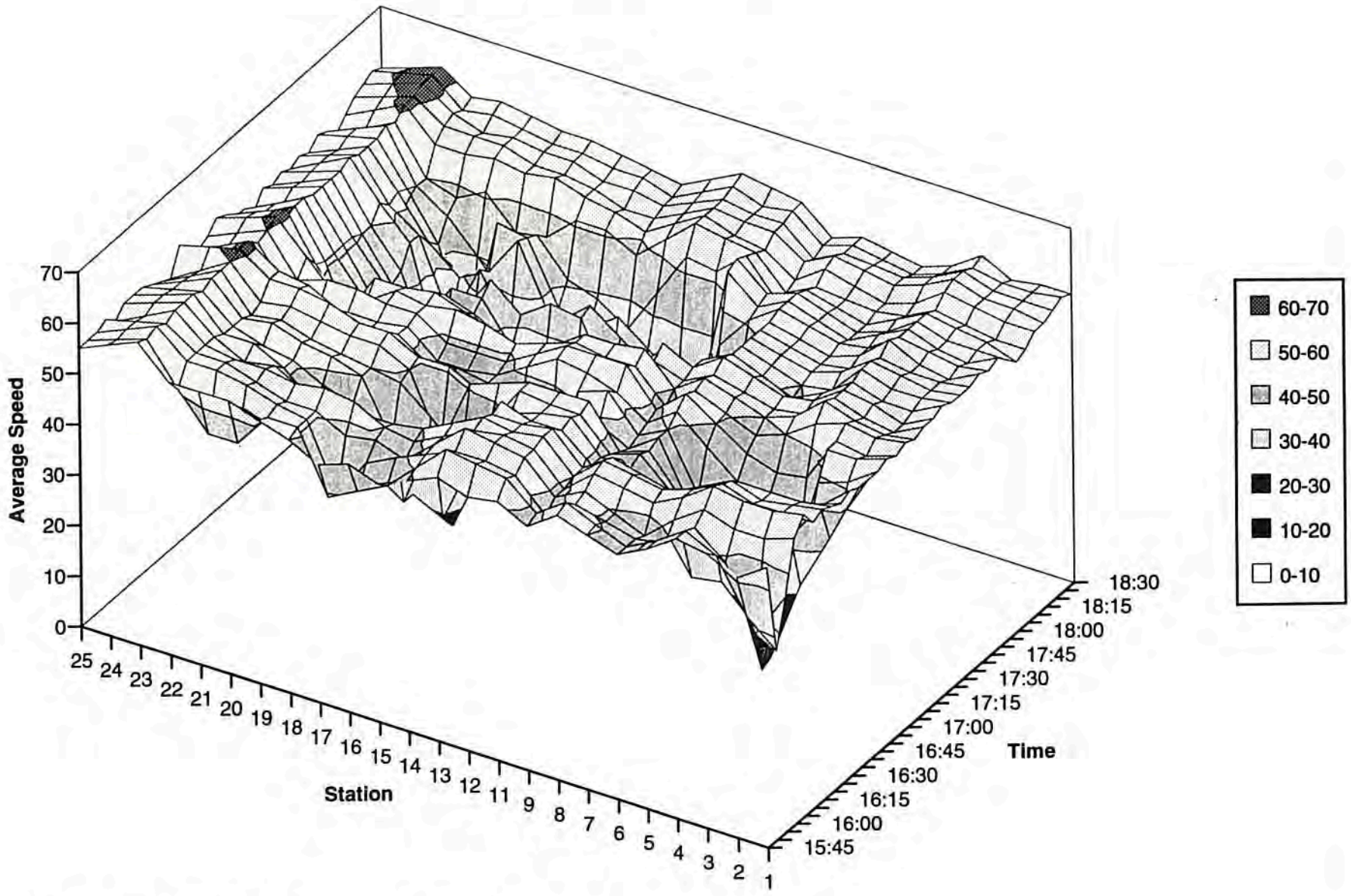
Day Number	Date	Ave. Speed (mph)	Ave. Travel Rate (min/mile)	Std Dev (min/mile)	R
1	07/13/93	44.2	1.359	0.171	0.291
2	07/15/93	16.6	3.608	0.512	2.428
3	07/20/93	30.2	1.984	0.630	0.885
4	07/21/93	25.5	2.357	0.597	1.239
5	08/23/93	42.6	1.408	0.181	0.337
6	08/24/93	46.7	1.286	0.123	0.221
7	08/25/93	44.2	1.358	0.143	0.290
8	08/26/93	24.1	2.487	0.497	1.363
9	08/27/93	16.5	3.630	0.627	2.449
10	08/30/93	45.9	1.308	0.140	0.243
11	08/31/93	28.9	2.075	0.530	0.971
12	09/01/93	32.6	1.841	0.325	0.749
13	09/02/93	38.9	1.543	0.189	0.466
14	09/03/93	29.6	2.026	0.343	0.925
15	09/07/93	39.9	1.504	0.292	0.428
16	09/08/93	33.6	1.787	0.427	0.698
17	09/09/93	18.0	3.338	0.335	2.171
18	09/10/93	32.1	1.872	0.290	0.778
19	09/13/93	35.1	1.710	0.055	0.625
20	09/14/93	44.4	1.350	0.262	0.283
21	09/15/93	33.8	1.774	0.229	0.685
22	09/16/93	29.0	2.071	0.216	0.968
23	09/17/93	30.3	1.982	0.206	0.882
24	09/20/93	28.7	2.087	0.212	0.983
25	09/21/93	32.3	1.859	0.377	0.766
26	09/29/93	32.2	1.864	0.270	0.771
27	09/30/93	29.8	2.013	0.286	0.912
28	10/01/93	28.2	2.131	0.218	1.025
29	10/04/93	38.7	1.549	0.177	0.472

Figure 5-1. Orlando I-4 NB
7/25/93 - Thursday



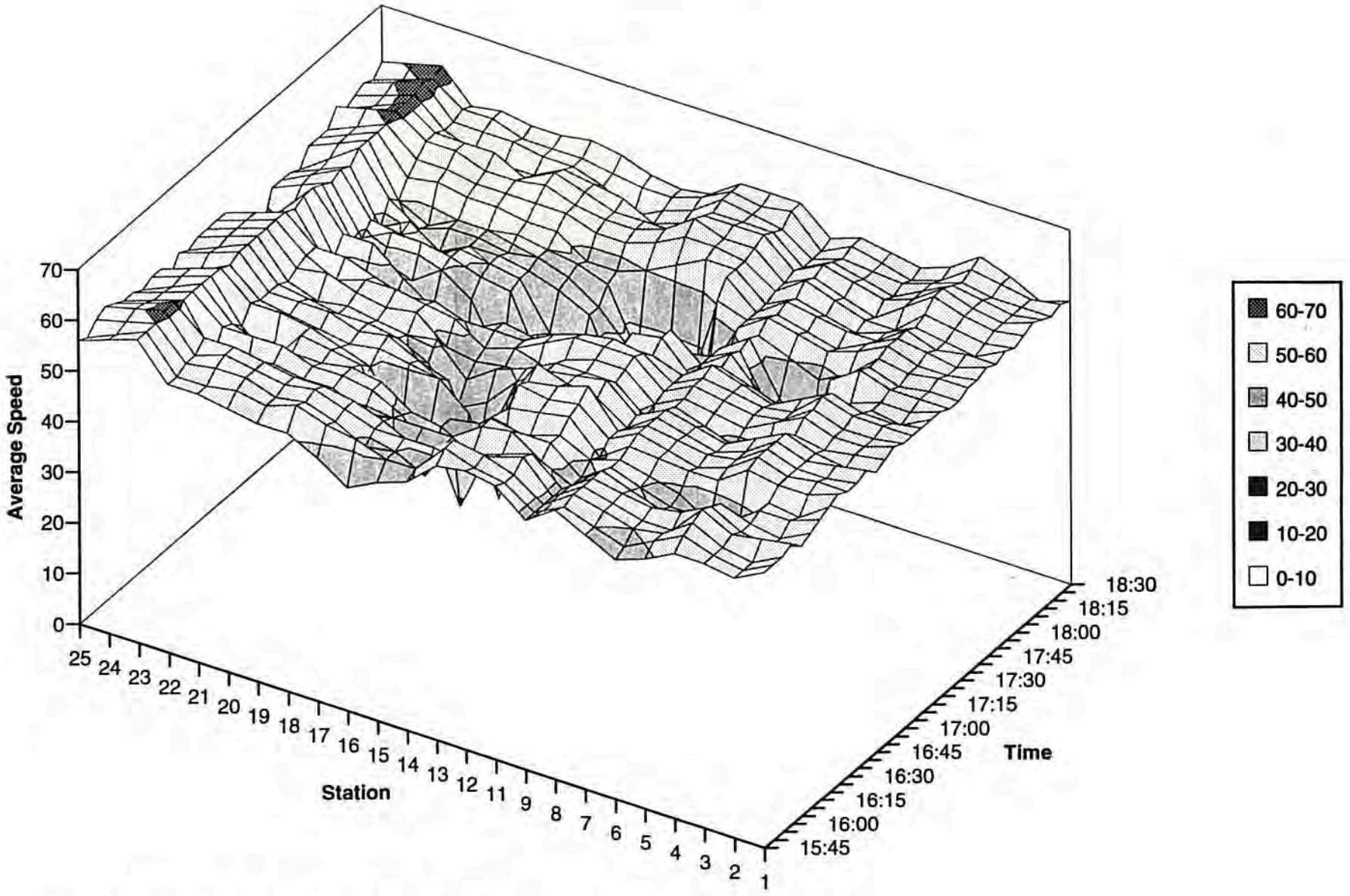
Note: Direction of travel is from Station 1 to Station 25

Figure 5-2. Orlando I-4 NB
8/23/93 - Monday



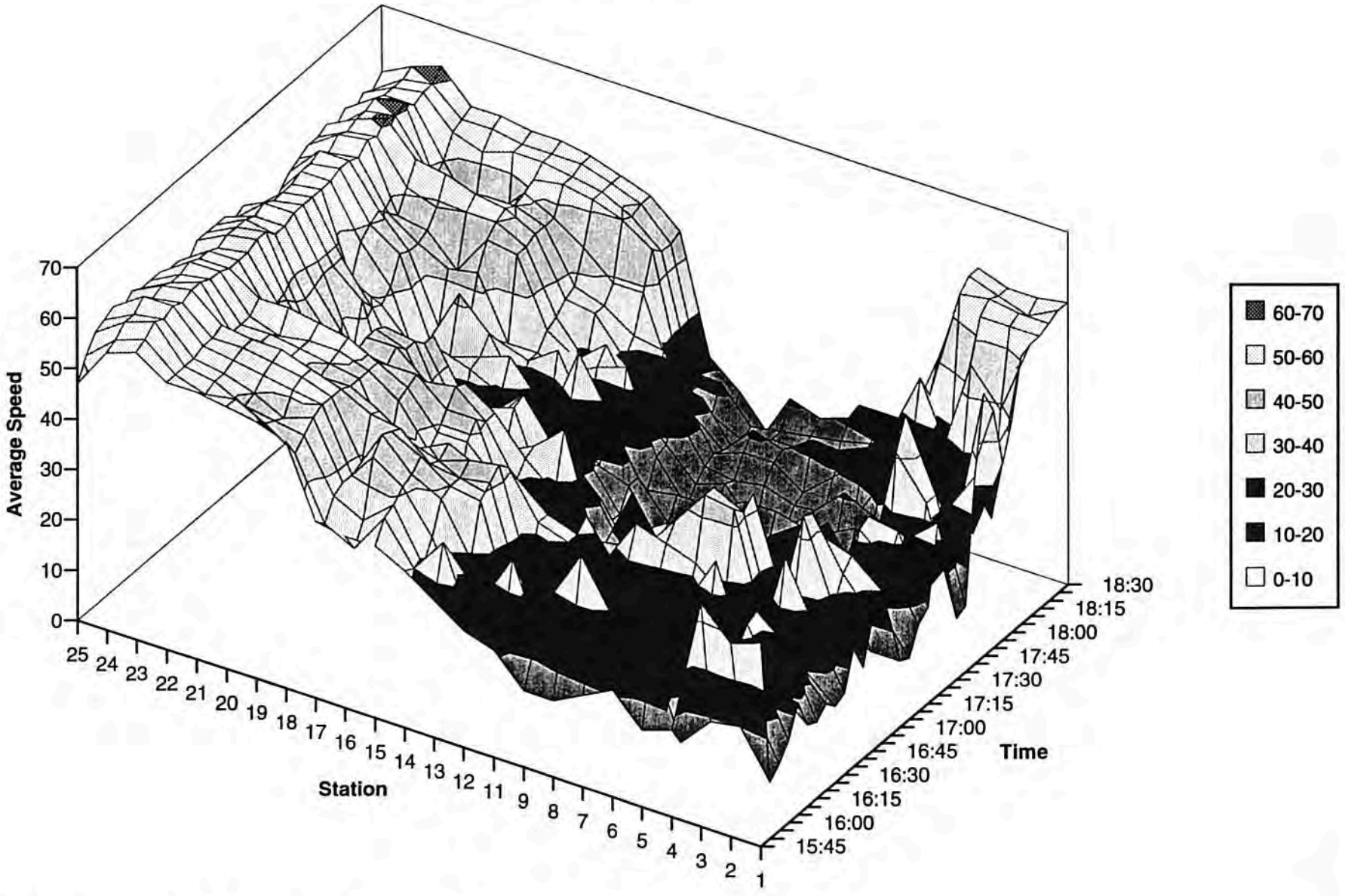
Note: Direction of travel is from Station 1 to Station 25

Figure 5-3. Orlando I-4 NB
8/24/93 - Tuesday



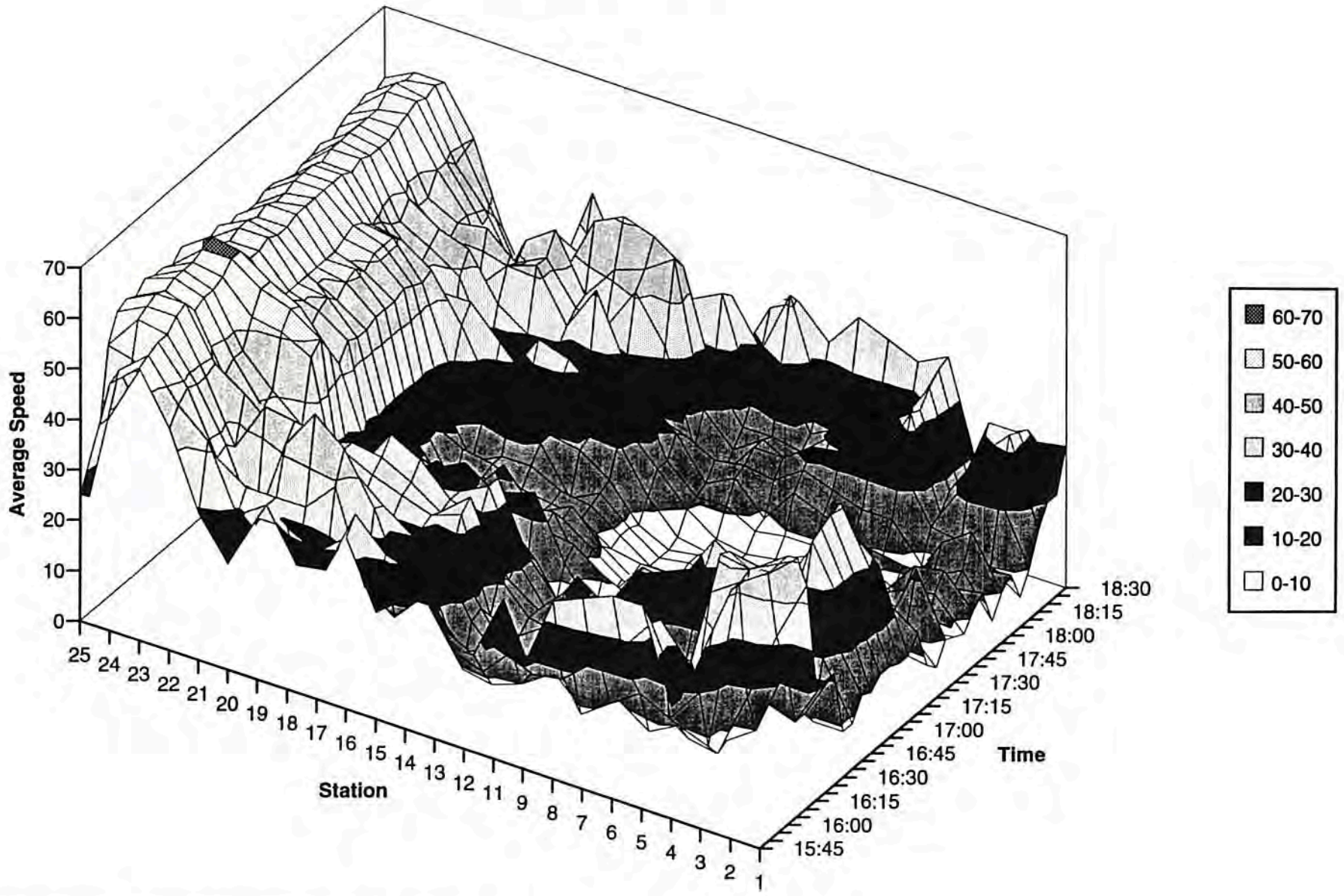
Note: Direction of travel is from Station 1 to Station 25

Figure 5-4. Orlando I-4 NB
8/26/93 - Thursday



Note: Direction of travel is from Station 1 to Station 25

Figure 5-5. Orlando I-4 NB
8/27/93 - Friday



Note: Direction of travel is from Station 1 to Station 25

Figure 5-6. Relationship of Relative delay Rate and Average Speed (Orlando)

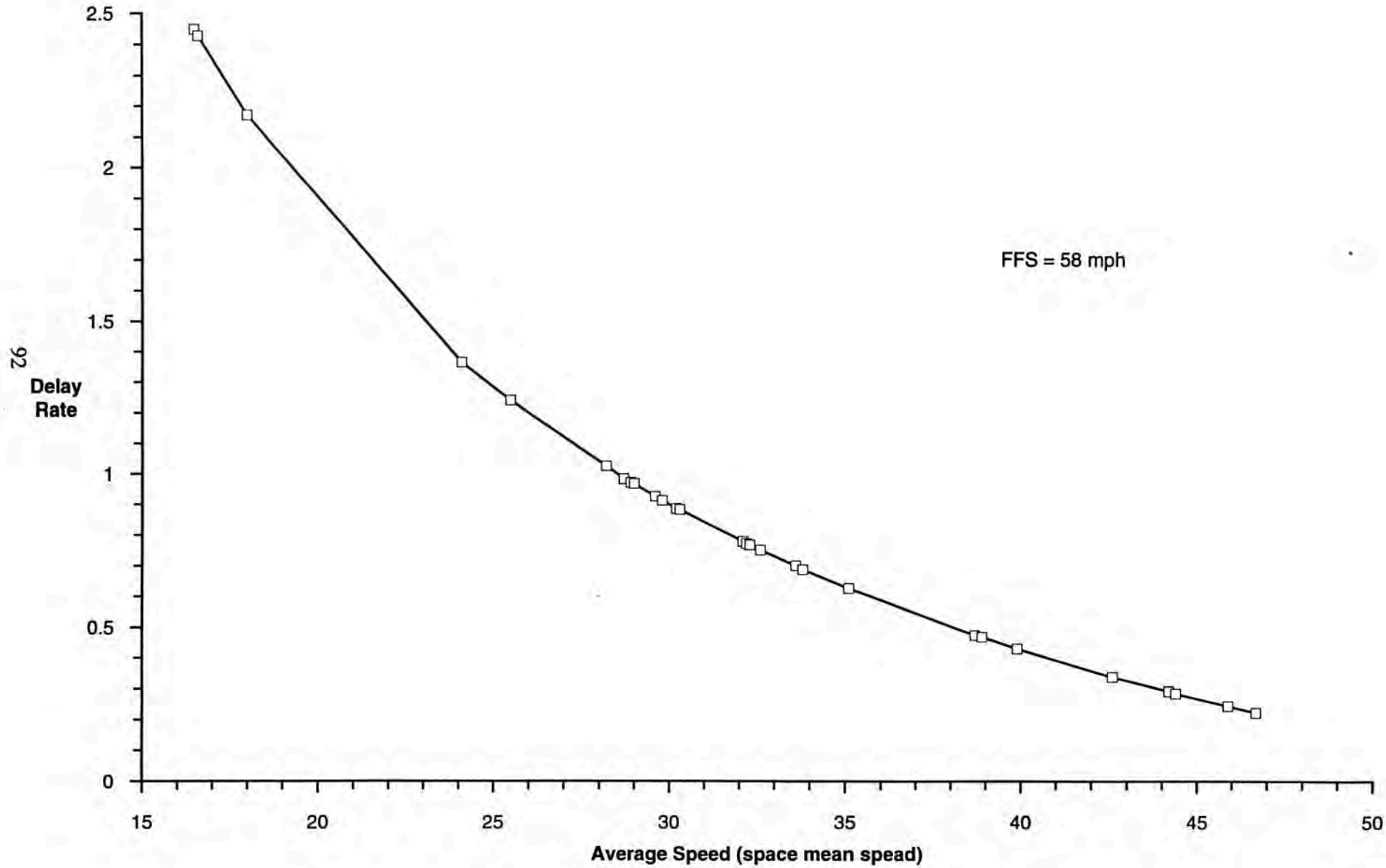


Figure 5-7. Influence of Vehicle Start Times on Average Systems Speeds Mondays on I-4 (Orlando)

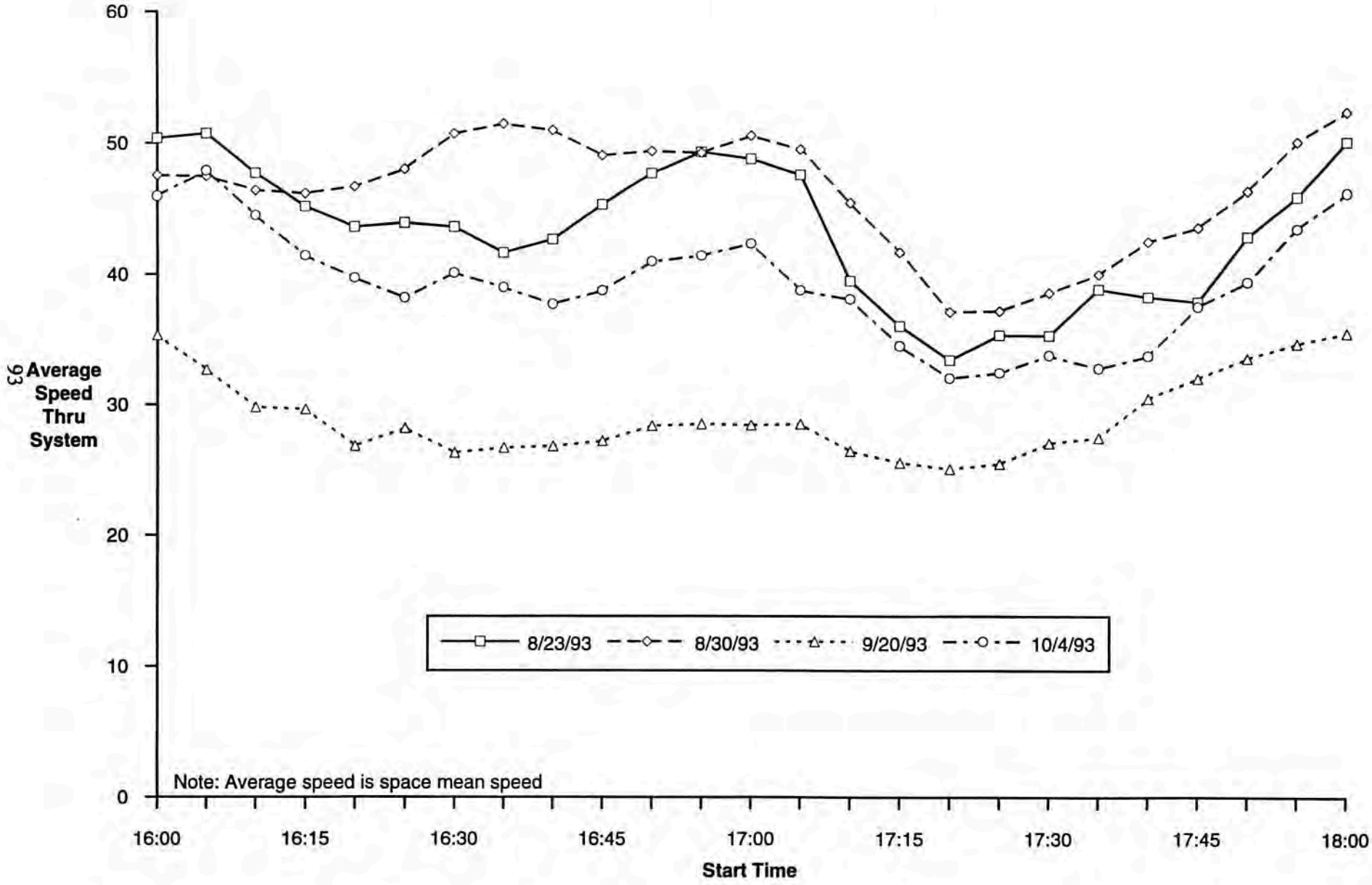


Figure 5-8. Influence of Vehicle Start Times on Average Systems Speeds Tuesdays on I-4 (Orlando)

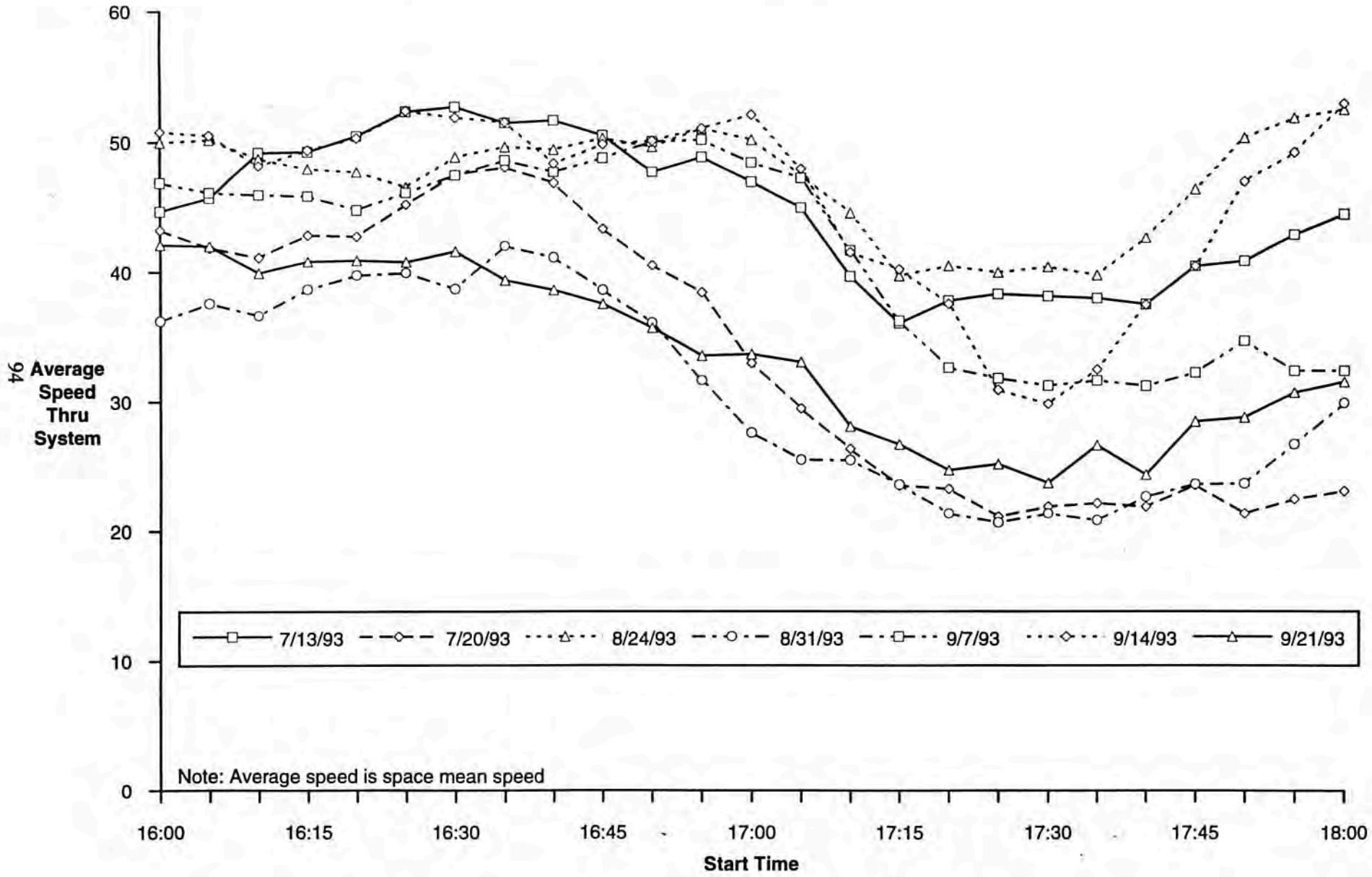


Figure 5-9. Influence of Vehicle Start Times on Average Systems Speeds Wednesdays on I-4 (Orlando)

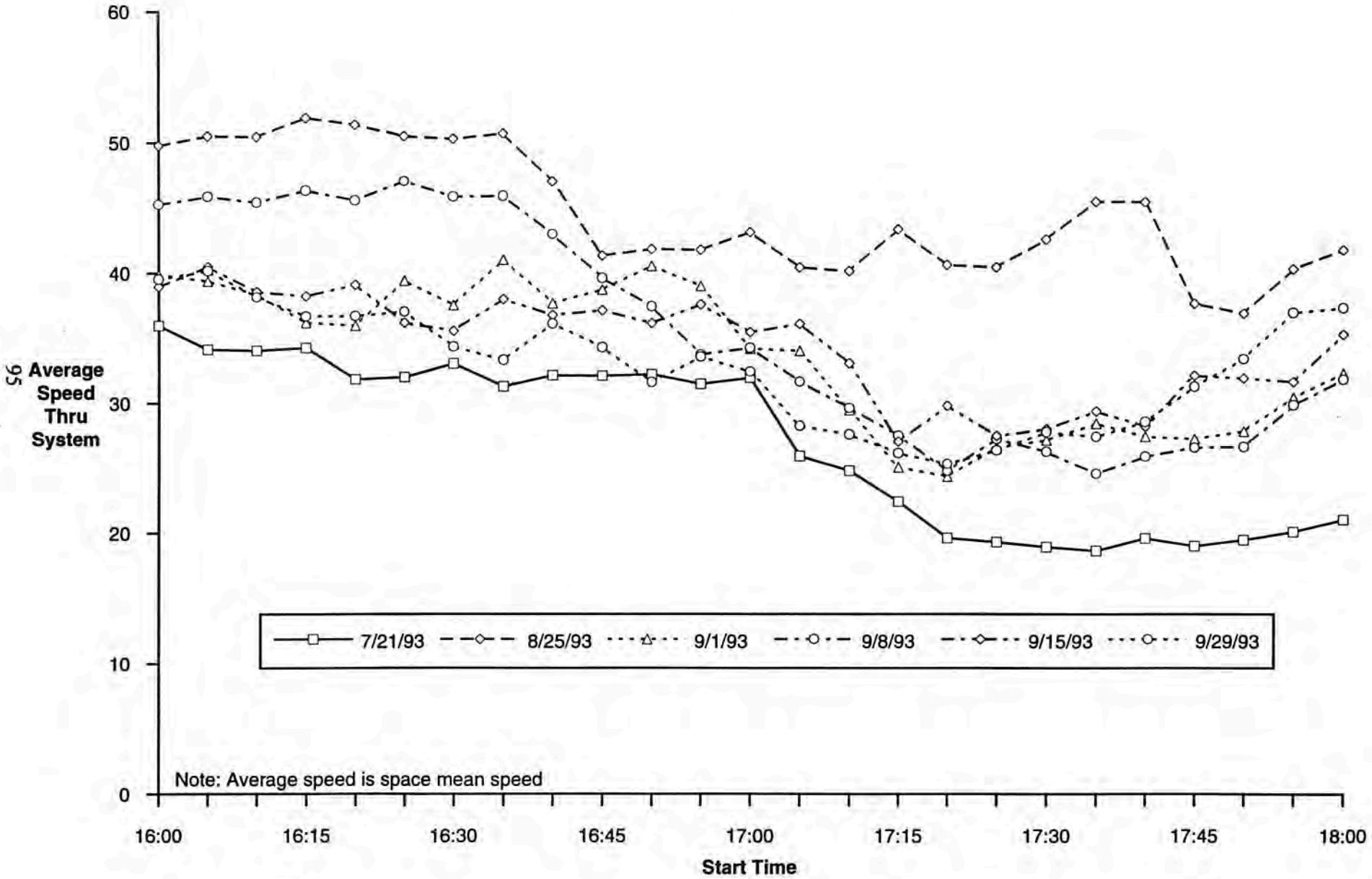
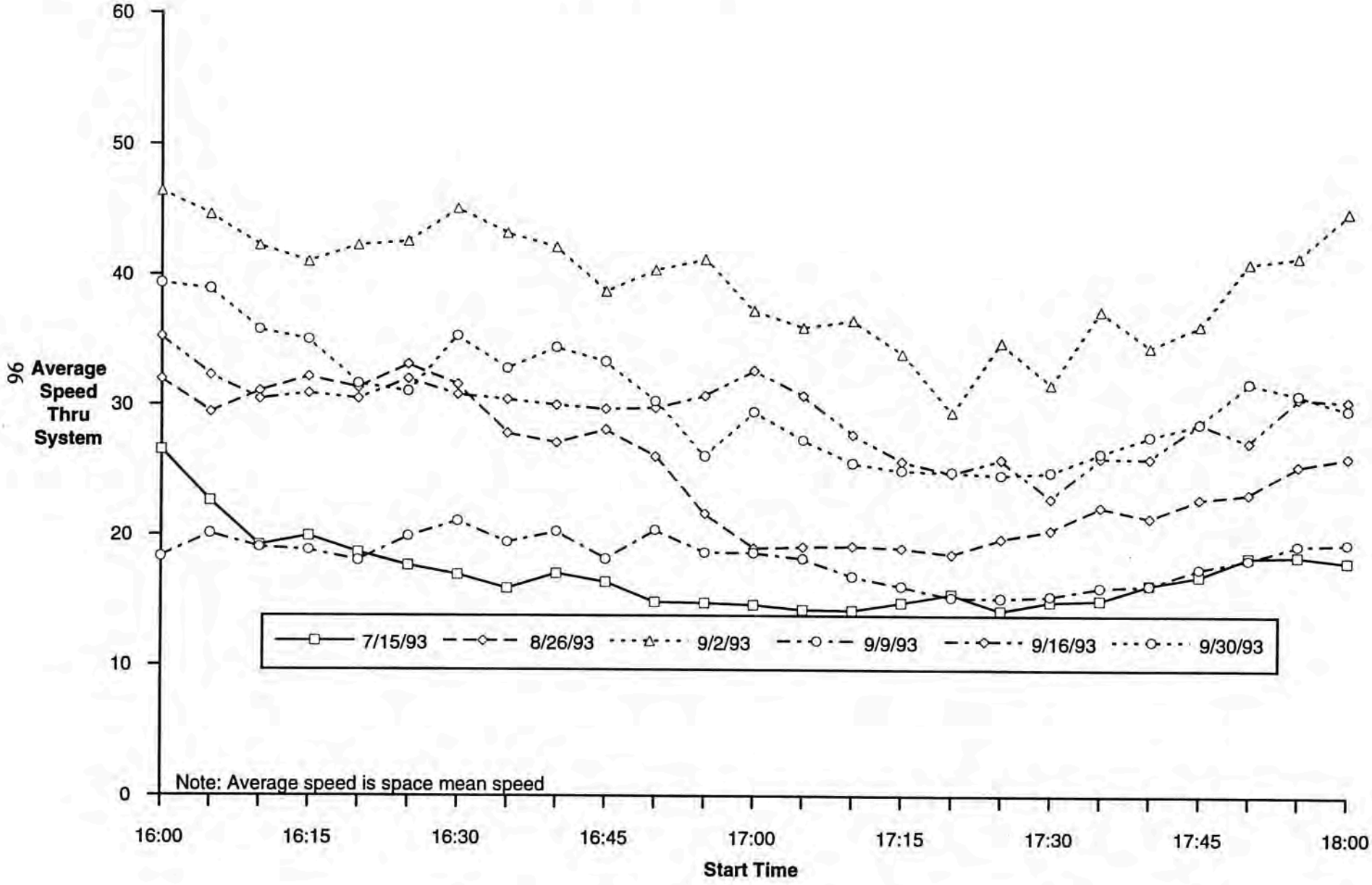
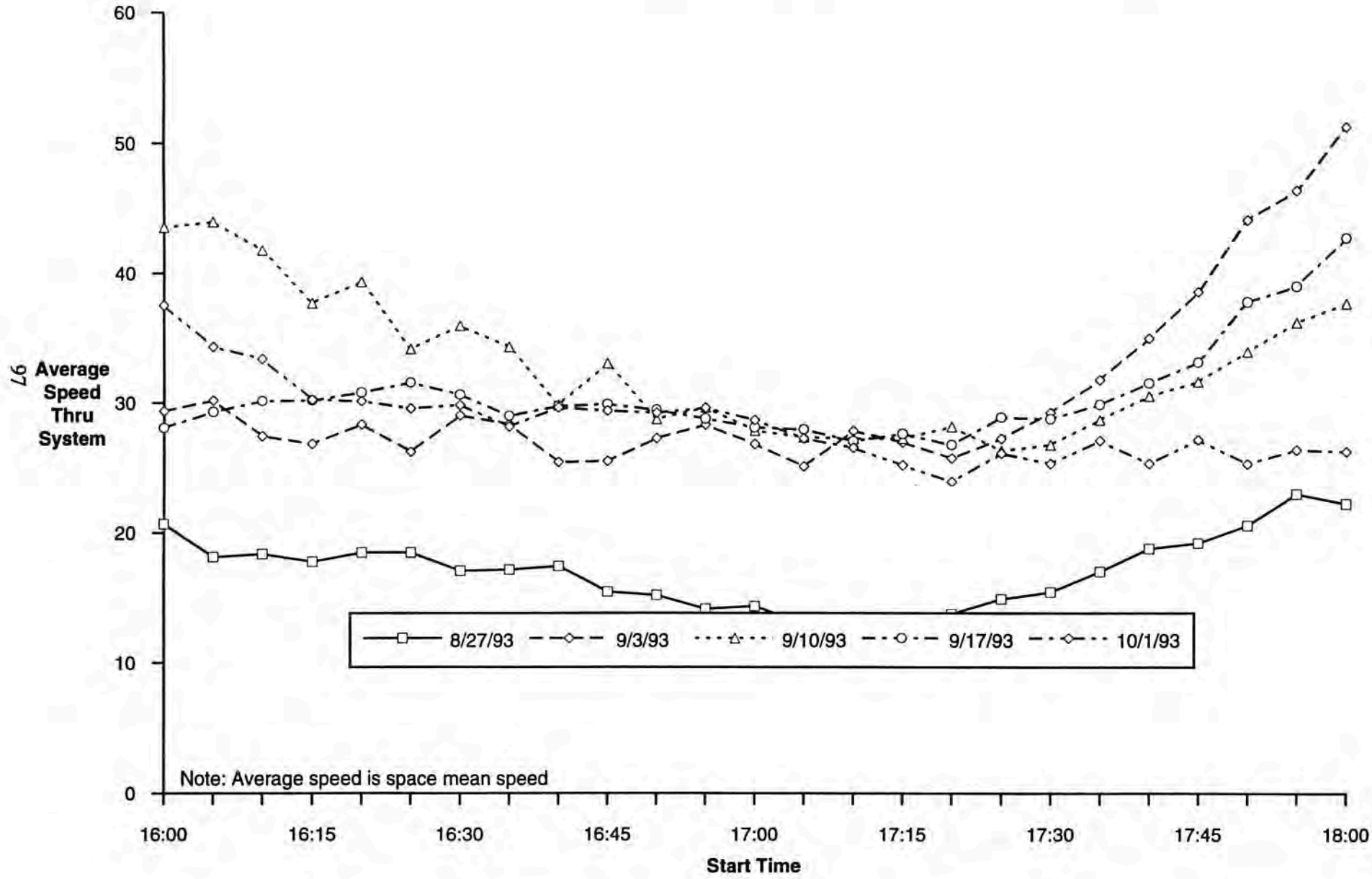


Figure 5-10. Influence of Vehicle Start Times on Average Systems Speeds Thursdays on I-4 (Orlando)



Figuure 5-11. Influence of Vehicle Start Times on Average Systems Speeds Fridays on I-4 (Orlando)



6. SUMMARY AND RECOMMENDATIONS

6.1 Project Summary

Overview

The main objective of this research was to enhance the urban usage patterns imbedded in the HPMS simulation models. One of the key underpinnings of the simulation models is the distribution of daily traffic at various congestion levels, as imbedded in the tables of AADT/C versus V/C. These tables are used to predict the congestion patterns of facilities, a central determinant of highway performance (as measured by user costs) in urban areas. The research revised these relationships and produced several other items of interest, as discussed below.

Products

Several specific products were delivered to VNTSC and FHWA as a result of this work.

- A data base of urban ATR traffic volumes for 1991 and 1992 that have undergone editing. A total of 713 ATR locations are included in this data base. A separate file contains supplemental data on the ATR locations compiled from 1992 HPMS data and a survey of state DOTs preformed as part of this study. Capacities are available for 579 of these sites.

- Data bases for three freeway surveillance systems (Seattle, Denver, and Orlando) and one arterial signal control system (Lexington). The freeway data are five minute volume, speed, and occupancy counts for stations spaced approximately every one-half mile along freeway sections. The Lexington data are midblock 15-minute volume and occupancy counts from locations distributed around the city. Together with the ATR data base, these data bases can be used for future research into congestion and can provide the basis for future data integration.

- Basic algorithms for detecting congestion from hourly volume counts on freeways. These were developed from examining the detailed freeway surveillance system data.

- Temporal distributions of urban travel distinguished by peak direction orientation (whether traffic peaks in the morning or afternoon in a particular direction), facility type (freeway and nonfreeway), and AADT/C range.

- Revised AADT/C vs. V/C relationships. The relationships are provided in both table and equation forms.

- Recalibrated congestion terms for the HPMS speed models. The terms were based on the temporal distributions developed by the study. A test of the new models to Orlando freeway data yielded on average an error rate of only about one percent, although wide variation in the error rates for individual days existed.

- A brief historical analysis was undertaken, comparing the current data with data from a 1972 report. As noted by other observers, peak spreading has occurred to a significant extent over the past twenty years.

- The data from the freeway surveillance systems were analyzed in several ways in order to depict congestion. The most valuable of these are the simultaneous speed-volume plots over time and the three-dimensional contour plots of speed, time, and location. These plots can aid future congestion researchers as well as to provide a graphical presentation format for the public.

- A simulation model was developed to convert freeway surveillance data into travel rate data to be compatible with emerging definitions of congestion. Application of the model to Orlando freeway data indicates that congestion varies not only from day to day but within what is normally thought of as peak periods. This latter finding indicates that if congestion is measured via standard travel time runs (i.e., the floating car method), congestion estimates are sensitive to when the vehicle is engaged.

6.2 Recommendations

The ATR dataset provided by FHWA was invaluable in producing the AADT/C vs. V/C relationships and the temporal distributions, the two key products of the study. Our recommendations for how ATRs should be used in the future are as follows.

1. ATR dataset in its current form should **not** be used to measure congestion directly, especially at the national level. Detecting congestion from hourly volume data is too difficult to be of value.

2. ATRs can be used as a research resource to develop input data that can be used by other methods to estimate congestion. This study is an example of this process.

3. Some new ATRs should be placed on highway sections that routinely experience congestion. Our research revealed that most ATRs are located on highways that do not routinely experience congestion. Future research efforts would profit from having additional information from ATRs on congested sections. One option for implementing this action is to ask states to consider a single location from a freeway surveillance system in a congested corridor as an ATR and to report its volume data to FHWA. FHWA should be flexible on how such data is submitted and not require that it be put into the standard 3-card format. (Simple customized programs can be written by FHWA to do this conversion.)

4. The supplemental data providing additional locational information on urban ATR sites should be maintained. The excellent response rate from our survey indicates that such data are available to states with little effort. States might be asked to supply these data once every two or three years for their urban ATRs to maintain these valuable data.

Freeway surveillance and arterial signal control systems represent a large untapped resource for congestion management. Currently, states and cities do essentially nothing with the data from these systems on a continuing basis. The general feeling we uncovered is that the mass of data collected by these systems is a secondary concern to the functioning of the systems for ramp metering and signal timing. The data are used to perform special studies periodically, but no one we encountered use the data for monitoring congestion for two reasons: (1) the data management and analysis functions of the systems are extremely limited and (2) standard methods for measuring congestion with this kind of data have not been developed. Therefore, we recommend the following three actions.

1. VNTSC and FHWA may want to consider a thorough review of the types of systems in place and what it would take to add user-friendly data management and analysis capabilities to them. This may involve the development of separate information systems that would interface with the existing hardware and software.

2. VNTSC and FHWA should foster standard measures of congestion and standardized methods for estimating them. It is likely that NCHRP Project 7-13 will recommend standard definitions and may provide guidance on their estimation. VNTSC and FHWA should follow the NCHRP project's recommendations closely and assess its value for use nationwide. Guidelines on how to estimate congestion from available data -- such as the simulation model to estimate vehicle travel rates with freeway surveillance data developed as part of this study -- should also be provided.

3. More work is needed in developing ways to use arterial signal control system data for congestion monitoring. Other than using the volume data as inputs to other analytical procedures (similar to how the ATR data were used), this research did not uncover any way to use the data in a meaningful way. The main problem is that the data provided to us was collected midblock; information on conditions at the upstream signals (such as queue length per cycle) would be extremely helpful in completing the congestion picture for signalized arterials.

This research just touched on historical changes in temporal distributions. VNTSC and FHWA may want to examine this point further with a more thorough analysis. Ideally, the same ATRs should be selected at two points in time for analysis. (This study compared individual urban ATRs from circa 1970 to the average from all urban ATRs in 1991 and 1992.) Clearly, peak spreading has prevented congestion from becoming as severe as it might have been if travel patterns had remained the same over the past twenty years. Some examination of whether this trend will continue appears to be warranted. In other words, has peak spreading gone as far as it can go or will travel continue to spread out to take advantage of excess highway supply in what are now offpeak periods? Will telecommuting allow highway users the flexibility to spread their travel times out even more or will IVHS strategies alleviate enough peak period congestion as to halt or shrink peak spreading?

The study defined three options for national congestion monitoring: (1) a revamped ATR system, (2) application of HPMS data and models, and (3) integration of state CMSs. Of these, the most feasible in the short-term is the application of HPMS data and models since the systems are already in place and no additional requirements need be placed on the states. However, the integration of state CMSs offers promise in the long-term. VNTSC and FHWA should follow the development of state CMSs with the goal of pulling their congestion monitoring data into a single national system. If this approach is acceptable, then the recommendation for standard congestion monitoring practices becomes even more critical.

Finally, with regard to the HPMS simulation models, consideration should be given to modeling the consequences of incidents on congestion. The current HPMS speed models account for recurring congestion only. Since a significant portion of total urban congestion is incident related, we recommend that the effect of incidents be taken into account within HPMS.