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Analysis of Cycle Overloads at Signalized Intersections

BY

Randall G. Sonnenberg

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science.

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Randall G. Sonnenberg
314 St. Andrew's Street
Stony Plain AB
T7Z 1K7

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UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Analysis of Cycle Overloads at Signalized Intersections submitted by Randall G. Sonnenberg in partial fulfillment of the requirements for the degree of Master of Science.

Dr. S. Teply

Dr. W.J. Sproule

Dr. S. M. AbouRizk

Dr. J. D. Whittaker

January 27, 1995

To

Audrey and Grant

ABSTRACT

The performance of signalized intersections is currently evaluated using delay as the primary me f effectiveness. Although delay is a valuable and useful tool, addition ls of evaluation are available to assess other aspects of intersection ormance. Load factor, defined as the ratio of fully loaded cycles to the total number of cycles during an evaluation period, was the primary characteristic upon which the levels of service were based in the 1965 American Highway Capacity Manual. The load factor could be measured in actual situations, but no procedure was initially available for the calculation of load factor. This limitation was a major reason for the adoption of average stopped delay as the basis for the levels of service in the 1985 Highway Capacity Manual.

Measures of effectiveness similar to the load factor, such as the probability of clearance and the cycle failure rate, were proposed and were used to supplement intersection analysis based on delay. These measures were calculable, but did not consider groups of consecutive cycles and were generally not well understood by traffic analysts. A measure called the overload factor, which includes only cycles with greater numbers of arrivals than capacity on a per lane basis, is proposed for inclusion in the 1994 Canadian Capacity Guide for Signalized Intersections. The overload factor is measurable and may be approximated by the probability of having at least one overloaded cycle in two consecutive cycles. This probability is not difficult to calculate and appears to be an acceptable surrogate for overload factor, based on a pilot study carried out at the University of Alberta in 1993.

The objective of this research was to investigate the relationship between the overload factor and several probabilities of encountering overloaded cycles. Overload factors were measured at several sites in Edmonton and were used to validate a simulation program. Large numbers of overload factors were generated using this program and were compared to several types of discharge overload probability, over a wide range of conditions.

The probability of one or more overloaded cycles in two consecutive cycles was found to be a valid approximation of overload factor for undersaturated

conditions, but tended to underestimate overload factor as traff w approached capacity. Combinations of more than one discharge verload probability were found to provide a more accurate surrogate fo overload factor, but were very difficult to calculate. No other single prob ility was found to provide a more accurate and practical epresentation of load factor over the entire rang of conditions than the probability of at least e overloaded cyc in two consecutive cycles.

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Chapter 1 - Introduction

1.1 BACKGROUND

Traffic flow through an urban roadway network is controlled by signalized intersections. Evaluation of signalized intersection performance is currently carried out using delay as the primary measure of effectiveness. In Canada, the quality of operation of signalized intersections is defined primarily by average overall delay, although several other measures of effectiveness, such as the probability of clearance and the number of stops, are also in use (1). The Highway Capacity Manual (2) used in the United States of America applies the average stopped vehicular delay as the sole characteristic of the Levels of Service. Overflow queues, delay, number of stops and queue lengths are used as the primary measures of effectiveness in Australia (3), with fuel consumption, exhaust emissions and cost as secondary measures.

The primary characteristic upon which the levels of service were based in the 1965 American Highway Capacity Manual (4) was the load factor, defined as the ratio of fully loaded cycles to the total number cycles during an evaluation period. The load factor was measurable, but no procedure was initially available for the calculation of load factors from traffic data. This limitation was one of the reasons for the adoption of delay as the basis for the levels of service in the subsequent edition of the Highway Capacity Manual (2).

Numerous forms of delay are currently in use, however, virtually all include a uniform component and an overflow component. The uniform portion of delay is caused by the operation of the signal, in that movement is prevented during the red interval of each cycle. Overflow delay occurs when more vehicles arrive during a cycle than can be serviced during the green interval of that cycle. This overflow component consists of two portions, continuous overflow and random overflow. Continuous overflows are caused by the mean of arrivals per cycle exceeding cycle capacity, while random overflows occur when cycle by cycle variation in the number of arrivals causes an overflow condition. Random overflows will rarely occur when the mean of the arrivals is much less than capacity.

Uniform delay and continuous overflow delay can be determined analytically using queuing theory (5). The nature of random overflow delay, however, is not well defined and additional evaluation tools which relate to random overflows have been proposed. An exact field measurement of delay is difficult (6), and the estimation of delay values using analytical formulae may result in values that vary significantly with the nature of the situation under investigation.

The load factor concept (4) was an attempt to provide a measure of effectiveness based on the presence and number of fully loaded and overloaded cycles. The 1984 Canadian Capacity Guide proposed a similar measure, called the probability of clearance, that was not only measurable but could be calculated.

An additional signalized intersection evaluation tool, related to the random overflow component of delay, was proposed by Teply in 1993 (7) for inclusion in the Second Edition of the Canadian Capacity Guide for Signalized Intersections. This measure, called the overload factor, was defined as the ratio of the number of overloaded cycles to the total number of cycles observed. An overloaded cycle was considered to be one in which the number of vehicles arriving exceeded capacity, or one in which the arrivals during the cycle plus the number of vehicles remaining after the previous cycle exceeded cycle capacity. The overload factor was intended to provide a means of evaluating specific lane problems, and to provide insight into the feasibility of network coordination. In addition, the overload factor concept was found to lend itself to estimation of random queue length variations (8), and to be valuable for the design of both turning lane/bay lengths and signal timing (9).

Previous research into the overload factor concept has indicated that the overload factor is measurable, and that simulated overload factors can be validated using field data (7). Although the overload factor is not directly calculable, early research results have indicated that average overload factors can be approximated by the probability of having at least one overloaded cycle in two consecutive cycles following a cycle that was not overloaded. This probability is not difficult to calculate and is proposed as a surrogate for the overload factor in the Final Draft of the Second Edition of the Canadian Capacity Guide for Signalized Intersections (10).

1.2 RESEARCH OBJECTIVES

The primary objective of this research was to investigate the relationship between overload factor and various probabilities of overload, and to validate or refine the probability surrogate for overload factor proposed by Teply. Practical application of the research results was to be realized through inclusion of the probability surrogate for overload factor in the Second Edition of the Canadian Capacity Guide for Signalized Intersections. Related research objectives included the following:

- to determine if a more accurate probability or combination of probabilities could be found to model the overload factor, and

- to consider the effect of the distribution of stopline capacities on the simulation of overload factors.

This research was based on data collected under typical summer conditions in Edmonton, Alberta. Only single intersection approach lanes with one permitted movement and a steady arrival mean over the evaluation time were considered. These data collection limitations provided a practical research base.

1.3 THESIS ORGANIZATION

A review of related previous research is presented in Chapter 2, "Literature Review".

Chapter 3, "Field Data Collection", describes the collection of overload factor data. The rationale for the selection of the various survey locations and the method of data collection are presented, along with a description of the sites and surveys. Chapter 3 also contains the results of the initial data reduction, and discusses the limitations of the data collection.

The distribution of vehicle arrivals in the lane under observation is analyzed in Chapter 4, "Distribution of Vehicle Arrivals". The actual measured distribution and the Poisson distribution, commonly used to model arrivals in an urban setting, are compared.

Chapter 5, "Variation in Stopline Capacity" presents a simple proposed capacity model based on cycle capacities observed during the field data collection. This analysis provided insight into an area wherein little previous research had been carried out.

The two computer programs developed and used to calculate probabilities of overload and to simulate overload factors are described in Chapter 6, "Computer Programs". The algorithms, as well as the validation of the programs, using measured overload factors, are discussed.

Chapter 7, "Data Analysis", presents the output from the simulation and calculation programs, and compares the overload factor to several probabilities of overload.

Conclusions and findings from this research are presented in Chapter 8, "Conclusions". Recommendations for further study are also included in this chapter.

Appendix A contains tables of all field data collected and detailed descriptions of each survey site, including drawings of each surveyed intersection approach. In addition, signal timing sheets and traffic volume counts for each site are included in this appendix.

A sample arrival data analysis spreadsheet is included in Appendix B. Plots of the observed arrival frequencies and Poisson probabilities not included in Chapter 4, and plots of observed arrivals per cycle for all surveys are also presented in Appendix B.

Appendix C contains the plots of observed cycle capacity frequencies and normally distributed frequencies that were not included in Chapter 5.

The source code listings for the PRADOL and DISCAPOS computer programs are included in Appendix D, along with the frequency plots of simulated overload factors that were not included in Chapter 6. Sample output sheets from the random number check program and a plot of the distribution of generated random numbers are also included in this appendix.

Chapter 2 - Literature Review

2.1 LOAD FACTOR

The 1965 Highway Capacity Manual (4) used load factor as the characteristic upon which the levels of service for signalized intersections were based. The load factor was defined as the ratio of the number of green intervals that are loaded or fully utilized by traffic to the total number of green intervals available for that lane during the same period. A loaded cycle was considered to occur when vehicles were available to enter the intersection during the entire green interval in the lane under observation. The ending of a loaded phase may, but will not necessarily require one or more vehicles to stop. Load factors can range from 0.0 to 1.0, representing conditions where none or all of the cycles evaluated are fully utilized. Although the load factor could be measured in the field, a procedure for the calculation of load factor was not initially available.

Field measurement of load factors resulted in one data point in a distribution of load factors for each field survey. A simulation study using random arrivals and constant capacity was carried out to generate additional load factors under constant conditions, and concurrently determine average overall delay (11). A subsequent study used a more complex arrival headway distribution and a two-stage capacity model (12). This research used event based simulations to allow the simultaneous calculation of delay. The results of these studies indicated that good agreement between measured and simulated load factors was possible, and that modifications to the existing load factor limits used for the levels of service were required. In addition, it was found that load factor related well with delay only below load factors of 0.6; above this point the relationship was unstable.

Based on the simulation studies, a computational procedure for estimating load factor was proposed by Miller in 1968 which considered the effects of queue spillover from one cycle to the next (13). The formula used an exponential relationship involving arrival and saturation flows, the effective green interval and cycle time. This concept was explored by Chang and Berry in a study on the capacity of signalized intersections in 1969 (14), although validation of Miller's proposed formula using field measurements was not within the scope of the research.

The importance of considering the effect that preceding cycles have on the cycle under consideration, and the difficulty in measuring load factors when upstream or downstream conditions influence behaviour at the intersection under observation were noted by Reilly and Seifert in 1970 (15). A cycle failure rate, defined as the probability of at least one more vehicle than capacity arriving during a given cycle, was proposed (16), and was subsequently used as an analysis tool in intersection capacity research (17). A comparison between Miller's calculated load factor and probability of queue failure, and the cycle failure rate for one example situation was carried out by Messer and Fambro, but was not investigated in detail (18).

Although the concept of load factor was well defined, field measurement of load factors was found to be difficult, due to the lack of physical confirmation of a zero length overflow queue and the variability in measured load factors at one location. This variability is due to the variation in arrivals and discharge around a mean (constant or changing), resulting in a distribution of load factors around a mean value of load factor. The numerous measured load factors needed to determine the nature of their distribution are impossible to collect, as base conditions such as arrival and discharge means vary significantly from day to day even at one location and time of day. The load factor could not be applied for the design of signalized intersections, and in light of the difficulties described above was not widely accepted as an evaluation tool. The load factor was therefore superceded by average stopped vehicular delay as the basis for the levels of service in the 1985 Highway Capacity Manual (2).

The concept of a measure of effectiveness based on cycle by cycle evaluation of overloads was not abandoned after 1985, and related intersection analysis tools were proposed and used in conjunction with delay. The 1984 Canadian Capacity Guide (1) included the probability of clearance as one of several additional evaluation methods. The probability of clearance was defined as the probability that the number of vehicle arrivals during a cycle would be less than cycle capacity. This measure considered only the arrivals during a given cycle, and did not evaluate the impact of vehicles that remained to be discharged from previous overloaded cycles. The probability of clearance would therefore underestimate actual conditions as the probability of encountering an overloaded cycle increased. This concept was generally not well understood by practitioners, and limited the usefulness of the probability of clearance.

In 1993 Teply proposed a modified measure of effectiveness called the overload factor for the Second Edition of the Canadian Capacity Guide which considered signalized intersection lane operation on a cycle by cycle basis (7). The overload factor was identical to the cycle failure rate described previously by Drew and Pinnell, and reflected the percentage of cycles wherein at least one vehicle was unable clear the intersection during the first available green interval.

The work by Teply forms the basis for this research, and is therefore reviewed in detail in the following sections.

2.2 PROBABILITY OF ARRIVAL OVERLOAD

The distribution of arrivals in a lane from cycle to cycle compared to the number of vehicles cleared during the green interval of each cycle defines the probability of encountering an overloaded cycle. For most urban signalized intersections, the Poisson distribution can be used to represent the number of vehicles arriving during a given cycle, provided that signal timing is constant and the mean of the distribution of arrivals does not vary significantly (1, 19, 20, 21, 22). It is important to note that the distribution of the arrivals within each cycle is not considered here; the Poisson distribution indicates the probability of encountering exactly "x" arrivals per cycle. Therefore, provided that the preceding cycle was not overloaded and no leftover queue exists, the probability of an overloaded cycle is the probability that the number of arrivals in that cycle is greater than capacity.

This probability is defined as the probability of an arrival overload, and is shown in the formula below as 1.0 minus the probability of not having an overload, such that the summation of arrival probabilities is from 0 to capacity, rather than from capacity to infinity. It appears that for practical purposes the probability of having a given event occur approaches zero near a limit of approximately 2 times the average arrival rate (3):

$$P(x > X) = 1.0 - (\Sigma((e^{-m} * m^i) / i!)) \qquad \text{for } i = 0 \text{ to } i = X$$

where: x = the number of arrivals in a given cycle

X = the capacity of a cycle

e = the basis of natural logarithms

m = the average number of arrivals in per cycle

The probability of arrival overload does not include the probability that leftover vehicles from the previous cycle may be present in the cycle being considered, and therefore accurately represents only cases where capacity significantly exceeds the average number of arrivals and the likelihood of consecutive overloaded cycles is consequently small.

The probabilities of an arrival overload as described above are calculated for a range of mean arrivals and are presented as Figure 2.2.1, adapted from Teply (7). Due to the probability of having zero arrivals in a cycle, particularly for the smaller values of average arrivals (m), the curves are not symmetrical about their midpoints. The probability of arrival overload is therefore less than 0.50 when the mean arrivals per cycle are equal to cycle capacity. For example, with m = 8 and X = 8, the probability of an arrival overload is 0.41.

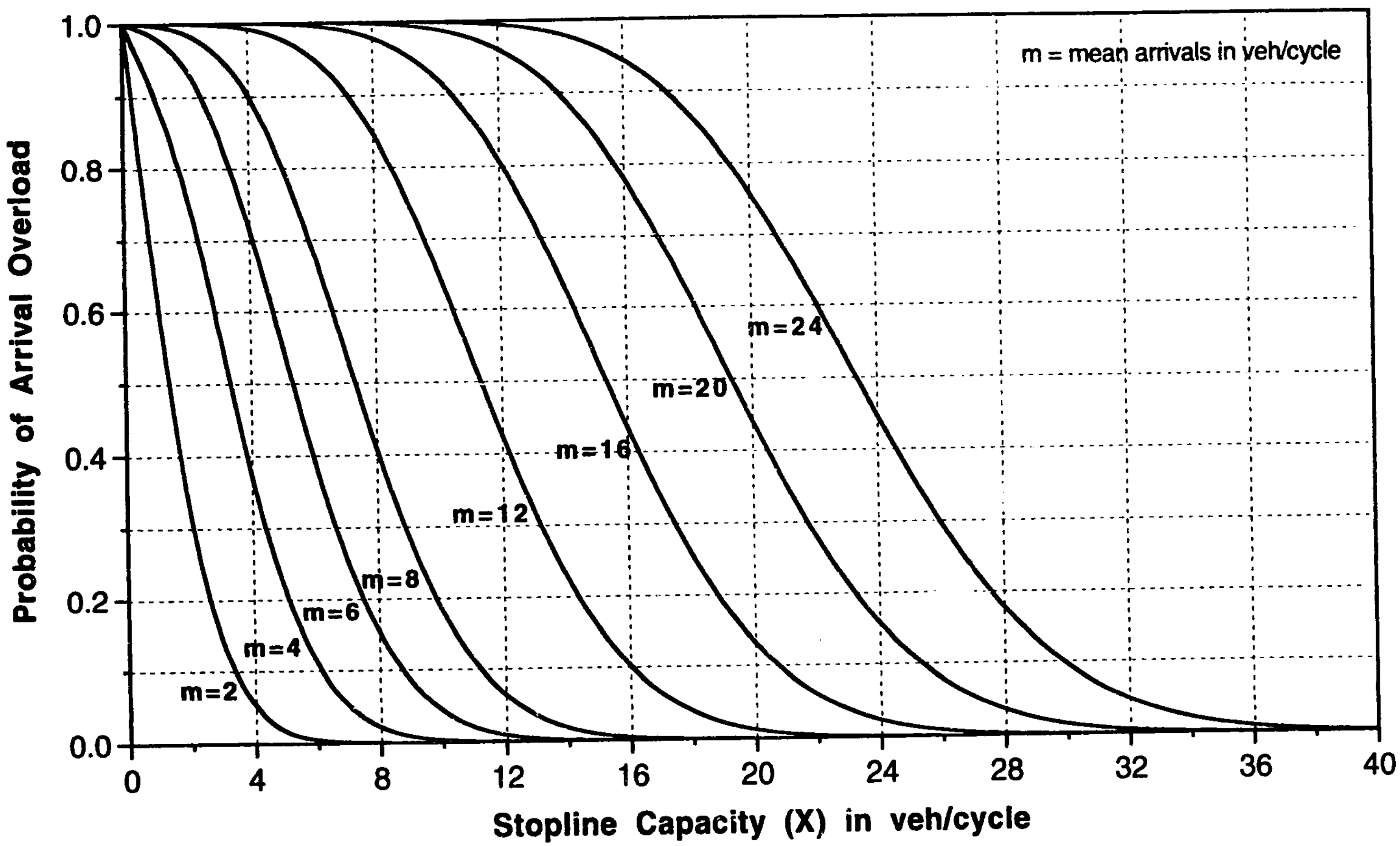


Figure 2.2.1 Probability of Arrival Overload for a Range of Mean Arrivals

2.3 PROBABILITY OF DISCHARGE OVERLOAD

Whenever a cycle is overloaded, by definition at least one vehicle remains in queue at the end of the green interval. This vehicle arrived in the overloaded cycle, and therefore is not included in the number of arrivals determined for the subsequent cycle. Any leftover vehicles will clear first in the following green interval, and will reduce the remaining capacity available to clear the vehicles that arrived in the second cycle of the series. If the number of arrivals in the second cycle is less than capacity minus the number of leftover vehicles, then no overload occurs and the situation returns to that represented by the probability of arrival overload.

If large numbers of leftover vehicles remain after an overloaded cycle, however, it is possible that the cycles following the overloaded cycle may also be overloaded, even with fewer arrivals than capacity. For a lane with a capacity of 6 veh/cycle and mean arrivals of 4 veh/cycle, 8 arriving vehicles (according to the Poisson distribution a 10% probability exists that this event will occur) will result in two leftover vehicles which will need to be cleared at the beginning of the subsequent cycle. The portion of capacity remaining for use by vehicles that arrive in the second cycle is therefore 4 vehicles. The probability of an overload in the second cycle is no longer equal to the probability of 7 or more arrivals, but rather the probability of 5 or more arrivals. This results in a greater probability that the second of two consecutive cycles will be overloaded. This probability is not represented by the arrival overload probability curves shown on Figure 2.2.1, and is defined as the probability of discharge overload. The difference between the probability of an arrival and a discharge overload is subtle, and was generally not well understood by traffic system designers and analysts.

The probability of discharge overload changes with the number of consecutive cycles considered. The form of several different types of discharge overload probabilities are shown graphically on Figure 2.3.1. As groups of consecutive cycles are considered, the probabilities of events in subsequent cycles are dependent on the probabilities of events in the

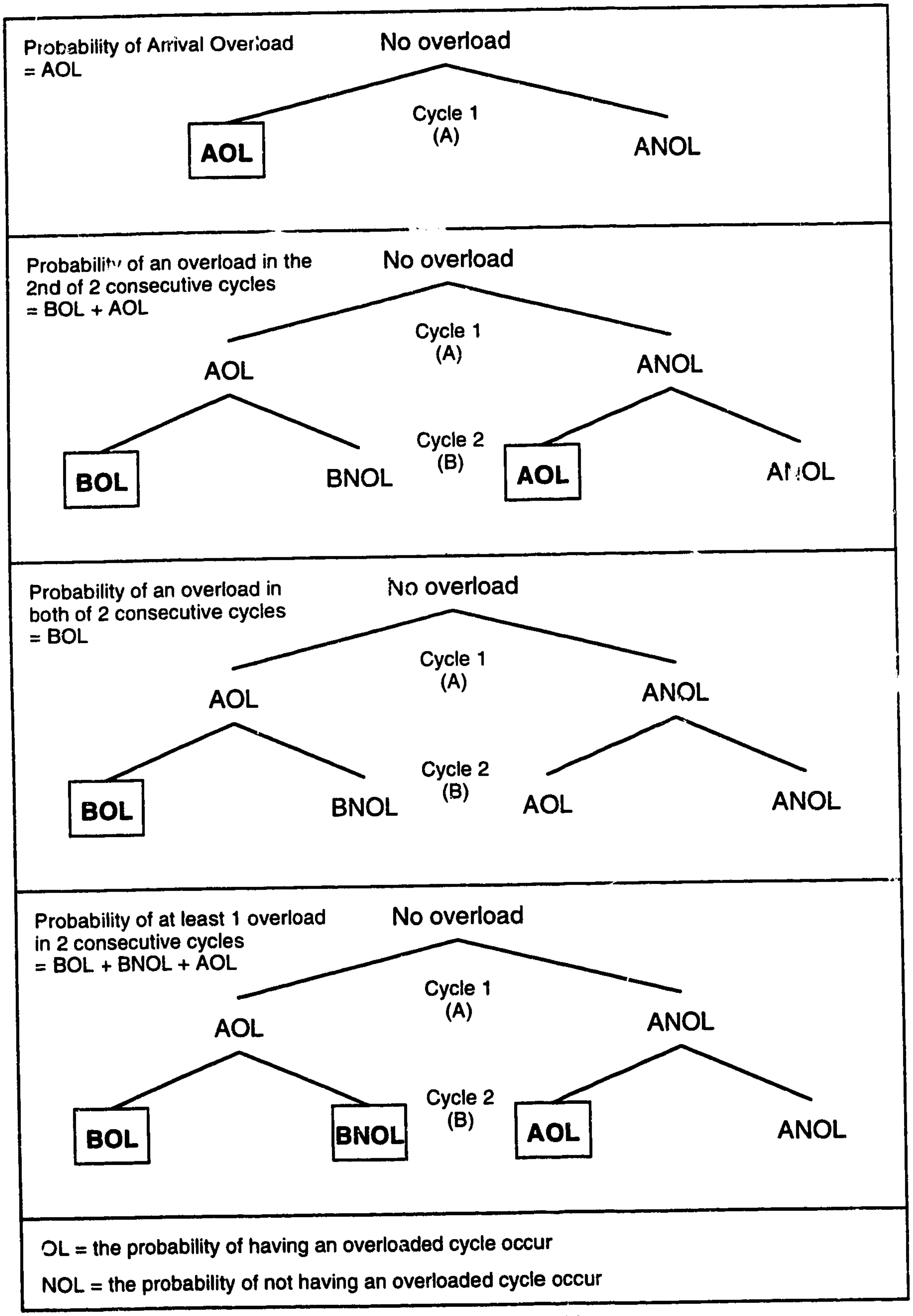


Figure 2.3.1 Four Types of Discharge Overload Probabilities

previous cycle. The probability of an overload in the cycle following an overloaded cycle (shown as the BOL probability on Figure 2.3.1) is therefore different than the probability of an overload in a cycle following a not overloaded cycle (AOL).

Although the calculation of the probability of discharge overload is a simple summation of probability products, as subsequent cycles are considered the number of calculations increases geometrically. For example, for the fifth consecutive cycle of a lane with a mean arrival rate of 16 veh/cycle, the probability of 40,358,373 possible sequences of events must be calculated.

The calculation of the probability of an overload in any, some or all of a group of consecutive cycles is computationally intensive but not difficult. The probability tree resets to the starting condition (no overload in the previous cycle) whenever a cycle with no overload occurs. Therefore, the probability of no overload in a cycle following a previous cycle with no overload is always the same, and the dependent probability is the probability in the first cycle raised to the power of the number of cycles under consideration. If this probability is subtracted from 1.0, the probability of an overload in at least 1 of the previous "n" cycles results. This probability is designated as P(1+ in n) and is shown in the following formula:

$$P(1+\text{ in } n) = 1.0 - (P(x \leq X))^n$$

where: x = the number of arrivals in a given cycle

X = the capacity of a cycle

n = the number of consecutive cycles being considered

A plot of these probability curves for an average arrival rate of 6 veh/cycle is adapted from Teply (7) on Figure 2.3.2. As the number of consecutive cycles increases, the probability that either the current cycle or at least one of the previous cycles will be overloaded increases rapidly. For example, for the given arrival rate and at a capacity of 6 veh/cycle it is virtually certain that at least one out of ten consecutive cycles will be overloaded.

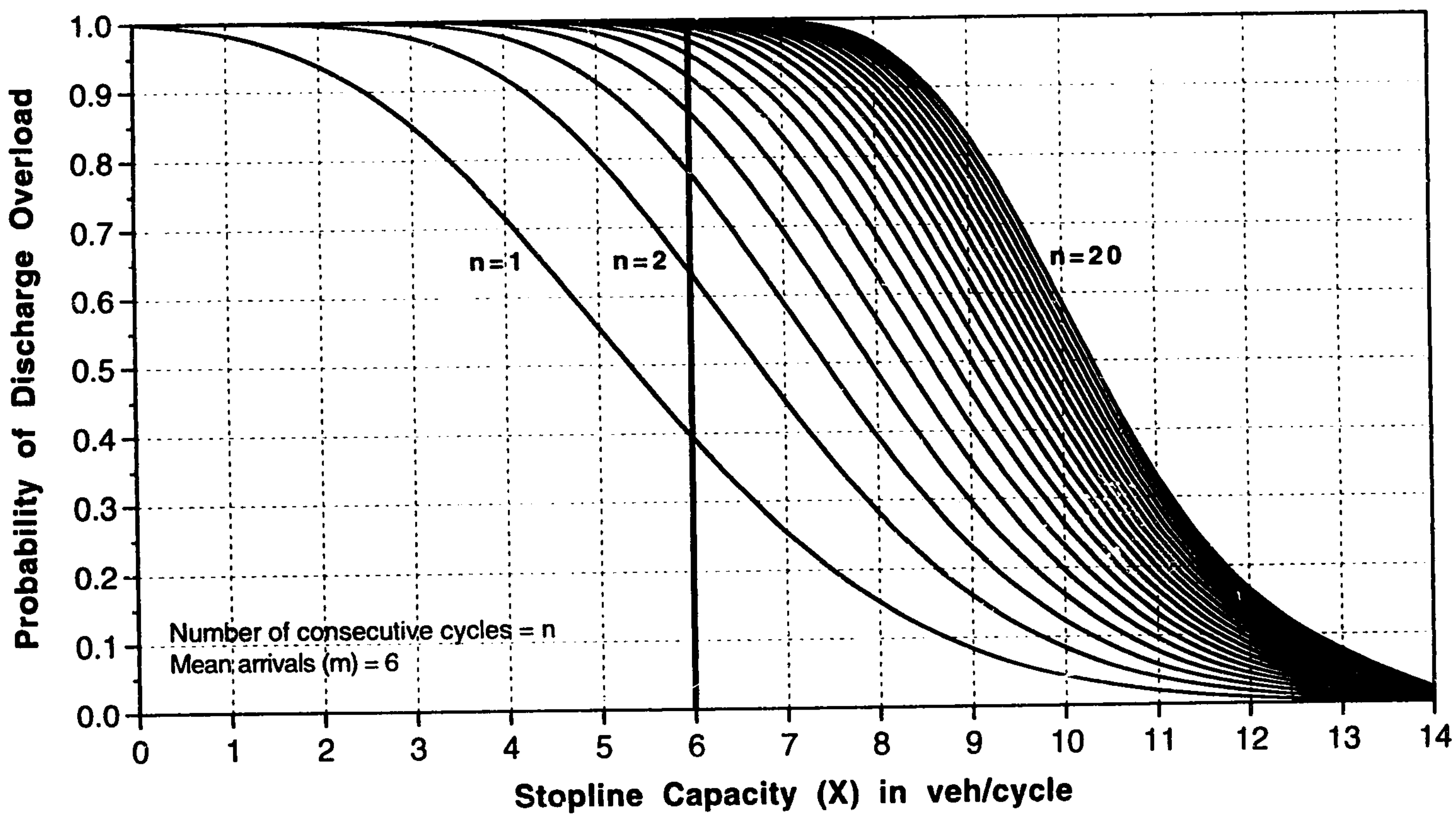


Figure 2.3.2 Probability of at Least 1 Overload in "n" Cycles for Mean Arrivals of 6 veh/cycle

2.4 FIELD SURVEYS AND SIMULATION

Overload factors were measured under actual conditions and simulated on a microcomputer in a pilot project at the University of Alberta in 1993 directed by Dr. S. Teply (7). Two locations were observed under three different sets of traffic conditions for the field study. Arrival rates were counted either at the stop line or the back of the queue (if present), while capacity was determined as the average of the number of vehicles discharged in all fully loaded or overloaded cycles. In addition, saturation flow data was obtained at the time of the surveys for comparison with the observed capacities. The determination of an overloaded cycle was carried out by observing the last vehicle to join the queue during the red interval. If this vehicle did not clear during the subsequent green interval, the cycle was recorded as overloaded.

This method of counting overloaded cycles may have been somewhat conservative. Cycles wherein vehicles arrived during a green interval but were unable to clear the intersection were not recorded as overloaded. This eliminated the difficulty of determining whether or not a vehicle that arrived at the back of a queue would have been able to reach the stop line during the green interval had queued vehicles not been present. The locations studied had short green intervals and low green ratios, hence the percentage of arrivals during the green interval was not great and the conservative method of counting did not significantly influence the number of overloaded cycles recorded.

A total of ten surveys were carried out at two locations, with an average of about 25 cycles per survey. Each lane under investigation had only one permitted movement, to allow accurate determination of stop line capacity. A summary of the conditions and results of the surveys, is shown on Table 2.4.1.

The mean arrivals and capacities determined from the field surveys were used as input for a cycle by cycle simulation spreadsheet, using a Poisson

Table 2.4.1 Summary of Survey Conditions and Results From a 1993 Overload Factor Study

Survey Number	Intersection	Period No. of Cycles	Direction Lane No.	Arrival Mean m (veh/cycle)	Cycle Capacity X (veh/cycle)	Measured Overload Factor	Simulated Overload Factor
1	87 Avenue 109 Street	P M 21	E B 2	10.8	12.9	0.286	0.226
2	87 Avenue 109 Street	P M 22	E B 2	9.3	12.2	0.227	0.160
3	87 Avenue 109 Street	P M 26	E B 2	9.2	12.6	0.154	0.111
4	72 Avenue 114 Street	A M 22	W B 1	5.9	7.6	0.455	0.226
5	72 Avenue 114 Street	P M 27	W B 1	5.1	7.7	0.111	0.066
6	72 Avenue 114 Street	P M 26	W B 1	5.3	7.1	0.192	0.175
7	72 Avenue 114 Street	P M 36	W B 1	5.8	6.8	0.222	0.281
8	72 Avenue 114 Street	P M 59	W B 1	5.2	7.0	0.169	0.156
9	87 Avenue 109 Street	P M 27	E B 2	8.7	12.2	0.074	0.101
10	72 Avenue 114 Street	A M 26	W B 1	6.6	7.0	0.500	0.515

distribution for the vehicle arrivals. The lane capacities for each survey were rounded to the nearest whole number, and simulated as constant values. The simulated data consisted of 10 groups of 10 series of 20 computer runs representing 20 consecutive cycles, for a total of 40,000 cycles and 2000 overload factors per data set. The overload factors were averaged, and the average standard deviation of the data from each 20 cycle simulation was determined.

The results of the pilot project indicated that the simulated results could be adequately represented by the probability of at least one overload in two consecutive cycles, denoted as P(1+ in 2), for all the data sets. The use of this probability of discharge overload as a surrogate for overload factor has been recommended in the Final Draft of the Second Edition of the Canadian Capacity Guide for Signalized Intersections (10).

Chapter 3 - Field Measurement of Overload Factors

3.1 INTRODUCTION

Overload factors were measured at ten locations in Edmonton, Alberta to provide data for the validation of a cycle by cycle lane simulation program. A total of 1069 cycles were observed in 21 groups. The data were collected between July 16 and August 30, 1993, during the AM and PM peak hours. The sites chosen for the surveys provided a range of green intervals, volume to capacity ratios and intersection geometries.

The surveys were carried out by observing the site from a vantage point where both the stopline and the end of the queue could be clearly seen. A minimum of 20 consecutive cycles were considered necessary to form a valid data set, however significantly greater numbers of cycles were generally observed to enhance accuracy. Although observation of both the stopline and the end of the queue was required, it was found that one person could successfully carry out both portions of the survey.

3.2 SITE SELECTION

Several criteria were used to determine the suitability of a site for observation. From previous research it was determined that overload factors were generally less than 0.005 (0.5%) for lanes with an approach volume to stopline capacity ratio of less than 0.50. To measure an overload factor of 0.005 or less, observation of very large numbers of consecutive cycles (>100) with relatively constant traffic flow patterns would be required. The chosen locations therefore had anticipated volume to capacity ratios greater than 0.50, with the exception of one site which was used to confirm the hypothesis that the overload factor would be very close to zero at lower volume to capacity ratios. The expected volume to capacity ratios were determined by prior observation and from a City of Edmonton map that identified locations with high V/C ratios. Additional site selection criteria based on vehicle arrival patterns are discussed in Chapter 4.

Once an intersection with an appropriate V/C ratio was selected, one lane was chosen for evaluation. Only exclusive through lanes or unopposed left turn lanes were considered for observation at this time, as relatively consistent stopline capacity between cycles was required. The variation in the number of vehicles cleared during a cycle for lanes with all or some vehicles turning across opposing traffic or pedestrians would make simulation difficult, particularly at lower volume to capacity ratios.

In addition, it was important that significant numbers of vehicles did not leave the queue in the chosen lane, either to enter a turning lane or bay or to enter a less utilized lane. To limit these occurrences, turning lanes or bays adjacent to the chosen lanes were required to be longer than the farthest average queue reach. Shorter turning lanes or bays were acceptable if the number of turning vehicles was less than 5% of the through traffic volume. To limit the number of vehicles moving into less utilized lanes, the lane chosen for observation at an intersection was generally the one with the shortest average queue length, based on prior observation of the intersection.

The chosen sites represented a variety of roadway types, geometric conditions, green intervals and cycle lengths, as described in Section 3.4. Surveys were carried out during the morning and afternoon peak hours exclusively, as sufficient traffic volumes to cause overloaded cycles were generally present only during the peak hours.

3.3 SURVEY METHODOLOGY

Prior to beginning a count, the chosen intersection was observed for a period of time and the green, amber and red intervals were determined using a stopwatch. A suitable vantage point for observing the intersection was chosen, and basic parameters such as the date, time and location of the survey, the signal timing plan, the prevailing weather conditions and a sketch of the intersection showing the chosen lane were recorded.

The data collection process was related directly to the formation and dispersion of queues, hence, a cycle was defined as a red interval followed by a green and then an amber interval (an effective red interval followed by an effective green interval). Each cycle therefore began with the formation of a queue, rather than with the discharge of a queue already present at the start of the green interval.

Standing queue lengths were counted beginning with the queue at the start of the red interval, followed by the queue at the beginning of the subsequent green interval. Once the green interval commenced, the end of the queue was observed to determine the last vehicle to join the queue. A vehicle was assumed to join the queue if it slowed to approximately 5 km/h, even if the distance between the observed vehicle and a stopped vehicle in the queue was greater than would normally be expected for queued stopped vehicles. Vehicles that were forced to decrease their speed due to the presence of a moving queue were also considered to have joined the queue. Although it was often found to be difficult to determine whether or not a given vehicle was decelerating to join a moving queue, the appearance of brake lights was used as an indication that the vehicle was to be included as part of the queue.

The last vehicle to join the queue, representing the farthest reach of the queue, was continuously observed as it proceeded toward the stopline. If this vehicle cleared the intersection (crossed the stopline) before the start of the red interval, then any additional vehicles which were also available and able to cross the stopline were added to the farthest reach of queue count to determine the number of vehicles cleared during the cycle. If the last vehicle to join the queue was unable to clear the intersection during the first available green interval, then the cycle was noted as overloaded, and the number of vehicles stopped up to and including the last vehicle to join the queue were noted. The number of vehicles unable to clear the intersection after having joined the queue were recorded as the queue at the beginning of the subsequent red interval (the start of the following cycle).

Cycles were noted as being fully loaded when the last vehicle to join the queue was the final vehicle to clear the intersection during the effective green interval. As well, a cycle could be defined as fully loaded if a dense platoon of vehicles arrived as the last of the queued vehicles was clearing the intersection, even if no deceleration was required by the arriving vehicles, provided the arrival rate was approximately the same as the flow rate of the clearing queued vehicles (the saturation flow rate).

Some judgment on the part of the person carrying out the surveys was required to determine whether or not a vehicle joined a stationary or moving queue. Although decisions of this nature were not required frequently, the decisions could have had significant impacts on the measured overload factor for the survey. For example, if four overloaded cycles were recorded for a 50 cycle period at a given location, two cycles incorrectly defined as overloaded would have caused a 50% error in the measured overload factor. For this reason, the cycles during a survey where judgment was applied were noted on the field data sheets, along with the reasons for the decision.

Classification of vehicles by type was not carried out during the surveys; hence queue lengths and numbers of vehicles cleared during a green interval are in vehicles rather than in passenger car units (pcu). This was to minimize the number of variables being recorded, and to ensure that the required information was not compromised by attempting to observe too many additional variables. A correction was applied for any motorcycles or heavy trucks in the queue, however, in cycles that were either fully loaded or overloaded. Motorcycles were counted as 0.5 vehicles, while heavy trucks (those with more than 2 axles) were represented by 2 vehicles. Classification of trucks into smaller categories was not considered practical. If the pace of the counting permitted, the cycles where these corrections were applied were noted on the field data sheets.

Any changes in weather or traffic conditions during the course of the survey were noted on the field data sheets. Parameters calculated from the data collected during each survey consist of the following (on a per lane basis):

1. the average standing queue at the start of the green interval

   $Q_{ave} = Q_{te} / n$

   where: Q_{te} = the total number of vehicles counted in queue at the start of all green intervals

   n = the total number of cycles observed

2. the average number of vehicles arriving per cycle

   $m = M_{te} / n$

   where: M_{te} = the total number of vehicles arriving at the intersection in the observation period

   n = the total number of cycles observed

3. the average stopline capacity per cycle

   $C_c = \Sigma X / n_{FL}$

   where: X = the number of vehicles observed crossing the stopline in a fully loaded or overloaded cycle

   n_{FL} = the total number of fully loaded or overloaded cycles

4. the volume to capacity ratio

   $= m / X$

   where: m = the average number of vehicles arriving per cycle

   X = the average stopline capacity per cycle

5. the average arrival flow rate in vehicles per hour

   $q = M_{te} / t_e$

   where: M_{te} = the total number of vehicles arriving at the intersection in the evaluation period

   t_e = the evaluation time in hours

6. the calculated saturation flow rate

$$s_{calc} = (X / g_e) * 3600$$

where: $X =$ the average stopline capacity per cycle

$g_e =$ the effective green interval in seconds

7. the progression factor

$$PF = (M_r / M_{te}) * (1 - g / c)$$

where: $M_r =$ the number of vehicles arriving during the red interval

$M_{te} =$ the total number of vehicles arriving at the intersection during the evaluation period

$g =$ the displayed green interval in seconds

$c =$ the cycle length in seconds

8. the load factor

$$LF = n_{FL} / n$$

where: $n_{FL} =$ the total number of fully loaded or overloaded cycles

$n =$ the total number of cycles observed

9. the overload factor

$$OF = n_{OL} / n$$

where: $n_{OL} =$ the total number of overloaded cycles

$n =$ the total number of cycles observed

In addition, the variance of both the arrival and capacity data was determined, and these date were grouped to allow the preparation of frequency plots.

Survey locations are identified by the letters A to J, and the individual surveys are numbered from 1 to 21, in the order in which they were carried out. Pertinent data from each survey are summarized on Table 3.3.1. Spreadsheets containing the field data and including the calculations described above are included in Appendix A as Tables A-3.1 to A-3.21.

Table 3.3.1 Summary of Survey Data

Survey Number	Site	Date	Time	No. Cycles	m	m/s2	X	[illegible] (V/C)	Prog. Factor	Load Factor	No. OL	Overload Factor
1	A	16-Jul-93	07:15 to 09:30	64	5.25	0.62	9.09	0.58	[illegible]	0.17	4	0.06
2	B	16-Jul-93	15:15 to 17:15	72	14.51	1.02	22.17	0.66	0.33	0.08	0	0.00
3	A	19-Jul-93	07:30 to 09:30	56	6.05	0.85	8.76	0.69	0.73	0.30	2	0.04
4	C	19-Jul-93	15:30 to 16:30	37	7.81	1.17	11.67	0.67	0.57	0.08	2	0.05
5	D	20-Jul-93	15:55 to 17:25	54	10.30	1.04	12.80	0.80	0.56	0.37	10	0.19
6	E	21-Jul-93	07:30 to 08:30	36	11.11	0.77	16.75	0.66	0.44	0.11	2	0.06
7	F	21-Jul-93	16:00 to 17:30	54	16.07	1.11	18.50	0.87	0.31	0.48	13	0.24
8	G	23-Jul-93	15:45 to 17:15	54	19.15	1.44	20.03	0.96	0.33	0.72	24	0.44
9	D	26-Jul-93	16:00 to 17:45	63	9.76	1.04	14.00	0.70	0.50	0.13	6	0.10
10	H	27-Jul-93	07:30 to 08:30	40	5.45	1.56	13.00	0.42	0.58	0.00	0	0.00
11	C	27-Jul-93	15:30 to 17:00	54	7.76	0.68	12.75	0.61	0.50	0.15	5	0.09
12	E	28-Jul-93	07:25 to 08:45	49	9.53	0.48	16.75	0.57	0.44	0.16	4	0.08
13	G	28-Jul-93	16:00 to 16:40	24	17.50	1.08	21.10	0.83	0.31	0.42	3	0.13
14	F	29-Jul-93	16:00 to 17:30	55	17.89	0.98	18.26	0.98	0.44	0.86	39	0.71
15	D	12-Aug-93	15:45 to 17:15	56	10.89	1.35	13.50	0.81	0.54	0.29	6	0.11
16	G	13-Aug-93	15:40 to 17:20	54	19.87	2.57	20.11	0.99	0.38	0.87	37	0.69
17	I	25-Aug-93	16:00 to 17:30	55	19.76	1.08	24.14	0.82	0.32	0.23	9	0.16
18	F	26-Aug-93	15:50 to 17:20	54	18.50	0.64	18.85	0.98	0.38	0.89	42	0.78
19	J	27-Aug-93	07:15 to 08:20	50	9.50	1.34	13.22	0.72	0.45	0.18	4	0.08
20	I	27-Aug-93	16:00 to 16:50	32	21.88	0.72	20.78	1.05	0.26	0.84	24	0.75
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.11	12.85	0.77	0.41	0.23	7	0.13

Although all surveys were started after a non-overloaded cycle, several surveys ended on an overloaded cycle. Very high volume to capacity ratios were encountered during these surveys, and large numbers of continuous overloads were occurring. This was not felt to be significant, as the conditions at the end of a cycle influence only the subsequent cycles.

3.4 SITE PARAMETERS

Ten sites (A to J inclusive) were chosen for the field studies as detailed on Table 3.4.1. The approximate locations of the 10 sites are shown on a map of the City of Edmonton (Figure 3.4.1). More detailed survey locations, including the intersection approaches and movements observed are shown on Figures 3.4.2 and 3.4.3, adapted from City of Edmonton base maps. Drawings of intersection geometry for all 10 sites are included with the detailed site descriptions in Appendix A.

The roadways studied ranged from a major four lane arterial (Site G) to a single lane collector (Site A). The shortest green interval observed was 17 seconds at Site A, and the longest was 42 seconds at Sites B and I. Cycle times ranged from 80 to 130 seconds, with the majority of sites having a 100 second cycle length. The average number of consecutive cycles counted was 51.

Through lanes were chosen for data collection at all sites except Site C, where an exclusive and unopposed left turn lane was observed. Drawings of intersection geometry, signal timing plans and the latest traffic volume counts were obtained from the City of Edmonton Transportation Department. The signal timing plans and the traffic volume sheets are included in Appendix A as Figures A-4.11 to A-4.20 and A-4.21 to A-4.30 respectively.

Weather conditions did not influence the collected data other than for Survey 5 at Site D and Survey 20 at Site I, where moderate to heavy rainfall decreased stopline capacities by approximately 10%.

Table 3.4.1 Characteristics of the Field Data Collection Sites

Site	Survey Number	Location	Time	Green Interval	Cycle Length	g/c	Capacity	m/X	Calculated Sat. Flow
A	1 3	72 Avenue WB at 114 Street Lane # 2	AM	17	130	0.13	9.09 8.76	0.58 0.69	1820 1750
B	2	Whyte (82) Avenue EB at 75 Street Lane # 2	PM	42	[illegible]	0.42	22.17	0.66	1860
C	4 11	87 Avenue EB at 109 Street Lane # 1	PM	28	[illegible]	0.28	11.67 12.75	0.67 0.61	1450 1580
D	5 9 15	99 Street SB at 63 Avenue Lane # 3	PM	28	100	0.28	12.80 14.00 13.50	0.80 0.70 0.81	1590 1740 1680
E	6 12	Whyte (82) Avenue WB at 109 Street Lane # 2	AM	36	100	0.36	16.75 16.75	0.66 0.57	1630 1630
F	7 14 18	75 Street SB at Whyte (82) Avenue Lane # 3	PM	37	100	0.37	18.50 18.26 18.85	0.87 0.98 0.98	1750 1730 1790
G	8 13 16	104 Street SB at Whitemud Drive Lane # 2	PM	38	100	0.38	20.03 21.10 20.11	0.96 0.83 0.99	1850 1950 1860
H	10	87 Avenue EB at 170 Street Lane # 2	AM	27	90	0.30	13.00	0.42	1670
I	17 20	Argyll Road EB at 86 Street Lane # 2	PM	42	100	0.42	24.14 20.78	0.82 1.05	2020 1740
J	19 21	Whyte (82) Avenue WB at 99 Street Lane # 1	AM	27	80	0.34	13.22 12.85	0.72 0.77	1680 1650

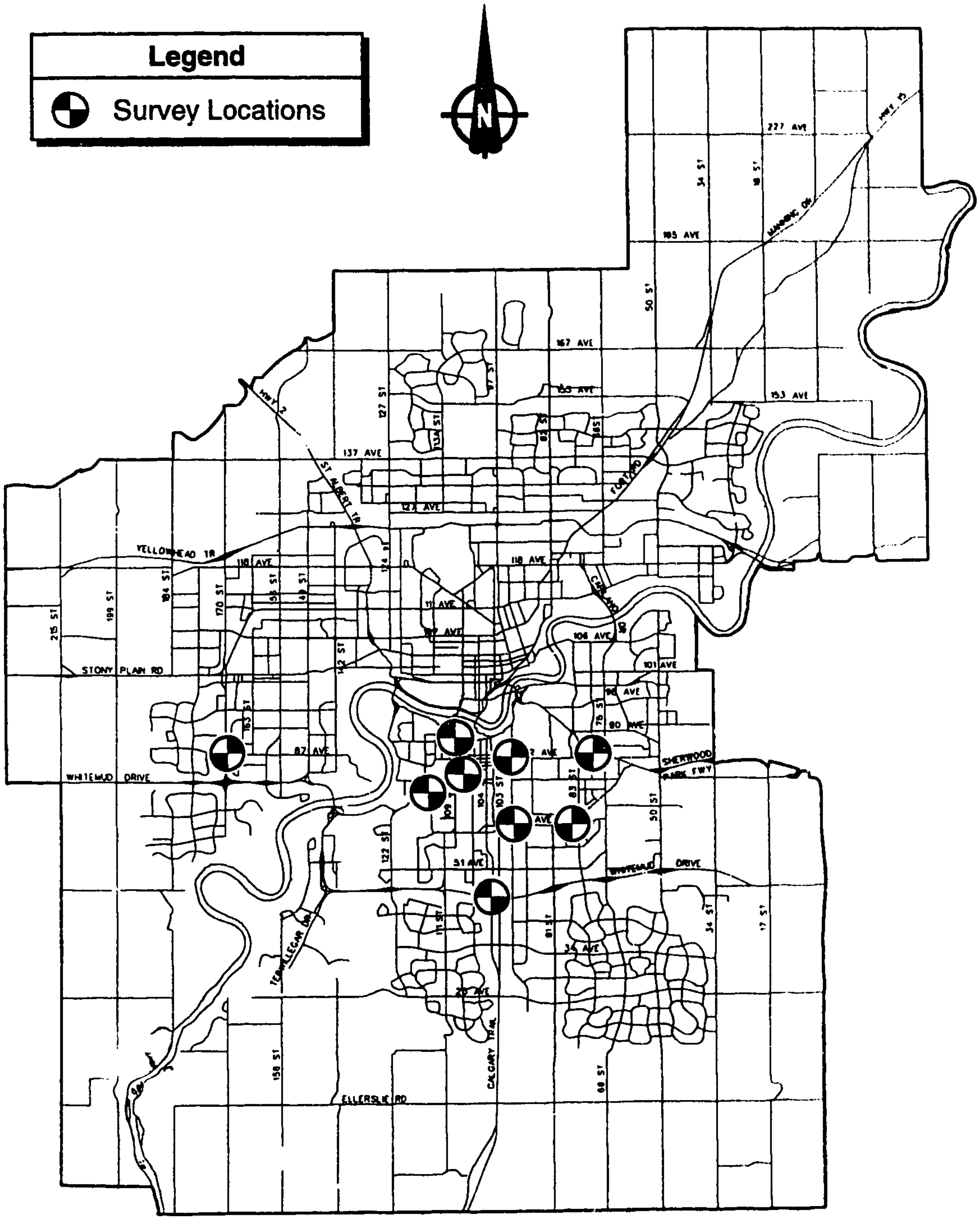


Figure 3.4.1 Locations of Field Data Collection Sites

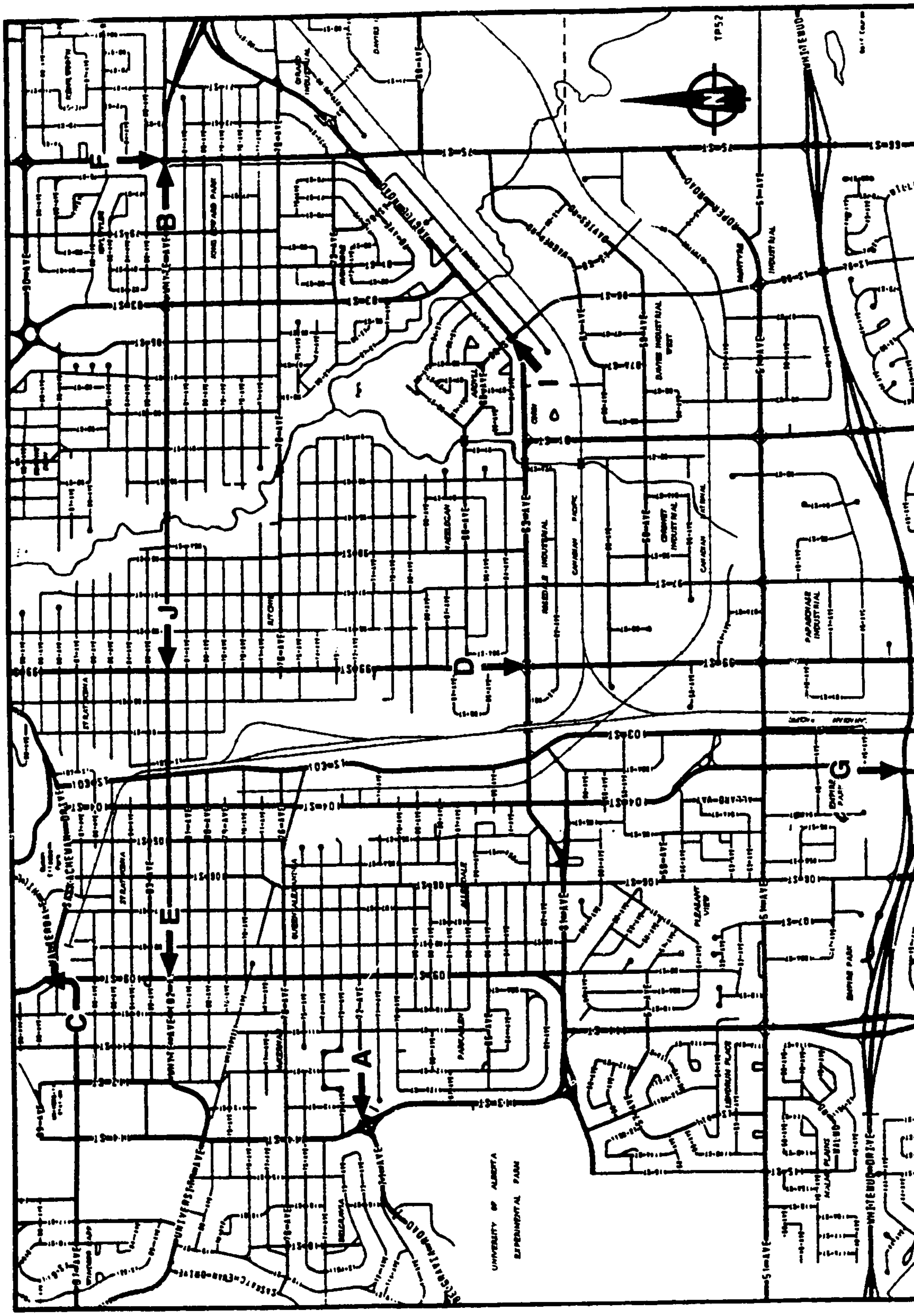


Figure 3.4.2 Location and Movement Observed for Sites A to G, I, and J

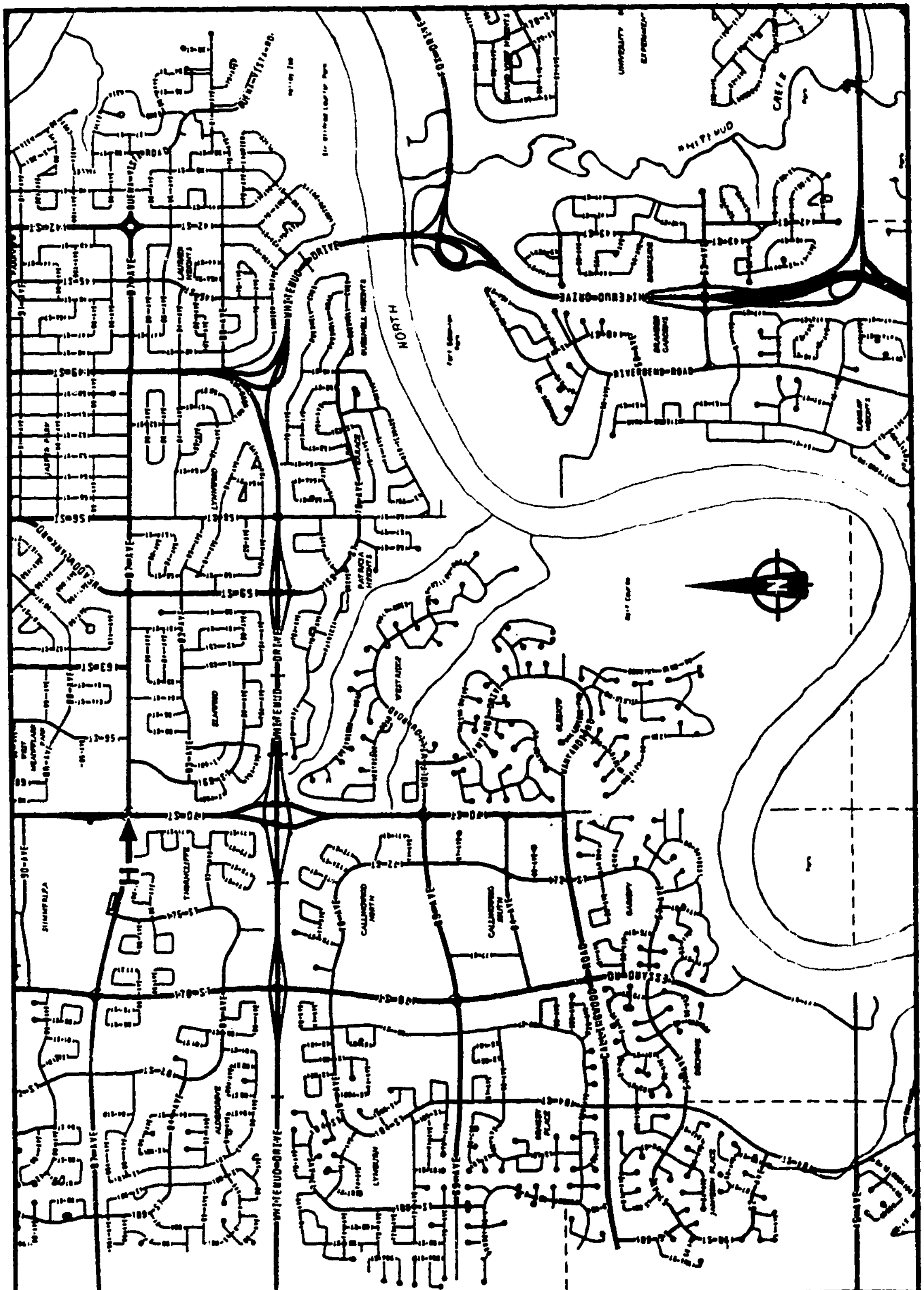


Figure 3.4.3 Location and Movement Observed for Site H

3.5 SUMMARY

The data collected in the 21 surveys are representative of actual field conditions at the time of the observations. Although there were instances where some judgement on the part of the observer was required, the following data analyses did not reveal any systematic errors or discrepancies among the sites and individual surveys. The large number of sites and cycles observed provided an adequate statistical base for further analysis.

The initial experience gained during the pilot project surveys in 1993 and at locations with lower degrees of saturation proved to be valuable during surveys at locations with higher degrees of saturation.

Chapter 4 - Distribution of Vehicle Arrivals

4.1 INTRODUCTION

The Poisson counting distribution is widely accepted as being a practical representation of the distribution of the number of vehicles arriving per cycle at signalized intersections (1, 19, 20, 21, 22). This does not necessarily imply that the vehicle arrival pattern within the cycle is random, rather that the variation in the total number of vehicles that have appeared by the end of the cycle is random.

As part of the data collection process described in Chapter 3, the number of vehicles arriving in each cycle was recorded. These data were investigated to ensure that the Poisson distribution was appropriate for the modelling of vehicle arrivals on a cycle by cycle basis in a computer simulation program.

The assumption of random vehicular arrivals per cycle is subject to two important conditions:

1. that the influence of upstream traffic signals is either eliminated by platoon dispersion over a long distance, or confined within a cycle by having the same cycle length at both signals, and
2. that the variation in queue lengths is not large enough the alter the arrival pattern due to a shifting of the reference point for counting.

The locations chosen for the data collection were selected with these considerations in mind. Specifically, upstream traffic signals were generally at least 500 m from the intersections being observed and had identical cycle lengths. In addition, locations with constantly growing queues (V/C > 1.0) were not chosen.

To confirm that the Poisson distribution was an appropriate representation of the actual arrival patterns recorded during the surveys the coefficient of variation (CoV) of the arrival data was calculated. To determine the goodness of fit between the actual and the predicted arrival frequencies, three common statistical tests were used.

4.2 COEFFICIENT OF VARIATION

For a group of data points, the coefficient of variation is defined as the mean of the data divided by its variance. The coefficient of variation for each set of data was calculated on the data reduction spreadsheets included in Appendix A, and is included on Table 4.2.1.

Data that can be accurately represented by the Poisson distribution have coefficients of variation near 1.0 (1, 19, 20, 21, 22). Of the 21 surveys, 16 have arrival data with a coefficient of variation between 0.7 and 1.6. Only one set of data, from Survey 16 at Site G, is outside the range of 0.5 to 1.6. Some difficulty with the counting of arrivals at the ends of long queues was encountered during Survey 16, however the other surveys at this site (8 and 13) had coefficients of variation of 1.44 and 1.08 respectively, which fall within the acceptable range.

Based on the coefficients of variation, use of the Poisson distribution to model arrivals on a per cycle basis is appropriate. While the coefficient of variation indicates whether or not the field data are distributed in agreement with the Poisson distribution, it does not provide an indication of the goodness of fit between the predicted and the actual arrival distributions.

4.3 GOODNESS OF FIT TESTS

4.3.1 Introduction

Three methods of testing the goodness of fit between the actual and the predicted frequencies of vehicle arrivals per cycle were used:

Table 4.2.1 Coefficient of Variation and Goodness of Fit Test Results

Survey Number	CoV ($\mu/\sigma 2$)	K-S "d" Ratio at 5%	Rank	$\chi 2$ Ratio at 5%	Rank	Summed Ranking	Overall Rating	Group Rating
1	0.62	1.735	19	1.007	19	38	19	-
2	1.02	1.979	17	1.766	14	31	16	-
3	0.85	2.796	12	1.407	17	29	14	/
4	1.17	4.658	2	5.668	1	3	1	+
5	1.04	6.855	1	5.233	2	3	2	+
6	0.77	2.042	15	1.859	12	27	13	/
7	1.11	2.938	9	1.489	16	25	12	/
8	1.44	1.969	17	1.791	13	30	15	/
9	1.04	2.904	10	3.141	6	16	7	/
10	1.56	2.622	13	3.026	8	21	11	/
11	0.68	3.034	8	4.617	3	11	5	+
12	0.48	1.868	18	1.689	15	33	18	-
13	1.08	3.910	4	3.893	5	9	4	+
14	0.98	1.206	21	0.599	21	42	21	-
15	1.35	3.786	5	4.175	4	9	3	+
16	2.57	1.392	20	0.745	20	40	20	-
17	1.08	4.075	3	2.728	9	12	6	+
18	0.64	2.343	14	1.370	18	32	17	-
19	1.34	3.497	7	2.072	11	18	10	/
20	0.72	2.796	11	3.032	7	18	9	/
21	1.11	3.563	6	2.399	10	16	8	/

- visual inspection,
- the Kolmogorov-Smirnov test, and
- the Chi-Square test.

A data analysis spreadsheet was prepared for each data set to generate frequency plots and to calculate the Kolmogorov-Smirnov and chi-square statistics. A sample spreadsheet is included in Appendix B as Table B-3.1.

The arrival data for each site were first sorted in ascending order, and the frequency of each of the values represented was counted. The frequency values were normalized by dividing each value by the total number of observations, to allow comparison between data sets of differing sizes. The corresponding Poisson frequencies calculated from the average number of arrivals in a cycle were generated on a separate spreadsheet and normalized as described above. The predicted number of cycles with "x" arrivals were calculated by multiplying the predicted Poisson frequency of "x" arrivals by the total number of cycles counted. The cumulative frequency distributions for both the actual and the predicted data were also calculated on the spreadsheet.

4.3.2 Visual Inspection

The predicted and the observed frequencies of arrivals for Surveys 1 through 21 were plotted from the calculated data, in both singular and cumulative form. Sample plots showing good (Survey No. 5), average (Survey No. 21) and poor (Survey No. 16) fits are presented on Figures 4.3.1 to 4.3.3, respectively. The remainder of the plots are included in Appendix B as Figures B-3.1 to B-3.18. The mean of the arrival data and the coefficient of variation for the data are indicated on the plots. The number of arrivals in each cycle and a moving average of three for the same data were plotted in the order that they were observed, to determine if the arrival rate decreased or increased during the course of each survey. These plots are included in Appendix B as Figures B–3.19 to B–3.39.

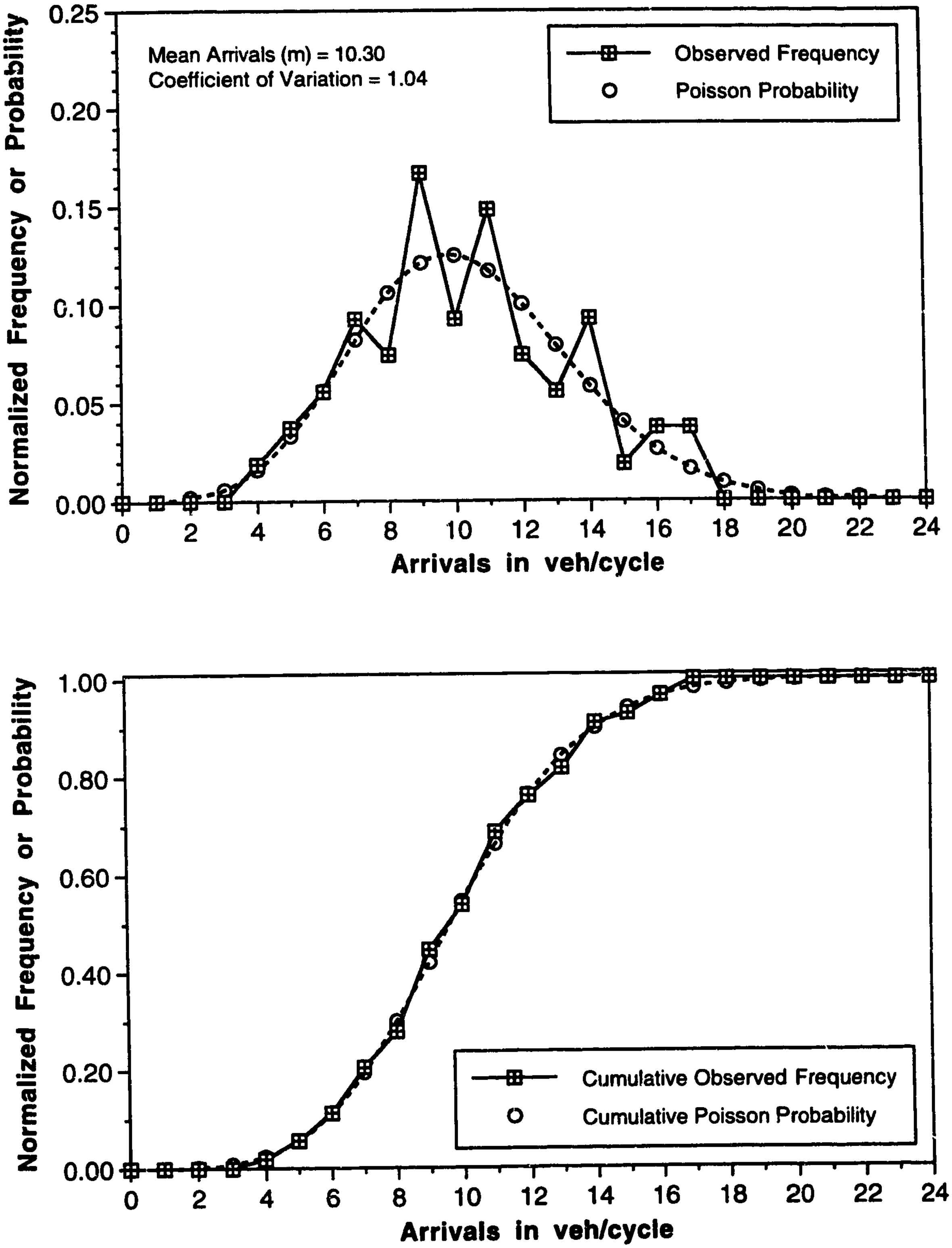
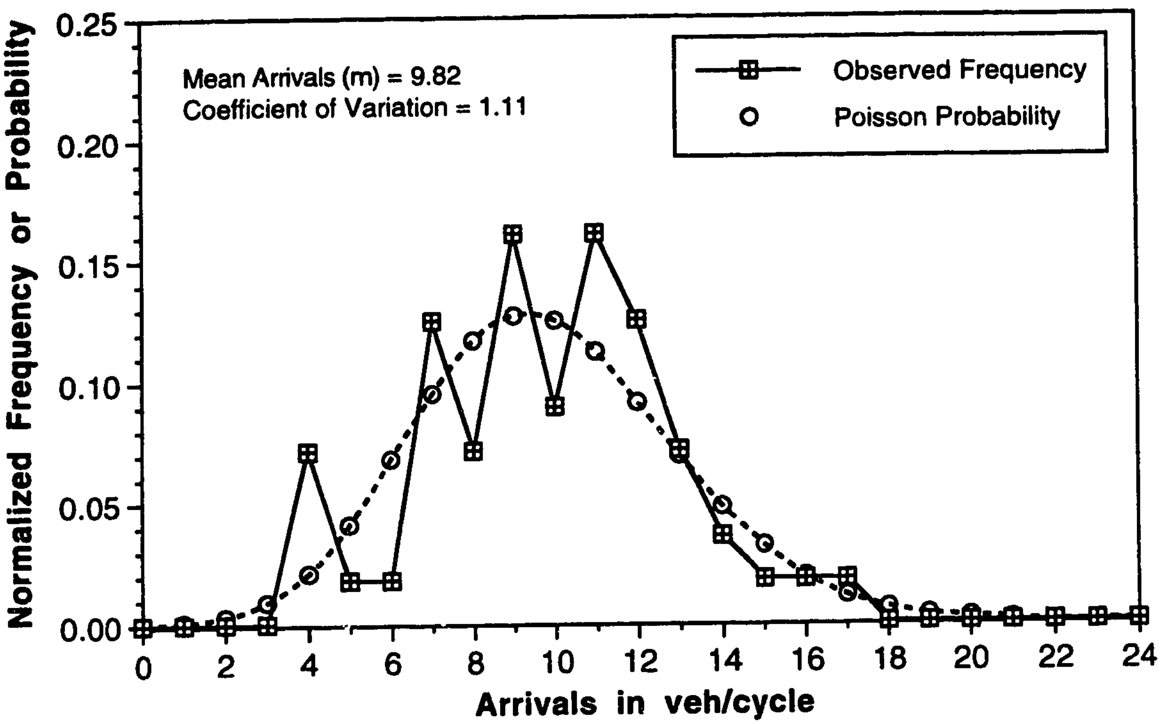


Figure 4.3.1 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 5



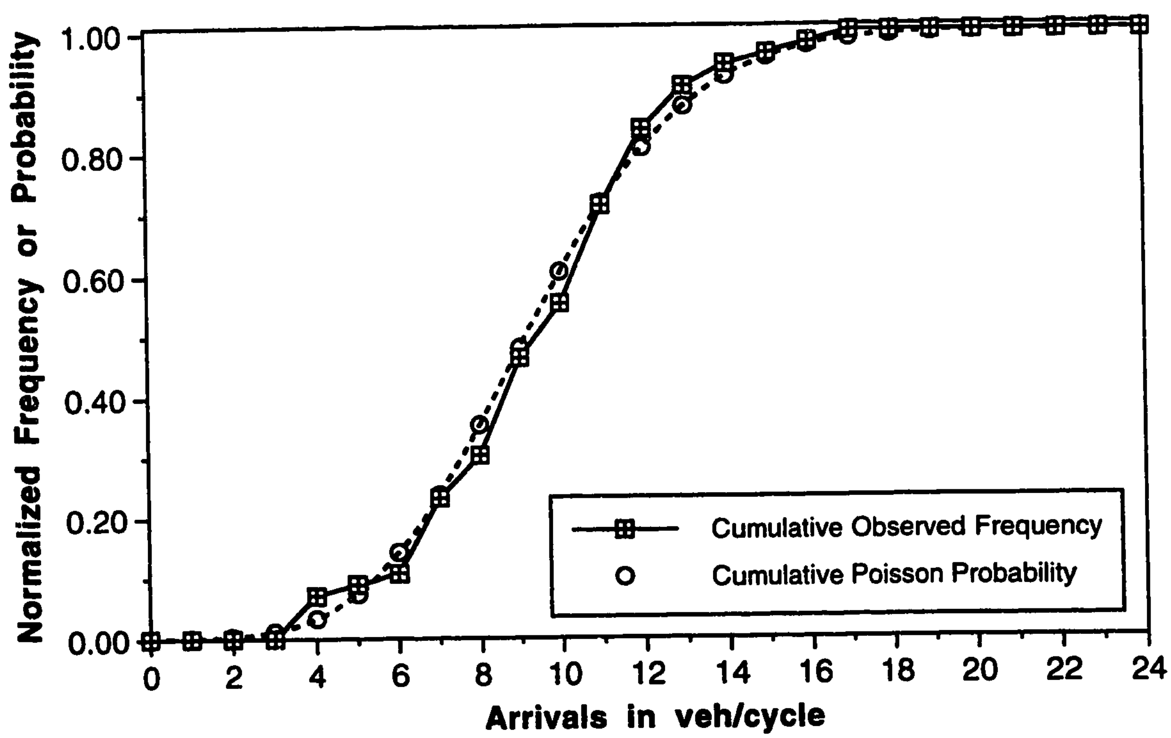
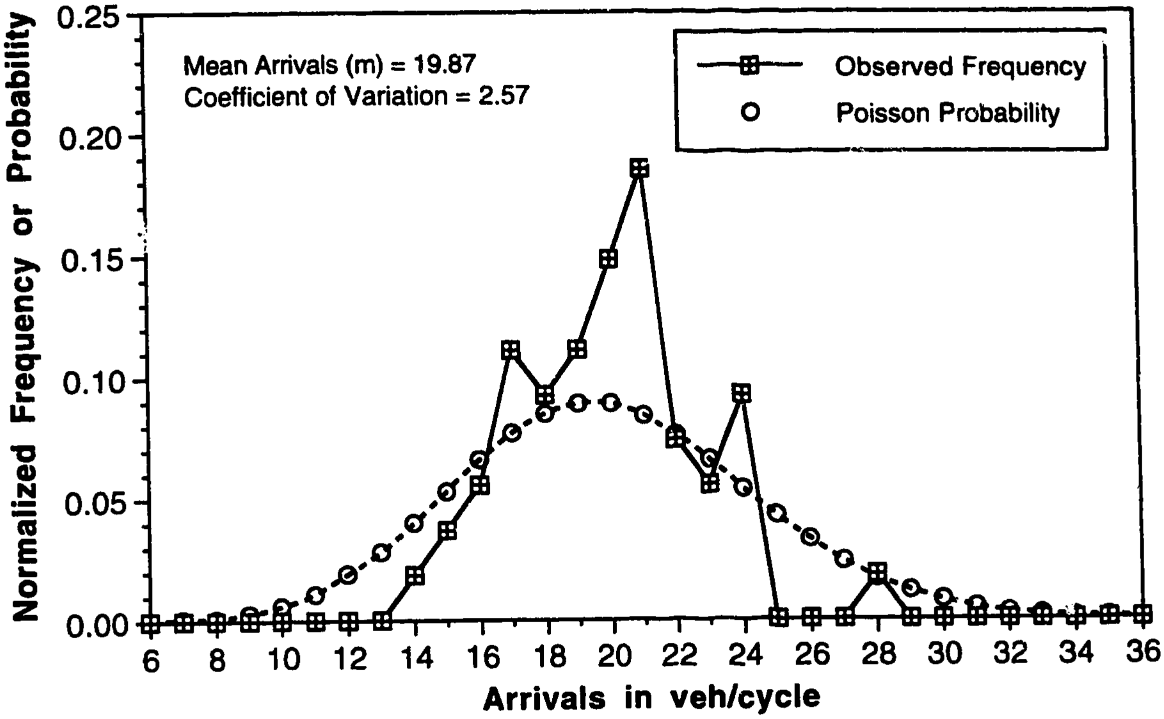


Figure 4.3.2 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 21



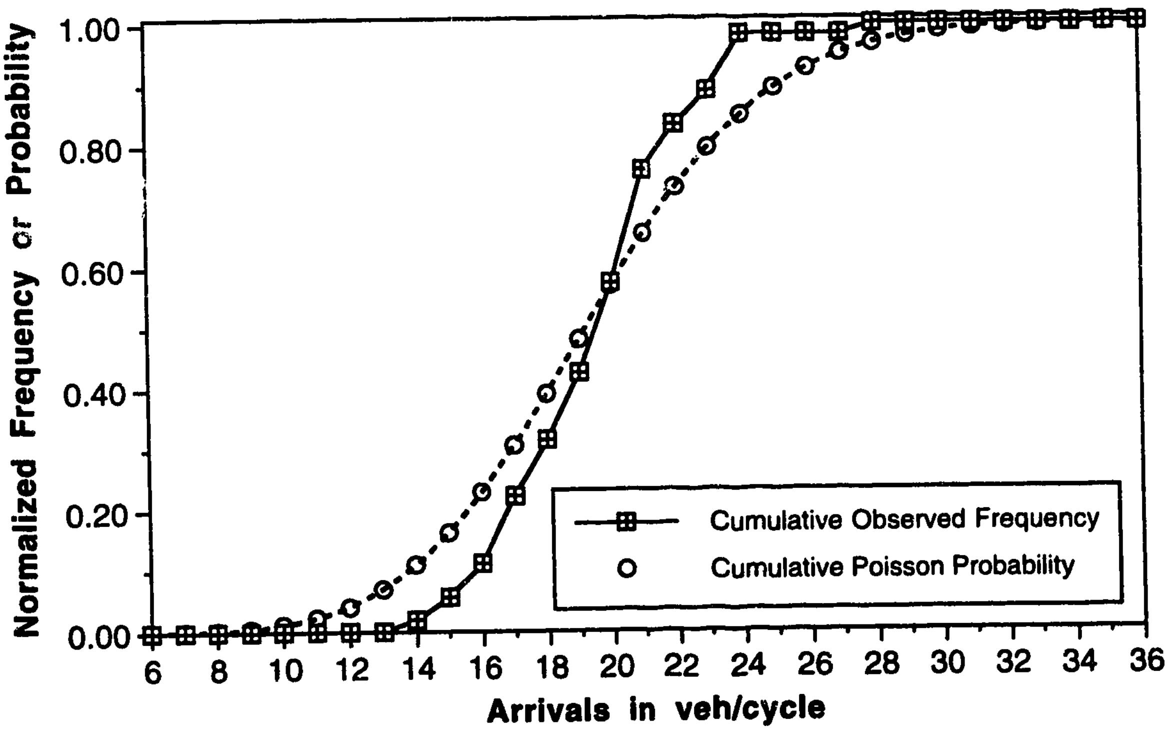


Figure 4.3.3 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 16

Observation of the cumulative frequency plots indicated that the fit of the observed data to the Poisson frequencies was generally very good. The majority of the data sets were similar to those shown on the good or average plots (Figure 4.3.1 and 4.3.2). Some variability in the observed data was inevitable due to the small number of data points collected for each survey, as one observation well above or below the mean could alter the shape of the distribution significantly. The fit of the distributions in the 0.80 to 1.00 frequency range was of particular importance for surveys with lower volume to capacity ratios, and was determined to be acceptable.

4.3.3 Kolmogorov-Smirnov Test

The Kolmogorov-Smirnov test requires that the maximum difference between the predicted and actual cumulative frequency distributions be determined. The absolute value of the difference between the cumulative frequency curves was calculated for each interval of arrivals in a cycle on the spreadsheet. The resulting values were inspected to determine the maximum difference.

The Kolmogorov-Smirnov statistic at the 0.05 (5%) level of significance was calculated for each data set using the following formula (21):

$$\text{Kolmogorov-Smirnov "d"} = 1.36/\sqrt{n}$$

where: n = sample size

The previously determined maximum difference was divided by the Kolmogorov-Smirnov "d" value to provide a measure of the relative goodness of fit beyond the 5% level of significance. These ratios ranged from 6.855 for Survey 5 (best) to 1.206 for Survey 14 (worst) and are included on Table 4.2.1. Each data set was ranked from 1 to 21, with higher ratios indicating a better fit of the actual to the predicted frequencies.

The Kolmogorov-Smirnov test is not normally applied when the population parameters are estimated from the data sample. To overcome this limitation, the data can be divided into two halves, with one half being used to estimate the population parameters and the other half being tested for goodness of fit. This procedure was not carried out in this research, as an absolute measure of goodness of fit was not required. Hence, only the relative goodness of fit between different data sets was determined.

The data sets with the best fit by the Kolmogorov-Smirnov test all have coefficients of variation very near to 1.0. In addition, the data sets with coefficients of variation greater than 1.6 or less than 0.6 are determined to have poor fits between the actual and the predicted data. This indicates that the Kolmogorov-Smirnov test, even when the population parameters are estimated from the sampled data, provides a reliable indication of goodness of fit.

4.3.4 Chi-Square Test

The chi-square test is a common measure of goodness of fit. The chi-square statistic is calculated by the following formula (21):

$$\chi^2 = \sum_{i=1}^{g} \frac{(f_i - F_i)}{F_i}$$

where: f = the observed frequency for an interval or group of intervals

F = the theoretical frequency for the same interval or group

g = the number of intervals or groups of intervals

The degrees of freedom for fitting a Poisson distribution are determined by:

$$\nu = g - 2$$

where: g = the number of intervals or groups of intervals

This value of ν is valid only if the predicted number of occurrences in each interval or group is greater than 5. This generally requires that the intervals at the tails of the distribution be cor ed into groups for calculation of the chi-square statistic.

The calculation of the value of chi-square for each data set was carried out on a spreadsheet (Table B-3.1). The number of intervals or groups was determined, and ν was calculated. The corresponding value of chi-square at the 0.05 (5%) level of significance was determined from statistical tables (21), and divided by the calculated value of chi-square. This ratio provided a relative measure of goodness of fit beyond the 5% level of significance, and allowed the data sets to be ranked based on goodness of fit. The range of the calculated ratios was from 5.668 for Survey 4 (best) to 0.599 for Survey 14 (worst). The ratios and the ranking of the data sets based on the chi-square test are included on Table 4.2.1.

The ranking of the data sets based on the results the chi-square test is very similar to the ranking based on the Kolmogorov-Smirnov test. The following observations are based on the results of the chi-square test:

1. sites with good chi-square fits all have a CoV near 1.0, and
2. sites with a CoV significantly different from 1.0 have poor chi-square fits.

The fit of the Poisson distribution to the observed arrival data at the 5% level of significance would be rejected only for Surveys 14 and 16, with ratios of 0.599 and 0.745 respectively.

4.4 SUMMARY AND CONCLUSIONS

The summed ranking, the overall ranking and the group rating for each data set are presented on Table 4.2.1. The summed ranking is calculated by adding the ranking values from both tests. These values are then ranked again from best to worst as an overall rating, and grouped into thirds. The three groups are indicated by "+", "/" and "-" for the top, middle and bottom thirds respectively.

The data sets with "+" ratings have CoV values near 1.0, which is expected as a good fit between the actual and the predicted data requires that the correct distribution be applied. Conversely, the data sets with CoV values significantly different from 1.0 have "-" ratings, although a data set with a poor fit may have a CoV near 1.0.

For all but two of the 21 surveys, the fit of the actual arrival frequencies in a cycle to the frequencies predicted by the Poisson distribution cannot be rejected at the 0.05 level of significance based on the chi-square test. This confirms that the use of the Poisson distribution to model the cycle by cycle arrivals for this research is appropriate.

Chapter 5 - Variation in Stopline Capacity

5.1 INTRODUCTION

Stopline capacity is defined as the maximum number of vehicles able to cross the stopline in one lane at a signalized intersection during one cycle. Traditionally, average stopline capacity has been determined by multiplying the saturation flow rate (in vehicles or pcu per hour of green) by an effective green interval (1). In Edmonton, the effective green interval has been established as the displayed green interval plus one second. Previous research (23, 24) has indicated that saturation flow rates are relatively constant from cycle to cycle, as well as over longer periods of time.

During the overload factor data collection process, the number of vehicles clearing an intersection during fully loaded or overloaded cycles were recorded. Vehicles which entered the observed lane prior to reaching the stopline to fill a long gap in the moving traffic stream were included in the counted capacity values. Values of stopline capacity were obtained at 9 of the 10 sites studied, with a total of 335 observations collected. Data from different surveys at a given site were analysed separately, and were not combined to provide larger data sets.

The observed values of stopline capacity are included on Tables A-3.1 to A-3.21 in Appendix A. An analysis of these data was carried out to determine the distribution of observed values of stopline capacity, and to determine the relationship between the calculated and observed capacities.

Predicted values of stopline capacity were generated for all surveys, based on appropriate values of saturation flow multiplied by an effective green interval. The observed and predicted capacities were compared to determine if the predicted values accurately modelled the observed capacities, and to determine if a more accurate estimate of stopline capacity could be obtained for data sets with small numbers of field capacity data.

5.2 DATA REDUCTION

The stopline capacities observed during each survey were entered into a spreadsheet, and their mean (μ) and standard deviation (σ) were calculated. A summary of the calculated values for each survey is included on Table 5.2.1, along with the number of stopline capacities (n) observed during the survey.

The number of observed values of stopline capacity varied from 3 (Survey 4) to 48 (Survey 18), with none observed during Survey 10. Although 15 observations are considered a minimum to generate a valid interval in the measurement of saturation flow (1), data sets with 10 or more observations were chosen for the initial analysis of the capacity data. These 13 valid data sets are noted on Table 5.2.1.

Frequency plots were generated from the field data spreadsheets by sorting the data and counting the frequency of each capacity observation. The frequencies were normalized by dividing by the total number of observations. To determine if a common trend existed in the frequency plots, the plots were shifted to have the mean of the observations equal to zero. The combined frequency plot for all valid data sets is included as Figure 5.2.1. From an initial inspection of this combined frequency plot, it appeared that the magnitude and variance of all the frequency plots were relatively consistent. The average standard deviation for the valid data sets was found to be 1.08. Frequency values based on the normal distribution with a mean of zero and a standard deviation of 1.1 were calculated on a spreadsheet and were also plotted on Figure 5.2.1.

Although the data presented on Figure 5.2.1 were obtained from 9 different sites, at different times of day and days of the week and with different green intervals and cycle lengths, remarkable consistency between the observed data sets is observed. When these data are compared to the normally distributed frequencies it appears that this distribution may be a

Table 5.2.1 Stopline Capacity Data Analysis

Survey Number	Mean (μ)	Standard Deviation (σ)	Number of Observations (n)	Valid Data Set	Bartlett Statistic (0.10)	Bartlett Statistic (0.05)
1	9.09	0.94	11	Yes		
2	22.17	1.17	6	No		
3	8.77	1.25	17	**Yes**	0.8707	0.8975
4	11.67	1.53	3	No		
5	12.80	0.70	19	**Yes**	0.8903	0.9132
6	16.85	1.50	4	No		
7	18.50	0.95	26	**Yes**	0.9158	0.9336
8	20.03	1.31	39	**Yes**	0.9455	0.9572
9	14.00	0.54	8	No		
10	N/A	N/A		No		
11	12.75	0.89	8	No		
12	16.75	1.83	8	No		
13	21.10	0.88	10	Yes		
14	18.26	1.24	47	**Yes**	0.9564	0.9658
15	13.50	0.89	16	**Yes**	0.8625	0.8909
16	20.11	1.29	47	**Yes**	0.9564	0.9658
17	24.14	1.23	14	**Yes**	0.8426	0.8748
18	18.85	1.15	48	**Yes**	0.9564	0.9658
19	13.22	0.67	9	No		
20	20.78	1.22	27	**Yes**	0.9190	0.9361
21	12.85	0.99	13	Yes		

Tabulated values of Bartlett Statistic
0.929 0.944

Population Variance = 1.3795
Calculated Bartlett Statistic = 0.9536

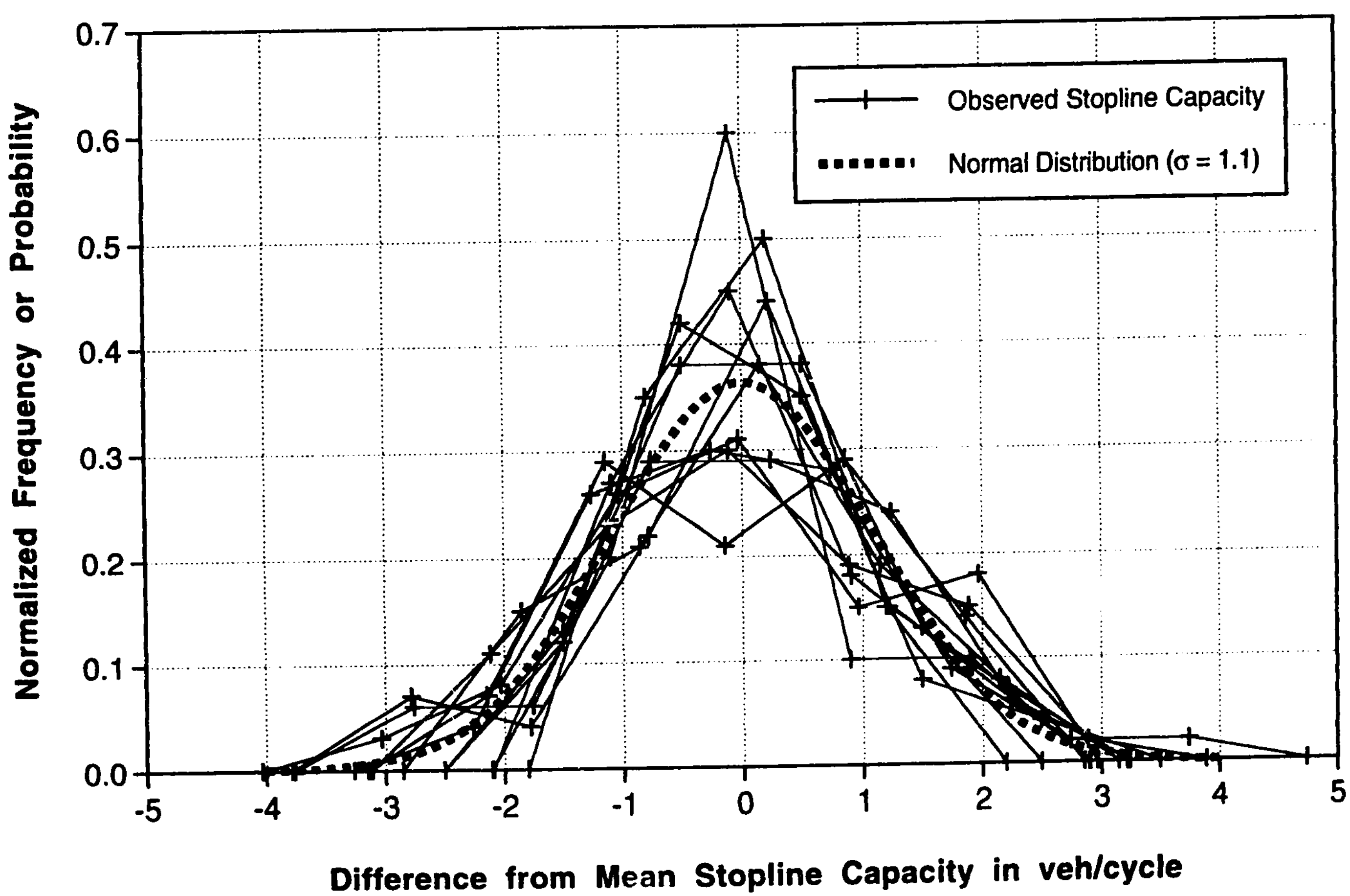


Figure 5.2.1 Normalized Frequency Plots for All Valid Capacity Data Sets

usable surrogate for the variation in stopline capacity. Some differences between the actual and predicted frequencies at the mean are noted, however, the fit in the tails of the distribution is very good.

The quartile-quartile (Q-Q) plot is a common test for normality. The first, middle and third quartiles of the observed stopline capacities were determined and compared to the quartiles of the normal distribution. The Q-Q plot based on the actual standard deviations of the field data, rather than the average standard deviation of 1.08, is included as Figure 5.2.2. The fit of the data to the 1:1 line indicates that the stopline capacities observed in the field are normally distributed.

5.3 ANALYSIS OF STANDARD DEVIATION

To use the normal distribution to model the variation in stopline capacity, both the mean and the standard deviation of the capacity must be known. Although the mean may be determined by using the formula for average stopline capacity described in Section 5.1 or may be easily measured in the field, the standard deviation of stopline capacities is not commonly available. From the initial investigation of the data collected during the surveys, it appeared that the standard deviation of stopline capacity data did not vary significantly with variations in site, time of day, sample size or mean capacity. This does not necessarily imply that the variables associated with the operation of signalized intersections have no impact on the variance of stopline capacity, but rather that the combined effect of these variables on the variance is relatively constant.

It was expected that the variable most likely to affect the variance of stopline capacity would be the length of the green interval. As the green interval increased, the variance of the stopline capacity was expected to increase. To determine if this was occurring, a plot of standard deviation vs mean capacity (as a surrogate for green interval) was prepared for all valid data sets (Figure 5.3.1). The values of standard deviation appear to be

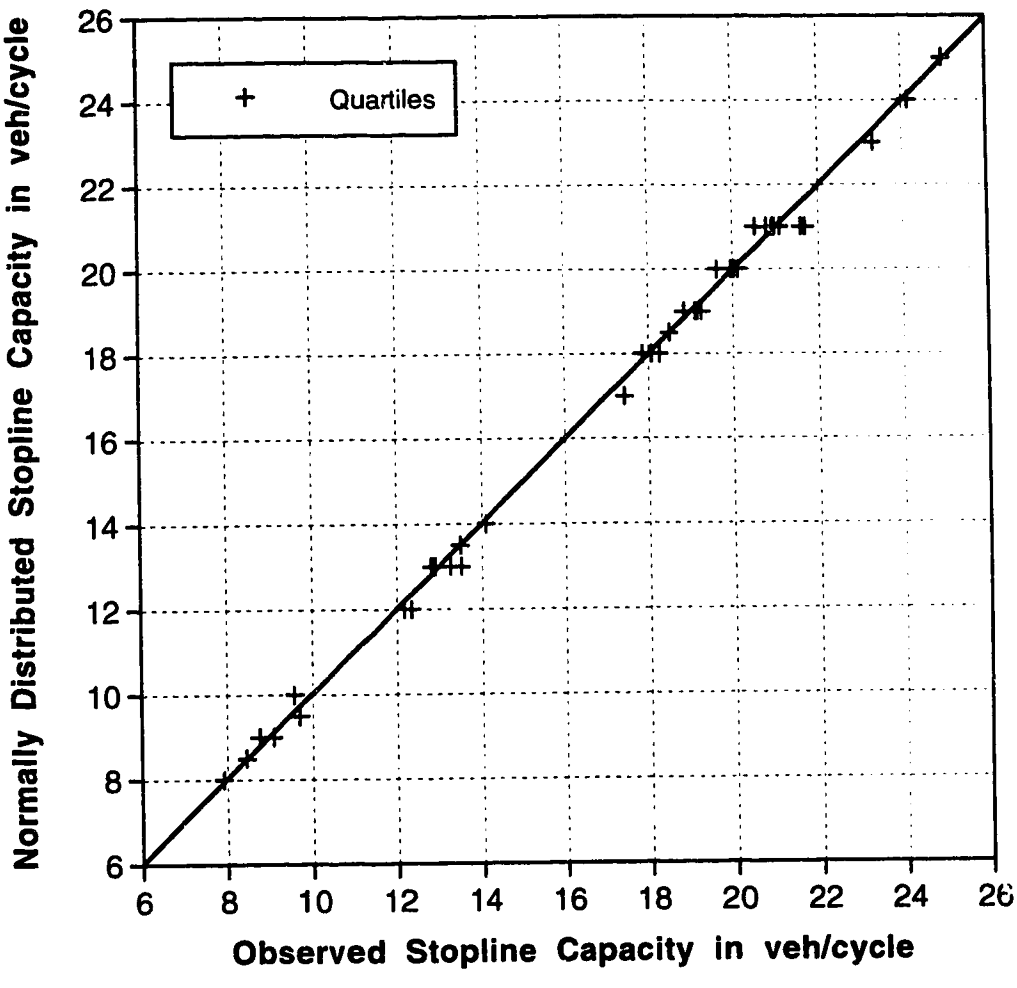


Figure 5.2.2 Q-Q Plot for Stopline Capacity Data

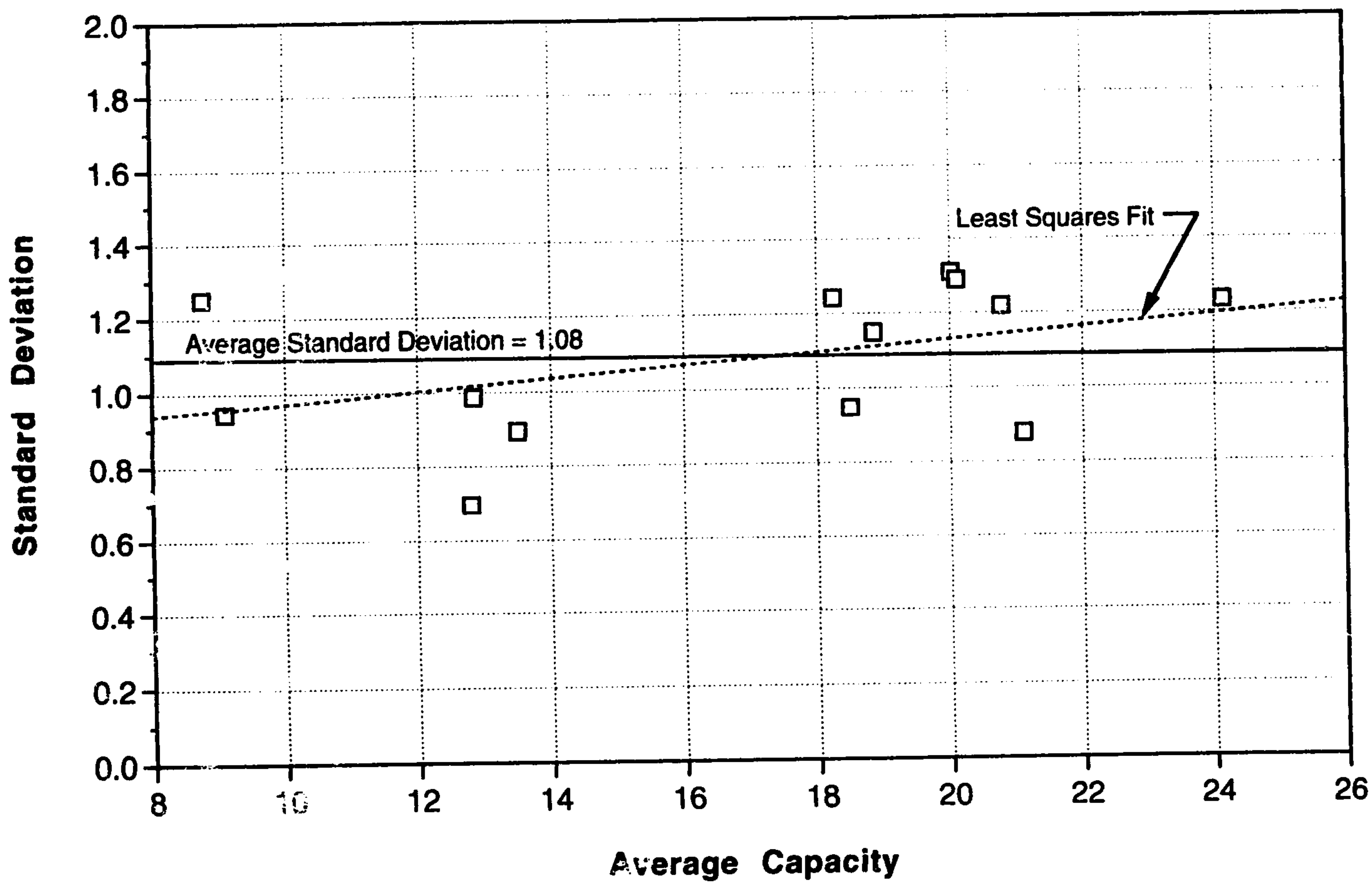


Figure 5.3.1 Standard Deviation vs Mean Capacity for Capacity Data Sets with 10 or more Observations

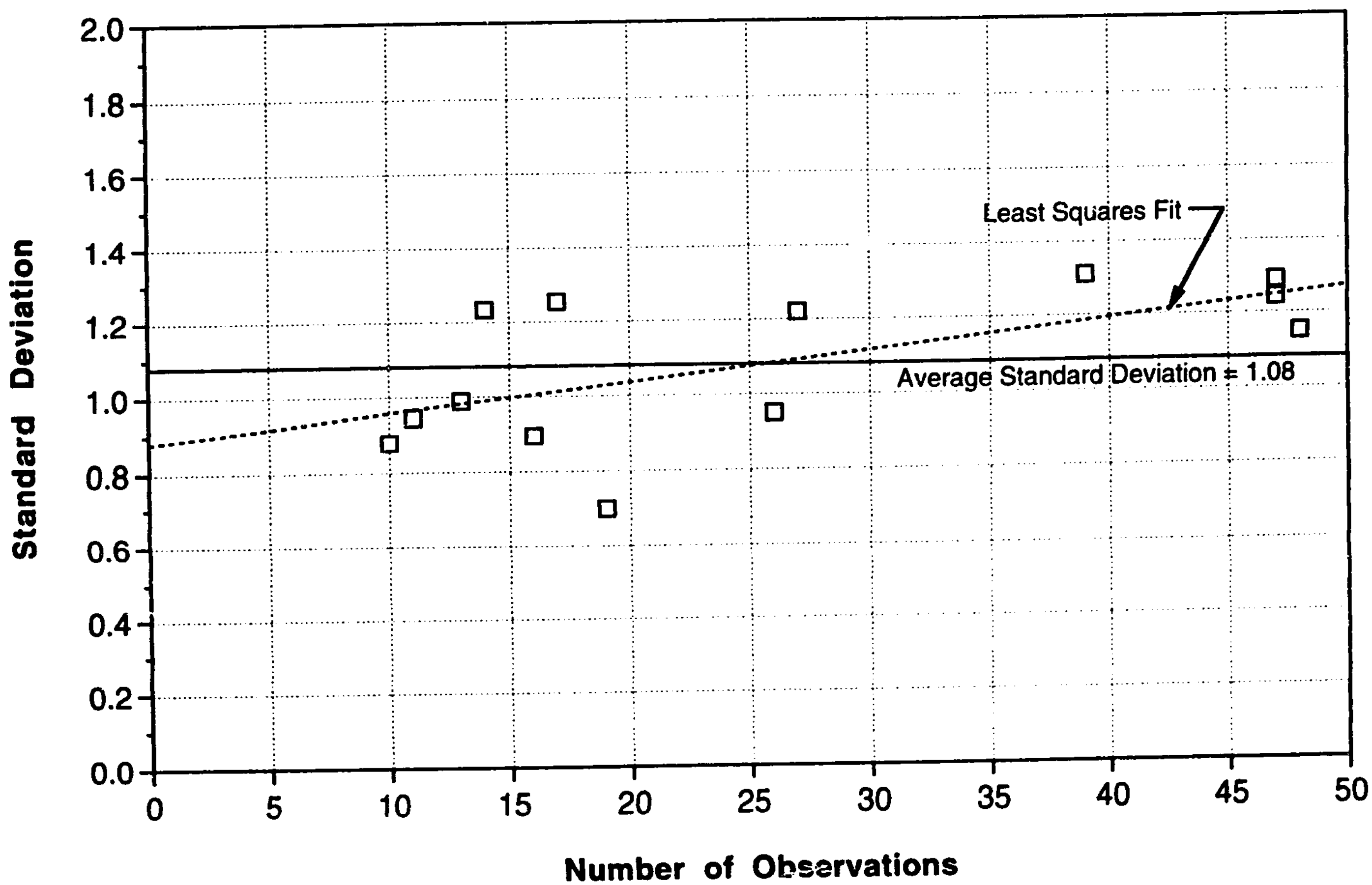


Figure 5.3.2 Standard Deviation vs Number of Observations for Capacity Data Sets with 10 or more Observations

unaffected by changes in green interval length. Although a least squares linear regression indicates that the best fit line has a small positive slope, values of standard deviation above and below the average value are observed at both high and low mean capacities. This implies that the variance of stopline capacities is independent of the mean, which is not the case with the Poisson distribution used to model the distribution of arrivals in a cycle.

The calculation of the average standard deviation of all valid stopline capacity data sets was not proportioned using the number of observations in each set. Therefore, the impact of the number of observations in a data set (the reliability of the data) on standard deviation was also considered. A plot of standard deviation versus number of observations in a data set for all valid data sets is included as Figure 5.3.2. A least squares linear regression line shows that the values of standard deviation increase slightly as the number of observations increase. However, the data sets with large numbers of capacity observations are from two sites (F and G) and the larger variances may be related to conditions at these sites.

Although the capacity data set variances (σ^2) appear to be unaffected by changes in the length of the green interval and the number of observations, a statistical test for the equality of several variances was carried out. Bartlett's test (25) was applied to the 10 largest data sets, as indicated by bold type on Table 5.2.1. The values for the population variance, the calculated sample Bartlett statistic and the tabulated values of the Bartlett statistic at the 0.10 (10%) and the 0.05 (5%) level of significance are also shown on Table 5.2.1. Based on this test, the 10 variances are not different at either the 10% or the 5% levels of significance.

From the comparison of standard deviation with green interval length and number of observations, and based on the results of Bartlett's test for equality of variances the variance of the distribution of stopline capacities at the observed sites is relatively constant at a value of approximately 1.1.

quency plot was prepared for each of the valid data sets, which
;:

the normalized frequency plot of the observed data,
the normally distributed frequencies based on the standard deviation of the observed data set, and
the normally distributed frequencies based on the average standard deviation ($\sigma = 1.1$), calculated from all valid observed data sets

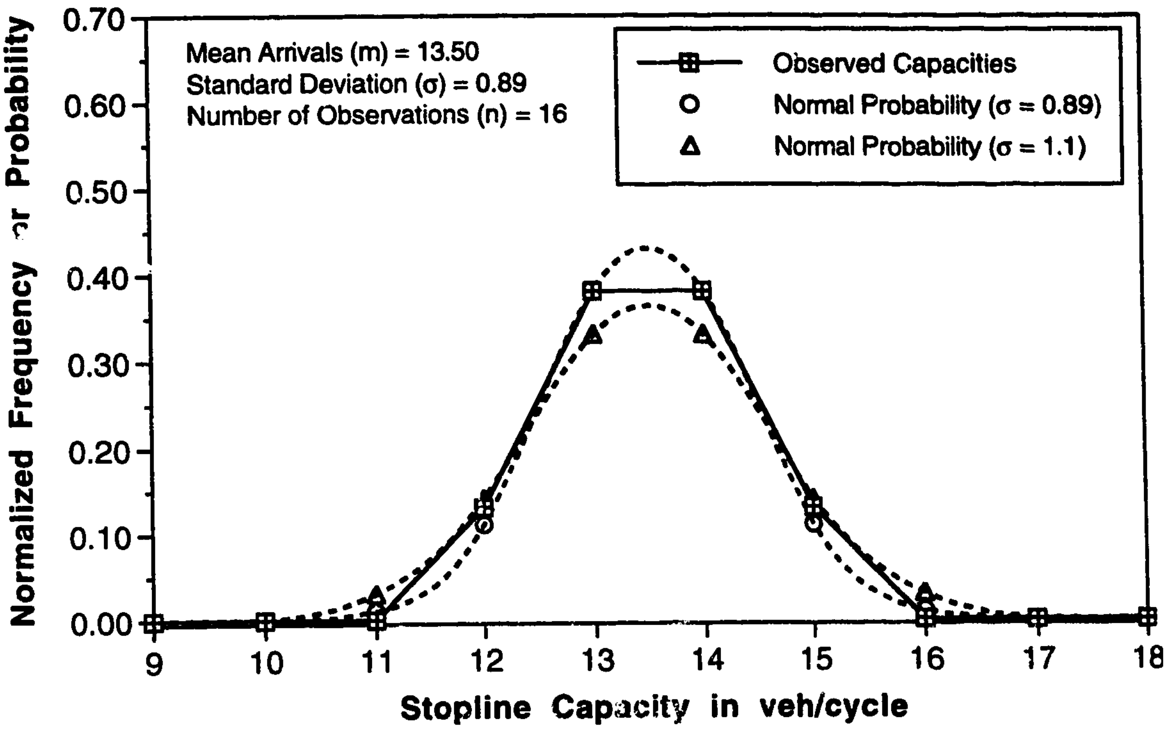
singular and cumulative form. Sample plots showing good No. 15), average (Survey No. 14) and poor (Survey No. 21) fits are ed on Figures 5.4.1 to 5.4.3, respectively. Plots from the other 10 valid s are included in Appendix C as Figures C-4.1 to C-4.10. The fit of the d to the observed data was not statistically tested. From observation lots it appears that the fit is acceptable, even for surveys where the d deviation of the observed data set is somewhat different from the standard deviation.

Saturation Flow

predicted values of saturation flow and the corresponding capacities survey are shown on Table 5.4.1. The base saturation flows used for ulations are 1800 pcu/hg for through lanes and 1650 pcu/hg for ve left turn lanes. Correction factors were applied to the base ion flows as described in the Final Draft of the Second Edition of the an Capacity Guide for Signalized Intersections (10). In addition some s in the effective green interval were applied based on observations of flow during the field surveys. An explanation of the corrections is ted below:

Table 5.4.1 Summary of Observed and Calculated Stopline Capacity Data

Survey Number	Site	Observed Cycle Capacity	Number of Capacity Observations	Predicted Saturation Flow (CCG)	Predicted Capacity	Percent Difference	Observed m/X	Predicted m/X
1	A	9.1	11	1710	9.0	0.7%	0.58	0.58
2	B	22.2	6	1800	21.5	3.0%	0.65	0.67
3	A	8.8	17	1710	9.0	-3.0%	0.69	0.67
4	C	11.7	3	1650	**12.8**	**-10.0%**	0.67	**0.61**
5	D	12.8	19	Rain	N/A	N/A	0.80	N/A
6	E	16.8	4	1650	17.0	-1.2%	0.66	0.66
7	F	18.5	26	1800	19.0	-2.7%	0.87	0.85
8	G	20.0	39	1800	20.1	-0.3%	0.96	0.95
9	D	14.0	8	1750	14.1	-0.7%	0.70	0.69
10	H	N/A	0	1800	14.0	N/A	N/A	0.39
11	C	12.8	8	1650	12.8	-0.7%	0.61	0.60
12	E	16.8	8	1650	17.0	-1.2%	0.57	0.56
13	G	21.1	10	1800	20.1	4.7%	0.83	0.87
14	F	18.3	47	1800	19.0	-4.1%	0.98	0.94
15	D	13.5	16	1750	14.1	-4.4%	0.81	0.77
16	G	20.1	47	1800	20.1	0.0%	0.99	0.99
17	I	24.1	14	**1950**	23.8	1.3%	0.82	0.83
18	F	18.9	48	1800	19.0	-0.8%	0.98	0.97
19	J	13.2	9	1710	13.3	-0.6%	0.72	0.71
20	I	20.8	27	Rain	N/A	N/A	1.05	N/A
21	J	12.9	13	1710	13.3	-3.5%	0.76	0.74



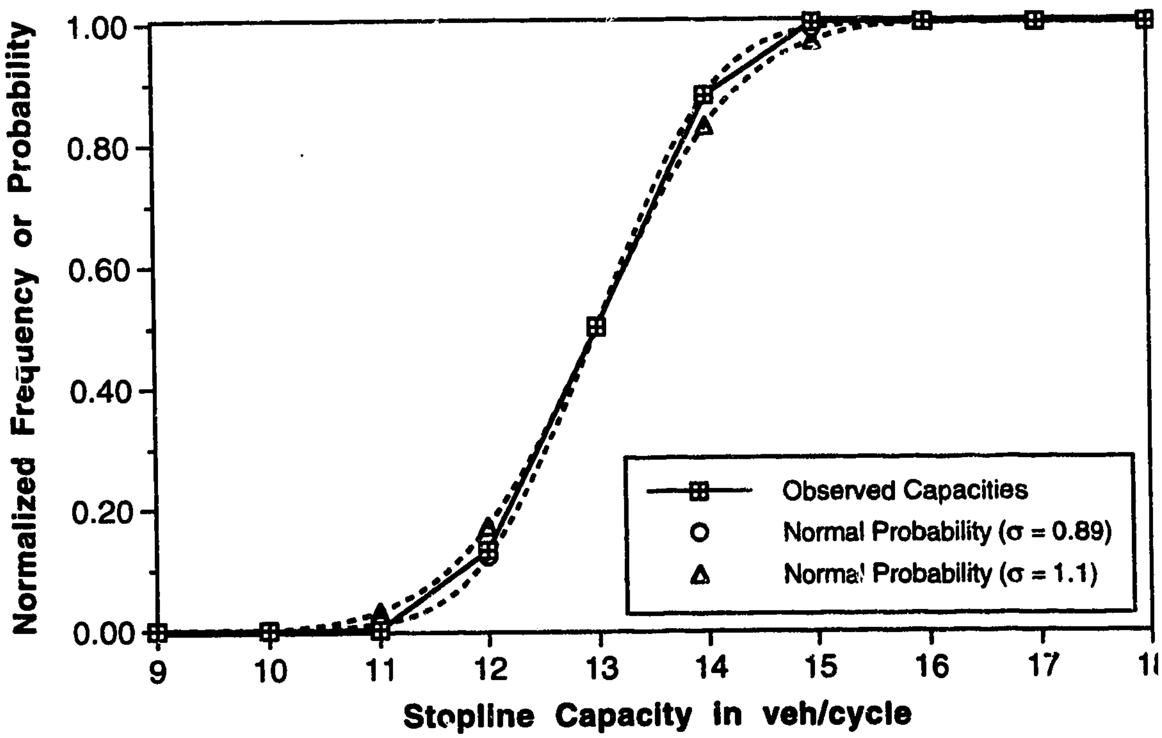
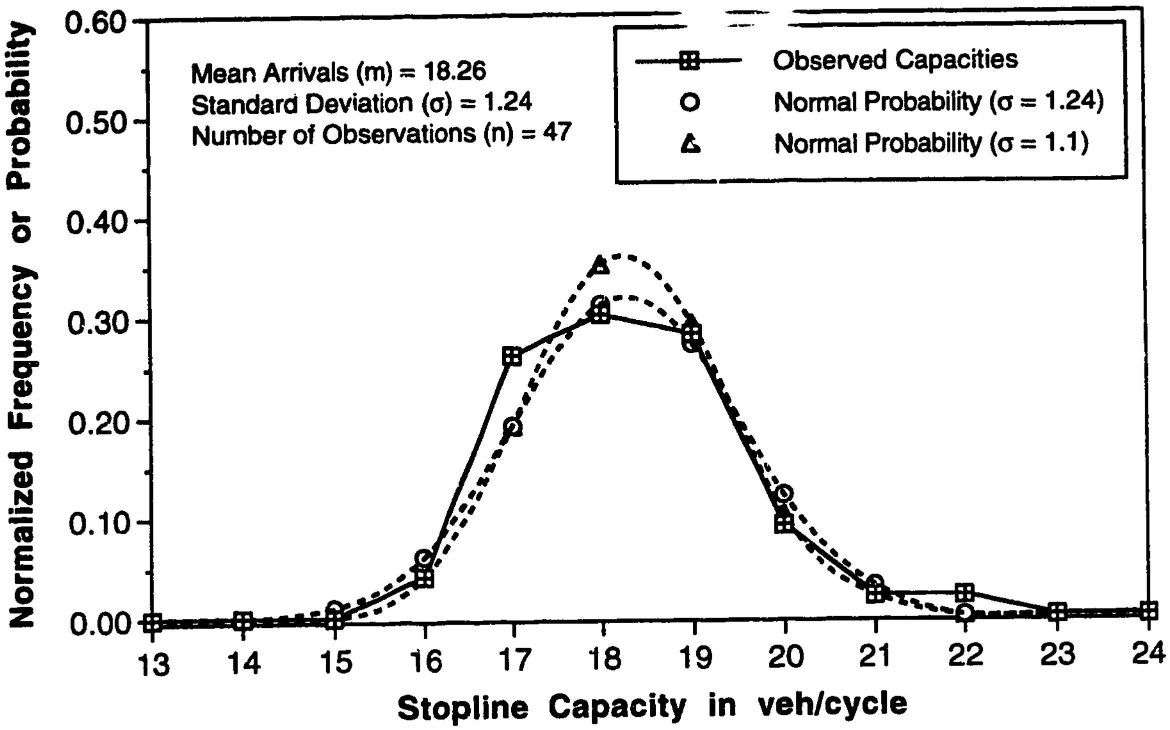


Figure 5.4.1 Comparison between Observed Cycle Capacities and Normally Distributed Capacities for Survey No. 15



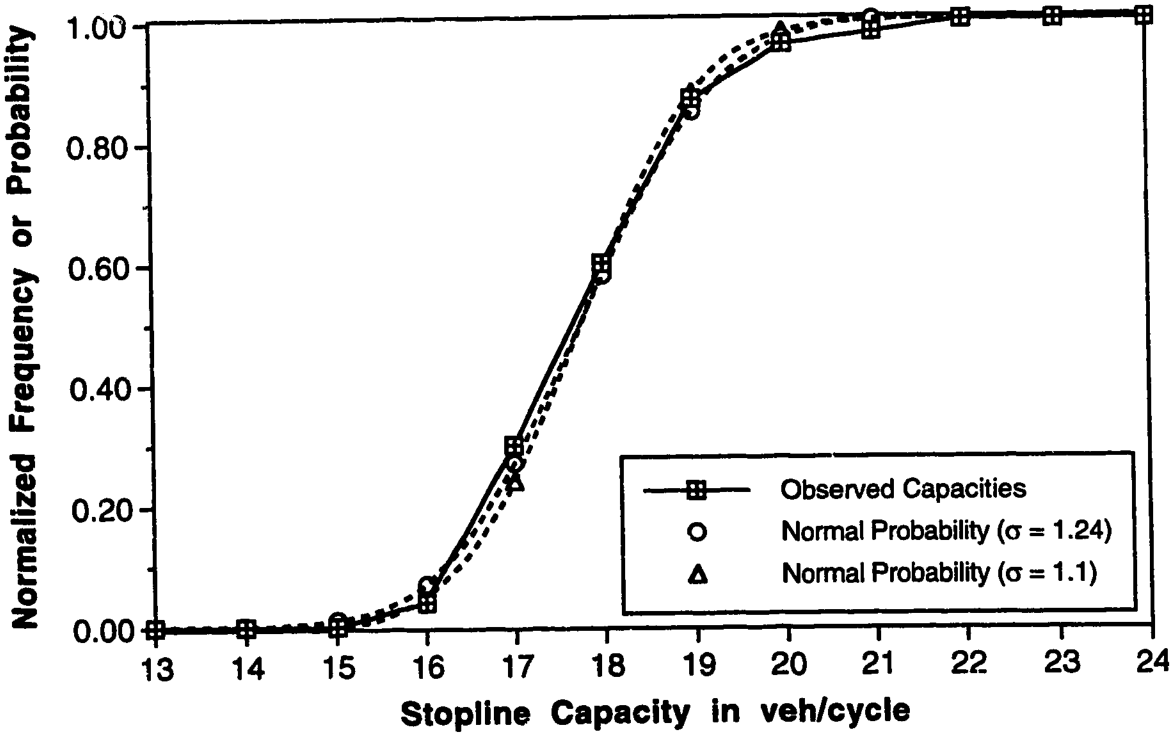


Figure 5.4.2 Comparison between Observed Cycle Capacities and Normally Distributed Capacities for Survey No. 14

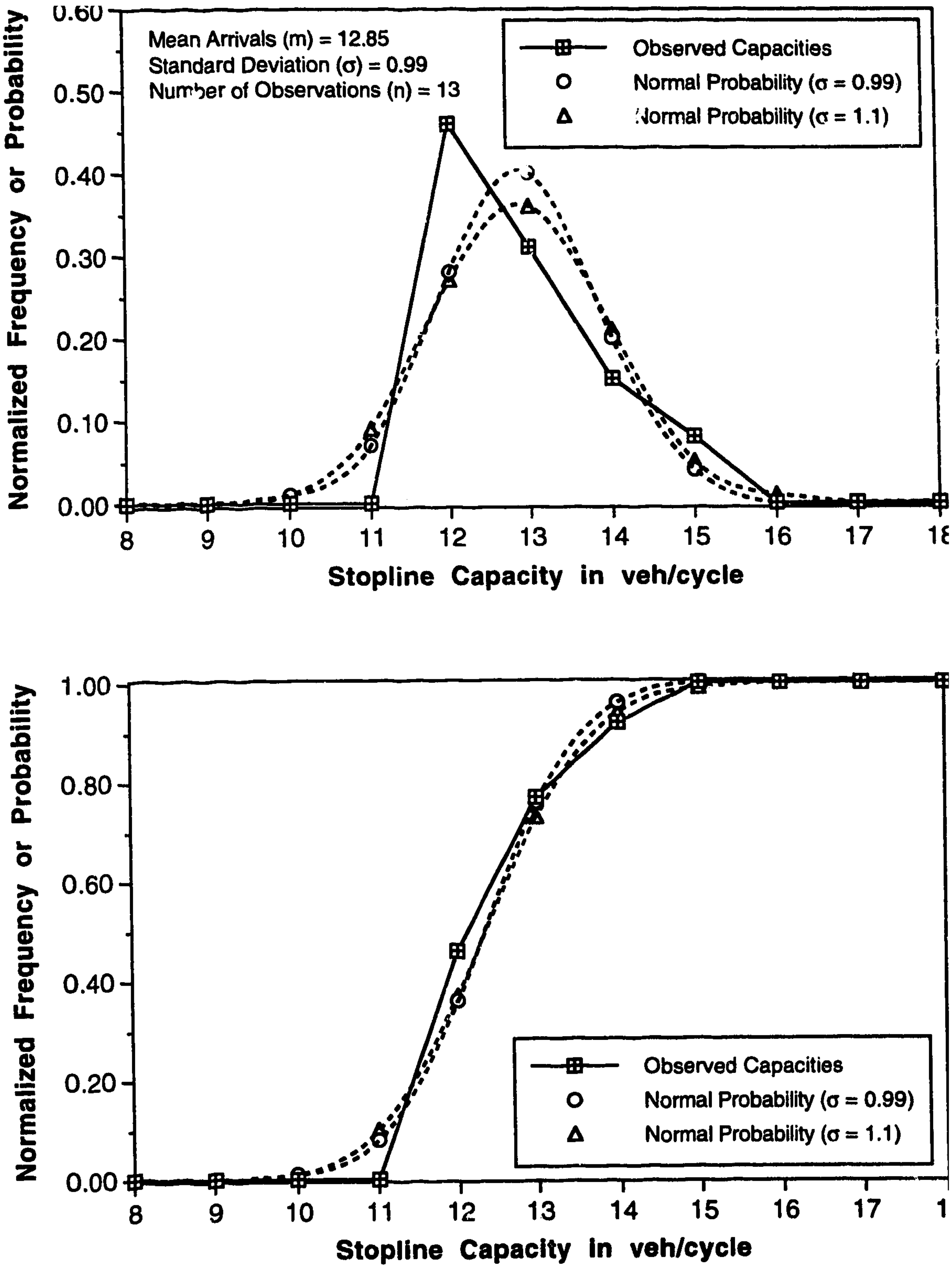


Figure 5.4.3 Comparison between Observed Cycle Capacities and Normally Distributed Capacities for Survey No. 21

Site A: The saturation flow rate was reduced by 5% to 1710 pcu/hg due to the short green interval (17 s). The effective green interval was increased to the displayed green interval plus 2 seconds due to the observed very high values of amber overrun.

Site B: The base value of 1800 pcu/hg was applied at this site.

Site C: The base saturation flow value of 1650 pcu/hg was used, and an effective green interval equal to the displayed green interval was applied to account for the high values of start loss observed at this site. The excessive start loss value was due to late clearing of the intersection by northbound left turning vehicles.

Site D: The presence of a far side bus stop reduced the saturation flow rate by 3% to 1750 pcu/hg.

Site E: The observed capacity data indicated that a saturation flow rate in the order of 1650 pcu/hg was appropriate for this site, although no correction to the base saturation flow value of 1800 was indicated. Only 4 and 8 capacity observations were recorded during the two surveys, however, the observed capacities were very consistent. It appears that the saturation flow rate may be influenced by the high degree of pedestrian activity at the time of the surveys, the converging angle of the lanes as they cross the intersection, the turning movements into and out of a shopping centre parking lot just downstream of the intersection and the start of very large tree growth in the median and on the sides of the roadway. The base saturation flow rate was therefore reduced by 10% at this site.

Site F: The base saturation flow rate of 1800 pcu/hg was applied at this site.

Site G: Due to the consistently large values of amber overrun observed, the base saturation flow of 1800 pcu/hg was used with an effective green interval equal to the displayed green interval plus 2 seconds.

Site H: The 1800 pcu/hg saturation flow rate was used at this site.

Site I: Very large values of stopline capacity were observed during Survey 17 at this site, and no corrections to the base saturation flow rate were found to be applicable. A saturation flow survey was therefore carried out, and the data are shown on Table 5.4.2. The cumulative saturation flow calculations are also shown on Table 5.4.2, and include values based on all observed cycles as well as values calculated from only the fully loaded or overloaded cycles. A plot showing both cumulative saturation flow curves is included as Figure 5.4.4. It is felt that the saturation flow based only on fully loaded and overloaded cycles was appropriate for use in this analysis because stopline capacity by definition requires full cycle utilization. In addition, the average stopline capacity observed during the saturation flow survey was found to be virtually identical to the capacity observed during the overload factor survey. A saturation flow rate of 1950 pcu/hg was therefore used, and due to the large values of amber overrun documented during the saturation flow survey an effective green interval equal to the displayed green interval plus 2 seconds was chosen. This saturation flow rate is significantly higher than the norm of the City of Edmonton.

Site J: The base saturation flow rate was reduced by 5% at this site due to the approximately 5% uphill grade near the intersection. This resulted in a saturation flow rate of 1710 pcu/hg.

For Surveys 5 and 20 where saturation flows were reduced by heavy rainfall, sufficient numbers of capacity observations (19 and 27 respectively) were recorded to provide confidence that accurate representation of actual capacity was occurring. Conversely, no cycle capacities were observed during Survey 10, and the stopline capacity was therefore based on the appropriate base saturation flow rate multiplied by the displayed green interval plus one second.

A comparison between the predicted and the actual capacities is also shown on Table 5.4.1. Differences of less than 5% were not considered significant, and were attributed to random variations. Only one of the 21

.2 Saturation Flow Data And Calculations for Site I

e er	Time Intervals (sec) 0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	Cycle Capacity
	2	2	3	3	2	3	2	3	
	2	3							
	2	3							
	2	3	3						
	2	2	3	3	3	3			
	1	3	3	3	3	2			
	2	3	3	2	3	2	3		
	2	3	3	2	3	4	3	4	26
	2	3	2	3	2	2	3	2	23
	1	2	2	3	3	3	3		
	2	2	3	3	3	3	3	3	24
	2	3							
	3	3							
	2	3							
	2	3	2	3	2				
	2	1	3	2	4				
	2	2	3	2	3	2	2	3	
	2	3	2	3					
	2	3	2	3					
	2	3							
	2								
	2	2							
	2	3	3	2	3				
	2	3	3						
	1	2	3	3					
	3	3	3	3					
	2	3	3	3	2	3	3	3	24
	2	3	3	3	3	2	3	2	23
	2	3	3	2	3	2	4	3	24
	1	4	3	3	3	5	2	2	26
	2	3	3	4	3	2			
	2	2	2	4					
	1	3	3	3					
	2	3							
	2								

ion Flow calculations for all cycles counted

lices	35	33	25	23	17	14	11*	9*	
rage	1.91	2.73	2.76	2.83	2.82	2.71	2.82	2.78	
umul	1.91	2.32	2.47	2.56	2.61	2.63	2.65	2.67	
Flow	1378	1671	1776	1841	1879	1892	1911	1923	

ion Flow calculations based on fully loaded and overloaded cycles

rage	1.86	3.00	2.86	2.71	2.71	3.00	3.00	2.71	**24.3**
umul	1.86	2.43	2.57	2.61	2.63	2.69	2.73	2.73	
Flow	1337	1749	18[illegible]1	1877	1893	1937	1969	1967	

stionable statistical validity.

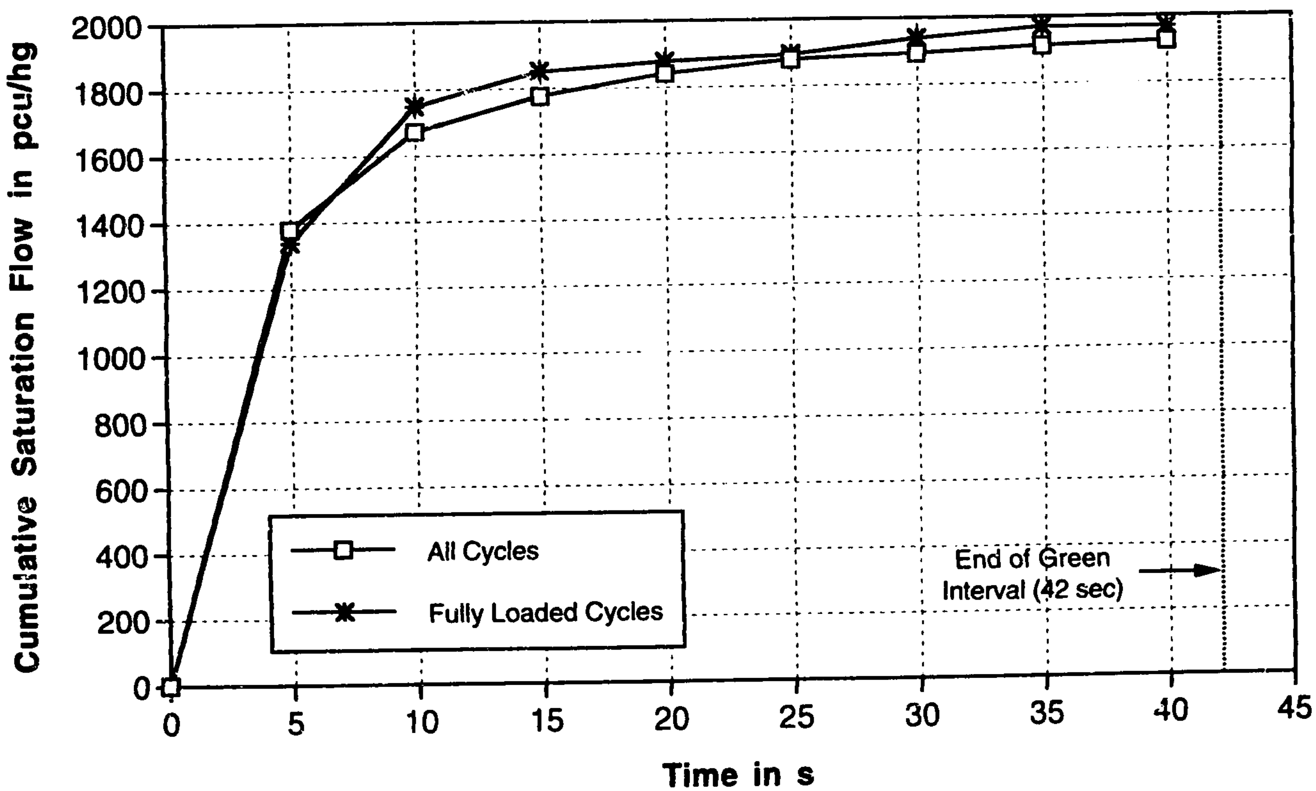


Figure 5.4.4 **Cumulative Saturation Flow Diagram for Site I**

surveys did not meet this criterion (Survey 4), with a 10% difference calculated. With only three cycles loaded to capacity during this survey, the calculated capacity was likely more representative of actual conditions at this site than the average of the three measured values. The predicted stopline capacity, which showed good agreement with the average capacity observed during the second survey at this site, was therefore used to represent the conditions during Survey 4. The observed capacities were used for all other surveys. The observed and predicted mean arrival to stopline capacity ratios (m/X) are also included on Table 5.4.1.

5.5 CONCLUSIONS

An analysis of the data collected at the 10 survey locations strongly suggests that stopline capacities are normally distributed with a consistent standard deviation of about 1.1. This result was not initially expected, due to the wide range of conditions encountered during the surveys. In particular, the duration of the green and amber intervals, and the green ratio were expected to affect stopline capacity variability at a site. It was anticipated that longer green intervals would result in greater capacity variability due to small variations in the saturation flow rate. Long amber intervals were expected to allow a larger range of vehicles to have to chose whether to stop or continue and cause greater variability in amber overrun. In addition, it was initially hypothesised that low green ratios would encourage amber overrun by users that were aware of the long red interval, and conversely discourage amber overrun at locations with high green ratios.

The constant variance in the stopline capacities observed at the different sites was unexpected, however, observations of traffic flow during the field data collection have provided insight into possible reasons for this behaviour. The saturation flow rate at various times in the green interval was found to be quite consistent between cycles. For example, a very long headway was generally followed by one or more very short headways. This self-correcting mechanism resulted in relatively small and consistent variations in the number of vehicles crossing the stopline during the green interval, regardless of its length. This behaviour was particulary pronounced when the first vehicle in the queue was slow in responding to the green signal. This potential reduction in stopline capacity was generally corrected with very short headways in the subsequent two or three vehicles.

Good agreement was found between measured and calculated stopline capacities. Accurate calculation of stopline capacity, however, required careful application of saturation flow correction factors. Incorrect use of the correction factors resulted in large changes in the calculated stopline capacities. In addition, modification of the effective green interval based on field observations was required at several sites.

Chapter 6 - Computer Programs

6.1 INTRODUCTION

Two computer programs were developed to allow a comparison between the various probabilities of discharge overload and mean overload factors. The first of these, designated PRADOL (PRobability of Arrival and Discharge OverLoad) was used to calculate the probability of various combinations of overloaded and non-overloaded cycles, for a given cycle capacity and mean arrival rate. The second program, DIStributed CAPacity Overload Simulation (DISCAPOS), was used to generate overload factors by simulation.

Both programs were written in Pascal and were compiled and executed on a Macintosh computer platform using Symantec's Think Pascal development environment. Due to the large number of calculations required by the iterative routines, a computer of the MC68040 family was required to achieve reasonable execution speed. For simplicity, the program listings and discussion thereof do not include the routines used for menu support, dialog boxes, and file saving or printing, and use an early text based data input and output system.

The use of a packaged simulation language for the overload factor simulation program was considered, however, due to the simplicity of the simulation algorithms and the requirement for extensive and flexible output analysis the development of a dedicated program was valuable and not difficult. If further research into the simulation of overload factors is carried out a much more complex model of intersection traffic, likely based on headways rather than cycle by cycle variations, will be required. Duplication of DISCAPOS for further research may be easily accomplished by experienced users of simulation packages such as GPSS or SLAM.

Both PRADOL and DISCAPOS were divided into three units called Main Program, SubPrograms and SubSubPrograms. Procedure and function calls from the Main Program are located in the SubProgram module, while SubProgram calls are found in the SubSubProgram module. The source code listings for PRADOL and DISCAPOS are included in Appendix D.

6.2 PRADOL

6.2.1 Principles

To calculate the probability that a single cycle at a signalized intersection will be overloaded, the summed probabilities of the arrivals up to and including cycle capacity are subtracted from 1.0, as described in Chapter 2. The probability of a subsequent cycle being overloaded, however, is dependent on what happened in the previous cycles and the calculation of these probabilities must consider all possible combinations of prior events. The computer hardware available for this research limited the number of consecutive cycles evaluated to five.

Before beginning the development of the program, the nature of the cycle by cycle overload structure was studied. As discussed previously (Chapter 2), the probability tree of overloaded and non-overloaded cycles resets itself to the starting condition every time a non-overloaded cycle occurs. In the program, the first cycle following a non-overloaded cycle is designated as "A", and the probability of an overload in this cycle is saved as the variable AOL. If the AOL probability is subtracted from 1.0, the probability of not having an overload (ANOL) is determined.

Subsequent cycles (designated B - E) are treated in an identical manner, as shown on Figure 6.2.1. The branch of the tree following any NOL case returns to the AOL / ANOL probabilities. Once the overload / non-overload probabilities for the required number of consecutive cycles are calculated, the determination of the various dependent probabilities involves only multiplication and addition of the appropriate OL and NOL probabilities (Figure 2.3.1).

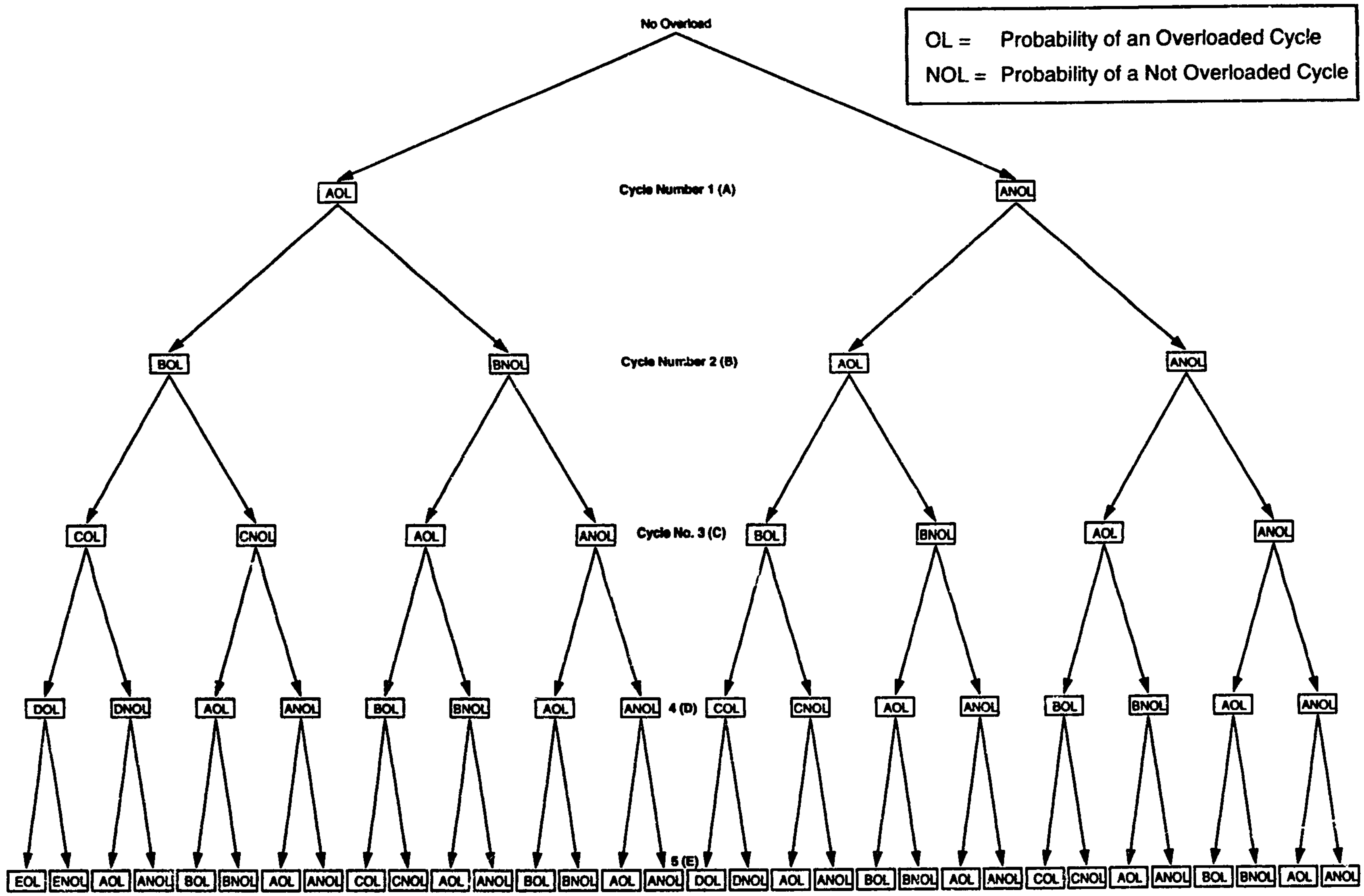


Figure 6.2.1 Probability Tree of Overloaded and Non-overloaded Conditions for Five Consecutive Cycles

The Poisson probability distribution was used to model the variation in cycle by cycle arrivals, as discussed in Chapters 2 and 4. The Poisson distribution has a lower bound of zero, and the probability calculations were carried out to arrival values approximately two times the mean number of arrivals, using a rule developed from the Poisson probability curves for several test cases. This upper bound for calculations (Max) was determined to be in the region where the probability of "x" arrivals was zero at the accuracy level of a single precision real variable, and was confirmed in the Australian Road Research Board Report 123 (3).

6.2.2 Program Algorithms

The program begins by requesting the input of capacity and mean arrivals, both of which are required to be greater than zero and less than 60. The value of mean arrivals is stored as a real number, but because only integer capacities can be used for a cycle by cycle comparison, the actual capacity value is stored as a rounded down integer (CapLow), a rounded up integer (CapHigh) and a real number representing the amount the desired capacity is above CapLow (Percent). The number of consecutive cycles to be evaluated is also requested, and is required to be an integer in the range of 1 to 5. If the combination of input variables would result in very long program execution times, the user is warned and asked to confirm the program run.

The program then calculates the probability of exactly "x" arrivals for all integer values of "x" between zero and Max, and places them in a vector (PVect). The value of Max is then recalculated based on the input capacity rather than mean arrivals. The main program calls the appropriate number of cycle routines, based on the input data, for both CapLow and CapHigh. The following probabilities are returned from the calculation procedures:

- the probability that the last cycle is overloaded,
- the probability that any one or more of the cycles is overloaded, and
- the probability that all of the cycles are overloaded.

The cycle routines which calculate the OL / NOL probabilities use nested repeat loops which calculate whether or not an overload has occurred for all combinations of numbers of arrivals in each cycle. Only one new OL / NOL pair is required for each additional consecutive cycle considered, as all other probabilities at that level have been calculated at previous levels (Figure 6.2.1) The combined dependent probabilities are calculated by multiplying and adding the appropriate OL / NOL probabilities which are then passed back to the main program.

The final dependent probabilities for the actual capacities are determined by interpolation between the values calculated using the CapLow and CapHigh variables, using the Percent variable. A sample of the program output is shown on Figure 6.2.2.

6.2.3 Validation

The output from PRADOL was validated using a Microsoft Excel spreadsheet. Linked cells were required to allow calculations to three consecutive cycles, and comparison of results at the four and five consecutive cycle levels was not feasible using the spreadsheet. Although the validation could only be carried out for small values of mean arrivals and capacity, and used only integer capacities, the two methods produced identical results. Plots of PRADOL output for the fourth and fifth consecutive cycles followed the trends observed in the validated cycle levels and provided confidence that no errors were present in the output from the higher levels.

6.3 DISCAPOS

6.3.1 Introduction

The simulation of overload factors using a computer program was based on the definition of overloaded cycles as follows: a cycle is considered to be

```
Welcome to PRADOL - the Probability of Arrival and Discharge Overload Calculation Program
                         © Randall Sonnenberg - 1993

Enter CAPACITY of Lane, in veh/cycle:
8.53

Enter MEAN ARRIVALS, in veh/cycle:
6.22

Enter number of consecutive cycles to be evaluated (1 to 5):
5
Execution time may be greater than 5 minutes on many computers, enter "1" to continue or "2" to
1

Probability of an Overload in cycle 1 is 0.136

Probability of an Overload in cycle 2 is 0.169
Probability of an Overload in cycles 1 and 2 is 0.053
Probability of an Overload in cycles 1 or 2 is 0.2[illegible]

Probability of an Overload in cycle 3 is 0.207
Probability of an Overload in cycles 1 and 2 and 3 is 0.051
Probability of an Overload in cycles 1 or 2 or 3 is 0.351

Probability of an Overload in cycle 4 is 0.242
Probability of an Overload in cycles 1 and 2 and 3 and 4 is 0.051
Probability of an Overload in cycles 1 or 2 or 3 or 4 is 0.436

Probability of an Overload in cycle 5 is 0.27[illegible]
Probability of an Overload in cycles 1 and 2 and 3 and 4 and 5 is 0.051
Probability of an Overload in cycles 1 or 2 or 3 or 4 or 5 is 0.509

Enter "1" for further calculations with new input values, or "2" to quit PRADOL
2
```

Figure 6.2.2 Sample Output from the PRADOL Computer Program

overloaded if the number of vehicles arriving during the cycle added to the number of vehicles remaining at the end of the previous cycle is greater than the cycle capacity. Although the simulation of the events is simple, a large number of cycles or groups of cycles is required for accurate evaluation.

The simulation program created for this research uses the probability distributions discussed in Chapters 4 and 5 to model the arrival and discharge patterns. Random numbers between 0 and 1 were generated using the Think Pascal function "Random", and were checked for validity using a separate computer program. The check program compared the first random number generated (before reduction to the 0 to 1 range) with all of the following random numbers. If a match was found, the number of random numbers generated to that point was recorded. The next two random numbers were then compared to the second and third numbers generated, to determine if the sequence of random numbers was repeating.

The first random number was found to repeat approximately every 29,000 numbers. The subsequent random numbers, however, were always different for the 1,000,000 consecutive random numbers generated. Sample output from the check program is included in Appendix D. The 1,000,000 random numbers generated were also converted to values between 0 and 1 and were sorted into groups (bins) 0.02 wide, each of which should contain 2% of the random numbers. The quantities of random numbers in each bin are included on the sample output sheets in Appendix D, and are plotted on Figure D-3.1.

As a further check on both the random numbers and the accuracy of the arrival and capacity generation algorithms a program that produced 1000 arrivals and capacities was developed. The mean of the generated data sets were compared to their input means, and the coefficient of variation of the arrival data and the standard deviation of the capacity data were calculated. The expected and generated values from one trial are shown in Table 6.3.1 below.

Table 6.3.1 Comparison Between Expected and Generated Arrivals and Capacities

	Mean of Arrivals (m)	Coefficient of Variation (CoV)	Mean of Capacities (X)	Standard Deviation (σ)
Expected	10.5	1	10.5	1.1
Generated	10.46	1.03	10.5	1.12

The program provided data indicating that the algorithms used for the generation of arrivals and stopline capacities were correct, and that the random number generation was free of bias.

The simulation of 1000 series of cycles was found to produce overload factors that did not vary significantly between simulation runs, without causing excessively long program execution times. The actual number of cycles measured in the field were simulated for the comparisons between measured and simulated overload factors, while 50 consecutive cycles were simulated when generating data for comparison with calculated probabilities. In total, more than 2,500,000 cycles were simulated for the program validation and the generation of data.

6.3.2 Program Algorithms

The input of mean capacity, mean arrivals and number of cycles to be simulated is carried out as described in section 6.2.2 for the PRADOL program. The cycle capacity and mean arrivals must be between 0 and 60, while the number of consecutive cycles is constrained to the range of 5 to 250. The upper bound for the arrival distribution (Poisson) and the upper and lower bounds for the discharge distribution (Normal) are calculated using the rule developed for the PRADOL program.

Before the program enters the two nested while loops which count the number of cycles and series which have been simulated, the comparison vectors for the arrival (ADist) and discharge (CDist) distributions are created.

These vectors contain the cumulative probabilities which are calculated by summing the singular probabilities generated as described for PRADOL. Due to the importance of having accurate numbers for comparison, particularly in the tails of the distributions, both the arrival distribution vector (ADist) and the stopline capacity distribution vector (CDist) are designated as double precision variables.

The program then enters two nested while loops which count the number of cycles and series of cycles simulated. The simulation is carried out by generating two random numbers and comparing them to the probability vectors to determine the integer arrivals and capacity for the current cycle. The capacity is reduced to an effective capacity by subtracting any leftover vehicles, and a cycle is recorded as overloaded if the number of arrivals is greater than effective capacity. Any remaining vehicles are counted (OLveh) for use in the subsequent cycle.

Two methods for analyzing the variation of data generated by the simulation program were used. The distribution of overload factors from each series of simulated data was initially assumed to be normal, and the standard deviation of the generated overload factors was calculated in a separate procedure (CalcSTDev). In addition, the number of series with overload factors in each 0.05 interval from 0.00 to 1.00 were tabulated, to permit generation of frequency plots of the simulated overload factors. Sample output from the DISCAPOS program is included as Figure 6.3.1.

6.3.3 Validation

Frequency plots of the generated overload factors in 20 groups 5% wide were prepared using the 1000 series of data from each simulation run using the field survey conditions as input. Three sample frequency plots, along with the measured overload factors from the surveys, for low (Survey No. 11), medium (Survey No. 7) and high (Survey No. 20) overload factors are presented on Figures 6.3.2, 6.3.3 and 6.3.4 respectively. The remainder of

```
Welcome to DISCAPOS - the Variable Capacity Overload Factor Simulation Program
                              © Randall Sonnenberg - 1993


Enter STOPLINE CAPACITY of Lane, in veh/cycle:
12.27

Enter MEAN ARRIVALS for Lane, in veh/cycle:
9.82

Enter number of consecutive cycles to be simulated:
47

IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII

 1000 series of 47 cycles were simulated

Average Overload Factor =  0.26          Standard Deviation =  0.09
   Average OLF minus 1 Standard Deviation =  0.17
   Average OLF plus 1 Standard Deviation =  0.36

Distribution of Overload Factors in groups of 0.05
   2  18 110 135 196 240 120  85  62  21   6   4   1   0   0   0   0   0   0   0

Percentiles of Overload Factor Distribution
90th Percentiles = 0.13   0.43
66th Percentiles = 0.17   0.36
50th Percentiles = 0.19   0.32

Excecution time was  1 minutes and 30 seconds

Enter 1 to rerun simulation with same input data, or any other number to continue
2

Enter 1 to continue with new input data, or any other number to quit
2
```

Figure 6.3.1 Sample Output from the DISCAPOS Computer Program

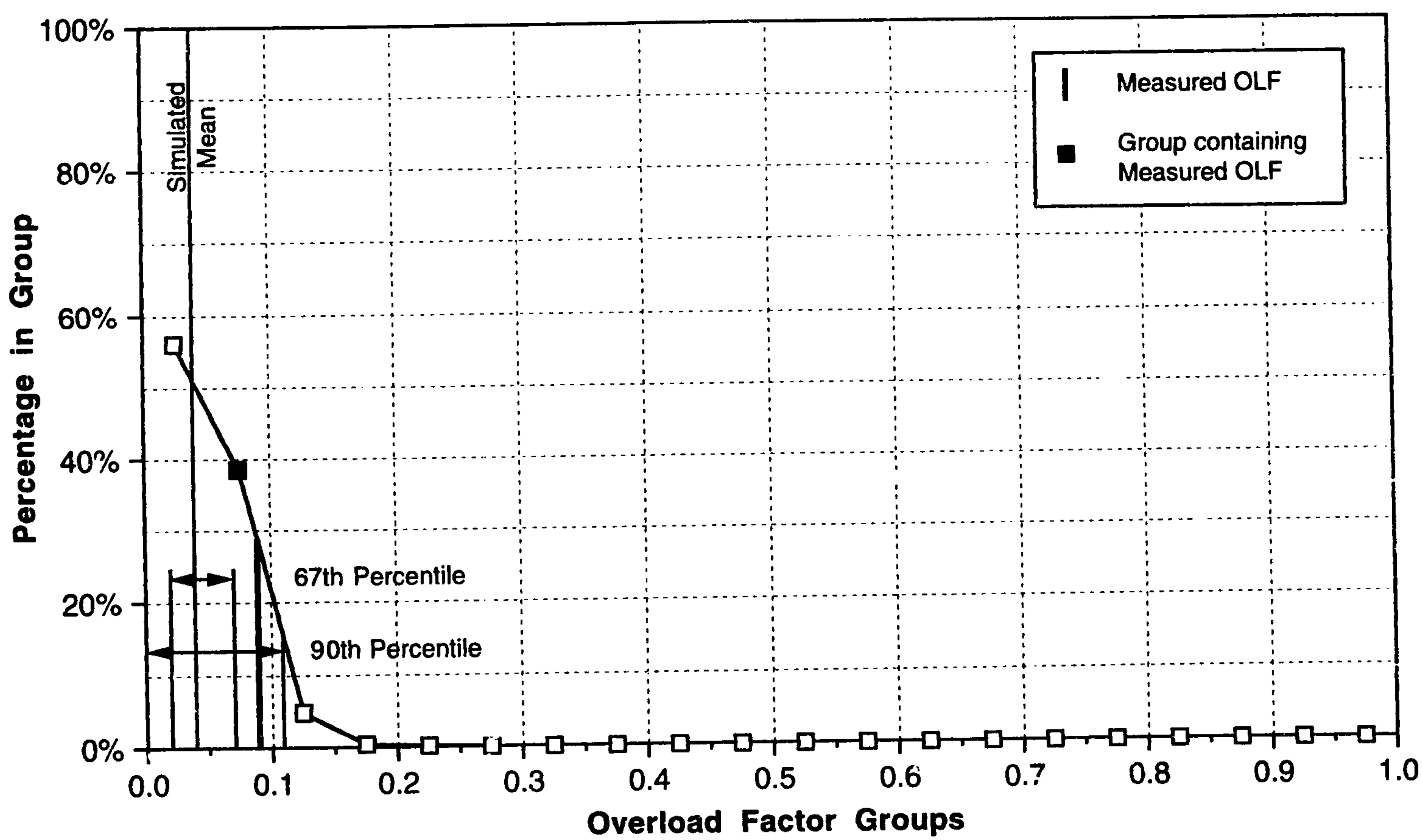


Figure 6.3.2 **Frequency Plot of Simulated Overload Factors for Survey No. 11**

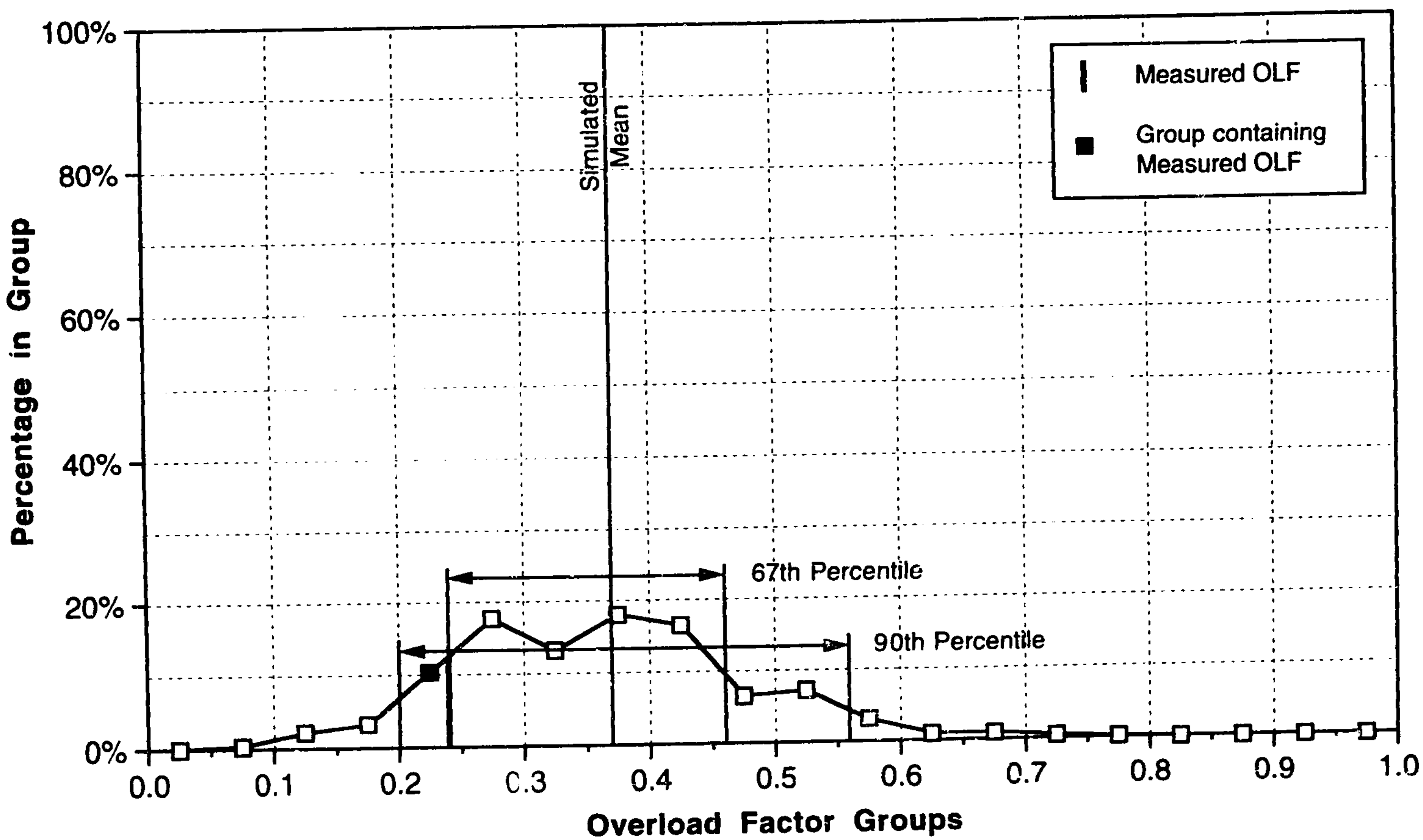


Figure 6.3.3 Frequency Plot of Simulated Overload Factors for Survey No. 7

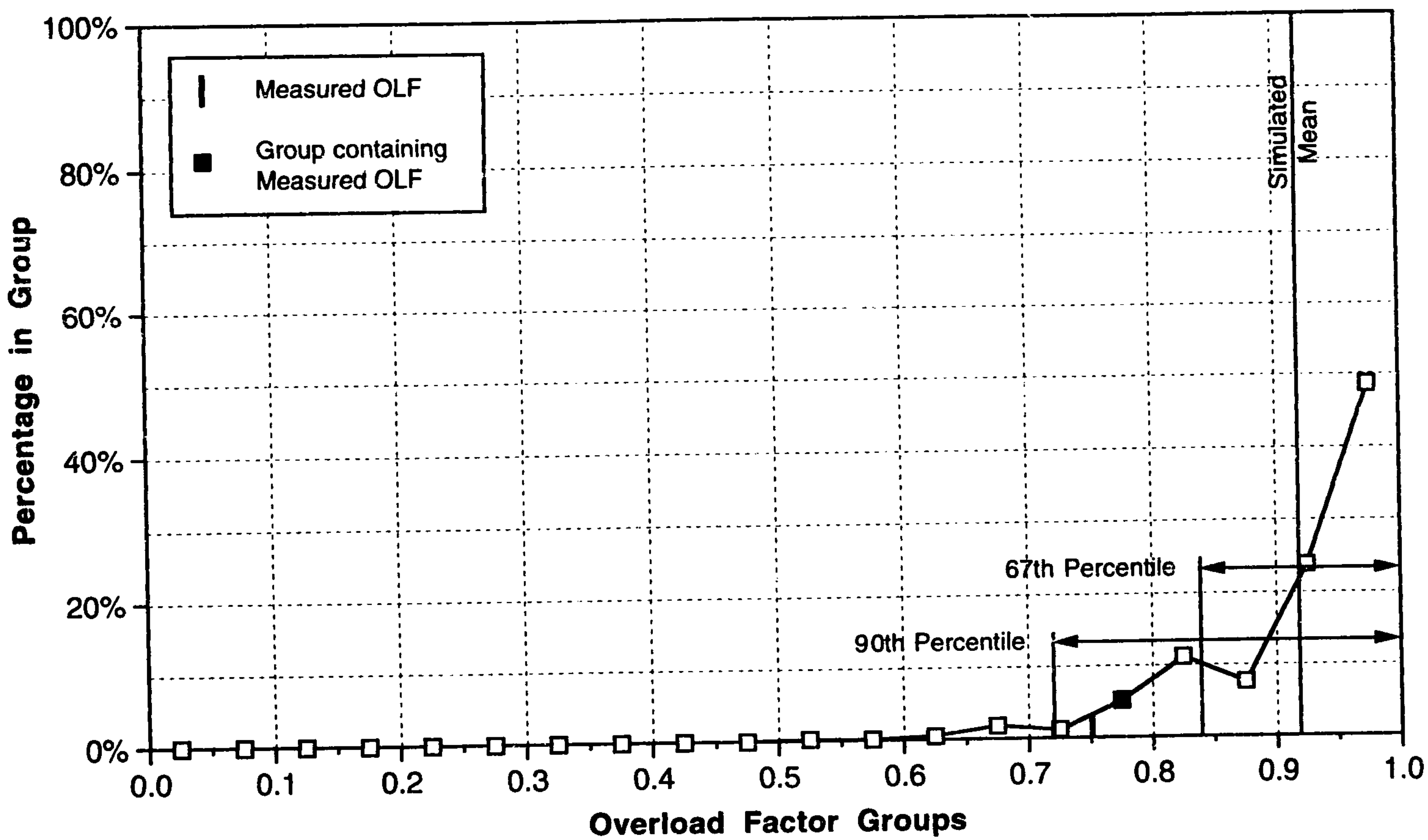


Figure 6.3.4 Frequency Plot of Simulated Overload Factors for Survey No. 20

the plots are included in Appendix D as Figures D-3.2 to D-3.19.

The majority of the frequency plots of generated overload factors were found to be non-symmetrical, particularly those with means approaching 0.0 or 1.0 which were truncated by these bounds. For this reason, no attempt was made to create symmetrical bands of standard deviations around the simulated means as a method for evaluating whether or not the field data points could be members of the generated data set.

The generated overload factors were sorted and the 90th, 67th and 50th percentiles around the mean were determined from the values of overload factor at the corresponding points in the distribution. The limits of the 90th and 67th percentiles are included on Figures 6.3.2 to 6.3.4. The locations of the field data points within these percentiles were analyzed with the following results:

- 18 of 21 field data points (86%) are within the 90th percentile,
- 13 of 21 field data points (62%) are within the 67th percentile, and
- 9 of 21 field data points (43%) are within the 50th percentile.

Based on the results of this analysis, it is likely that the field survey data are members of the population of overload factors generated by the simulation program.

The overload factors determined from the field surveys were grouped by similar mean arrivals for trend analysis. Five groups of mean arrivals were created, as shown below:

Group 1 - 5.5 arrivals / cycle

Survey 1	m = 5.3
Survey 3	m = 6.1
Survey 10	m = 5.5

Group 2 - 8.0 arrivals / cycle

Survey 4	m = 7.8
Survey 11	m = 7.8

Group 3 - 10.0 arrivals / cycle

Survey 5	m = 10.3
Survey 6	m = 11.1
Survey 9	m = 9.8
Survey 12	m = 9.5
Survey 15	m = 10.9
Survey 19	m = 9.5
Survey 21	m = 9.8

Group 4 - 17.5 arrivals / cycle

Survey 2	m = 14.5
Survey 7	m = 16.1
Survey 13	m = 17.5
Survey 14	m = 17.9
Survey 18	m = 18.5

Group 5 - 20.0 arrivals / cycle

Survey 8	m = 19.1
Survey 16	m = 19.9
Survey 17	m = 19.8
Survey 20	m = 21.9

Plots showing mean simulated overload factors for 1000 series of 50 cycles at the group mean arrival rates, as well as the surveyed overload factors and simulated values for the exact field conditions were prepared, and are shown on Figures 6.3.5 to 6.3.9. The plots also include the 67th percentiles around the mean of the simulated values, to give an indication of the dispersion of the generated overload factors.

Although the analysis of overload factors and their distribution was confined to m/X ratios of 0.4 to 1.1, a sample plot of simulated overload factors and their standard deviation for mean arrivals of 6 veh/cycle over a range of m/X ratios from 0.2 to 1.8 is included as Figure 6.3.10.

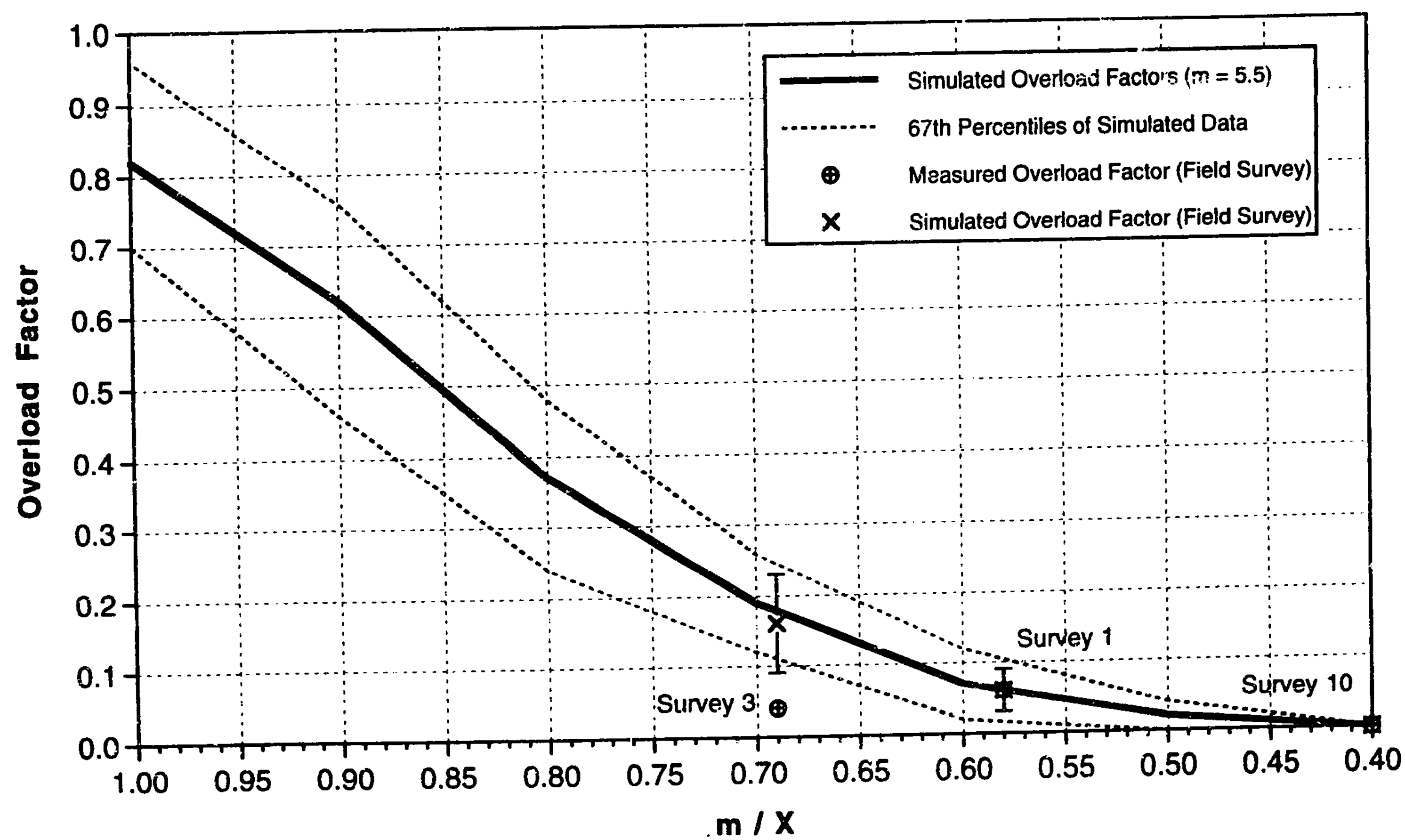


Figure 6.3.5 Simulated and Measured Overload Factors for Mean Arrivals Near 5.5 veh/cycle

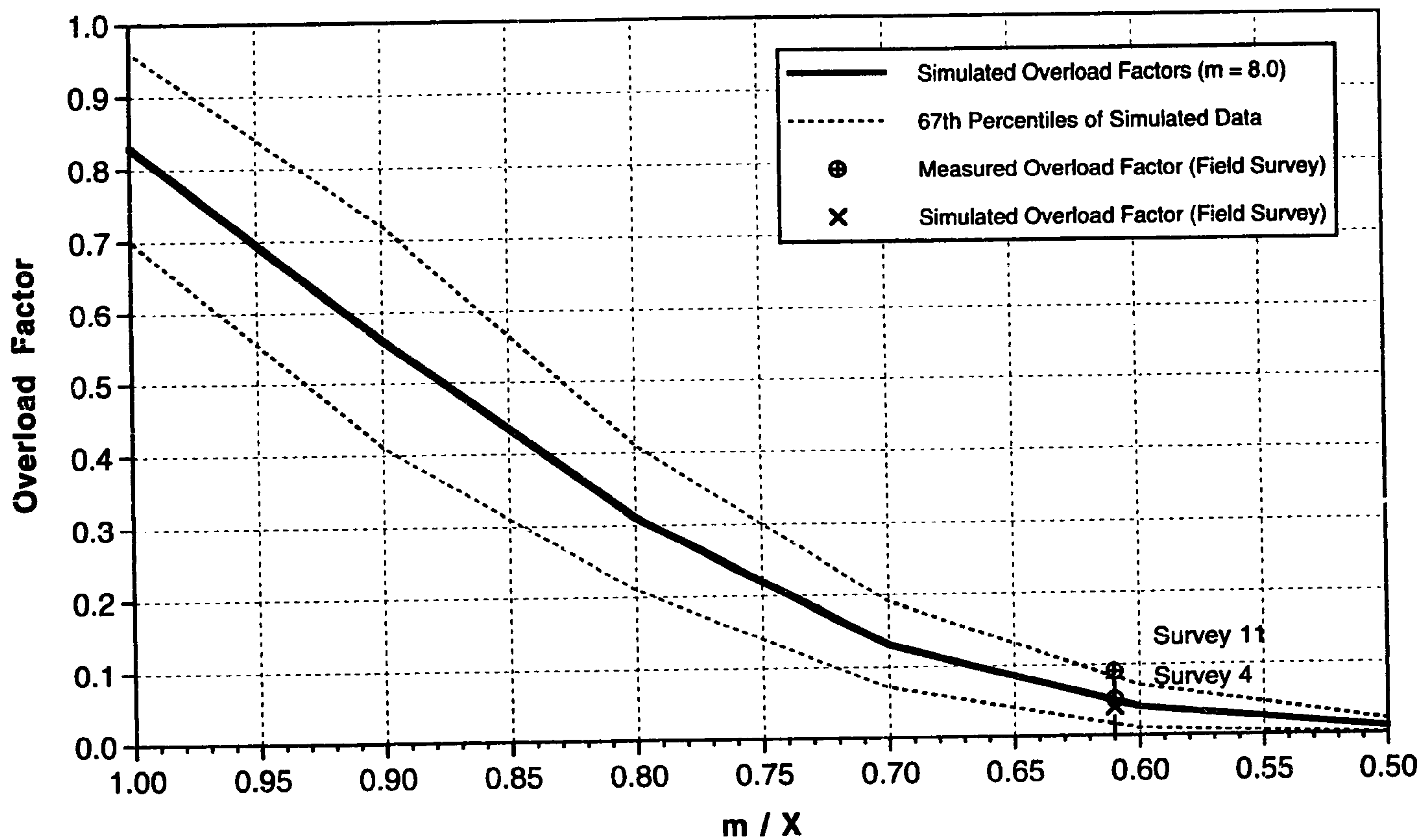


Figure 6.3.6 Simulated and Measured Overload Factors for Mean Arrivals Near 8.0 veh/cycle

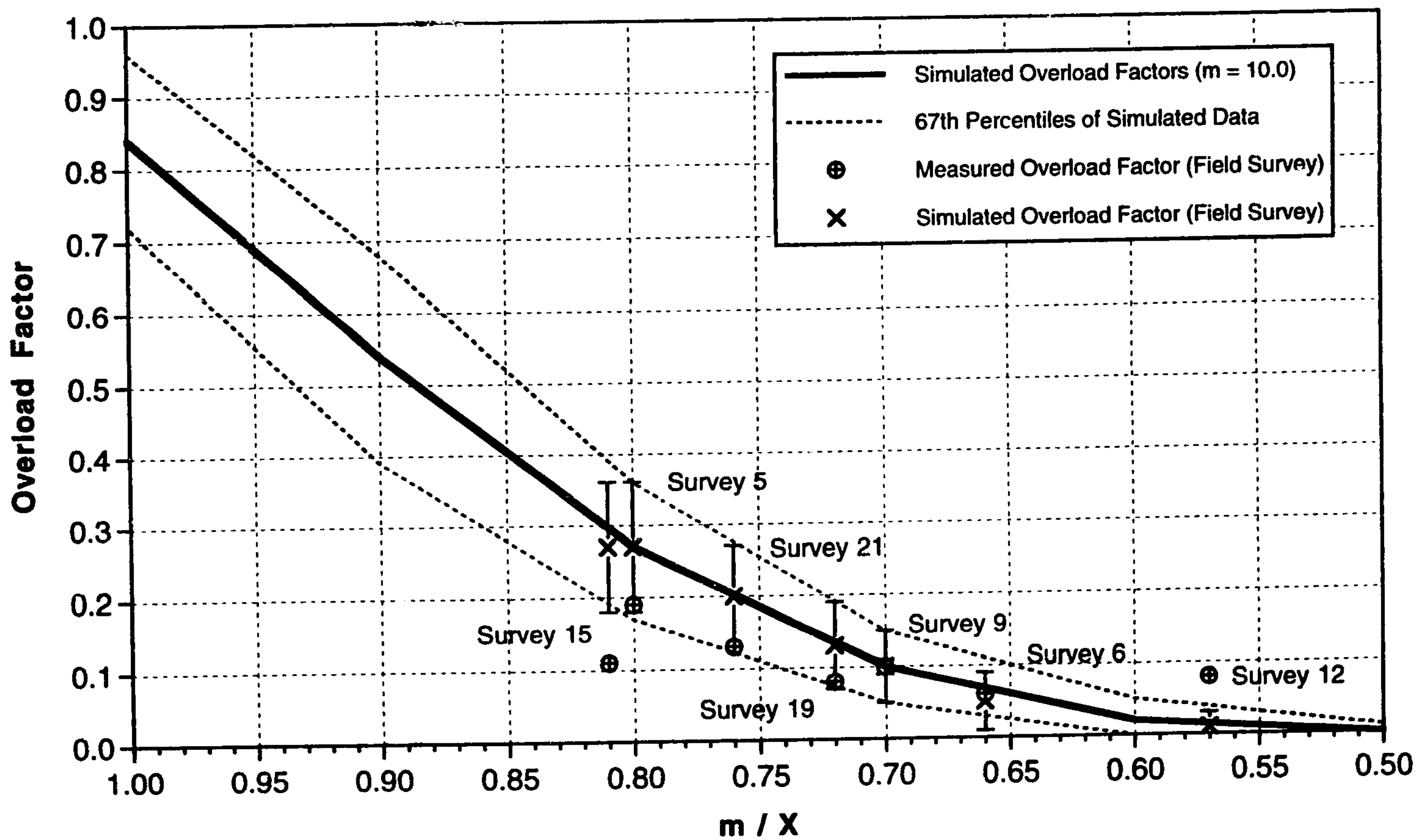


Figure 6.3.7 Simulated and Measured Overload Factors for Mean Arrivals Near 10.0 veh/cycle

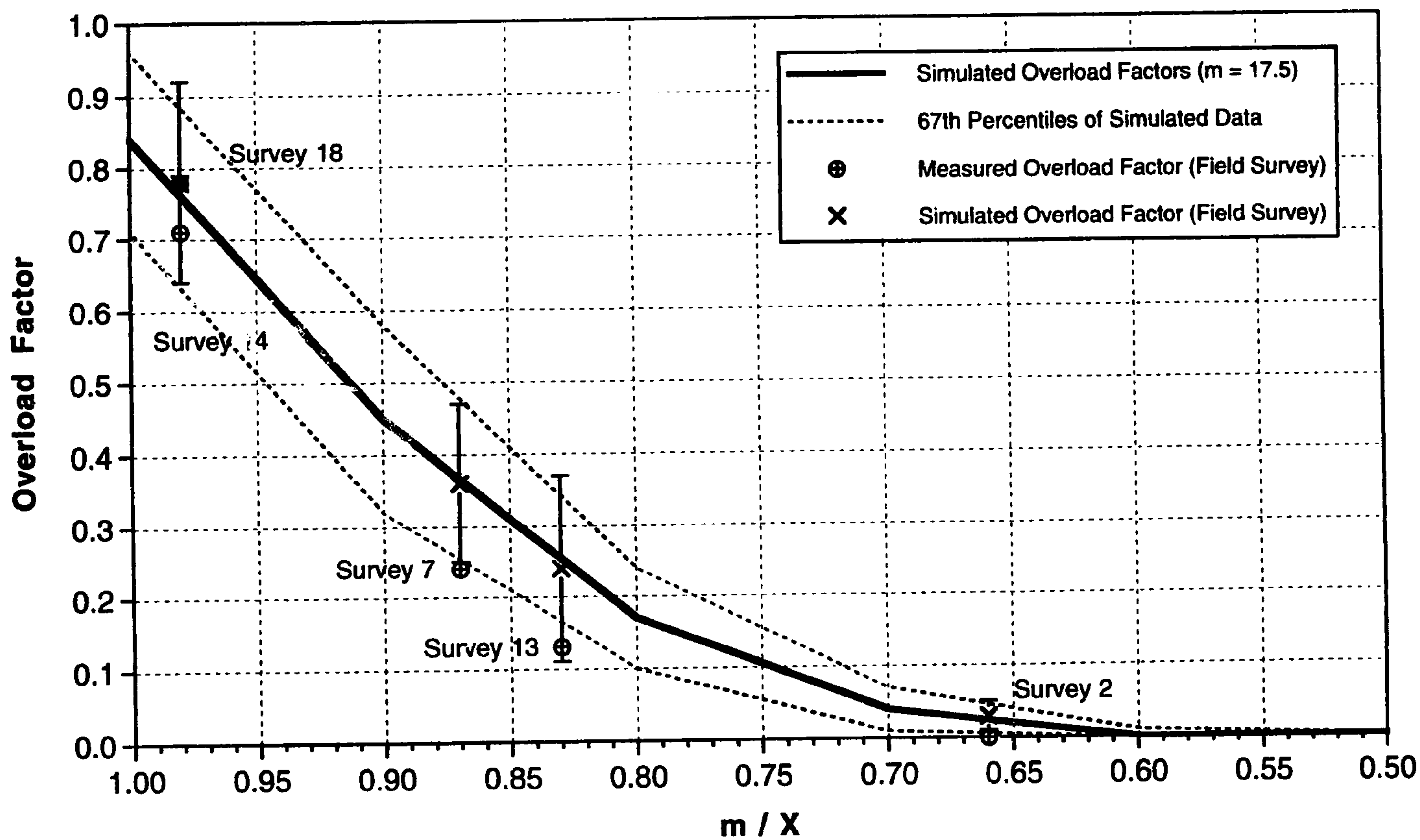


Figure 6.3.8 Simulated and Measured Overload Factors for Mean Arrivals Near 17.5 veh/cycle

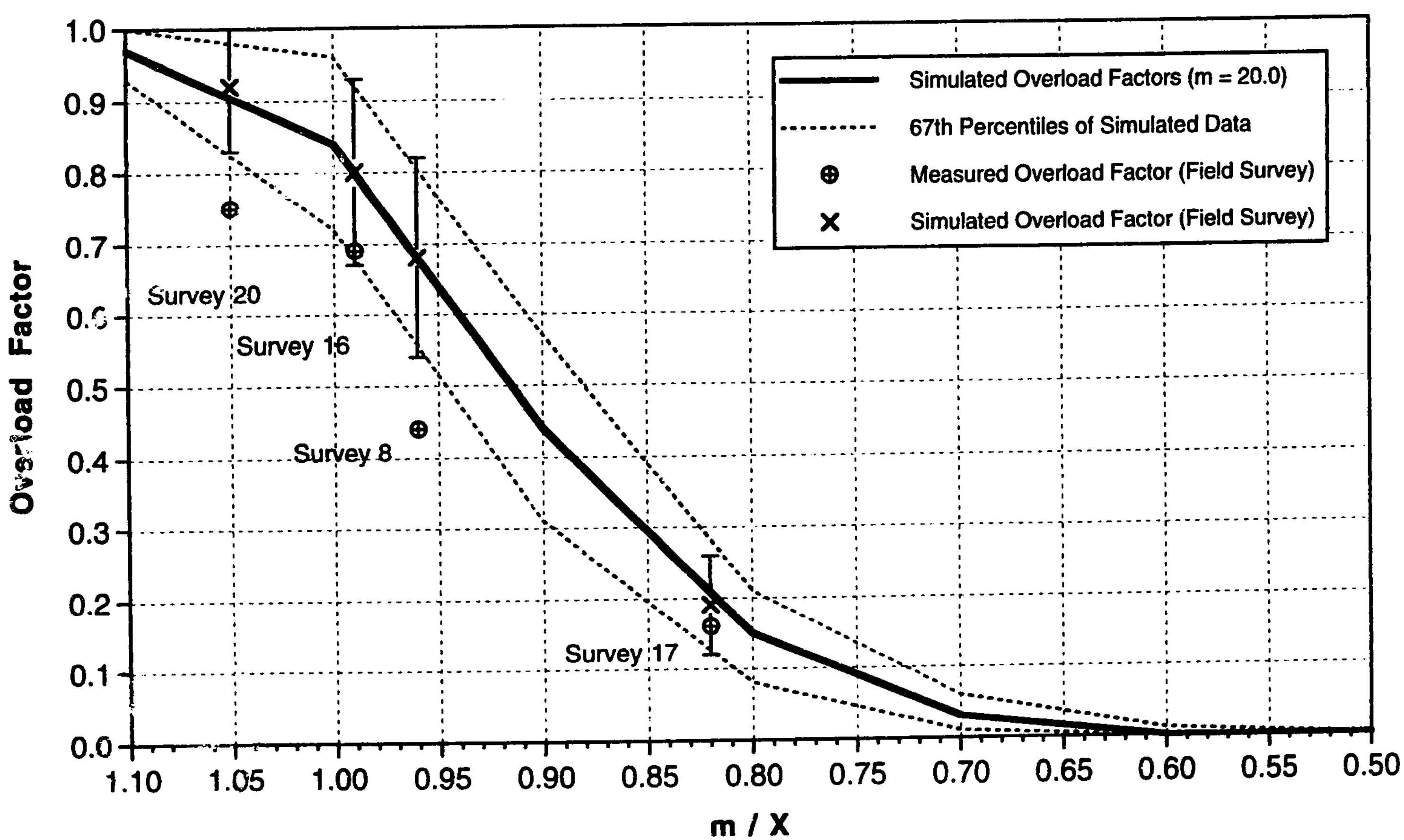


Figure 6.3.9 Simulated and Measured Overload Factors for Mean Arrivals Near 20.0 veh/cycle

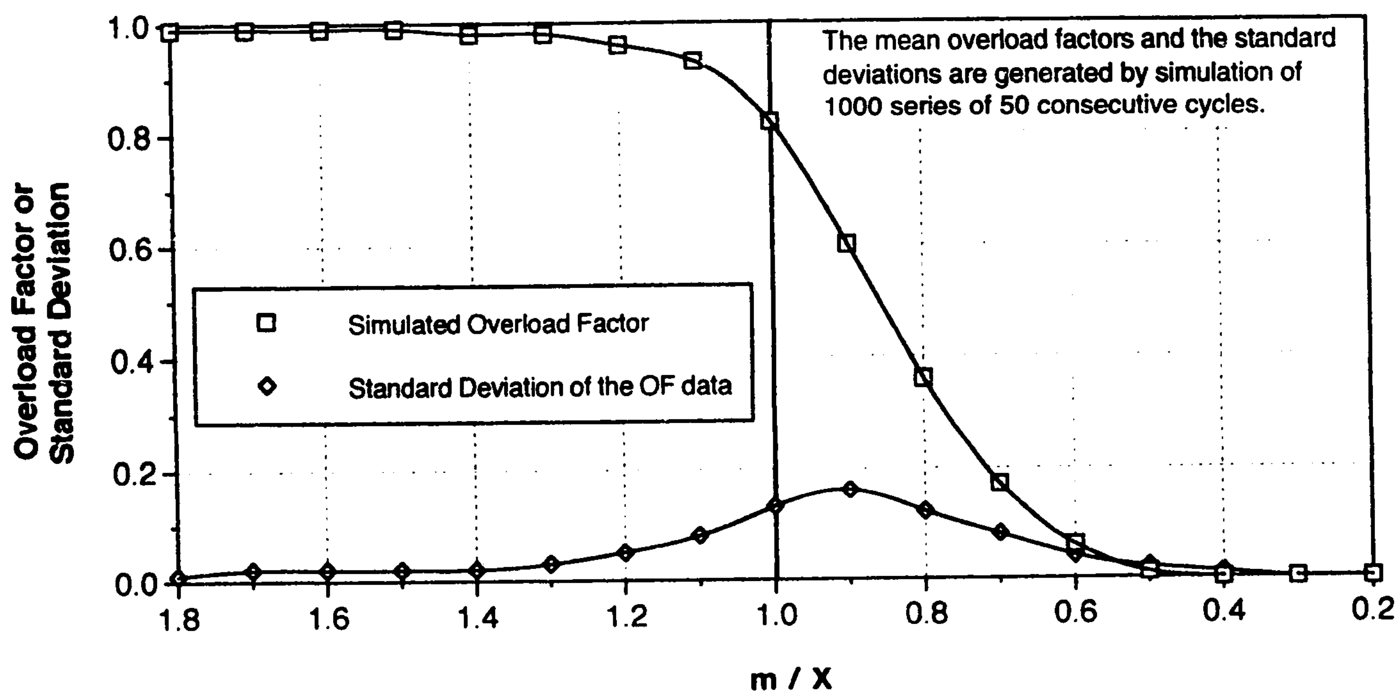


Figure 6.3.10 Simulated Overload Factors and Standard Deviations for Mean Arrivals of 6 veh/cycle

The standard deviation of the simulated data is essentially zero at very small and very large values of m/X, and reaches a peak at m/X values of approximately 0.90. This trend is due to the truncation and narrowing of the overload factor frequency plots as m/X ratios approach 1.5 and 0.0. In addition, it can be seen that the overload factor does not reach 1.0 until the lane under investigation is well beyond capacity (m/X = 1.0). This is caused by the assumption that the first cycle of the series of cycles being considered is follows a non-overloaded cycle. With no leftover vehicles, and therefore no reduction in effective capacity, the first cycle has some small probability of not being overloaded. Once the first cycle overload occurs at m/X ratios greater than 1.0, however, it is a virtual certainty that all subsequent cycles will be overloaded.

The number of field data points within the various probability regions calculated from the simulated overload factors are approximately as expected. The three data points not contained within the 90% confidence interval were compared to the sorted frequency values manually, to confirm that the overload factor observed in the field did occur at least once during the simulation. All three data points were able to meet this criterion. As well, an inspection of the frequency plots provides no reason to reject the hypothesis that the individual field data points fit into the distributions of overload factors generated by simulation. There is no data point in a group containing less than 2.5% of the simulated values, and only 6 of the 21 field data points are in groups of 10% or less. Although the group containing the mean simulated value is not always the largest, it should be noted that 11 field points are below the group containing the simulated mean value, while only two points are above. It is difficult to determine with certainty whether this is due to random variation or to an undetermined bias in the field counts.

Chapter 7 - Analysis

7.1 INTRODUCTION

The primary goal of the simulation program development was to provide a means of generating large amounts of overload factor data, which could be compared to the various probabilities of discharge overload to determine if the surrogate for average overload factor developed by Teply (7) and proposed for use in the Second Edition of the Canadian Capaci[illegible]le for Signalized Interse[illegible]ns (10) is valid.

To reflect the variable conditions encountered in traffic operations, the mean arrival groups created in the previous chapter were used as the basis for this analysis. The mean arrivals of 5.5 represent approximately the number of vehicles that would clear an intersection lane during the minimum green interval (10 seconds) recommended in Canada (1). The largest mean arrival group used in the analysis (20 vehicles/cycle) would require a green interval of about 45 seconds to clear an intersection, which is typical of the maximum green interval used in Edmonton.

7.2 ANALYSIS

Plots showing the simulated overload factors (1000 series of 50 cycles), and the nine dependent probabilities calculated by the PRADOL program are presented on Figures 7.2.1 to 7.2.5, for the five mean arrival groups described previously. The probabilities are of two types: the probability of having an overload in the cycle under consideration, and the probability that at least one of the cycles considered was overloaded. The nine probabilities and their designations on the plots are tabulated below:

- P(1+ in 2) = the probability that at least one (or both) of two consecutive cycles are overloaded

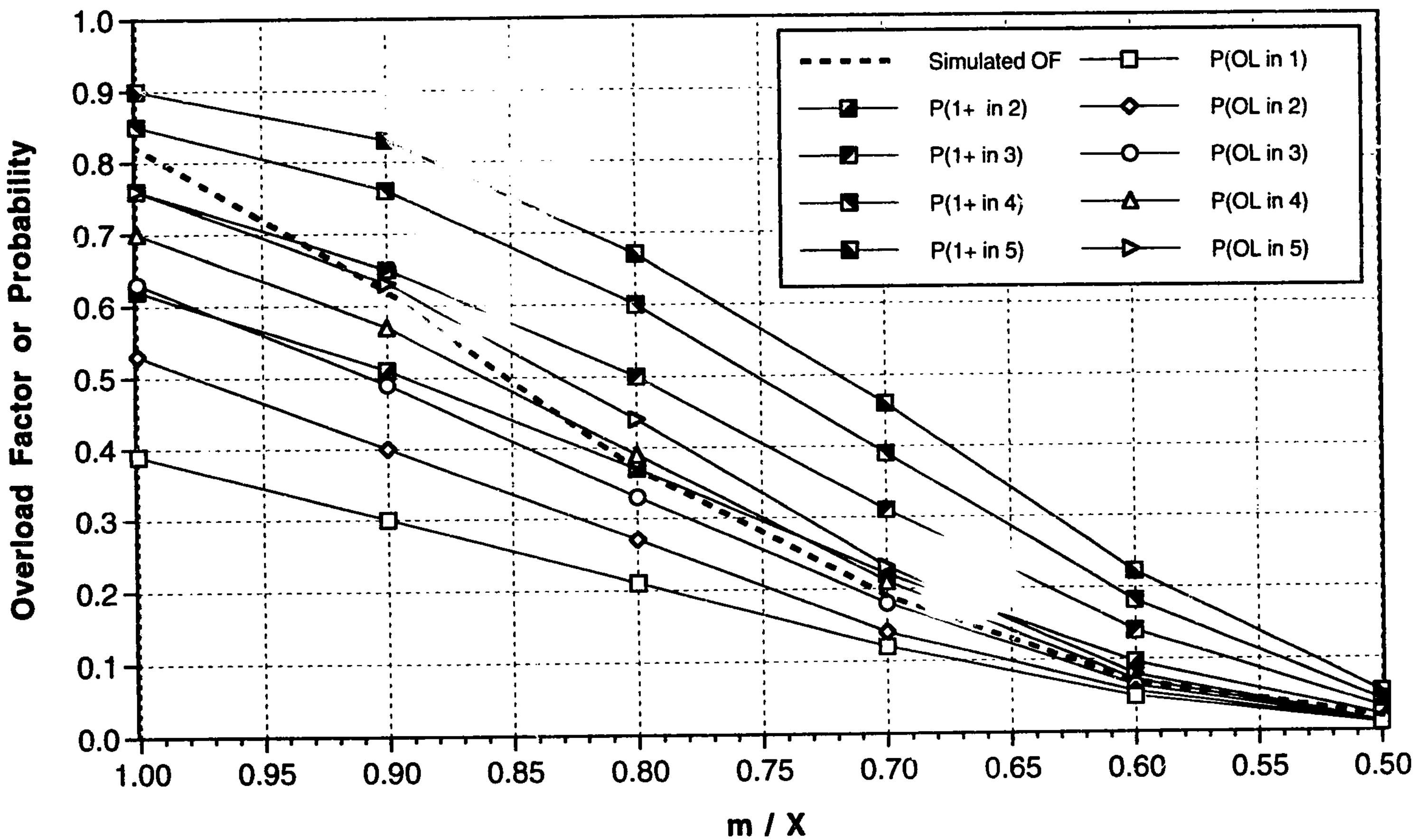


Figure 7.2.1 **Simulated Overload Factors and Several Types of Probabilities of Discharge Overload for Mean Arrivals of 5.5 veh/cycle**

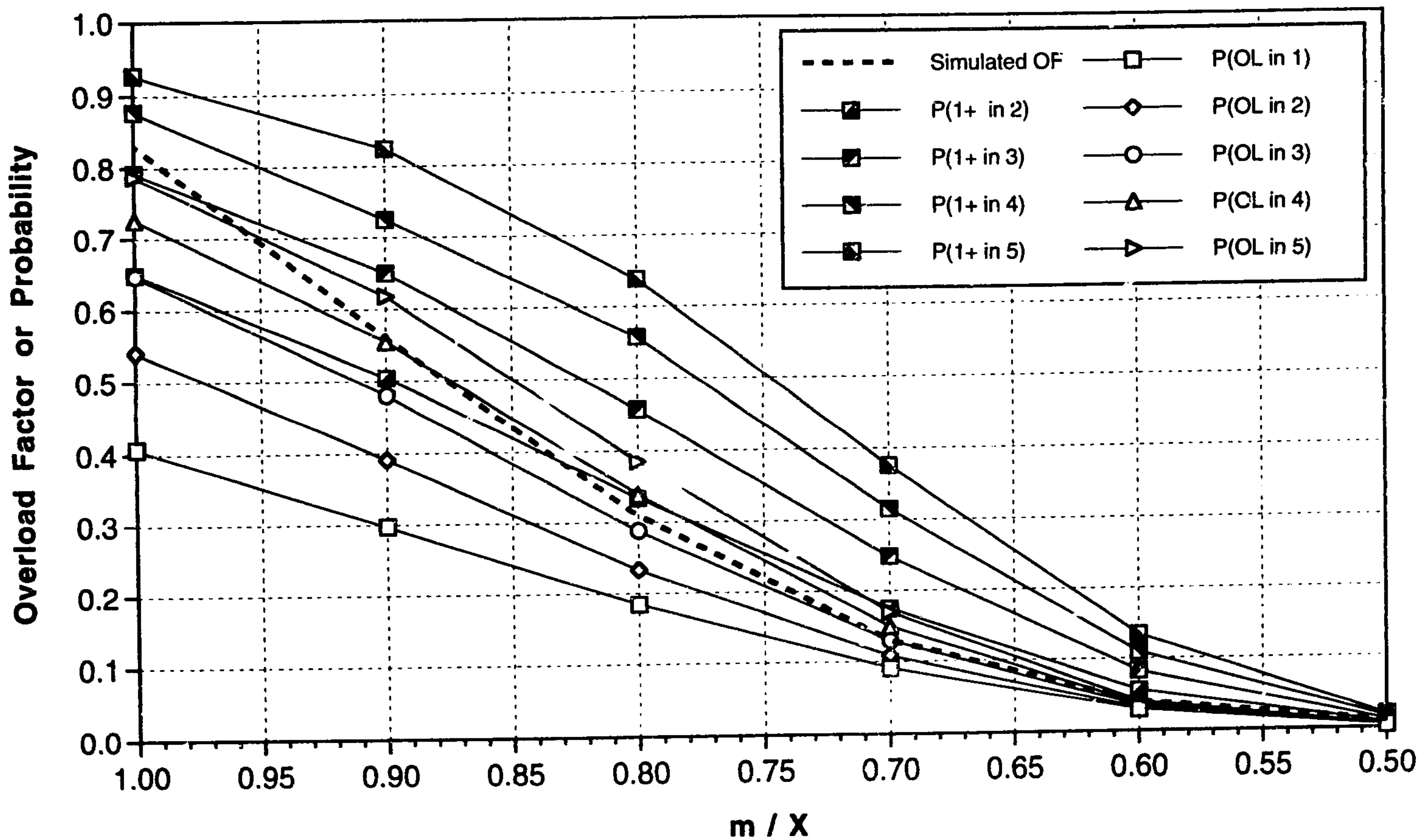


Figure 7.2.2 Simulated Overload Factors and Several Types of Probabilities of Discharge Overload for Mean Arrivals of 8.0 veh/cycle

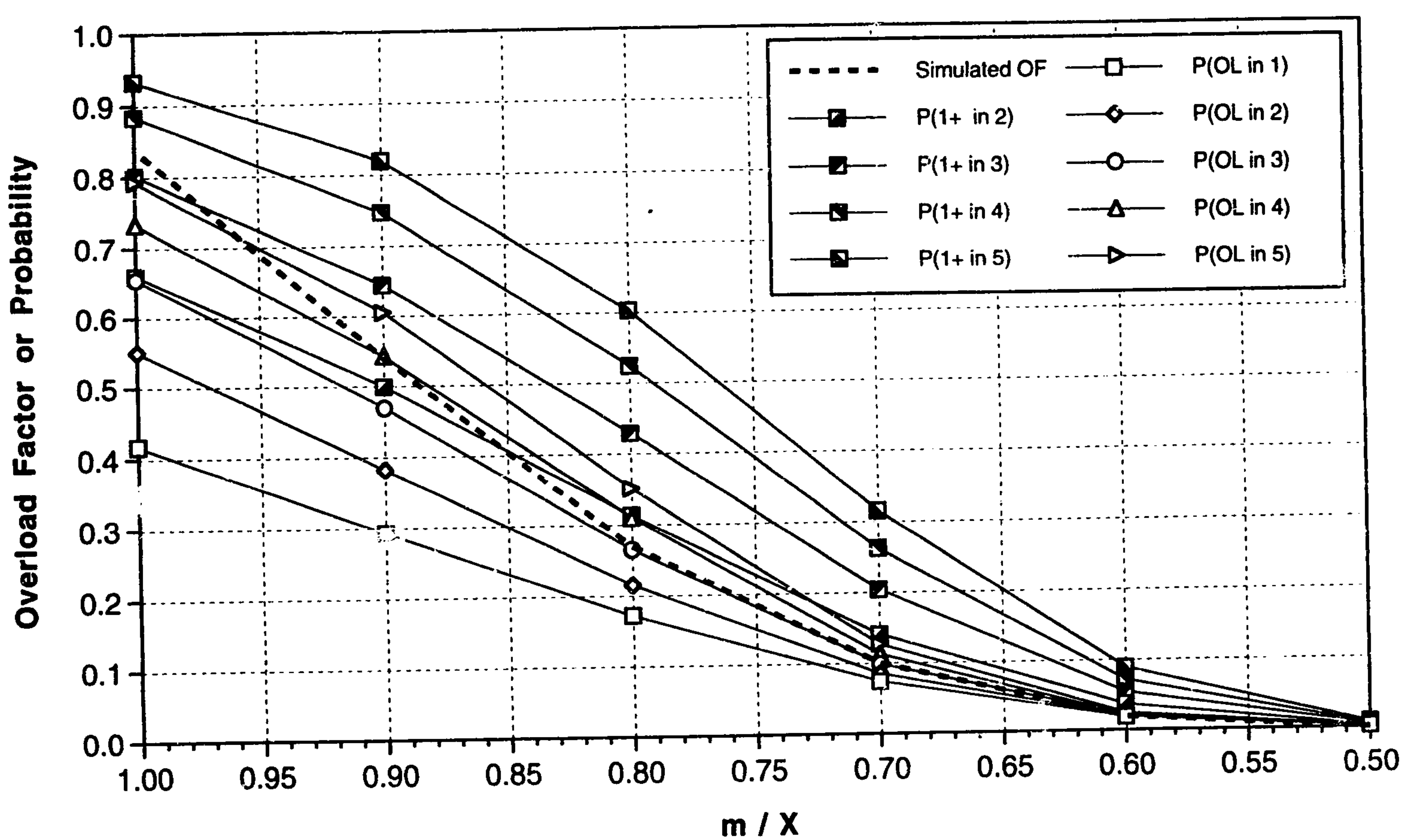


Figure 7.2.3 **Simulated Overload Factors and Several Types of Probabilities of Discharge Overload for Mean Arrivals of 10.0 veh/cycle**

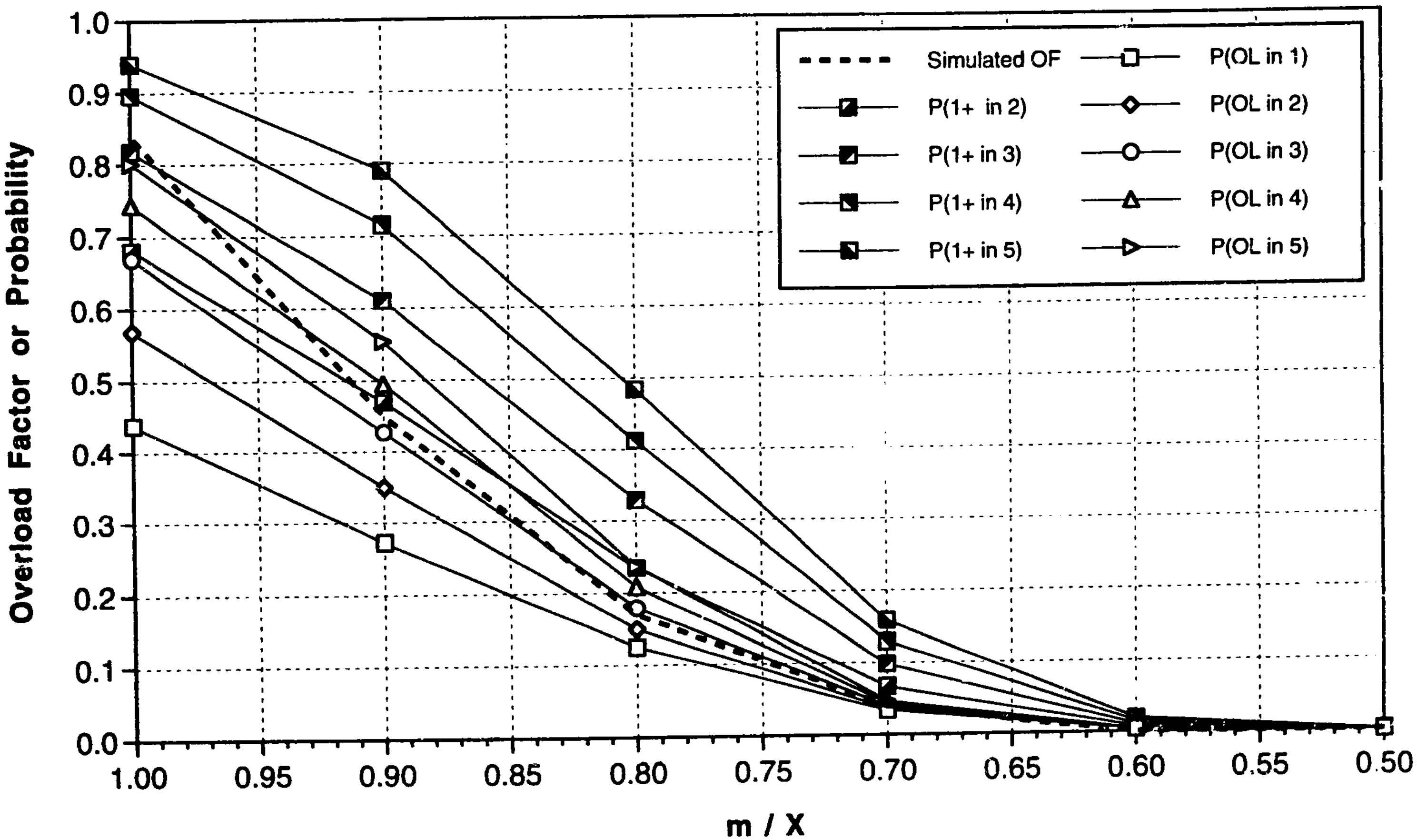


Figure 7.2.4 Simulated Overload Factors and Several Types of Probabilities of Discharge Overload for Mean Arrivals of 17.5 veh/cycle

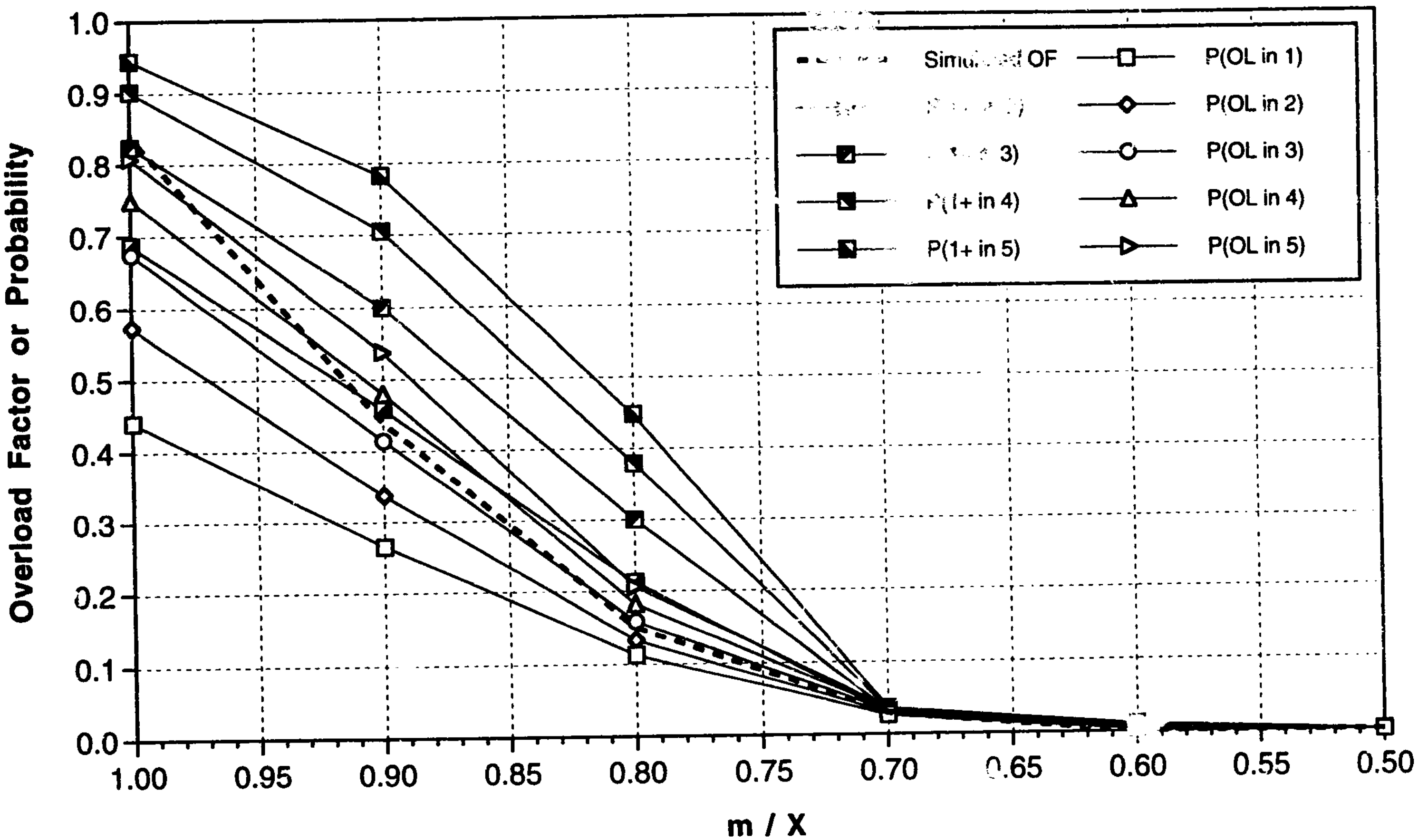


Figure 7.2.5 Simulated Overload Factors and Several Types of Probabilities of Discharge Overload for Mean Arrivals of 20.0 veh/cycle

- P(1+ in 3) = the probability that at least one (or more) of three consecutive cycles are overloaded
- P(1+ in 4) = the probability that at least one (or more) of four consecutive cycles are overloaded
- P(1+ in 5) = the probability that at least one (or more) of five consecutive cycles are overloaded
- P(OL in 1) = the probability that the number of arrivals in a cycle is greater than cycle capacity (probability of arrival overload)
- P(OL in 2) = the probability that the second of two consecutive cycles following a not overloaded cycle is overloaded
- P(OL in 3) = the probability that the third of three consecutive cycles following a not overloaded cycle is overloaded
- P(OL in 4) = the probability that the fourth of four consecutive cycles following a not overloaded cycle is overloaded
- P(OL in 5) = the probability that the fifth of five consecutive cycles following a not overloaded cycle is overloaded

It should be noted that the P(1+ in "n") probabilities are relatively simple to calculate, while the P(OL in "n") probabilites for even three consecutive cycles can only be calculated efficiently using a computer program (7). The probability of having at least one overloaded cycle in two consecutive cycles (either the first, the second or both cycles) following a not overloaded cycle is proposed as a surrogate for overload factor in the Final Draft of the Second Edition of the Canadian Capacity Guide (10).

From an inspection of Figures 7.2.1 to 7.2.5 it is apparent that no single probability, of the ones considered, closely matches the simulated overload factors throughout the range of m/X from 0.50 to 1.00. As well, the relationship between the simulated data and the various probabilities varys significantly with changes in mean arrivals. Based on these observations, two formulae were developed using combinations of several probabilities to model the overload factor. The first formula is applied if the mean arrivals in the lane being investigated are less than 10 veh/cycle, while the second formula is appropriate for cases where the mean arrivals a[illegible] eater than 10 veh/cycle. The formulae are presented in Table 7.2.1, and pl[illegible] of the simulated overload factors and the combined probability [illegible]es generated by the formulae are [illegible]own on Figures 7.2.6 ar[illegible] 7.2.7.

Table 7.2.1 Probability Based Surrogates for Overload Factor

Formula A m < 10.0	m/X < 0.70 P(OL in 3)	.85 ≤ m/X < .90 P(OL in 4)	m/X = 1.00 P(1+ in 4)
Formula B m ≥ 10.0	m/X < 0.90 P(OL in 3)	.95 ≤ m/X ≤ 1.00 P(OL in 5)	

Note: Linear interpolation between the calculated probabilities is required for m/X regions between those defined above.

The formula developed for situations with mean arrivals less than 10 veh/cycle (Formula A on Table 7.2.1) uses the probability of having an overload in the third of three consecutive cycles, P(OL in 3), to model average overload factor for mean arrival to capacity ratios (m/X) below 0.70. The value of this probability at m/X = 0.70 is connected by a straight line to the probability of having an overload in the fourth of four consecutive cycles at m/X = 0.85. This P(OL in 4) probability is applied between m/X = 0.85 and m/X = 0.90, and is joined by a straight line to the probability of at least one overload in four consecutive cycles, P(1+ in 4) at m/X = 1.00.

Formula B (Table 7.2.1) is used for situations with mean arrivals greater than or equal to 10 veh/cycle. This formula uses the probability of having an overload in the third of three consecutive cycles, P(OL in 3), to model average overload factor for m/X ratios below 0.90. The probability of an overload in the fifth of five consecutive cycles, P(OL in 5) is applied from m/X = 0.95 to m/X = 1.00, and a straight line is used to connect the calculated probabilities between m/X = 0.90 and m/X = 0.95.

The straight lines connecting the various probabilities were needed to provide a gradual transition between the calculated values, and prevent large differences between the probability based overload factor approximations at m/X ratios just above and below a transition point.

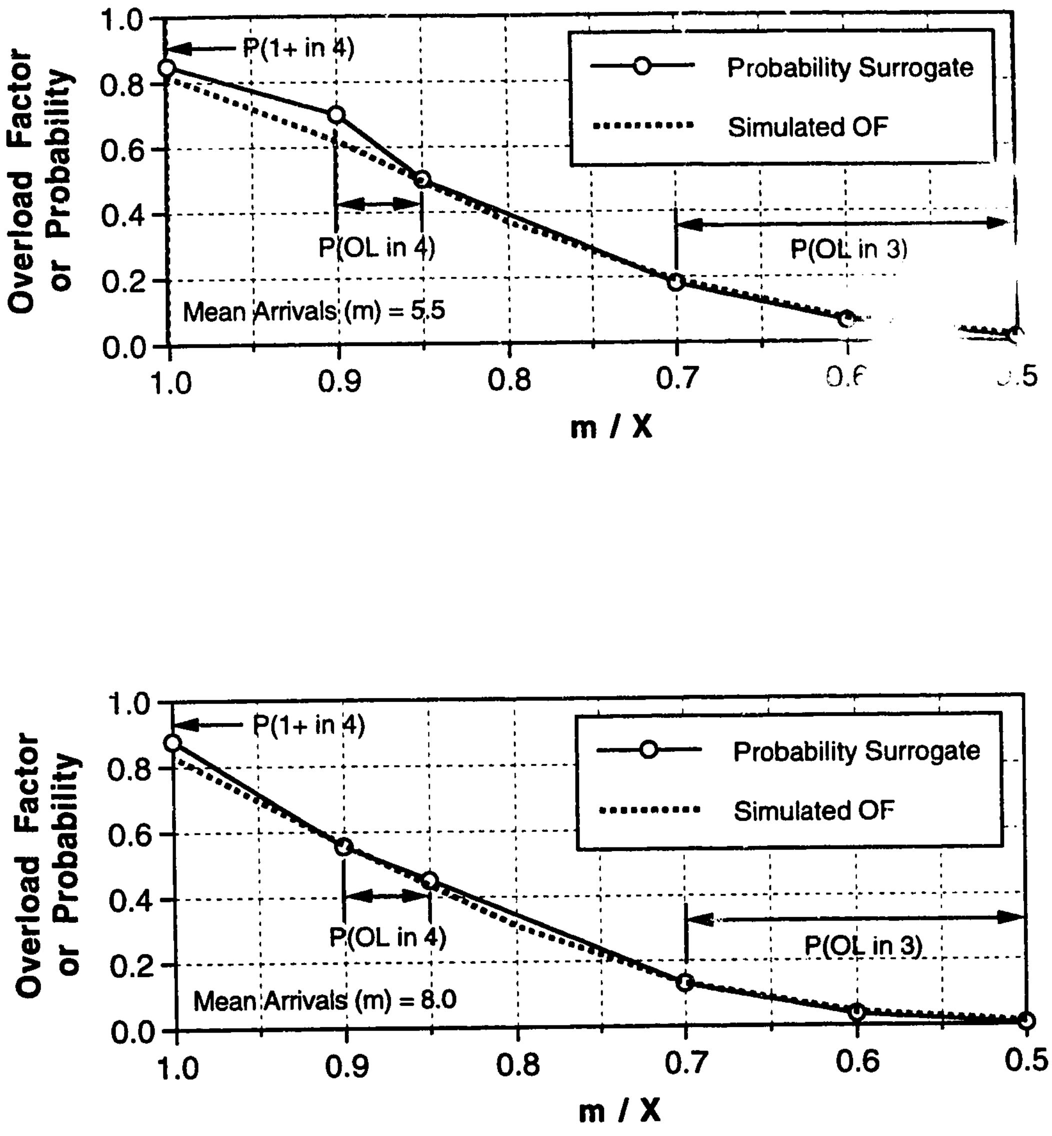


Figure 7.2.6 Simulated Overload Factors and Combined Probability Surrogate (Formula A) for Mean Arrivals of 5.5 and 8.0 veh/cycle

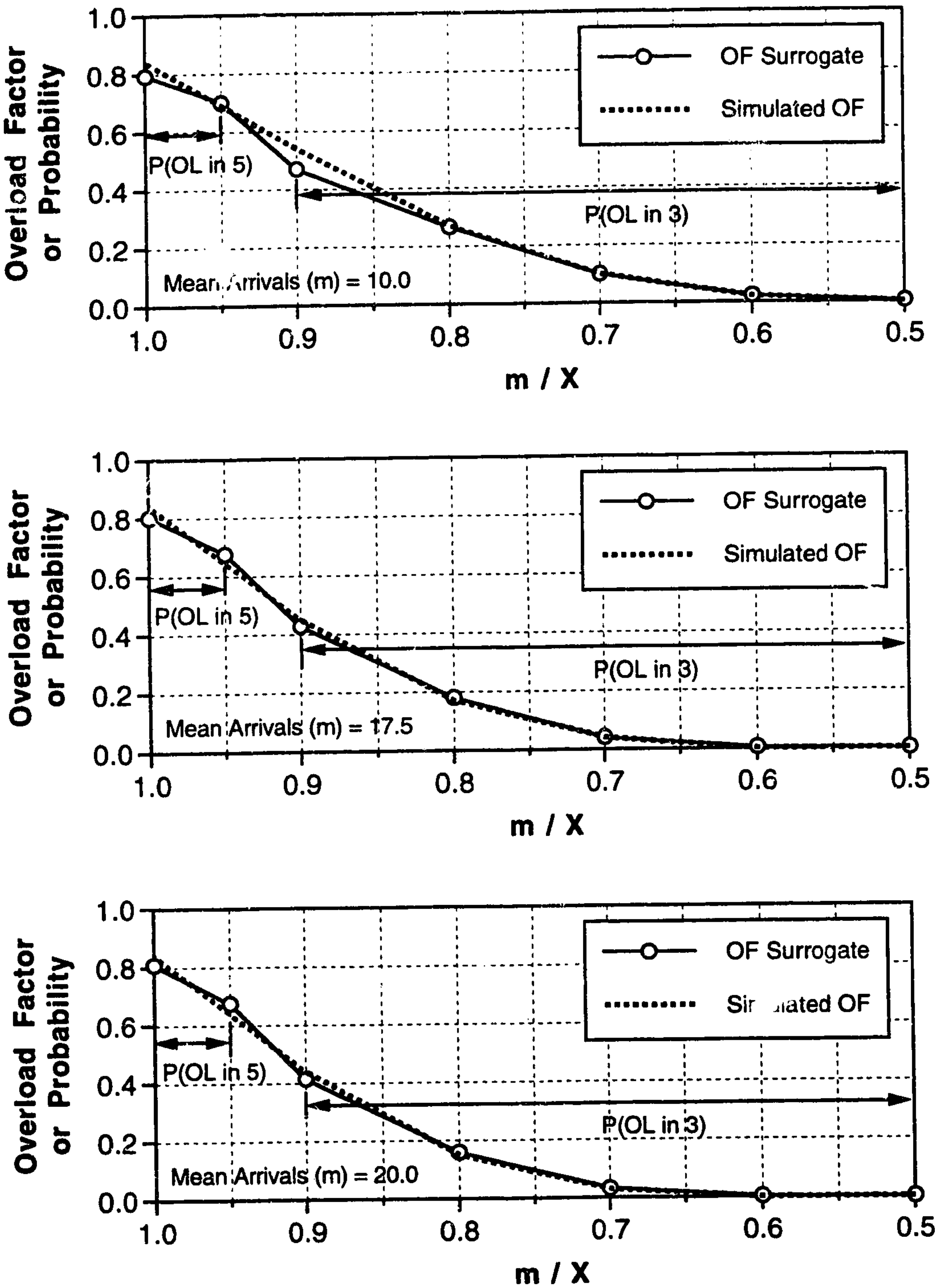


Figure 7.2.7 Simulated Overload Factors and Combined Probability Surrogate (Formula A) for Mean Arrivals of 10.0, 17.5 and 20.0 veh/cycle

7.3 SUMMARY

Based on the preceding plots, both formulae appear to be appropriate surrogates for average overload factor, within the range of mean arrivals studied and for m/X ratios below 1.0. Greater accuracy could likely be obtained, however, by using smaller ranges to define the limits for the application of various additional probabilities of discharge overload.

The calculation of both the various probabilities of discharge overload and the equations of the lines connecting these probabilities is complex and time consuming. Although the formulae proposed above are more accurate representations of overload factor than the single probability proposed by Teply (7), the chosen surrogate must balance the degree of accuracy obtained with the ease of use.

Chapter 8 - Conclusions

8.1 INTRODUCTION

The overload factor is a valuable tool for the analysis of signalized intersection performance. Overload factors can be reliably measured, however, only one point in a distribution of overload factors is obtained. Average overload factors can only be calculated from data generated by computer simulation of large numbers of overload factors using constant mean arrivals and stopline capacities. As an alternative to simulation, average overload factors may be approximated using probabilities of discharge overload. The proposed probability based surrogate proposed by Teply in 1993 (7) is calculated as the probability that at least one of two consecutive cycles will be overloaded. The formula assumes that the cycle preceding the evaluated cycles was not overloaded. The primary focus of this research was the validation or modification of this overload factor surrogate.

8.2 PROBABILITY SURROGATES

The results of this research show that that the proposed overload factor surrogate is a very good approximation of average overload factor at mean arrival to capacity ratios below 0.80. As the degree of saturation increases beyond 0.80, however, the probability begins to underestimate the overload factor. The degree of underestimation increases to around 0.17 for degrees of saturation approaching 1.00.

A more accurate approximation of overload factor was developed in this research. Two formulae were used, to model the ranges of mean arrivals above and below 10 veh/cycle. Both formulae consist of several probabilities of discharge overload which are applied in different regions of mean arrival to capacity ratios. Both the "one or more overloads in n cycles" probabilities and the "overload in cycle n" probabilities are used in the formulae.

Although the "one or more" probabilities, such as proposed by Teply, are relatively easily calculated, the calculation of "overload in n" probabilities is very difficult. The generation of the probabilities used in these formulae therefore requires the use of a computer program, which may limit the usefulness of this method.

An intersection lane simulation program can provide very accurate modelling of average overload factors, but requires development of a computer program. More advanced computer programs than the cycle by cycle model used in this research would likely be required to accurately simulate more complex lane conditions than those investigated to date.

Considering the complexity of alternative calculation methods and that the formula suggested for the Second Edition of the Canadian Capacity Guide for Signalized Intersections (10) yields a reasonable approximation of average overload factor, its use for practical purposes is justified.

The accurate calculation of overload factor surrogates or the simulation of overload factors requires correct input data. The probability calculation or overload factor simulation processes are very sensitive to errors in the input data, hence, mean arrivals and stopline capacities must be carefully determined. Mean arrivals per cycle can be derived from standard traffic flow surveys, and stopline capacities can be calculated using the appropriate saturation flow rate and effective green interval. Field observation to confirm the calculated input data, however, is advisable in all instances.

8.3 OTHER FINDINGS

Further general conclusions on areas that were not the primary focus of this research are as follows:

- the usefulness of the Poisson distribution in modelling the random variation in cycle by cycle vehicle arrivals was confirmed,

- investigation of the distribution of stopline capacities indicated that cycle capacities are normally distributed with a standard deviation of about 1.1, regardless of the magnitude of capacity,
- use of the saturation flow adjustment factors in the Final Draft of the Second Edition of the Canadian Capacity Guide (10), and effective green intervals between 0 and 2 seconds longer than displayed green intervals results in good agreement between calculated and observed stopline capacities, and
- an average effective green interval 1 second longer than the displayed green interval is appropriate for use in Edmonton.

8.4 FURTHER STUDY

8.4.1 Introduction

Several factors that may have an impact on overload factors could not be adequately investigated during the course of this research. These factors are discussed in the following paragraphs.

8.4.2 Stopline Capacity

Although the simulation program (DISCAPOS) used a capacity distribution derived from field measurements, further investigation into the nature of variations in stopline capacity would be most valuable. In particular, it appears from observations of driver behaviour during the field surveys that there may be a relationship between the number of arrivals in a cycle and stopline capacity. A preliminary model of this relationship was developed, but insufficient data were available to validate the model. In addition, the impact of factors such as the absolute duration of the green interval, the ratio of green interval to cycle time, traffic progression and amber intervals requires further study.

8.4.3 Distribution of Overloaded Cycles

This research did not investigate the distribution of overloaded cycles within the group of consecutive cycles considered. Because the probability of encountering an overloaded cycle is dependent on the events in previous cycles, short surges in demand can cause a series of overloaded cycles, even if the average number of arrivals is much less than capacity. The probability of encountering an overloaded cycle when the preceding cycle is overloaded is greater than when the preceding cycle is not overloaded. If the simulation of overloads based on a steady arrival mean results in no consecutive overloaded cycles, but demand surges cause consecutive overloads in the actual situation, the simulation would underestimate the actual overload factor. Further research of site specific modelling of arrival patterns would add reliability to the simulation of overload factors.

8.4.4 Use of the Overload Factor

The use of overload factors to help in the coordination of corridors or networks of signalized intersections may also merit further research. If very high overload factors are encountered, the impact of leftover queues prevents effective coordination. The point at which this effect becomes significant, and conversely the impact of coordination on measured overload factors was not investigated in this research.

8.4.5 Analysis of Intersection Approaches

The lanes chosen for investigation in this research did not contain shared movements or movements that crossed opposing traffic or pedestrian flows. Techniques are available for assigning volumes and calculating saturation flows for these lanes, but the application of the overload factor evaluation method for lanes with opposing vehicular or pedestrian traffic, or for lanes with shared movements will require further research.

8.5 CONCLUDING REMARKS

The overload factor is proposed as a tool to provide additional insight into the operation of signalized intersections, in conjunction with other methods of evaluation such as delay. The use of the probability of discharge formula proposed by Teply (7) as an approximation of the average overload factor is recommended.

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Appendix A

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Table A-3.1 Measured Data and Calculations for Survey No. 1

Survey No: 1 **Site:** A **Cycle Time** = 130
Date/Time: July 16, 1993 - 07:15 to 09:30 **g/c** = 0.13
Location: 72 Avenue at 114 Street WB Lane #1
Green: 17 **Amber:** 3 **Red:** 110

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	9	9	0	9	
2	0	2	3	-1	3	
3	0	2	2	0	2	
4	0	7	7	0	7	
5	0	1	1	0	1	
6	0	5	6	-1	6	
7	0	4	5	-1	5	
8	0	6	6	0	6	
9	0	1	2	-1	2	
10	0	3	3	0	3	
11	0	4	4	0	4	
12	0	2	2	0	2	
13	0	9	9	0	9	FL
14	0	4	4	0	4	
15	0	6	6	0	6	
16	0	10	9	1	11	OL
17	2	7	8	-1	6	FL
18	0	10	10	0	10	FL
19	0	10	8	2	10	OL
20	2	6	8	-2	6	
21	0	3	3	0	3	
22	0	2	3	-1	3	
23	0	3	4	-1	4	
24	0	4	4	0	4	
25	0	2	2	0	2	
26	0	4	4	0	4	
27	0	1	1	0	1	
28	0	12	10	2	13	OL
29	3	10	10	0	7	
30	0	7	8	-1	8	
31	0	6	7	-1	7	
32	0	1	1	0	1	
33	0	2	4	-2	4	
34	0	6	6	0	6	
35	0	6	7	-1	7	
36	0	7	7	0	7	
37	0	3	5	-2	5	
38	0	11	11	0	11	FL
39	0	1	2	-1	2	
40	0	7	7	0	7	
41	0	5	5	0	5	
42	0	7	9	-2	9	FL
43	0	10	9	1	11	OL

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44	2	5	7	-2	5	
45	0	3	4	-1	4	
46	0	5	5	0	5	
47	0	3	5	-2	5	
48	0	2	3	-1	3	
49	0	8	8	0	8	FL
50	0	8	9	-1	9	FL
51	0	2	2	0	2	
52	0	6	6	0	6	
53	0	[illegible]	2	0	2	
54	0	8	8	0	8	
55	0	4	5	-1	5	
56	0	2	3	-1	3	
57	0	5	7	-2	7	
58	0	6	6	0	6	
59	0	1	1	0	1	
60	0	4	4	0	4	
61	0	3	3	0	3	
62	0	1	1	0	1	
63	0	4	4	0	4	
64	0	1	2	-1	2	
65	0					

Queue (start green) = 4.86 **m = 5.25**

Capacity (veh/cycle) = 9.09 **V/C (m/C) = 0.578**

Evaluation Time (hrs) = 2.31
Arrival Rate (veh/hr) = 145

for s = 1700 green eff = 2.3
1750 1.7
1820 1.0

Progression Factor = 0.78

Mean Arrivals: 5.250
Standard Deviation: 2.911
Coeffecient of Variation: 0.62

Sum of Squares: 8.74
$\chi 2$: 12.51 (df = 6)
Kolmogorov-Smirnov "d": 0.098 (n = 64)

OLF = 0.063 **LF = 0.172**

Table A-3.2 Measured Data and Calculations for Survey No. 2

Survey No: 2 **Site:** B **Cycle Time** = 100
Date/Time: July 16, 1993 - 15:15 to 17:15 **g/c** = 0.42
Location: 82 Avenue at 75 Street EB Lane #2
Green: 42 **Amber:** 4 **Red:** 54

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	3	14	-11	14	
2	0	4	6	-2	6	
3	0	7	9	-2	9	
4	0	6	9	-3	9	
5	0	3	11	-8	11	
6	0	5	12	-7	12	
7	0	6	13	-7	13	
8	0	7	13	-6	13	
9	0	5	11	-6	11	
10	0	5	14	-9	14	
11	0	4	12	-8	12	
12	0	3	6	-3	6	
13	0	6	14	-8	14	
14	0	9	11	-2	11	
15	0	8	17	-9	17	
16	0	10	13	-3	13	
17	0	6	11	-5	11	
18	0	6	12	-6	12	
19	0	7	16	-9	16	
20	0	5	13	-8	13	
21	0	10	19	-9	19	
22	0	5	9	-4	9	
23	0	6	10	-4	10	
24	0	16	17	-1	17	
25	0	6	10	-4	10	
26	0	12	13	-1	13	
27	0	7	14	-7	14	
28	0	7	20	-13	20	
29	0	8	13	-5	13	
30	0	8	14	-6	14	
31	0	6	12	-6	12	
32	0	5	14	-9	14	
33	0	9	18	-9	18	
34	0	11	16	-5	16	
35	0	4	12	-8	12	
36	0	5	14	-9	14	
37	0	11	19	-8	19	
38	0	17	24	-7	24	FL
39	0	16	20	-4	20	
40	0	10	15	-5	15	
41	0	13	22	-9	22	FL

42	0	10	12	-2	12	
43	0	6	16	-10	16	
44	0	10	13	-3	13	
45	0	8	18	-10	18	
46	0	4	12	-8	12	
47	0	5	9	-4	9	
48	0	9	17	-8	17	
49	0	12	22	-10	22	FL
50	0	9	12	-3	12	
51	0	7	14	-7	14	
52	0	10	20	-10	20	
53	0	8	15	-7	15	
54	0	16	23	-7	23	FL
55	0	12	21	-9	21	FL
56	0	7	16	-9	16	
57	0	6	13	-7	13	
58	0	8	14	-6	14	
59	0	17	17	0	17	
60	0	9	15	-6	15	
61	0	5	13	-8	13	
62	0	13	18	-5	18	
63	0	14	21	-7	21	FL
64	0	14	18	-4	18	
65	0	9	14	-5	14	
66	0	8	15	-7	15	
67	0	9	14	-5	14	
68	0	7	15	-8	15	
69	0	5	13	-8	13	
70	0	8	14	-6	14	
71	0	6	13	-7	13	
72	0	10	16	-6	16	
73	0					

Queue (start green) = 8.17 **m = 14.51**

Capacity (veh/cycle) = 22.17 **V/C (m/X) = 0.655**

Evaluation Time (hrs) = 2.00
Arrival Rate (veh/hr) = 523

for s = 1700	green eff = 4.9
1750	3.6
1855	1.0

Progression Factor = 0.33

Mean Arrivals:	14.514	Sum of Squares:	4.63	
Standard Deviation:	3.772	$\chi 2$:	8.78	(df = 8)
Coeffecient of Variation:	1.02	Kolmogorov-Smirnov "d":	0.081	(n = 72)

OLF = 0.000 **LF = 0.083**

Table A-3.3 **Measured Data and Calculations for Survey No. 3**

Survey No: 3 **Site:** A **Cycle Time** = 130
Date/Time: July 19, 1993 - 07:30 to 09:30 **g/c** = 0.13
Location: 72 Avenue at 114 Street WB Lane #1
Green: 17 **Amber:** 3 **Red:** 110

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	1	1	0	1	
2	0	1	2	-1	2	
3	0	4	7	-3	7	FL
4	0	2	2	0	2	
5	0	7	8	-1	8	FL
6	0	5	7	-2	7	
7	0	6	7	-1	7	
8	0	7	9	-2	9	FL
9	0	5	5	0	5	
10	0	8	8	0	8	FL
11	0	5	6	-1	6	
12	0	2	2	0	2	
13	0	1	6	-5	6	
14	0	6	7	-1	7	
15	0	4	7	-3	7	
16	0	7	8	-1	8	FL
17	0	2	2	0	2	
18	0	3	3	0	3	
19	0	8	10	-2	10	FL
20	0	4	6	-2	6	
21	0	3	3	0	3	
22	0	9	9	0	9	FL
23	0	4	4	0	4	
24	0	8	11	-3	11	FL
25	0	9	9	0	9	FL
26	0	8	10	-2	10	FL
27	0	7	8	-1	8	
28	0	4	5	-1	5	
29	0	6	7	-1	7	
30	0	6	6	0	6	
31	0	3	6	-3	6	
32	0	11	10	1	12	OL
33	2	8	8	0	6	FL
34	0	7	7	0	7	
35	0	5	5	0	5	
36	0	9	9	0	9	FL
37	0	7	7	0	7	
38	0	4	6	-2	6	FL
39	0	3	3	0	3	
40	0	5	5	0	5	
41	0	4	5	-1	5	

42	0	2	5	-3	5	
43	0	5	6	-1	6	
44	0	11	10	1	12	OL
45	2	9	9	0	7	FL
46	0	0	0	0	0	
47	0	4	4	0	4	
48	0	7	8	-1	8	FL
49	0	4	5	-1	5	
50	0	2	2	0	2	
51	0	5	5	0	5	
52	0	2	3	-1	3	
53	0	4	5	-1	5	
54	0	5	7	-2	7	
55	0	4	6	-2	6	
56	0	7	8	-1	8	
57	0					

Queue (start green) = 5.16 **m = 6.05**

Capacity (veh/cycle) = 8.76 **V/C (m/X) = 0.691**

Evaluation Time (hrs) = 2.02
Arrival Rate (veh/hr) = 168

for s =		green eff =
	1700	1.6
	1750	1.0
	1800	0.5

Progression Factor = 0.73

Mean Arrivals: 6.054
Standard Deviation: 2.673
Coeffecient of Variation: 0.85

Sum of Squares.: 8.23
$\chi 2$: 7.87 (df = 5)
Kolmogorov-Smirnov "d": 0.065 (n = 56)

CLF = 0.036 **LF = 0.304**

Table A-3.4 Measured Data and Calculations for Survey No. 4

Survey No: 4 **Site:** C **Cycle Time** = 100
Date/Time: July 19, 1993 - 15:30 to 16:30 **g/c** =).28
Location: 87 Avenue at 109 Street EB Lane #1
Green: 28 **Amber:** 3 **Red:** 69

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	2	3	-1	3	
2	0	1	3	-2	3	
3	0	4	6	-2	6	
4	0	2	6	-4	6	
5	0	6	7	-1	7	
6	0	3	5	-2	5	
7	0	4	5	-1	5	
8	0	4	4	0	4	
9	0	9	10	-1	10	
10	0	4	6	-2	6	
11	0	7	9	-2	9	
12	0	6	8	-2	8	
13	0	6	8	-2	8	
14	0	3	4	-1	4	
15	0	4	7	-3	7	
16	0	4	9	-5	9	
17	0	7	8	-1	8	
18	0	6	8	-2	8	
19	0	5	6	-1	6	
20	0	9	10	-1	10	
21	0	4	9	-5	9	
22	0	6	8	-2	8	
23	0	7	9	-2	9	
24	0	11	10	1	10	OL
25	0	12	13	-1	13	OL
26	0	14	12	2	12	FL
27	0	9	11	-2	11	
28	0	8	9	-1	9	
29	0	9	11	-2	11	
30	0	8	10	-2	10	
31	0	9	12	-3	12	
32	0	5	5	0	5	
33	2	6	8	-2	6	
34	0	6	7	-1	7	
35	0	9	11	-2	11	
36	0	4	8	-4	8	
37	0	6	6	0	6	
38	0					

Queue (start green) = 6.19 **m =** 7.81

Capacity (veh/cycle) =	**11.67**		**V/C (m/X) =**	**0.669**	
			Evaluation Time (hrs) =	1.03	
for s = 1400	green eff = 2.0		Arrival Rate (veh/hr) =	281	
1450	1.0				
1500	0.0		Progression Factor =	0.57	
Mean Arrivals:	7.811		Sum of Squares:	3.78	
Standard Deviation:	2.580		χ^2:	1.67	(df = 4)
Coeffecient of Variation:	1.17		Kolmogorov-Smirnov "d":	0.048	(n = 37)

OLF = 0.054 **LF = 0.081**

Table A-3.5 Measured Data and Calculations for Survey No. 5

Survey No: 5 **Site:** D **Cycle Time =** 100
Date/Time: July 20, 1993 - 15:55 to 17:25 **g/c** = 0.28
Location: 99 Street at 63 Avenue NB Lane #3
Green: 28 **Amber:** 4 **Red:** 68

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	7	11	-4	11	
2	0	2	8	-6	8	
3	0	8	9	-1	9	
4	0	9	11	-2	11	
5	0	3	6	-3	6	
6	0	6	6	0	6	
7	0	4	4	0	4	
8	0	5	9	-4	9	
9	0	2	5	-3	5	
10	0	7	7	0	7	
11	0	8	8	0	8	
12	0	15	14	1	17	OL
13	3	10	13	-3	10	FL
14	0	13	13	0	16	OL
15	3	13	12	1	11	OL
16	2	13	12	1	14	OL
17	4	12	12	0	10	OL
18	2	6	10	-4	8	
19	0	11	12	-1	12	FL
20	0	17	13	4	16	OL
21	3	11	12	-1	9	FL
22	0	3	7	-4	7	
23	0	7	10	-3	10	
24	0	10	10	0	10	
25	0	7	11	-4	11	
26	0	10	13	-3	13	FL
27	0	8	9	-1	9	
28	0	6	11	-5	11	
29	0	6	11	-5	11	
30	0	9	12	-3	12	
31	0	13	14	-1	14	FL
32	0	4	7	-3	7	
33	0	10	12	-2	12	FL
34	0	11	11	0	11	
35	0	8	14	-6	14	FL
36	0	6	9	-3	9	
37	0	3	5	-2	5	
38	0	3	9	-6	9	
39	0	9	10	-1	10	
40	0	8	13	-5	13	FL
41	0	11	13	-2	14	OL

42	1	12	13	-1	12	FL
43	0	5	8	-3	8	
44	0	17	13	4	17	OL
45	4	11	11	0	7	
46	0	13	13	0	13	FL
47	0	11	13	-2	15	OL
48	2	8	11	-3	9	
49	0	11	12	-1	14	OL
50	2	9	11	-2	9	
51	0	6	11	-5	11	
52	0	5	7	-2	7	
53	0	6	6	0	6	
54	0	7	9	-2	9	
55	0					

Queue (start green) = 8.43 **m = 10.30**

Capacity (veh/cycle) = 12.80 **V/C (m/X) = 0.804**

Evaluation Time (hrs) = 1.50
Arrival Rate (veh/hr) = 371

for s = 1750 green eff = -1.7
1800 -2.4
1590 1.0

Progression Factor = 0.56

Mean Arrivals: 10.296
Standard Deviation: 3.148
Coeffecient of Variation: 1.04

Sum of Squares: 3.85
$\chi 2$: 2.41 (df = 6)
Kolmogorov-Smirnov "d": 0.027 (n = 54)

OLF = 0.185 **LF = 0.370**

Table A-3.6 Measured Data and Calculations for Survey No. 6

Survey No: 6 **Site:** E **Cycle Time** = 100
Date/Time: July 21, 1993 - 07:30 to 08:30 **g/c** = 0.36
Location: 82 Avenue at 109 Street WB Lane #2
Green: 36 **Amber:** 3 **Red:** 61

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	9	12	-3	12	
2	0	5	8	-3	8	
3	0	7	8	-1	8	
4	0	7	10	-3	10	
5	0	12	16	-4	17	OL
6	1	8	13	-5	12	
7	0	9	12	-3	12	
8	0	10	13	-3	13	
9	0	12	14	-2	14	
10	0	15	16	-1	16	
11	0	8	14	-6	14	
12	0	14	19	-5	22	OL
13	3	11	16	-5	13	FL
14	0	9	15	-6	15	
15	0	10	15	-5	15	
16	0	10	14	-4	14	
17	0	9	16	-7	16	FL
18	0	5	8	-3	8	
19	0	11	11	0	11	
20	0	10	13	-3	13	
21	0	5	7	-2	7	
22	0	6	8	-2	8	
23	0	6	8	-2	8	
24	0	6	9	-3	9	
25	0	3	9	-6	9	
26	0	8	12	-4	12	
27	0	6	8	-2	8	
28	0	8	13	-5	13	
29	0	4	9	-5	9	
30	0	5	5	0	5	
31	0	8	11	-3	11	
32	0	3	8	-5	8	
33	0	8	13	-5	13	
34	0	5	7	-2	7	
35	0	2	5	-3	5	
36	0	2	5	-3	5	
37	0					

Queue (start green) = 7.67 **m =** 11.11

Capacity (veh/cycle) = 16.75 **V/C (m/X) =** 0.663

for s = 1700	green eff = -0.5	Evaluation Time (hrs) =	1.00		
1750	-1.5	Arrival Rate (veh/hr) =	400		
1630	1.0	Progression Factor =	0.44		

Mean Arrivals:	11.111	Sum of Squares:	13.93	
Standard Deviation:	3.801	$\chi 2$:	5.10	(df = 4)
Coeffecient of Variation:	0.77	Kolmogorov-Smirnov "d":	0.111	(n = 36)

OLF = 0.056 **LF = 0.111**

Table A-3.7 Measured Data and Calculations for Survey No. 7

Survey No: 7 **Site:** F **Cycle Time =** 100
Date/Time: July 21, 1993 - 16:00 to 17:30 **g/c** = 0.37
Location: 75 Street at 82 Avenue SB Lane #3
Green: 37 **Amber:** 4 **Red:** 59

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	8	11	-3	11	
2	0	11	18	-7	18	FL
3	0	8	17	-9	17	
4	0	6	18	-12	18	FL
5	0	10	15	-5	15	
6	0	5	8	-3	8	
7	0	6	19	-13	19	FL
8	0	6	18	-12	18	FL
9	0	7	18	-11	24	OL
10	6	20	19	1	21	OL
11	8	15	17	-2	9	
12	0	20	20	0	23	OL
13	3	13	21	-8	19	OL
14	1	16	19	-3	21	OL
15	3	10	19	-9	16	FL
16	0	5	15	-10	15	
17	0	9	10	-1	10	
18	0	7	16	-9	16	
19	0	5	11	-6	11	
20	0	9	18	-9	18	FL
21	0	5	11	-6	11	
22	0	7	7	0	7	
23	0	15	18	-3	19	OL
24	1	6	15	-9	14	
25	0	5	14	-9	14	
26	0	5	15	-10	15	
27	0	10	18	-8	19	OL
28	1	10	18	-8	19	OL
29	2	3	15	-12	13	
30	0	8	11	-3	11	
31	0	9	18	-9	18	FL
32	0	10	16	-6	16	
33	0	7	13	-6	13	
34	0	9	13	-4	13	
35	0	4	15	-11	15	
36	0	11	17	-6	19	OL
37	2	14	19	-5	17	FL
38	0	9	15	-6	15	
39	0	4	19	-15	19	FL
40	0	8	16	-8	16	
41	0	8	19	-11	19	FL

42	0	7	17	-10	17	
43	0	5	18	-13	18	FL
44	0	7	15	-8	15	
45	0	6	17	-11	17	FL
46	0	9	17	-8	21	OL
47	4	12	20	-8	18	OL
48	2	10	16	-6	14	
49	0	10	19	-9	20	OL
50	1	7	15	-8	14	
51	0	12	18	-6	24	OL
52	6	7	19	-12	13	FL
53	0	10	14	-4	14	
54	0	8	14	-6	14	
55	0					

Queue (start green) = 8.76 **m = 16.07**

Capacity (veh/cycle) = 18.50 **V/C (m/X) = 0.869**

Evaluation Time (hrs) = 1.50

for s = 1700 green eff = 2.2
1750 1.1
1755 0.9

Arrival Rate (veh/hr) = 579

Progression Factor = 0.31

Mean Arrivals: 16.074
Standard Deviation: 3.806
Coeffecient of Variation: 1.11

Sum of Squares: 6.51
$\chi 2$: 9.45 (df = 7)
Kolmogorov-Smirnov "d": 0.063 (n = 54)

OLF = 0.241 **LF = 0.481**

Table A-3.8 Measured Data and Calculations for Survey No. 8

Survey No: 8 **Site:** G **Cycle Time =** 100
Date/Time: July 23, 1993 - 15:45 to 17:15 **g/c** = 0.38
Location: 104 Street at Whitemud Drive SB Lane #2
Green: 38 **Amber:** 4 **Red:** 58

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	6	17	-11	17	
2	0	8	19	-11	19	FL
3	0	5	16	-11	16	
4	0	10	20	-10	20	FL
5	0	4	12	-8	12	
6	0	8	17	-9	17	
7	0	8	17	-9	17	FL
8	0	10	20	-10	20	FL
9	0	8	19	-11	19	FL
10	0	9	13	-4	13	
11	0	3	15	-12	15	
12	0	10	18	-8	18	
13	0	6	21	-15	21	FL
14	0	10	20	-10	20	FL
15	0	13	20	-7	22	OL
16	2	16	20	-4	22	OL
17	4	14	18	-4	17	OL
18	3	14	19	-5	23	OL
19	7	13	17	-4	10	
20	0	9	18	-9	20	OL
21	2	17	20	-3	18	FL
22	0	15	21	-6	26	OL
23	5	16	22	-6	20	OL
24	3	25	22	3	27	OL
25	8	20	19	1	16	OL
26	5	14	20	-6	16	OL
27	1	7	19	-12	18	FL
28	0	11	19	-8	21	OL
29	2	12	21	-9	19	FL
30	0	10	21	-11	21	FL
31	0	15	20	-5	26	OL
32	6	20	22	-2	23	OL
33	7	19	19	0	19	OL
34	7	24	20	4	16	OL
35	3	15	21	-6	22	OL
36	4	16	22	-6	18	FL
37	0	17	22	-5	25	OL
38	3	13	22	-9	19	FL
39	0	9	18	-9	18	
40	0	3	17	-14	17	
41	0	8	18	-10	18	
42	0	12	22	-10	24	OL
43	2	8	17	-9	15	

44	0	6	18	-12	18	
45	0	7	19	-12	22	OL
46	3	22	21	1	24	OL
47	6	15	18	-3	12	
48	0	6	18	-12	18	FL
49	0	12	20	-8	24	OL
50	4	16	19	-3	18	OL
51	3	14	19	-5	16	
52	0	13	20	-7	22	OL
53	2	13	19	-6	17	FL
54	0	13	20	-7	23	OL
55	3					

Queue (start green) = 11.98 **m = 19.15**

Capacity (veh/cycle) = 20.03 **V/C (m/X) = 0.956**

Evaluation Time (hrs) = 1.50
Arrival Rate (veh/hr) = 689

for s = 1700	green eff = 4.4
1750	3.2
1850	1.0

Progression Factor = 0.33

Mean Arrivals:	19.148	Sum of Squares:	4.23	
Standard Deviation:	3.652	$\chi 2$:	7.86	(df = 7)
Coeffecient of Variation:	1.44	Kolmogorov-Smirnov "d":	0.094	(n = 54)

OLF = 0.444 **LF = 0.722**

Table A-3.9 Measured Data and Calculations for Survey No. 9

Survey No: 9 **Site:** D **Cycle Time =** 100
Date/Time: July 26, 1993 - 16:00 to 17:45 **g/c** = 0.28
Location: 99 Street at 63 Avenue SB Lane #3
Green: 28 **Amber:** 4 **Red:** 68

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	6	7	-1	7	
2	0	6	10	-4	10	
3	0	3	5	-2	5	
4	0	10	11	-1	11	
5	0	10	14	-4	16	OL
6	2	6	6	0	4	
7	0	6	7	-1	7	
8	0	9	14	-5	15	OL
9	1	10	12	-2	11	
10	0	7	10	-3	10	
11	0	8	11	-3	11	
12	0	3	8	-5	8	
13	0	9	11	-2	11	
14	0	5	11	-6	11	
15	0	7	9	-2	9	
16	0	10	12	-2	12	
17	0	7	9	-2	9	
18	0	6	11	-5	11	
19	0	9	9	0	9	
20	0	9	10	-1	10	
21	0	2	8	-6	8	
22	0	6	7	-1	7	
23	0	10	11	-1	11	
24	0	10	15	-5	15	FL
25	0	8	11	-3	11	
26	0	5	6	-1	6	
27	0	7	12	-5	12	
28	0	13	13	0	18	OL
29	5	14	14	0	12	OL
30	3	6	11	-5	8	
31	0	6	7	-1	7	
32	0	14	14	0	15	OL
33	1	9	11	-2	10	
34	0	6	8	-2	8	
35	0	9	14	-5	15	OL
36	1	8	13	-5	12	
37	0	10	11	-1	11	
38	0	10	13	-3	13	
39	0	6	10	-4	10	
40	0	7	12	-5	12	
41	0	8	8	0	8	
42	0	3	9	-6	9	
43	0	5	9	-4	9	

44	0	[illegible]	8	-2	8	
45	0	[illegible]	8	-4	8	
46	0	6	8	-2	8	
47	0	8	9	-1	9	
48	0	4	12	-8	12	
49	0	9	9	0	9	
50	0	2	2	0	2	
51	0	7	12	-5	12	
52	0	6	9	-3	9	
53	0	8	14	-6	14	FL
54	0	6	9	-3	9	
55	0	10	12	-2	12	
56	0	8	10	-2	10	
57	0	4	4	0	4	
58	0	7	8	-1	8	
59	0	3	4	-1	4	
60	0	5	8	-3	8	
61	0	7	11	-4	11	
62	0	4	7	-3	7	
63	0	2	7	-5	7	
64	0					

Queue (start green) = 7.05 **m = 9.76**

Capacity (veh/cycle) = 14.00 **V/C (m/X) = 0.697**

Evaluation Time (hrs) = 1.75

for s = 1700 green eff = 1.6 Arrival Rate (veh/hr) = 351
1750 0.8
1735 1.0 Progression Factor = 0.50

Mean Arrivals: 9.762
Standard Deviation: 3.057
Coeffecient of Variation: 1.04

Sum of Squares: 6.89
$\chi 2$: 4.01 (df = 6)
Kolmogorov-Smirnov "d": 0.059 (n = 63)

OLF = 0.095 **LF = 0.127**

Table A-3.10 Measured Data and Calculations for Survey No. 10

Survey No: 10 **Site:** H **Cycle Time** = 90
Date/Time: July 27, 1993 - 07:30 to 08:30 **g/c** = 0.30
Location: 87 Avenue at 170 Street EB Lane #2
Green: 27 **Amber:** 4 **Red:** 59

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	5	6	-1	6	
2	0	3	3	0	3	
3	0	6	8	-2	8	
4	0	5	7	-2	7	
5	0	4	6	-2	6	
6	0	2	3	-1	3	
7	0	3	4	-1	4	
8	0	3	4	-1	4	
9	0	8	9	-1	9	
10	0	6	6	0	6	
11	0	4	4	0	4	
12	0	4	5	-1	5	
13	0	3	4	-1	4	
14	0	4	4	0	4	
15	0	4	6	-2	6	
16	0	9	9	0	9	
17	0	4	7	-3	7	
18	0	4	5	-1	5	
19	0	6	7	-1	7	
20	0	5	5	0	5	
21	0	4	5	-1	5	
22	0	2	2	0	2	
23	0	5	5	0	5	
24	0	6	7	-1	7	
25	0	7	8	-1	8	
26	0	6	4	2	4	
27	0	6	5	1	5	
28	0	5	6	-1	6	
29	0	5	7	-2	7	
30	0	3	4	-1	4	
31	0	5	9	-4	9	
32	0	2	4	-2	4	
33	0	2	2	0	2	
34	0	3	3	0	3	
35	0	3	4	-1	4	
36	0	3	5	-2	5	
37	0	8	8	0	8	
38	0	4	5	-1	5	
39	0	5	6	-1	6	
40	0	6	7	-1	7	
41	0					

Queue (start green) = 4.55 **m =** 5.45

Capacity (veh/cycle) = 13.00 **V/C (m/X) = 0.419**

Evaluation Time (hrs) = 1.00
Arrival Rate (veh/hr) = 218

Progression Factor = 0.58

Mean Arrivals:	5.450	Sum of Squares:	6.36	
Standard Deviation:	1.867	$\chi 2$:	3.14	(df = 4)
Coeffecient of Variation:	1.56	Kolmogorov-Smirnov "d":	0.082	(n = 40)

OLF = 0.000 **LF = 0.000**

Note: Capacity based on saturation flow rate of 1650 veh/hr green and effective green interval of :

Table A-3.11 Measured Data and Calculations for Survey No. 11

Survey No: 11 **Site:** C **Cycle Time =** 100
Date/Time: July 27, 1993 - 15:30 to 17:00 **g/c** = 0.28
Location: 87 Avenue at 109 Street EB Lane #1
Green: 28 **Amber:** 3 **Red:** 69

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	2	3	-1	3	
2	0	6	7	-1	7	
3	0	1	5	-4	5	
4	0	7	11	-4	11	
5	0	4	6	-2	6	
6	0	3	5	-2	5	
7	0	8	9	-1	9	
8	0	2	2	0	2	
9	[illegible]	3	4	-1	4	
10	[illegible]	6	7	-1	7	
11	[illegible]	4	7	-3	7	
12	[illegible]	7	10	-3	10	
13	[illegible]	2	3	-1	3	
14	[illegible]	4	5	-1	5	
15	[illegible]	2	5	-3	5	
16	0	6	8	-2	8	
17	0	8	9	-1	9	
18	0	4	7	-3	7	
19	0	8	9	-1	9	
20	0	4	6	-2	6	
21	0	4	6	-2	6	
22	0	6	9	-3	9	
23	0	8	14	-6	14	FL
24	0	8	12	-4	12	FL
25	0	8	10	-2	10	
26	0	6	10	-4	10	
27	0	10	10	0	10	
28	0	9	12	-3	14	OL
29	2	12	13	-1	13	OL
30	2	9	12	-3	11	OL
31	1	6	8	-2	7	
32	0	6	10	-4	10	
33	0	15	14	1	18	OL
34	4	10	12	-2	8	
35	0	5	6	-1	6	
36	0	7	8	-1	8	
37	0	2	3	-1	3	
38	0	3	7	-4	7	
39	0	3	8	-5	8	
40	0	5	6	-1	6	
41	0	7	12	-5	12	FL
42	0	6	10	-4	10	
43	0	10	13	-3	14	OL

44	1	3	6	-3	5	
45	0	6	10	-4	10	
46	0	7	8	-1	8	
47	0	2	2	0	2	
48	0	7	8	-1	8	
49	0	3	3	0	3	
50	0	4	6	-2	6	
51	0	3	6	-3	6	
52	0	3	5	-2	5	
53	0	3	4	-1	4	
54	0	5	8	-3	8	
55	0					

Queue (start green) = 5.59 **m = 7.76**

Capacity (veh/cycle) = 12.75 **V/C (m/X) = 0.609**

Evaluation Time (hrs) = 1.50
Arrival Rate (veh/hr) = 279

Progression Factor = 0.50

for s = 1450 green eff = 3.7
1500 2.6
1585 1.0

Mean Arrivals: 7.759
Standard Deviation: 3.375
Coeffecient of Variation: 0.68

Sum of Squares: 5.34
$\chi 2$: 2.73 (df = 6)
Kolmogorov-Smirnov "d": 0.061 (n = 54)

OLF = 0.093 **LF = 0.148**

Table A-3.12 **Measured Data and Calculations for Survey No. 12**

Survey No: 12 **Site:** E **Cycle Time =** 100
Date/Time: July 28, 1993 - 07:25 to 08:45 **g/c** = 0.36
Location: 82 Avenue at 109 Street WB Lane #2
Green: 36 **Amber:** 3 **Red:** 61

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	3	5	-2	5	
2	0	4	7	-3	7	
3	0	10	11	-1	11	
4	0	1	1	0	1	
5	0	6	11	-5	11	
6	0	2	6	-4	6	
7	0	2	13	-11	13	
8	0	8	8	0	8	
9	0	6	10	-4	10	
10	0	11	13	-2	15	OL
11	2	12	16	-4	14	FL
12	0	6	13	-7	13	
13	0	5	8	-3	8	
14	0	3	9	-6	9	
15	0	15	16	-1	16	FL
16	0	9	10	-1	10	
17	0	10	10	0	10	
18	0	8	10	-2	10	
19	0	9	9	0	9	
20	0	15	17	-2	19	OL
21	2	17	17	0	15	FL
22	0	18	18	0	21	OL
23	3	17	19	-2	21	OL
24	5	13	18	-5	13	FL
25	0	10	13	-3	13	
26	0	7	13	-6	13	
27	0	2	6	-4	6	
28	0	9	12	-3	12	
29	0	4	6	-2	6	
30	0	2	9	-7	9	
31	0	4	5	-1	5	
32	0	6	8	-2	8	
33	0	7	10	-3	10	
34	0	3	7	-4	7	
35	0	6	7	-1	7	
36	0	5	12	-7	12	
37	0	0	1	-1	1	
38	0	9	9	0	9	
39	0	4	4	0	4	
40	0	8	8	C	8	
41	0	6	8	-2	8	
42	0	1	9	-8	9	
43	0	1	4	-3	4	

44	0	6	6	0	6	
45	0	7	10	-3	10	
46	0	3	6	-3	6	
47	0	3	3	0	3	
48	0	5	6	-1	6	
49	0	8	10	-2	10	
50	0					

Queue (start green) = 6.86 **m = 9.53**

Capacity (veh/cycle) = 16.75 **V/C (m/X) = 0.569**

Evaluation Time (hrs) = 1.36

for s = 1700 green eff = -0.5 Arrival Rate (veh/hr) = 343

1750 -1.5

1630 1.0 Progression Factor = 0.44

Mean Arrivals: 9.531 Sum of Squares: 8.14

Standard Deviation: 4.449 $\chi2$: 7.45 (df = 6)

Coeffecient of Variation: 0.48 Kolmogorov-Smirnov "d": 0.104 (n = 49)

OLF = 0.082 **LF = 0.163**

Table A-3.13 Measured Data and Calculations for Survey No. 13

Survey No: 13 **Site:** G **Cycle Time =** 100
Date/Time: July 28, 1993 - 16:00 to 17:30 **g/c** = 0.38
Location: 104 Street at Whitemud Drive SB Lane #2
Green: 38 **Amber:** 4 **Red:** 58

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	7	12	-5	12	
2	0	6	12	-6	12	
3	0	6	10	-4	10	
4	0	7	16	-9	16	
5	0	5	16	-11	16	
6	0	10	18	-8	18	
7	0	12	18	-6	18	
8	0	11	21	-10	21	FL
9	0	7	20	-13	20	FL
10	0	9	15	-6	15	
11	0	12	21	-9	21	FL
12	0	6	17	-11	17	
13	0	4	14	-10	14	
14	0	6	14	-8	14	
15	0	15	21	-6	24	OL
16	3	7	17	-10	14	
17	0	7	15	-8	15	
18	0	10	20	-10	20	FL
19	0	10	21	-11	25	OL
20	4	13	21	-8	17	FL
21	0	8	15	-7	15	
22	0	12	21	-9	22	OL
23	1	8	23	-15	22	FL
24	0	17	22	-5	22	FL
25	0					

Queue (start green) = 8.96 **m = 17.50**

Capacity (veh/cycle) = 21.10 **V/C (m/X) = 0.829**

Evaluation Time (hrs) = 0.67
Arrival Rate (veh/hr) = 630

for s = 1700 green eff = 6.7
1750 5.4
1950 1.0

Progression Factor = 0.31

Mean Arrivals: 17.500
Standard Deviation: 4.032
Coeffecient of Variation: 1.08

Sum of Squares: 9.37
$\chi 2$: 1.54 (df = 2)
Kolmogorov-Smirnov "d": 0.071 (n = 24)

OLF = 0.125 **LF = 0.417**

Table A-3.14 **Measured Data and Calculations for Survey No. 14**

Survey No: 14 **Site:** F **Cycle Time** = 100
Date/Time: July 29, 1993 - 16:00 to 17:30 **g/c** = 0.37
Location: 75 Street at 82 Avenue SB Lane #3
Green: 37 **Amber:** 4 **Red:** 59

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	13	17	-4	21	OL
2	4	9	15	-6	11	
3	0	10	16	-6	16	FL
4	0	7	10	-3	10	
5	0	15	17	-2	23	OL
6	6	12	17	-5	11	FL
7	0	14	19	-5	23	OL
8	4	13	18	-5	21	OL
9	7	22	16	6	20	OL
10	11	34	19	15	21	OL
11	13	25	19	6	13	OL
12	7	12	16	-4	9	
13	0	18	17	1	23	OL
14	6	26	17	9	21	OL
15	10	25	17	8	23	OL
16	16	20	22	-2	12	OL
17	6	22	18	4	22	OL
18	10	18	20	-2	12	OL
19	2	21	18	3	22	OL
20	6	18	18	0	12	FL
21	0	13	18	-5	22	OL
22	4	15	21	6	21	OL
23	4	13	18	5	14	FL
24	0	15	17	-2	17	FL
25	0	10	17	-7	22	OL
26	5	18	18	0	14	OL
27	1	10	18	-8	18	OL
28	1	13	17	-4	21	OL
29	5	20	19	1	22	OL
30	8	21	20	1	17	OL
31	5	19	19	0	20	OL
32	6	22	18	4	17	OL
33	5	26	19	7	24	OL
34	10	28	18	10	16	OL
35	8	30	18	12	22	OL
36	12	37	20	17	20	OL
37	12	32	18	14	20	OL
38	14	23	19	4	9	OL
39	4	15	19	-4	18	OL
40	3	15	19	-4	20	OL
41	4	10	20	-10	16	FL
42	0	8	17	-9	17	
43	0	9	15	-6	15	

44	0	3	14	-11	14	
45	0	8	15	-7	15	
46	0	10	19	-9	24	OL
47	5	20	19	1	20	OL
48	6	8	17	-9	11	FL
49	0	10	14	-4	14	
50	0	12	18	-6	18	FL
51	0	11	18	-7	20	OL
52	2	12	17	-5	18	OL
53	3	23	19	4	22	OL
54	6	18	19	-1	18	OL
55	5	19	17	2	22	OL
56	10					

Queue (start green) = 16.91 **m = 17.89**

Capacity (veh/cycle) = 18.26 **V/C (m/X) = 0.980**

Evaluation Time (hrs) = 1.53

for s = 1700 green eff = 1.7 Arrival Rate (veh/hr) = 644

1750 0.6

1730 1.0 Progression Factor = 0.44

Mean Arrivals: 17.891 Sum of Squares: 9.84

Standard Deviation: 4.272 $\chi 2$: 23.49 (df = 7)

Coeffecient of Variation: 0.98 Kolmogorov-Smirnov "d": 0.152 (n = 55)

OLF = 0.709 **LF = 0.855**

Table A-3.15 Measured Data and Calculations for Survey No. 15

Survey No: 15 **Site:** D **Cycle Time =** 100
Date/Time: Aug 12, 1993 - 15:45 to 17:15 **g/c =** 0.28
Location: 99 Street at 63 Avenue SB Lane #3
Green: 28 **Amber:** 4 **Red:** 68

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	4	9	-5	9	
2	0	5	9	-4	9	
3	0	11	12	-1	12	
4	0	6	7	-1	7	
5	0	5	7	-2	7	
6	0	10	13	-3	13	
7	0	6	9	-3	9	
8	0	3	5	-2	5	
9	0	9	11	-2	11	
10	0	7	10	-3	10	
11	0	7	12	-5	12	
12	0	7	10	-3	10	
13	0	12	12	0	12	FL
14	0	4	5	-1	5	
15	0	5	7	-2	7	
16	0	7	9	-2	9	
17	0	12	12	0	12	
18	0	7	10	-3	10	
19	0	11	11	0	11	
20	0	10	10	0	10	
21	0	10	13	-3	13	
22	0	8	11	-3	11	
23	0	11	12	-1	12	
24	0	7	11	-4	11	
25	0	14	15	-1	15	FL
26	0	8	13	-5	13	FL
27	0	8	9	1	9	
28	0	8	10	2	10	
29	0	9	14	-5	14	FL
30	0	14	13	1	17	OL
31	4	9	13	-4	9	
32	0	10	14	-4	14	FL
33	0	6	13	-7	13	
34	0	15	14	1	17	OL
35	3	8	10	-2	7	
36	0	13	13	0	16	OL
37	3	11	13	-2	10	FL
38	0	6	8	-2	8	
39	0	10	11	-1	11	
40	0	7	11	-4	11	
41	0	11	14	-3	14	FL
42	0	8	12	-4	12	FL
43	0	8	11	-3	11	

44	0	6	10	-4	10	
45	0	9	14	-5	16	OL
46	2	14	14	0	13	OL
47	1	6	9	-3	8	
48	0	7	8	-1	8	
49	0	6	9	-3	9	
50	0	5	8	-3	8	
51	0	7	13	-6	13	FL
52	0	9	13	-4	13	FL
53	0	15	15	0	16	OL
54	1	7	10	-3	9	
55	0	6	11	-5	11	
56	0	7	8	-1	8	
57	0					

Queue (start green) = 8.41 **m = 10.89**

Capacity (veh/cycle) = 13.50 **V/C (m/X) = 0.807**

Evaluation Time (hrs) = 1.56
Arrival Rate (veh/hr) = 392

for s = 1700 green eff = 0.6
1750 -0.2
1675 1.0

Progression Factor = 0.54

Mean Arrivals: 10.893
Standard Deviation: 2.839
Coeffecient of Variation: 1.35

Sum of Squares: 2.97
$\chi 2$: 3.37 (df = 7)
Kolmogorov-Sn irnov "d": 0.048 (n = 56)

OLF = 0.107 **LF = 0.286**

Table A-3.16 Measured Data and Calculations for Survey No. 16

Survey No: 16 Site: G Cycle Time = 100
Date/Time: August 13, 1993 - 15:40 to 17:10 g/c = 0.38
Location: 104 Street at Whitemud Drive SB Lane #2
Green: 38 Amber: 4 Red: 58

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	11	20	-9	20	FL
2	0	8	16	-8	16	
3	0	12	19	-7	19	FL
4	0	10	19	-9	20	OL
5	1	12	20	-8	19	FL
6	0	10	20	-10	20	FL
7	0	5	17	-12	17	
8	0	10	21	-11	21	FL
9	0	13	19	-6	19	FL
10	0	10	17	-7	17	
11	0	7	15	-8	15	
12	0	9	20	-11	20	FL
13	0	12	16	-4	16	
14	0	7	19	-12	19	FL
15	0	13	20	-7	24	OL
16	4	14	22	-8	18	FL
17	0	5	18	-13	18	
18	0	12	22	-10	23	OL
19	1	16	18	-2	23	OL
20	6	19	21	-2	19	OL
21	4	11	20	-9	18	OL
22	2	14	21	-7	21	OL
23	2	11	20	-9	20	OL
24	2	12	22	-10	21	OL
25	1	6	19	-13	18	FL
26	0	9	15	-6	15	
27	0	8	18	-10	21	OL
28	3	14	23	-9	21	OL
29	1	10	19	-9	20	OL
30	2	22	19	3	24	OL
31	7	15	22	-7	20	OL
32	5	11	19	-8	17	OL
33	3	16	21	-5	22	OL
34	4	17	20	-3	24	OL
35	8	25	18	7	20	OL
36	10	28	21	7	21	OL
37	10	29	20	9	21	OL
38	11	31	20	11	22	OL
39	13	24	20	4	16	OL
40	9	21	18	3	19	OL
41	10	30	20	10	22	OL
42	12	22	19	3	17	OL
43	10	27	22	5	18	OL

44	6	25	19	6	24	OL
45	11	26	21	5	17	OL
46	7	22	20	2	21	OL
47	8	22	21	1	21	OL
48	8	22	22	0	28	OL
49	14	26	21	5	17	OL.
50	10	25	19	6	21	OL
51	12	31	21	10	22	OL
52	13	36	20	16	23	OL
53	16	27	22	5	14	OL
54	8	29	18	11	24	OL
55	14					

Queue (start green) = 17.02 **m = 19.87**

Capacity (veh/cycle) = 20.11 **V/C (m/X) = 0.988**

Evaluation Time (hrs) = 1.50
Arrival Rate (veh/hr) = 715

for s = 1700 green eff = 4.6
1750 3.4
1855 1.0

Progression Factor = 0.38

Mean Arrivals: 19.870
Standard Deviation: 2.782
Coeffecient of Variation: 2.57

Sum of Squares: 7.29
$\chi 2$: 16.90 (df = 6)
Kolmogorov-Smirnov "d": 0.133 (n = 54)

OLF = 0.685 **LF = 0.870**

Table A-3.17 Measured Data and Calculations for Survey No. 17

Survey No: 17 **Site:** I **Cycle Time** = 100
Date/Time: August 25, 1993 - 16:00 to 17:30 **g/c** = 0.42
Location: Argyll Road at 86 Street EB Lane #2
Green: 42 **Amber:** 4 **Red:** 54

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	9	20	-11	20	
2	0	6	15	-9	15	
3	0	12	22	-10	22	
4	0	4	13	-9	13	
5	0	13	21	-8	21	
6	0	13	23	-10	23	FL
7	0	14	23	-9	23	FL
8	0	9	21	-12	21	
9	0	10	22	-12	22	
10	0	5	14	-9	14	
11	0	11	17	-6	17	
12	0	6	18	-12	18	
13	0	5	14	-9	14	
14	0	10	19	-9	19	
15	0	4	9	-5	9	
16	0	6	16	-10	16	
17	0	8	19	-11	19	
18	0	7	17	-10	17	
19	0	10	19	-9	19	
20	0	18	23	-5	23	FL
21	0	13	25	-12	25	FL
22	0	19	25	-6	26	OL
23	1	12	21	-9	20	
24	0	11	19	-8	19	
25	0	13	26	-13	26	FL
26	0	18	25	-7	29	OL
27	4	14	23	-9	19	
28	0	12	20	-8	20	
29	0	18	26	-8	28	OL
30	2	10	20	-10	18	
31	0	9	19	-10	19	
32	0	15	24	-9	25	OL
33	1	13	21	-8	20	
34	0	14	20	-6	20	
35	0	8	18	-10	18	
36	0	7	12	-5	12	
37	0	12	20	-8	20	
38	0	15	21	-6	21	
39	0	14	21	-7	21	
40	0	7	18	-11	18	
41	0	15	22	-7	23	OL
42	1	20	25	-5	28	OL
43	4	23	23	0	26	OL

44	7	31	24	7	26	OL
45	9	24	24	0	23	OL
46	8	13	22	-9	14	
47	0	10	16	-6	16	
48	0	11	21	-10	21	
49	0	8	20	-12	20	
50	0	6	16	-10	16	
51	0	9	18	-9	18	
52	0	8	14	-6	14	
53	0	9	21	-12	21	
54	0	8	17	-9	17	
55	0	6	15	-9	15	
56	0					

Queue (start green) = 11.55 **m = 19.76**

Capacity (veh/cycle) = 24.14 **V/C (m/X) = 0.819**

Evaluation Time (hrs) = 1.53
Arrival Rate (veh/hr) = 711

for s =	green eff =
1700	9.1
1750	7.7
2020	1.0

Progression Factor = 0.32

Mean Arrivals: 19.764
Standard Deviation: 4.277
Coeffecient of Variation: 1.08

Sum of Squares: 4.18
χ^2: 4.62 (df = 6)
Kolmogorov-Smirnov "d": 0.045 (n = 55)

OLF = 0.164 **LF = 0.255**

Table A-3.18 Measured Data and Calculations for Survey No. 18

Survey No: 18 **Site:** F **Cycle Time** = 100
Date/Time: August 26, 1993 - 15:50 to 17:20 **g/c** = 0.37
Location: 75 Street at 82 Avenue SB Lane #3
Green: 37 **Amber:** 4 **Red:** 59

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	9	19	-10	23	OL
2	4	13	19	-6	22	OL
3	7	23	21	2	21	OL
4	7	17	19	-2	17	OL
5	5	9	16	-7	11	
6	0	8	10	-2	10	
7	0	14	18	-4	26	OL
8	8	16	17	-1	15	OL
9	6	13	17	-4	13	OL
10	2	11	17	-6	15	
11	0	3	13	-10	13	
12	0	16	17	-1	20	OL
13	3	8	13	-5	10	
14	0	8	17	-9	23	OL
15	6	14	19	-5	16	OL
16	3	16	20	-4	17	FL
17	0	11	18	-7	18	FL
18	0	14	19	-5	26	OL
19	7	23	20	3	23	OL
20	10	33	20	13	26	OL
21	16	34	19	15	18	OL
22	15	29	17	12	20	OL
23	18	22	20	2	4	OL
24	2	16	20	-4	29	OL
25	11	26	19	7	16	OL
26	8	25	20	5	19	OL
27	7	27	18	9	22	OL
28	11	26	21	5	18	OL
29	8	12	19	-7	11	FL
30	0	8	18	-10	22	OL
31	4	8	18	-10	14	FL
32	0	7	17	-10	17	
33	0	11	18	-7	27	OL
34	9	24	20	4	21	OL
35	10	24	19	5	22	OL
36	13	22	19	3	12	OL
37	6	27	19	8	28	OL
38	15	24	20	4	18	OL
39	13	23	20	3	16	OL
40	9	24	19	5	21	OL
41	11	22	21	1	18	OL
42	8	25	21	4	23	OL
43	10	27	19	8	25	OL

44	16	26	18	8	13	OL
45	11	27	19	8	18	OL
46	10	22	18	4	19	OL
47	11	18	19	-1	16	OL
48	8	10	17	-7	9	FL
49	0	20	19	1	27	OL
50	8	15	18	-3	15	OL
51	5	11	18	-7	13	FL
52	0	14	19	-5	22	OL
53	3	9	19	-10	20	OL
54	4	14	17	-3	21	OL
55	8					

Queue (start green) = 17.74 **m = 18.50**

Capacity (veh/cycle) = 18.85 **V/C (m/X) = 0.981**

Evaluation Time (hrs) = 1.50
Arrival Rate (veh/hr) = 666

for s = 1700 green eff = 2.9
1750 1.8
1785 1.0

Progression Factor = 0.38

Mean Arrivals: 18.500
Standard Deviation: 5.393
Coeffecient of Variation: 0.64

Sum of Squares: 4.76
$\chi 2$: 9.19 (df = 6)
Kolmogorov-Smirnov "d": 0.079 (n = 54)

OLF = 0.778 **LF = 0.889**

Table A-3.19 Measured Data and Calculations for Survey No. 19

Survey No: 19 **Site:** J **Cycle Time** = 80
Date/Time: August 27, 1993 - 07:15 to 08:20 **g/c** = 0.34
Location: 82 Avenue at 99 Street WB Lane #1
Green: 27 **Amber:** 3 **Red:** 50

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	3	6	-3	6	
2	0	3	5	-2	5	
3	0	9	10	-1	10	
4	0	2	10	-8	10	
5	0	1	5	-4	5	
6	0	5	7	-2	7	
7	0	6	7	-1	7	
8	0	7	9	-2	9	
9	0	4	10	-6	10	
10	0	1	8	-7	8	
11	0	11	12	-1	12	
12	0	9	10	-1	10	
13	0	4	7	-3	7	
14	0	4	9	-5	9	
15	0	0	6	-6	6	
16	0	6	9	-3	9	
17	0	14	14	0	15	OL
18	1	11	11	0	10	
19	0	3	10	-7	10	
20	0	3	10	-7	10	
21	0	9	9	0	9	
22	0	13	13	0	13	FL
23	0	11	11	0	11	
24	0	8	13	-5	13	FL
25	0	2	7	-5	7	
26	0	6	8	-2	8	
27	0	11	11	0	11	
28	0	4	11	-7	11	
29	0	5	7	-2	7	
30	0	11	12	-1	12	
31	0	11	13	-2	13	FL
32	0	7	8	-1	8	
33	0	4	8	-4	8	
34	0	6	10	-4	10	
35	0	5	6	-1	6	
36	0	9	11	-2	11	
37	0	12	14	-2	14	FL
38	0	8	10	-2	10	
39	0	7	13	-6	13	FL
40	0	3	6	-3	6	
41	0	8	10	-2	10	
42	0	7	9	-2	9	
43	0	4	4	0	4	

44	0	6	13	-7	15	OL
45	2	7	14	-7	13	OL
46	1	8	10	-2	9	
47	0	10	10	0	10	
48	0	11	12	-1	13	OL
49	1	5	8	-3	7	
50	0	4	9	-5	9	
51	0					

Queue (start green) = 6.56 **m = 9.50**

Capacity (veh/cycle) = 13.22 **V/C (m/X) = 0.718**

Evaluation Time (hrs) = 1.11
Arrival Rate (veh/hr) = 428

for s =	1700	green eff =	1.0
	1750		0.2
	1800		-0.6

Progression Factor = 0.45

Mean Arrivals:	9.500	Sum of Squares:	8.50	
Standard Deviation:	2.659	χ^2:	6.08	(df = 6)
Coeffecient of Variation:	1.34	Kolmogorov-Smirnov "d":	0.055	(n = 50)

OLF = 0.080 **LF = 0.180**

Table A-3.20 Measured Data and Calculations for Survey No. 20

Survey No: 20 **Site:** I **Cycle Time** = 100
Date/Time: August 27, 1993 - 16:00 to 16:50 **g/c** = 0.42
Location: Argyll Road at 86 Street EB Lane #2
Green: 42 **Amber:** 4 **Red:** 54

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	11	19	-8	19	
2	0	10	22	-12	22	FL
3	0	10	18	-8	18	
4	0	9	17	-8	17	
5	0	9	20	-11	20	
6	0	7	19	-12	19	
7	0	15	18	-3	25	OL
8	7	13	21	-8	14	FL
9	0	14	21	-7	21	FL
10	0	18	21	-3	26	OL
11	5	15	21	-6	24	OL
12	8	20	21	-1	22	OL
13	9	17	22	-5	15	OL
14	2	20	22	-2	24	OL
15	4	21	21	0	25	OL
16	8	22	20	2	27	OL
17	15	20	18	2	17	OL
18	14	20	23	-3	20	OL
19	11	18	21	-3	11	OL
20	1	19	20	-1	24	OL
21	5	16	20	-4	18	OL
22	3	21	21	0	34	OL
23	16	27	21	6	30	OL
24	25	29	20	9	14	OL
25	19	31	21	10	31	OL
26	29	33	20	13	20	OL
27	29	33	19	14	24	OL
28	34	36	22	14	14	OL
29	26	36	21	15	26	OL
30	31	40	21	19	26	OL
31	36	39	20	19	23	OL
32	39	44	23	21	30	OL
33	46					

Queue (start green) = **21.66** **m =** **21.88**

Capacity (veh/cycle) = **20.78** **V/C (m/X) =** **1.053**

Evaluation Time (hrs) = 0.89
Arrival Rate (veh/hr) = 788

for s = 1700 green eff = 2.0
1750 0.7
1740 1.0

Progression Factor = 0.26

Mean Arrivals:	21.875	Sum of Squares:	7.40	
Standard Deviation:	5.493	$\chi 2$:	3.13	(df = 4)
Coeffecient of Variation:	0.72	Kolmogorov-Smirnov "d":	0.086	(n = 32)

OLF = 0.750 **LF = 0.844**

Table A-3.21 Measured Data and Calculations for Survey No. 21

Survey No: 21 **Site:** J **Cycle Time** = 80
Date/Time: August 30, 1993 - 07:30 to 08:45 **g/c** = 0.34
Location: 82 Avenue at 99 Street WB Lane #1
Green: 27 **Amber:** 3 **Red:** 50

Cycle	Queue (SR)	Queue (SG)	Cleared	Rem Veh	Arrivals	FL / OL
1	0	6	12	-6	12	
2	0	3	7	-4	7	
3	0	9	10	-1	10	
4	0	6	11	-5	11	
5	0	13	15	-2	17	OL
6	2	12	14	-2	13	OL
7	1	4	5	-1	4	
8	0	9	11	-2	11	
9	0	4	10	-6	10	
10	0	8	12	-4	12	
11	0	8	11	-3	11	
12	0	5	12	-7	12	
13	0	8	11	-3	11	
14	0	11	11	0	11	
15	0	3	11	-8	11	
16	0	7	13	-6	13	FL
17	0	2	6	-4	6	
18	0	11	12	-1	12	FL
19	0	8	12	-4	13	OL
20	1	8	10	-2	9	
21	0	1	4	-3	4	
22	0	4	10	-6	10	
23	0	7	11	-4	11	
24	0	12	12	0	12	FL
25	0	5	13	-8	13	FL
26	0	7	13	-6	14	OL
27	1	5	5	0	4	
28	0	8	12	-4	12	
29	0	7	7	0	7	
30	0	5	7	-2	7	
31	0	1	7	-6	7	
32	0	5	9	-4	9	
33	0	10	11	-1	11	
34	0	5	8	-3	8	
35	0	11	13	-2	16	OL
36	3	7	12	-5	9	
37	0	1	8	-7	8	
38	0	5	7	-2	7	
39	0	13	12	1	15	OL
40	3	9	12	-3	10	OL
41	1	5	11	-6	10	
42	0	4	9	-5	9	
43	0	5	14	-9	14	FL

44	0	2	5	-3	5	
45	0	8	9	-1	9	
46	0	5	12	-7	12	FL
47	0	9	9	0	9	
48	0	7	9	-2	9	
49	0	4	4	0	4	
50	0	8	11	-3	11	
51	0	7	8	-1	8	
52	0	6	7	-1	7	
53	0	4	7	-3	7	
54	0	1	9	-8	9	
55	0	3	8	-5	8	
56	0	3	9	-6	9	
57	0					

Queue (start green) = 6.32 **m = 9.82**

Capacity (veh/cycle) = 12.85 **V/C (m/X) = 0.765**

Evaluation Time (hrs) = 1.24
Arrival Rate (veh/hr) = 442

for s = 1700 green eff = 0.2
1750 -0.6
1650 1.0

Progression Factor = 0.41

Mean Arrivals: 9.821
Standard Deviation: 2.973
Coeffecient of Variation: 1.11

Sum of Squares: 6.55
$\chi 2$: 5.25 (df = 6)
Kolmogorov-Smirnov "d": 0.051 (n = 56)

OLF = 0.125 **LF = 0.232**

Site Descriptions

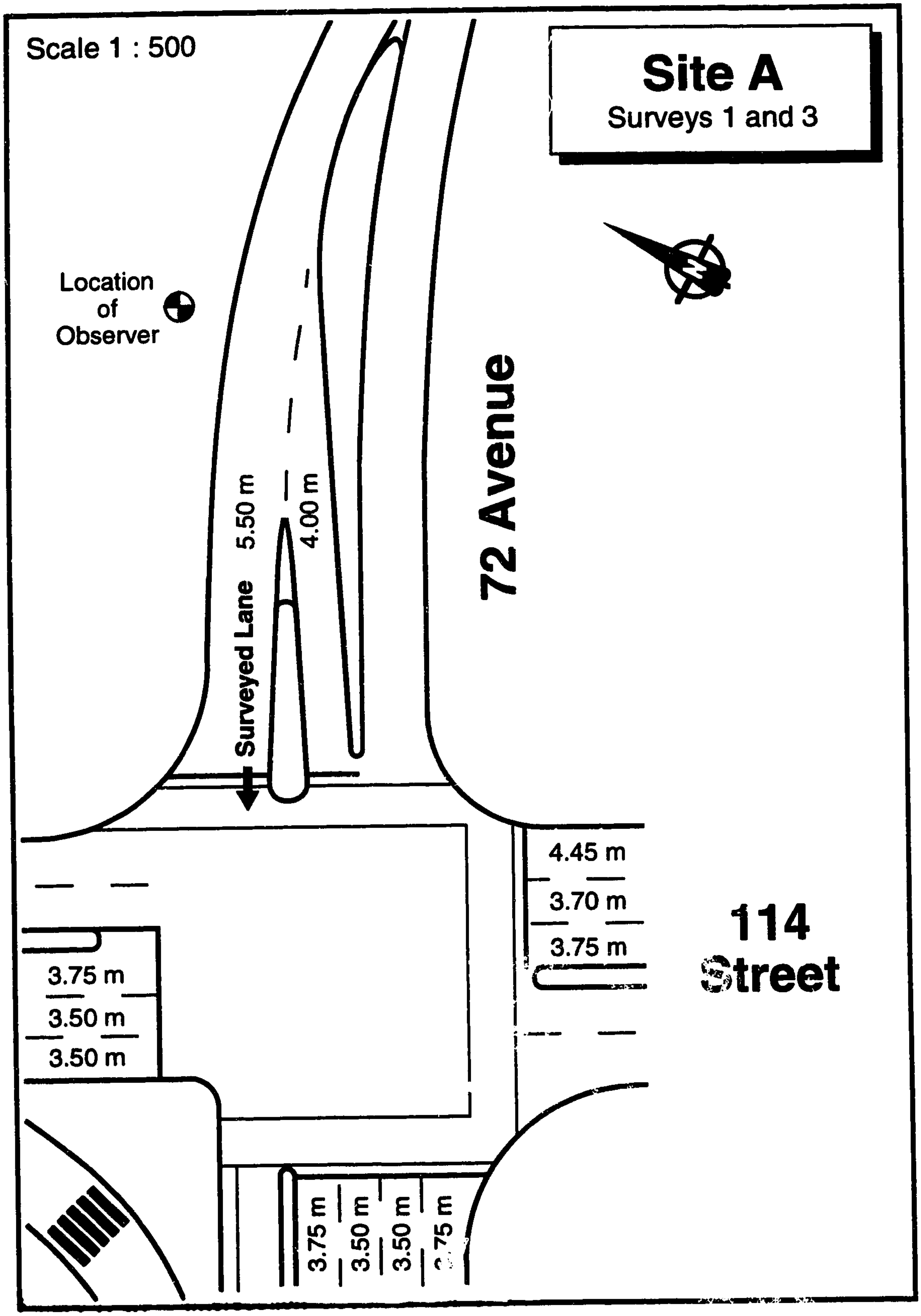
A-4.1 SITE A - 72 Avenue WB at 114 Street - Lane #2

Although traffic volumes are not large at this site, the intersection of the minor collector roadway being observed with a major arterial results in a very short green interval for traffic on the collector. The 17 second green interval coupled with a 130 second cycle length results in a green ratio of less than 0.15. The intersection has recently been reconstructed, and would be classified as HGS-LA.

An unexpectedly large stopline capacity of 9 vehicles per cycle was observed at this site, likely due to the very long wait during the red interval and prior knowledge of the following short green interval. Although the saturation flow rate did not appear to be exceptionally high, the accepted values of start loss and in particular end gain were not observed at this site. Very significant amber overrun, often several seconds into the red interval, was frequently observed.

The through lane being observed was 5.5 m wide, and right turning vehicles were generally able to bypass the queue of through vehicles, as detailed on Figure A-4.1. For the chosen approach, approximately 10% of all vehicles turn left onto 114 Street. Therefore, although the entrance to the 45 m long left turn bay is blocked after the queuing up of approximately 8 through vehicles, this generally does not influence the through traffic queue lengths appreciably. The number 40 bus turns right onto 114 Street at 30 minute intervals, but is usually able to proceed to the stopline beside the queued through traffic. No truck traffic is permitted on 72 Avenue, and very few motorcycles were observed during the surveys.

The nearest signalized intersection is approximately 850 m upstream, and significant numbers of vehicles turn onto 72 Avenue from the intersecting local roads. Flashing amber pedestrian crosswalks are found at 112 Street and


Scale 1 : 500
Site A
Surveys 1 and 3
Location of Observer
Surveyed Lane
5.50 m
4.00 m
72 Avenue
4.45 m
3.70 m
3.75 m
114 Street
3.75 m
3.50 m
3.50 m
3.75 m
3.50 m
3.50 m

113 Street, about 300 and 550 m upstream of the intersection, respectively. The traffic arrival pattern at this site appears to be random throughout the cycle. Due to the short green interval and correspondingly short queues, a vantage point about 50 m upstream of the intersection was found to provide good visibility of both the stopline and the end of the queue.

Two surveys were carried out at this site (1 and 3) during the morning peak hour. The weather conditions were the same for both surveys, with dry pavement and good visibility. The volume to capacity ratios for the two surveys were 0.58 and 0.69, with calculated saturation flow values (based on an effective green interval of 18 seconds) of 1820 and 1750 vehicles per hour of green. The progression factor for arriving vehicles at this site was 0.78 and 0.73 for Surveys 1 and 3 respectively, confirming that arrivals within the cycle were nearly random.

Although large numbers of consecutive cycles were observed during both surveys at this site, a total of only 6 overloaded cycles were observed during the two surveys. Any error in judgment in defining overloaded cycles could therefore have a significant impact on the reported overload factors at this site.

A-4.2 SITE B - Whyte (82) Avenue EB at 75 Street - Lane #2

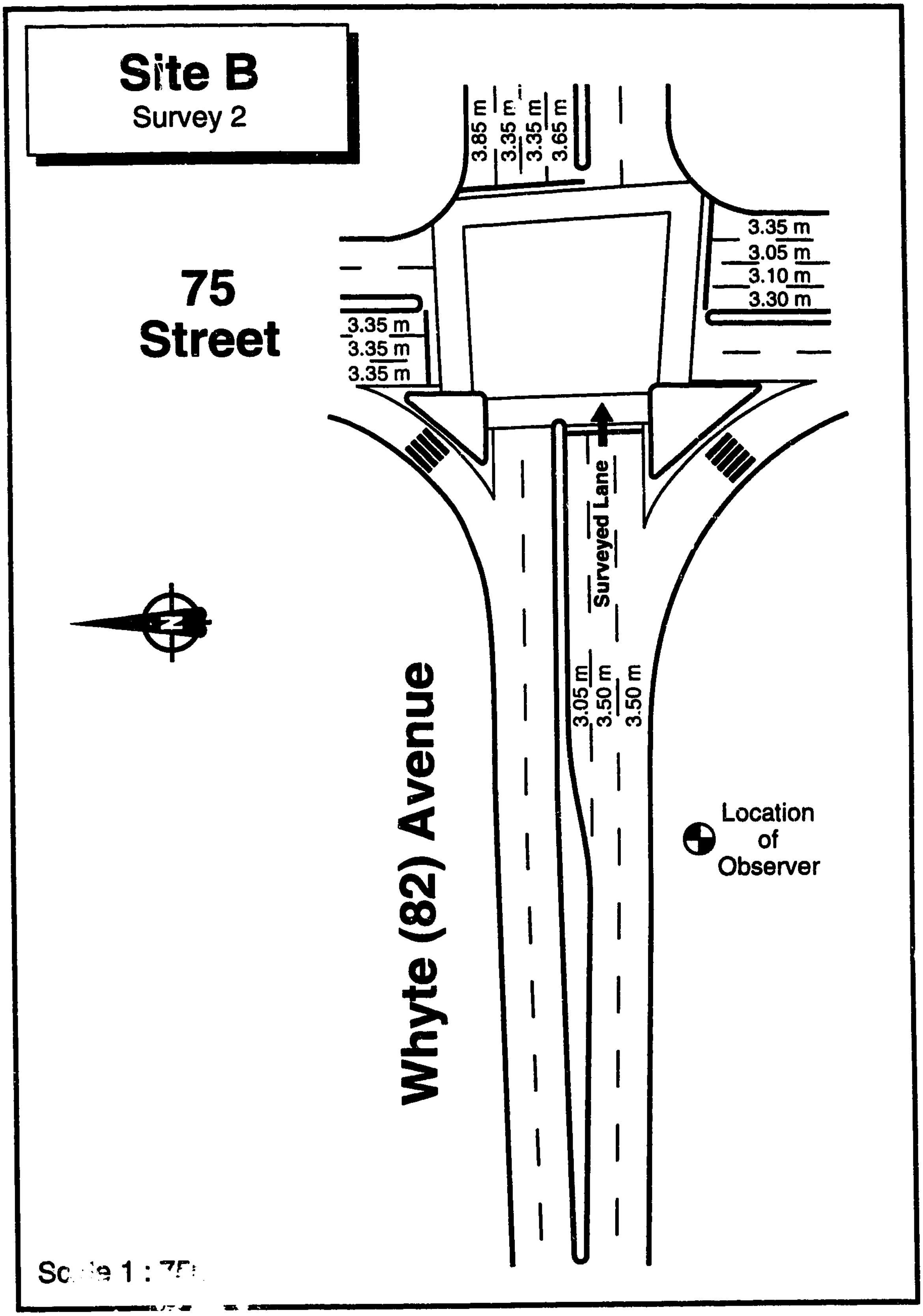
This site is located at the intersection of two major arterials, and would be classified as HGS-HA. Large traffic volumes in both directions during the peak hours result in this location having one of the highest volume to capacity ratios in the city. The long green interval (42 seconds) combined with a 100 second cycle length gave the highest green ratio of the 10 sites. Although no overloads were observed at this site, this appeared to be due to increases in stopline capacity during cycles with larger than average numbers of arrivals. Arrivals greater than average capacity were observed in several cycles, however the vehicles were able to clear the intersection due to increases in lane capacity . It is possible that the larger values of stopline capacity were due to pressure from greater numbers of arriving vehicles, and that these values more accurately represent the actual capacity, however insufficient data were collected to substantiate this hypothesis.

The through lane being observed was 3.50 m wide at the stopline, but narrowed to 3.35 m at the entrance to the adjoining left turn bay, about 50 m upstream, as shown on Figure A-4.2. Significant numbers of left turning vehicles were observed at this site, and several instances where the presence of these vehicles influenced the through traffic in the chosen lane were noted. This was due either to the queue of through vehicles extending beyond the entrance to the bay or by left turning vehicles spilling back beyond the end of the bay and blocking the through lane. These instances were noted on the field record sheets, however none of these events were felt to either cause or prevent an overloaded cycle.

The number 45 bus turns left onto 75 Street at 30 minute intervals, but does not influence the movement of vehicles in the through lane. As well, several County of Strathcona buses travel eastbound on Whyte Avenue, but always in lane 3. Significant numbers of trucks were observed at this site, however the majority of the truck traffic is in lane 3, and did not have an impact on the data collection.

A pedestrian activated signal is located about 350 m upstream of the intersection at 79 Avenue, but was used very rarely during the observation period. It does not appear that the timing of the pedestrian signal is coordinated with the traffic signal at 75 Street. The presence of long queues and large vehicles in the curb lane required that shifting of the vantage point for observationwas often required between cycles. The data collection was carried out from the south side of Whyte Avenue, between 50 and 100 m upstream (west) of 75 Street.

Only one survey (Survey 2) was carried out at this site during the afternoon peak hour, as the long queues combined with the inability to obtain an elevated vantage point, as well as the left turn bay conflicts, made


Site B
Survey 2
75
Street
3.85 m
3.35 m
3.35 m
3.65 m
3.35 m
3.05 m
3.10 m
3.30 m
3.35 m
3.35 m
3.35 m
Surveyed Lane
3.05 m
3.50 m
3.50 m
Whyte (82) Avenue
Location
of
Observer

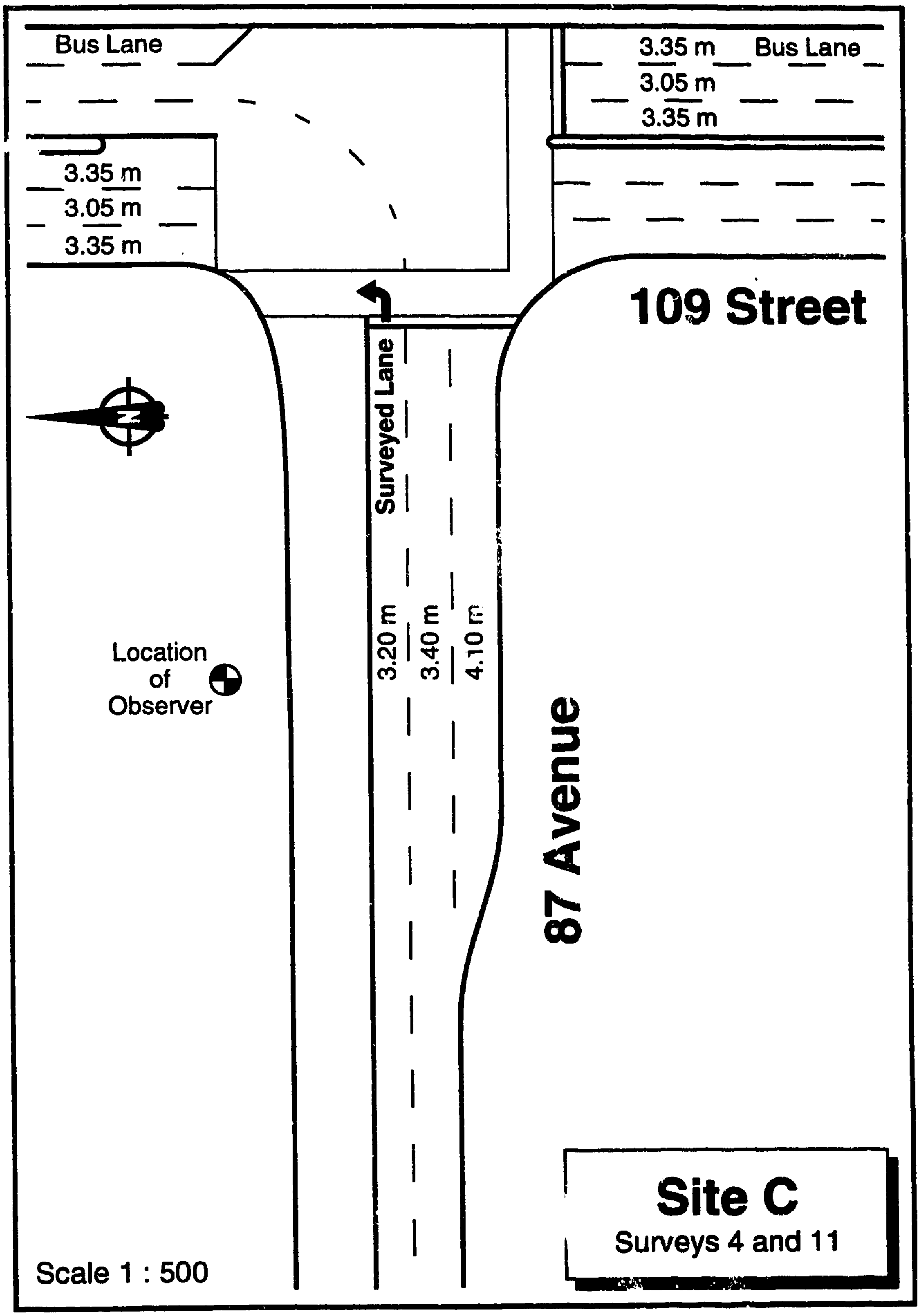
this a difficult site for data collection. The volume to capacity ratio for Survey 2 was 0.66, with a calculated saturation flow value (based on an effective green interval of 42 seconds plus 1 second) was 1860 vehicles per hour of green. The progression factor at this site was 0.33, indicating that the traffic signal at 83 Street (approximately 800 m upstream) did have an impact on the arrival pattern of vehicles within a cycle at 75 Street.

A total of 72 consecutive cycles were observed during Survey 2 at this site, with no overloaded cycles encountered, although the calculated volume to capacity ratio indicated that a small probability of overloaded cycles exists.

A-4.3 SITE C - 87 Avenue EB at 109 Street - Lane #1

The T intersection at this site allowed the observation of a long, exclusive left turn lane with no opposing traffic or crossing pedestrians. The intersection was defined as being HGS-HA. Traffic volumes at this site are generally well below capacity, however, a short afternoon peak occurs as students and employees of the University of Alberta leave the campus after 16:00 on weekdays. Although this arrival pattern is not ideal for data collection (the short duration of the higher traffic volumes limits the evaluation time available), the opportunity to obtain data on unopposed left turning movements was determined to be valuable.

The left turn lane under observation was 3.20 m wide, and was paired with a second left turn lane 3.40 m wide. The intersection geometry is shown on Figure A-4.3. Approximately 70% of all vehicles approach the intersection in the number 2 lane, either to have the option of turning onto Saskatchewan Drive after completing the left turn onto 109 Street, or to enter the right turn lane that begins about 50 m west of 109 Street. Although overloaded cycles appeared to be much more common in the number 2 lane, data collection from that lane was not possible due to the significant number of right turning vehicles and the relatively short right turn lane.

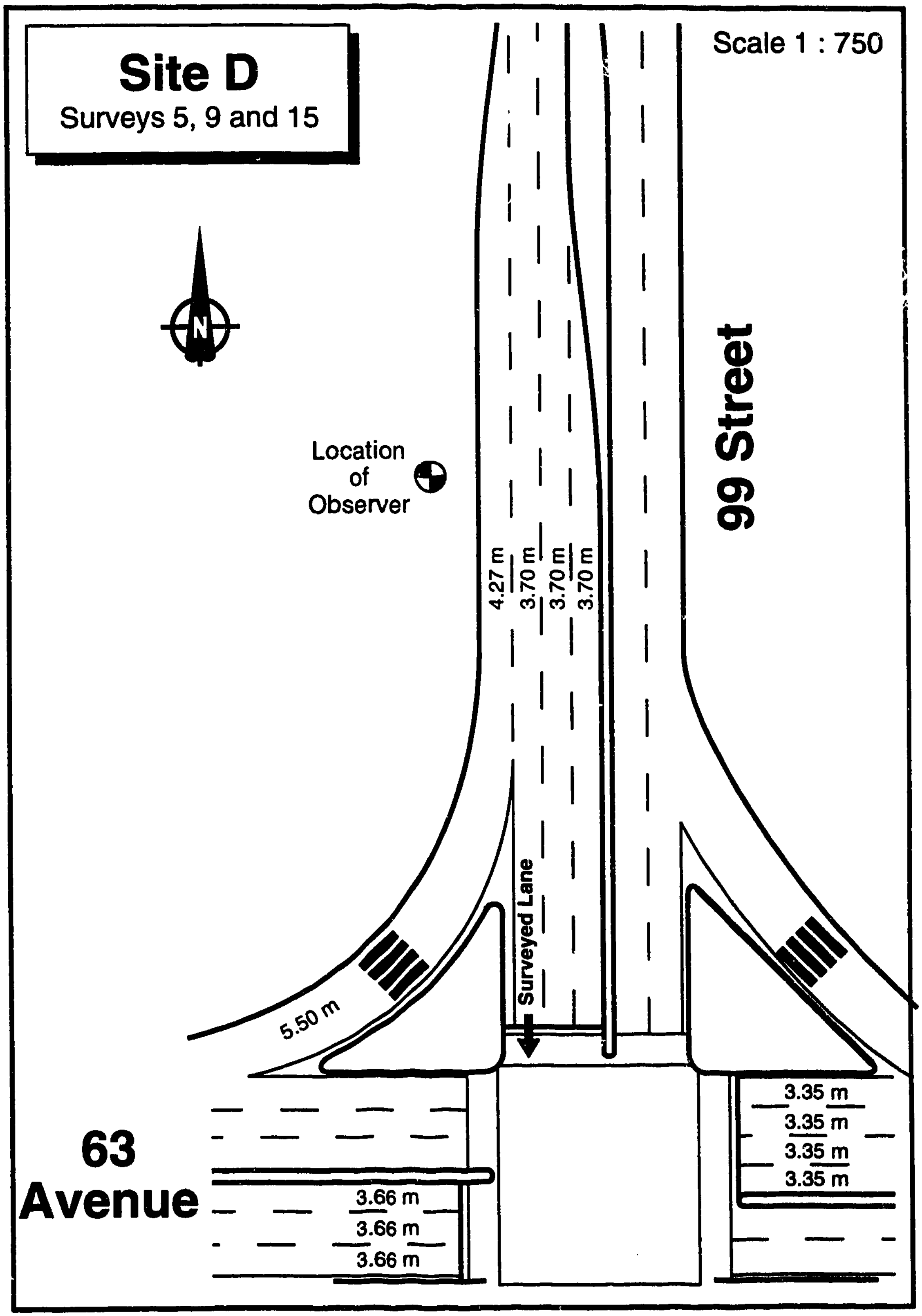

Bus Lane
3.35 m
Bus Lane
3.05 m
3.35 m
3.35 m
3.05 m
3.35 m
109 Street
Surveyed Lane
Location
of
Observer
3.20 m
3.40 m
4.10 m
87 Avenue
Site C
Surveys 4 and 11
Scale 1 : 500

There are no left turning buses at this intersection, and no heavy truck traffic was observed during the surveys. The nearest signalized intersection is about 400 m upstream at 111 Street, however a pedestrian crosswalk with flashing lights is located at 110 Street, about 200 m upstream of the intersection. The pedestrian crossing was used only occasionally during the data collection period, and as vehicles queued in the chosen lane never reached the crosswalk the impact of pedestrians was felt to be minimal. A vantage point about 50 m upstream of the intersection on the north side of 87 Avenue was found to provide acceptable visibility of both the stopline and the end of the queues.

Two surveys were carried out at this site (4 and 11) during the afternoon peak , which occurred between about 16:10 and 16:30. The volume to capacity ratios for the two surveys were 0.67 and 0.61, with calculated saturation flow values of 1450 and 1580 vehicles per hour of green. These low values for saturation flow are not unexpected for left turning traffic, however, an additional capacity penalty was created due to the regular all red interval intrusions by vehicles travelling northbound on 109 Street. This often caused larger than expected values of start loss for the left turning traffic being observed. The progression factor for arrivals at this site was 0.57 and 0.50 for Surveys 4 and 11 respectively, indicating that arrivals within the cycle were not completely random.

A-4.4 SITE D - 99 Street SB at 63 Avenue - Lane #3

The intersection of the two major arterials at this site is of the category HGS-HA. The through lane chosen for observation was 3.70 m wide, with a second through lane adjacent on the left and a 130 m long exclusive right turn lane on the right (Figure A-4.4). The entrance to the right turn lane was only blocked on cycles that were overloaded by more than about 10 vehicles. Although the approach to the intersection was approximately level, 99 Street downstream of the intersection has a slight (≈5%) uphill grade. A far side bus stop in the continuation of the chosen lane is located about 150 m



Site D
Surveys 5, 9 and 15
Scale 1 : 750
N
Location of Observer
99 Street
4.27 m
3.70 m
3.70 m
3.70 m
Surveyed Lane
5.50 m
63 Avenue
3.66 m
3.66 m
3.66 m
3.35 m
3.35 m
3.35 m
3.35 m

downstream (south) of the stopline, and a railroad crossing is encountered approximately 350 m downstream.

Although the railroad crossing is used only infrequently, a train did cause the premature end of one of the surveys at this site. The number 78 bus runs on a 30 minute headway on 99 Street, and some reduction in stopline capacity due to the bus stop is likely. Occasional heavy truck traffic was observed during the course of the data collection and correction for the heavy vehicles was carried out as described in Chapter 3.

The nearest signalized intersection is approximately 1400 m upstream at 76 Avenue, with pedestrian signals at 71 and 73 Avenues. The pedestrian signals were not used extensively during the data collection period and it appears than few vehicles turn on to or off of 99 Street between 76 Avenue and 63 Avenue, hence, the arrival pattern reflects progression from the upstream signal. Both the stopline and the end of the queue could be easily observed from a point about 80 m north of the intersection, on the west side of 99 Street.

Three surveys were carried out (5, 9 and 15) during the afternoon peak hours. Sufficient rainfall was encountered during the first survey (No. 5), to wet the roadway and require that drivers use their vehicle's windshield wipers. This resulted in the reduction of stopline capacity by approximately 7% from dry weather conditions. The volume to capacity ratios for the three surveys were 0.80, 0.70 and 0.81, with calculated saturation flow values (based on an effective green interval of 29 seconds) were 1590, 1740 and 1680 vehicles per hour of green. Progression factors of 0.56, 0.50 and 0.54 were calculated for the three surveys.

The number of overloaded cycles (10, 6 and 6 for the surveys 5, 9 and 15 respectively) observed at this site provided some confidence that even with small errors in judgment the overload factor data would accurately represent actual conditions.

A-4.5 SITE E - Whyte (82) Avenue WB at 109 Street - Lane #2

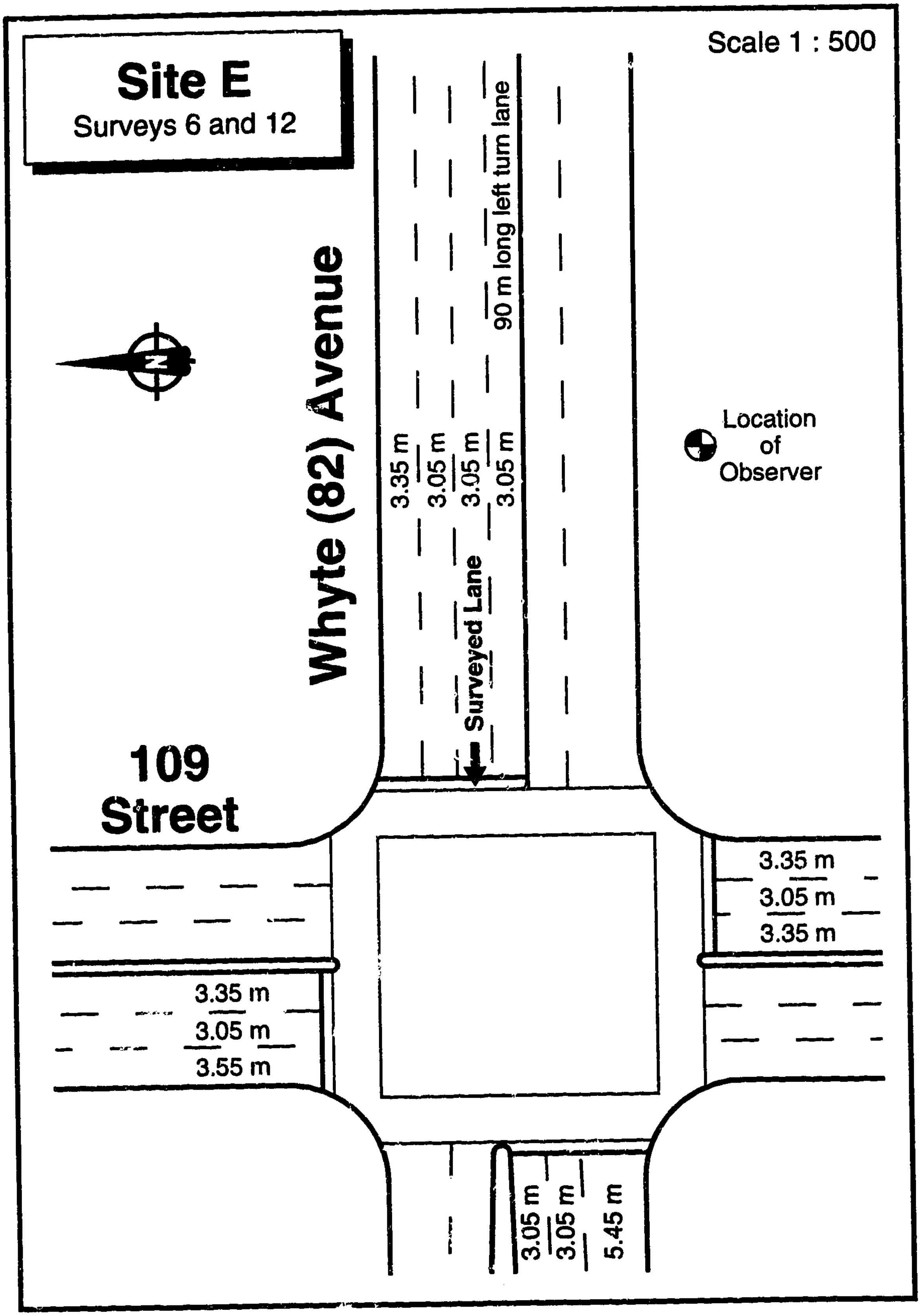
This site is located at the intersection of two major arterials, and is of the category HGS-HA. The lane chosen for observation was 3.05 m wide, with 2 lanes to the right and a 90 m long left turn lane on the left, as shown on Figure A-4.5. The length of the left turn lane was adequate to ensure that left turning vehicles were able to enter the lane behind any queued through vehicles. The volume of left turning vehicles was small, and had no impact on the data collection. The through lane under observation deviated somewhat from a straight line as it passed through the intersection, which may have the saturation flow rate during the data collection.

All bus traffic was confined to the curb lane, and did not have an impact on traffic behaviour in the lane under investigation. Some truck and motorcycle traffic was observed, and corrections were applied to the vehicle counts as required.

Although the nearest signalized intersection is approximately 750 m upstream at 105 Street and a pedestrian signal is present at 107 Street, the arrival pattern reflects progression from the upstream signal. This may be due to the limited use of the pedestrian signal at the time of the surveys, and the minimal numbers of vehicles turning onto or off of Whyte Avenue west of 105 Street. The lane was observed from the south side of Whyte Avenue, about 50 m east of 109 Street.

Two surveys (6 and 12) were carried out at this site, with dry weather conditions for both. The volume to capacity ratios for the two surveys were 0.66 and 0.57, with calculated saturation flow values were both 1630 vehicles per hour of green. The measured progression factors for both surveys were 0.44, indicating that coordination with the upstream traffic signal exists.

Only 2 and 4 overloaded cycles were observed during surveys 6 and 12 respectively.


Site E
Surveys 6 and 12
Scale 1 : 500
Whyte (82) Avenue
90 m long left turn lane
3.35 m
3.05 m
3.05 m
3.05 m
Surveyed Lane
Location of Observer
109 Street
3.35 m
3.05 m
3.35 m
3.35 m
3.05 m
3.55 m
3.05 m
3.05 m
5.45 m

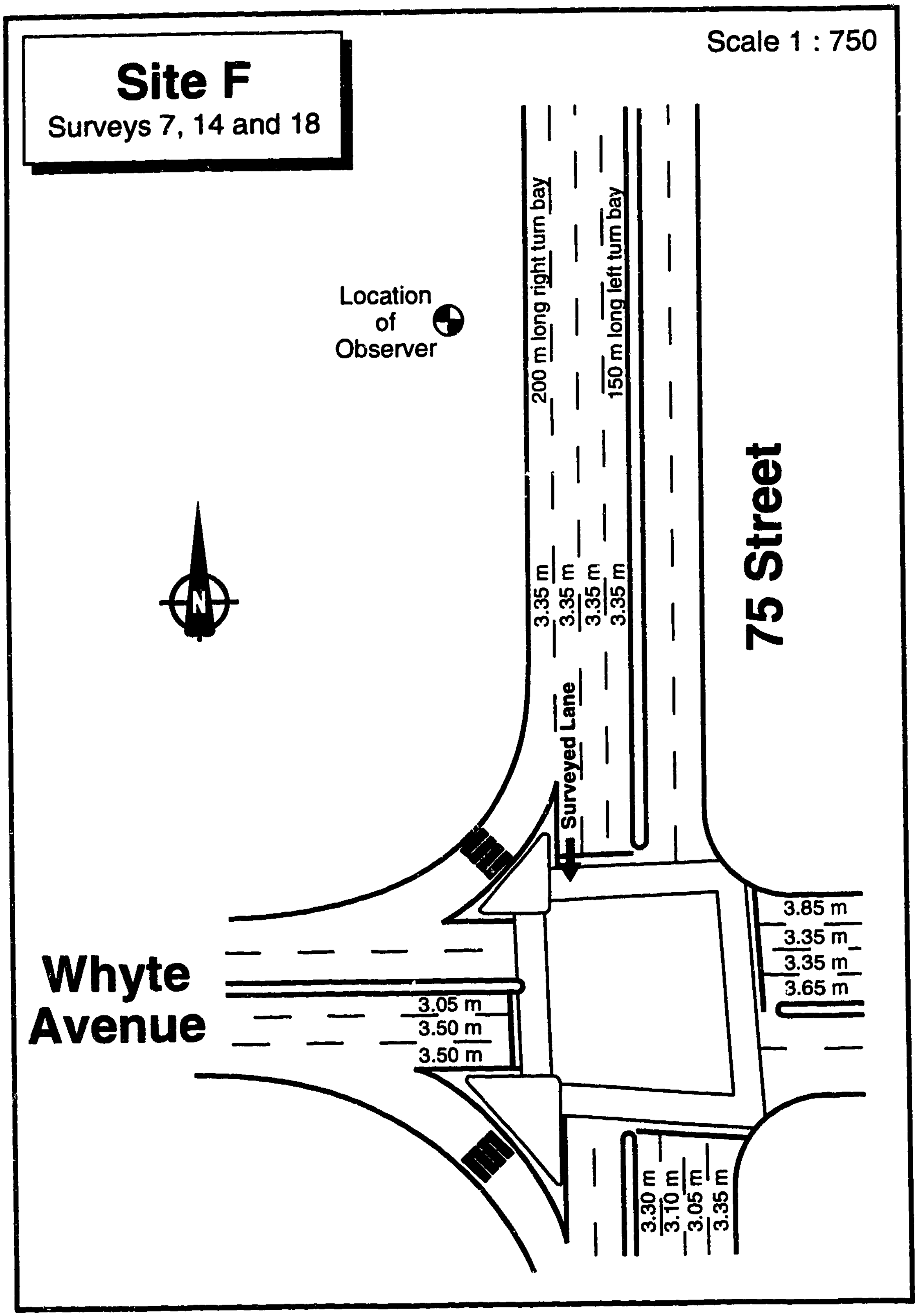
A-4.6 SITE F - 75 Street SB at Whyte (82) Avenue - Lane #3

The intersection under observation was the same one as for site B (Section A–4.2), however a southbound lane was chosen for study. This site closely resembles Site D described in Section A-4.4, with a 3.35 m wide through lane adjacent to a long (200 m) exclusive right turn lane (Figure A-4.6). As at site D the right turning traffic did not have any impact on the through traffic due to the long turning lane length. The entrance to the right turn lane was generally not blocked unless approximately 15 vehicles more than capacity were in queue.

No bus routes follow 75 Street south across Whyte Avenue, and only moderate numbers of trucks were observed during the course of the data collection at this site.

A pedestrian crossing signal is located at 86 Avenue, approximately 350 m upstream of the intersection. The pedestrian signal does not appear to be coordinated with the traffic signals, and was used only occasionally during the time of the surveys. Coordination between the upstream traffic signals at 90 Avenue and the signals at the intersection under observation resulted in good progression, even with occasional interruptions of flow due to the pedestrian signal. The intersection was observed from a location about 150 m north of Whyte Avenue on the west side of 75 Street.

The high volume capacity ratios and long durations of peak arrival rates at this site provided excellent data, hence, three surveys were carried out (7, 14 and 18) during the afternoon peak hours. Weather conditions did not influence the data collection during any of the surveys. The volume to capacity ratios for the three surveys were 0.87, 0.98 and 0.98, while calculated saturation flow values were very consistent at 1750, 1730 and 1790 vehicles per hour of green. Progression factors of 0.31, 0.44 and 0.38 were calculated for the three surveys, confirming the observations on arrival patterns and coordination described above.


Site F
Surveys 7, 14 and 18
Scale 1 : 750
Location of Observer
N
200 m long right turn bay
150 m long left turn bay
3.35 m
3.35 m
3.35 m
3.35 m
Surveyed Lane
75 Street
3.85 m
3.35 m
3.35 m
3.65 m
Whyte Avenue
3.05 m
3.50 m
3.50 m
3.30 m
3.10 m
3.05 m
3.35 m

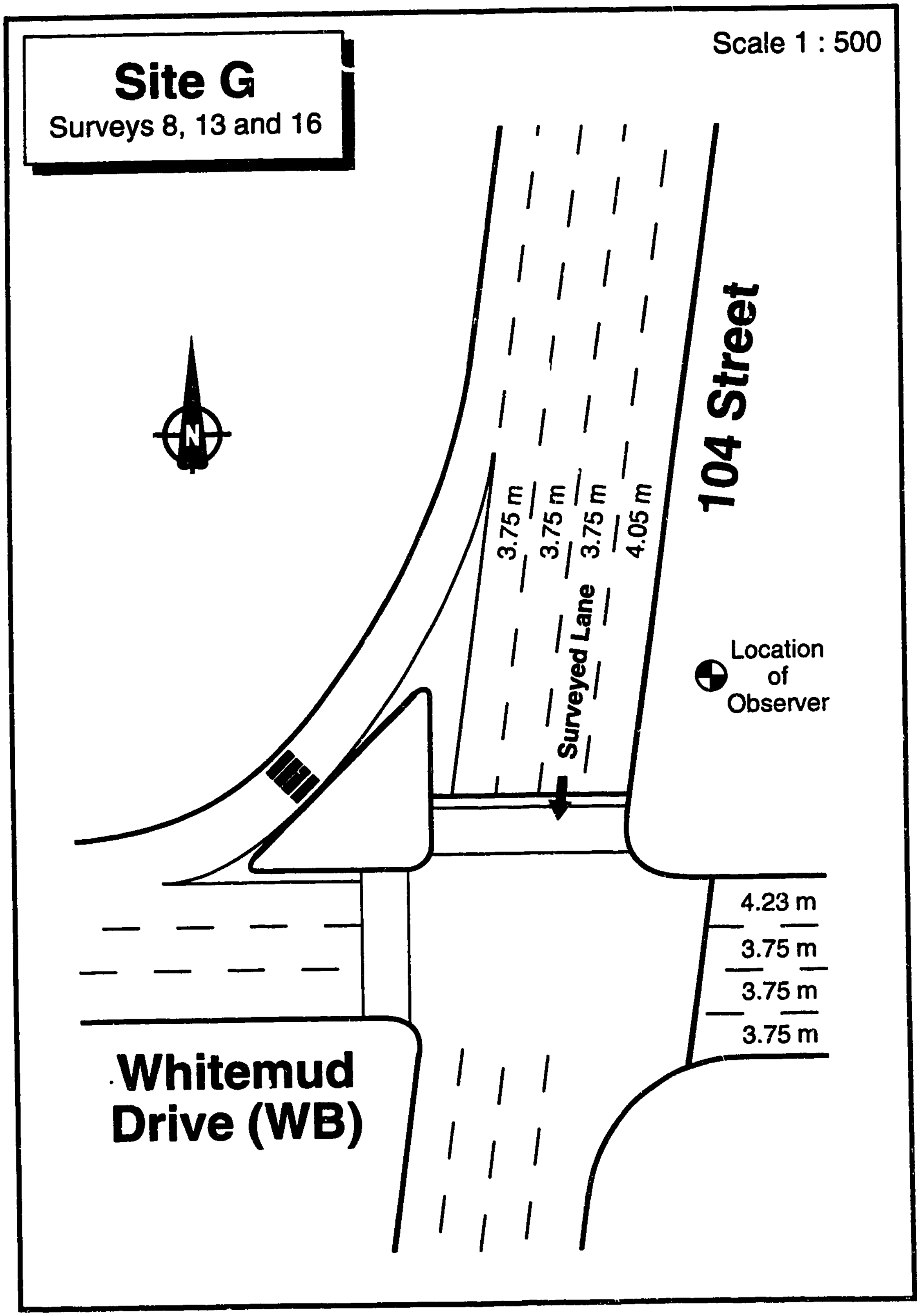
Data collected at this site was felt to be very reliable, as platoons of vehicles from the upstream signal tended to arrive during the green interval, but before the vehicles at the end of the standing queue began to move. It was therefore usually obvious which vehicles joined the queue, and little judgment was required to determine the last vehicle to join the queue. In addition, the large numbers of overloaded cycles provided a good estimate of stopline capacity and reduced the impact of occasional anomalies or errors in judgment.

A-4.7 SITE G - Calgary Trail SB at Whitemud Drive EB - Lane #2

This site is located at the intersection of two major one way arterials, and is classified as HGS-LA. Construction of a grade separation structure was underway at the time of the surveys, but did not appear to have an impact on the data collection. The lane chosen for observation was the second of four through lanes, and was 3.75 m wide. The intersection geometry is detailed on Figure A-4.7. No scheduled bus service exists at this location, and the majority of truck traffic was found to utilize the right hand lanes.

Coordination between the upstream traffic signals at 51 Avenue and 48A Ave and the signals at Whitemud Drive was similar to the previous site (Site F - Section A-4.6). The platoon of arriving vehicles would generally have to decelerate or stop at the back of the standing queue, often after the start of the green interval. As overloaded cycles occurred and the length of the standing queue increased, relatively straightforward determination of the last vehicle to join the queue was possible.

Although the chosen lane was observed from the roof of the Convention Inn parkade (approximately 10 m above the roadway) on the northeast corner of the intersection, it became difficult to accurately count the number of vehicles in the very long queues while also observing the stopline. This would not have an impact on the number of overloaded cycles counted, but may have caused the distribution of vehicle arrivals to be inaccurate.



Site G
Surveys 8, 13 and 16
Scale 1 : 500
N
104 Street
3.75 m
3.75 m
3.75 m
4.05 m
Surveyed Lane
Location of Observer
4.23 m
3.75 m
3.75 m
3.75 m
Whitemud Drive (WB)

As at the previous site, three surveys were carried out (8, 13 and 16) to take advantage of high volume to capacity ratios and long durations of peak arrival rates. Weather conditions did not influence the data collection during any of the surveys. The volume to capacity ratios for the three surveys were 0.96, 0.83 and 0.99, with calculated saturation flow values (based on an effective green interval of 39 seconds) were 1850, 1950 and 1860 vehicles per hour of green. Progression factors of 0.33, 0.42 and 0.38 were calculated for the three surveys.

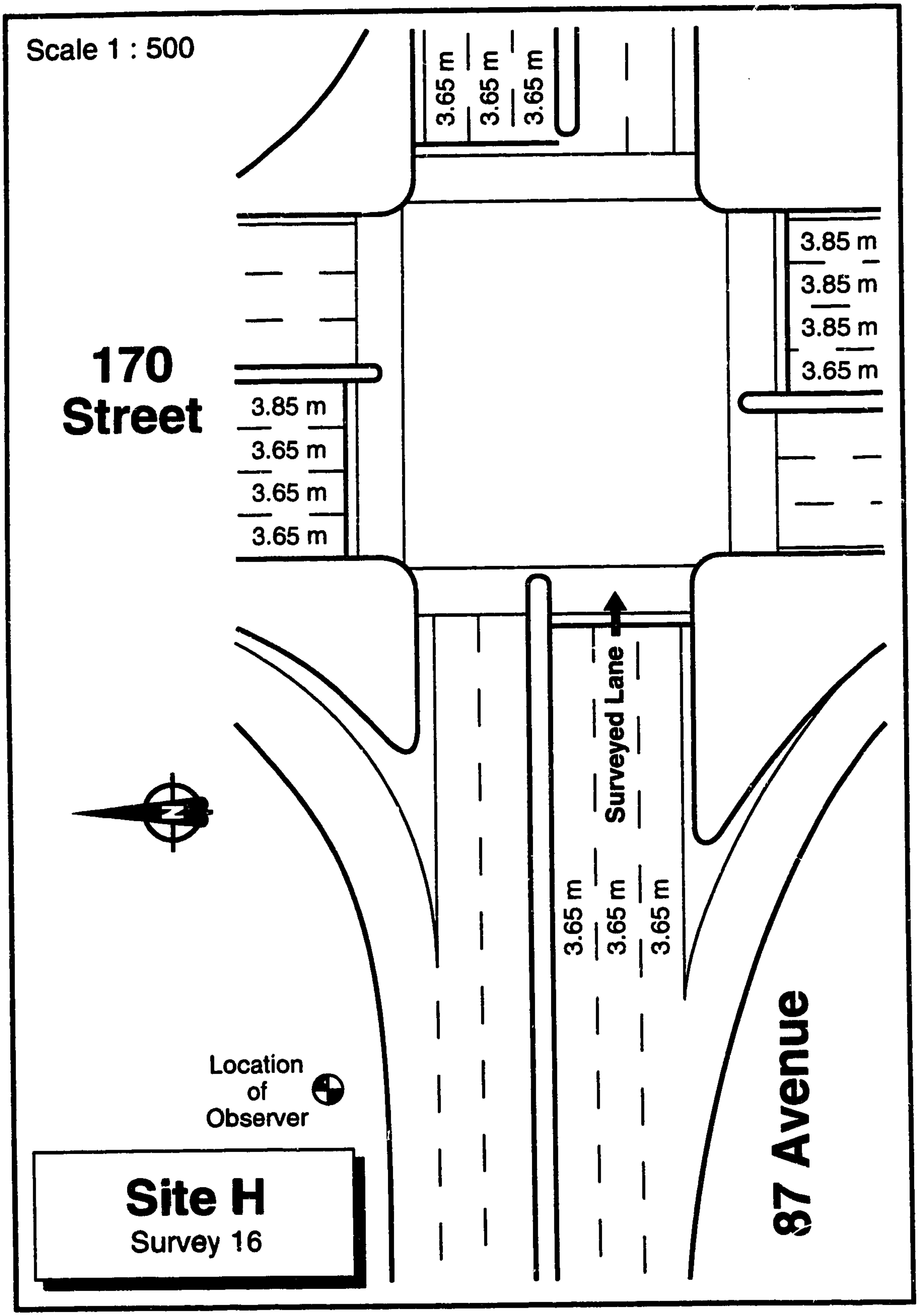
The large numbers of overloaded cycles observed at this site provided a good estimate of stopline capacity.

A-4.8 SITE H - 87 Avenue EB at 170 Street - Lane #2

This intersection of a minor east-west arterial with a major north-south arterial was classified as HGS-LA. The one survey (10) carried out at this site was intended to confirm that no overloaded cycles would be observed at the anticipated low volume to capacity ratio. The through lane being observed was 3.65 m wide, with a second through lane to the right and a 75 m long left turn lane on the right, as shown on Figure A-4.8.

No truck or bus traffic was observed in the chosen lane at the time of the data collection. Although four bus routes run past this site, all buses were found to travel in the curb lane.

Three signalized intersections exist between 170 Street and 178 Street to allow access into West Edmonton Mall, and it appears that at least two of these signals are traffic actuated. Very little traffic was observed turning into or out of the mall parking lots during the time of the survey, and it is likely that coordination between the signals at 178 Street, 175 Street and 170 Street along 87 Avenue was not influenced by the actuated signals. The vantage point chosen for the survey was on the north side of 87 Avenue, about 50 m west of 170 Street.


Scale 1 : 500
3.65 m
3.65 m
3.65 m
3.85 m
3.85 m
3.85 m
3.65 m
170
Street
3.85 m
3.65 m
3.65 m
3.65 m
Surveyed Lane
3.65 m
3.65 m
3.65 m
87 Avenue
N
Location
of
Observer
Site H
Survey 16

No overloaded or fully loaded cycles were observed during the survey, hence, capacity for the lane was based on an assumed value of saturation flow (1670 vehicles per hour of green) and an effective green interval of 28 seconds. This intersection lane operated at a volume to capacity ratio of 0.42. A progression factor of 0.58 indicates that good coordination with upstream signals is present.

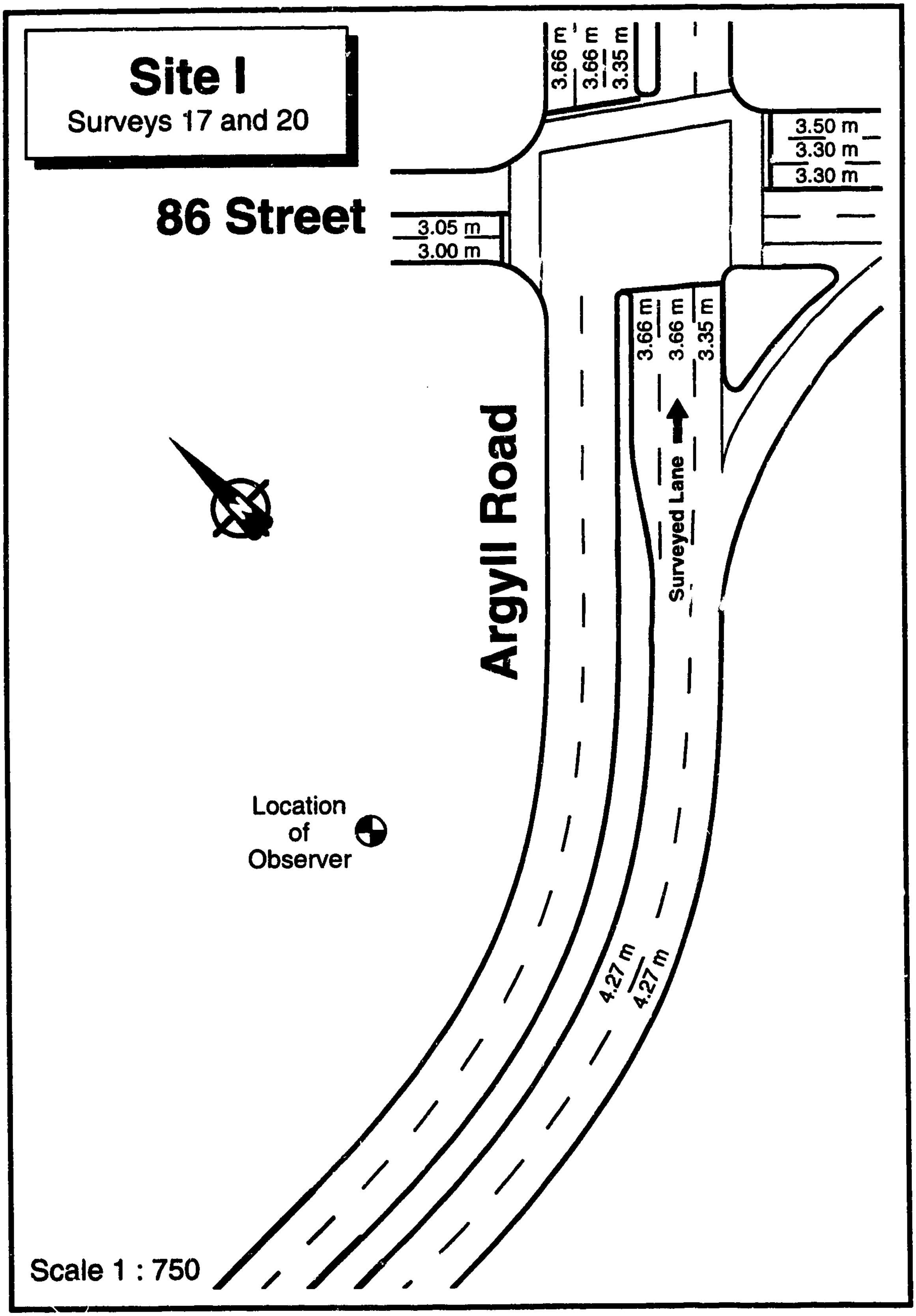
A-4.9 SITE I - Argyll Road EB at 86 Street - Lane #2

Argyll Road is a major arterial with considerable traffic volumes turning south onto 86 Street. The intersection was determined to be HGS-LA. The lane chosen for observation at this site was a 3.66 m wide through lane, with another through lane on the right and a 35 m long left turn lane on the left (Figure A-4.9). Low volumes of left turning vehicles prevented the relatively short left turn lane from having an impact on the through traffic. The approach to the intersection from the west contains a 40° curve of radius 150 m, beginning about 20 m west of the stopline. Although the curve itself would not significantly impede visibility of the intersection, trees and shrubs growing on the north side of Argyll Road can obscure the traffic signal heads. Drivers who are not in the first 20 to 25 vehicles in queue will likely not be able to see either signal head.

Based on observations during the data collection it appears that the free flow speed is significantly greater upstream than downstream of the intersection. Although lane widths are identical in both portions of the roadway, large numbers of vehicles enter Argyll Road eastbound at 86 Street.

The arrival of platoons from the traffic signal at 91 Street occurs well after the start of the green interval, with the following impacts:

1. The tail of the platoon is generally truncated by the 86 Street signal.
2. 5 to 10 vehicles are generally stopped for virtually the entire red interval.



Site I
Surveys 17 and 20
86 Street
Argyll Road
3.66 m
3.66 m
3.35 m
3.50 m
3.30 m
3.30 m
3.05 m
3.00 m
3.66 m
3.66 m
3.35 m
Surveyed Lane
4.27 m
4.27 m
Location of Observer
Scale 1 : 750

3. The drivers of these stopped vehicles are often impatient and are prepared to accelerate as soon as the green interval begins.
4. The tail of the average length standing queue (≈ 12 vehicles) is often just beginning to move as the first of the platooned vehicles arrive.
5. Very high stopline capacities were observed at this site, as the above factors tend to encourage small amounts of start loss and large amounts of end gain.

The pattern and timing of arrivals at this site makes the determination of fully loaded and overloaded cycles difficult, as many cycles require judgment to decide whether or not a vehicle joined a moving queue.

The green ratio for the chosen lane was 0.42 and stopline capacity was very high, however the large approach volumes caused conditions approaching capacity. Two surveys (17 and 20) were carried out at this site during the PM peak.

Weather conditions during the first of the two surveys were good, with dry pavement and good visibility. The volume to capacity ratio for this survey was 0.82, and a saturation flow rate of 2020 vehicles per hour or green was calculated.

Heavy rainfall began shortly after the start of the second survey, and reduced stopline capacity by approximately 13% from the value established during the first survey. Not only did the rainfall reduce visibility, but a large pool of water ponded in the chosen lane about 80 m upstream of the intersection. The speed of vehicles moving through this area was noticeably reduced, and large gaps were created between the area of ponded water and the stopline. Although the arrival flow rate did not increase significantly, the volume to capacity ratio for this survey was 1.05 due to the reduction in stopline capacity, while the observed stopline capacity indicated a saturation flow rate of 1740 vehicles per hour of green.

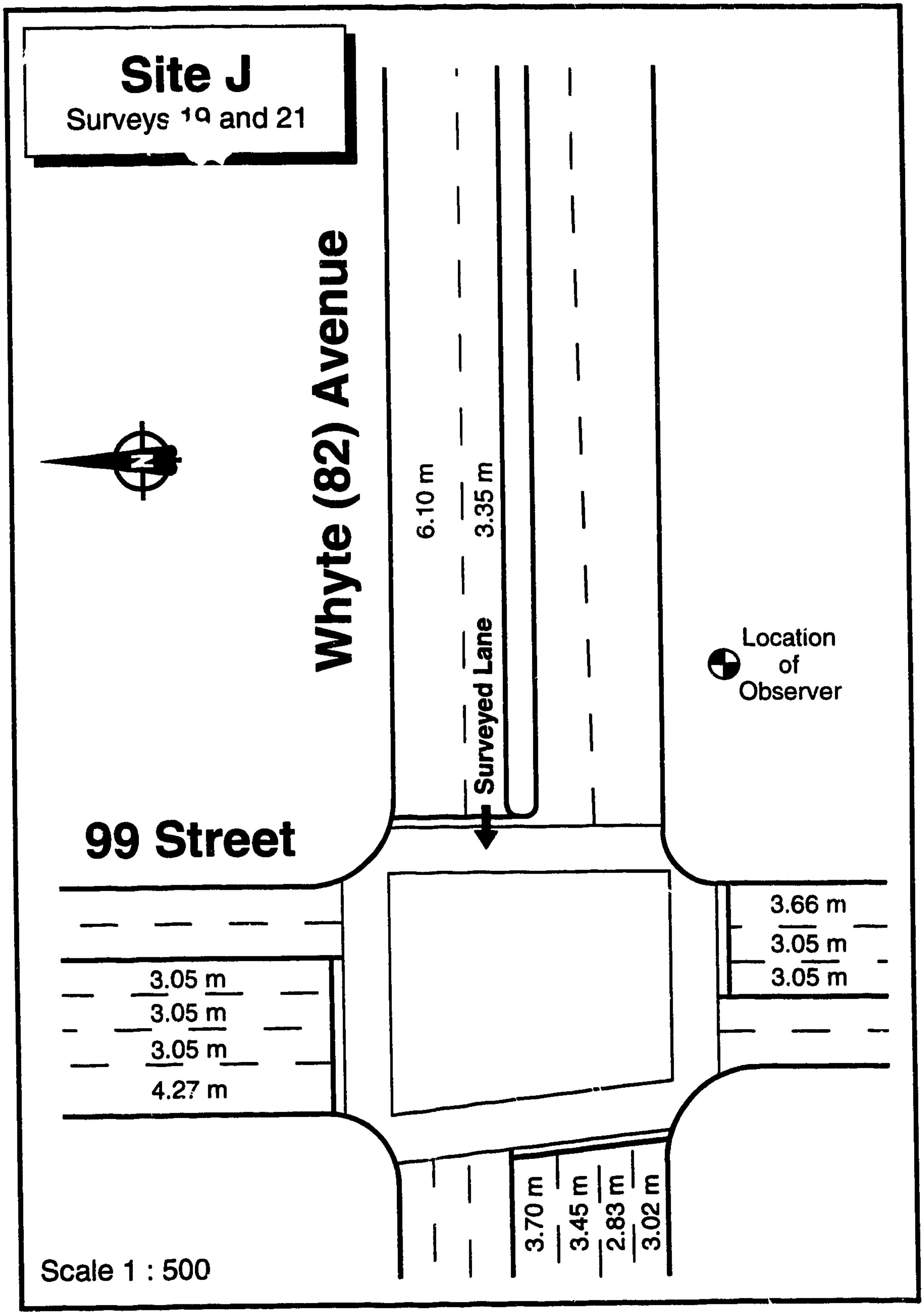
The data collection was carried out from the north side of Argyll Road, about 75 m upstream of the stopline. As the queue lengths became very long near the end of the second survey, it became extremely difficult to count the vehicles at the end of the queue, particularly in light of the heavy rainfall. The data collection for the second survey was therefore terminated after 32 cycles.

A-4.10 SITE J - Whyte (82) Avenue WB at 99 Street - Lane #1

Both Whyte Avenue and 99 Street are major arterials, and this intersection was classified as HGS-HA. Left turns by westbound traffic are not permitted at 99 Street, hence the lane chosen for observation was the 3.66 m wide inside through lane. To the right of the chosen lane is a 6.10 m wide through and right turn lane, which is used for parking upstream of the intersection and becomes essentially two lanes near the intersection (Figure A-4.10). An uphill grade of approximately 5% reduced the saturation flow rate for traffic in the lane being observed.

The nearest signalized intersection upstream of this site is approximately 1200 m distant, at 91 Street. Although considerable platoon dispersion would be expected in this distance, it appears that the majority of arrivals were occurring during the green interval. Regular speed enforcement along this section of Whyte Avenue may contribute to speed discipline and cohesive platoon behaviour. A pedestrian signal at 96 Street and a pedestrian crosswalk with flashing amber lights at 97 Street did not appear to have been activated with any frequency during the course of the surveys, and did not have an impact on the vehicle arrival pattern.

Although several bus routes run past this location, no buses were observed using the chosen lane. Heavy trucks were not observed in significant numbers at this site, however when large trucks were present near the start of a standing queue, larger corrections than used previously were


Site J
Surveys 19 and 21
Whyte (82) Avenue
6.10 m
3.35 m
Surveyed Lane
Location of Observer
99 Street
3.66 m
3.05 m
3.05 m
3.05 m
3.05 m
3.05 m
4.27 m
3.70 m
3.45 m
2.83 m
3.02 m
Scale 1 : 500

applied, due to the impact of the uphill grade. A correction of 2.5 to 3.0 pcu/truck was used, rather than the previously chosen correction of 2.0.

Two surveys (19 and 21) were carried out during the morning peak hour. A previous survey was abandoned after an emergency vehicle signal preemption changed the signal timing pattern. The volume to capacity ratios for the two surveys were 0.72 and 0.77. Based on an effective green interval of 28 seconds the calculated saturation flows were 1680 and 1650 vehicles per hour of green for surveys 19 and 21 respectively. The calculated progression factors of 0.45 and 0.41 indicate that good coordination exists between the intersection at 91 Street and the intersection under study, in spite of the long link length.

The site was observed from the south side of Whyte Avenue, approximately 50 m upstream of the intersection. Although the presence of large trees in the median did occasionally make observation difficult, the large trucks and buses present in the number 2 (and 3) lane prevented adequate visibility of the inside lane from the north side of the roadway.

TIMING SHEET

Location. BELGRAVIA RD - 114 ST

Analysed By CK

Approved

Implementation Date JAN 11/93 ✓

Date. JAN. 11, 93

Design for:

Problems:

Recommendations: (Capacity, Coordination)

Detailed Timings:

	N/S	EBD	E/W	NBD		
Direction Phase	↓↑		⇆			
Intergreen	3+2	3+0	3+2	3+0		
Ped. Clr.	17+5		17+5			

Time Plan	Cycle	Offset Ø1	Ø1	Ø2	Ø3	Ø4	Ø5	Ø6
NEW								
AM CRITICAL	130	64	36	64	17	X	{06:30 - 09:30}	
EXIST								
PM CRITICAL	120	17	44	19	27	14	{15:15 – 18:30}	
~~AM~~	~~110~~	~~95~~	~~26~~	~~47~~	~~14~~	~~7~~		
~~PM~~	~~100~~	~~3~~	~~42~~	~~11~~	~~21~~	~~10~~		
OFF	80	38	24	21	12	7		
NIGHT	60	11	25	X	25	X		
OLD								
AM CRITICAL	130	69	21	59	17	7		

1390

City of Edmonton

C1106

TIMING SHEET

Location 82 AVE - 75 ST

Date OCT 2/91
Design for

Analysed By
Approved
Implementation Date OCT 9/91

Problems

OFF-PEAK CONGESTION N-S, OK E-W

Recommendations (Capacity, Coordination)

INCREASE GREEN N-S; DECREASE E-W GREEN
TO EQUALIZE V/C'S.

Detailed Timings:

	Ø1	Ø2	Ø3	Ø4	Ø5	Ø6
Direction	N-S	E-W ARROWS	EBD FLASH	E-W	N-S ARROWS	NBD FLASH
Phase	↓ ↑					
Intergreen	4+1	4+0	4+0	4+1	4+0	4+0
Ped. Clr.	17+5			13+5		

Time Plan		Cycle	Offset Ø1	Ø1	Ø2	Ø3	Ø4	Ø5	Ø6
NEW OFF-PEAK		90	54	31	7	X	27	7	X
OLD OFF-PEAK		90	56	27	7	X	31	7	X (TP3)
EXISTING	AM	100	52	44	X	X	35	7	X (TP1)
	PM	100	54	37	X	10	28	X	7
	NIGHT	60	10	26	X	X	24	X	X (TP6)
HOCKEY	INBOUND	100	54	37	~~5~~X	~~5~~10	28	X	7 (TP5)
	OUTBOUND	110	20	54	6	X	24	8	X (TP10)

1990

City of Edmonton

[illegible] [illegible]

TIMING SHEET

Location 87 Ave 109 St

Analysed By CK

Approved

Implementation Date OCT 22 1992

Date: OCT 19, 92

Design for

Pm peak

Problems.

Recommendations (Capacity, Coordination)

NOTE Offsets based on ϕ_3

Detailed Timings:

Direction	N/S	NBD	MSG ϕ_3 SBRT EBD
Phase	↓ ↑	↰↑	↲ →
Intergreen	3+2	3+2	3+2
Ped Clr	16+5		16+5

Time Plan	Cycle	Offset ϕ_3	Ø1	Ø2	Ø3	Ø4	Ø5	Ø6
NEW								
Pm CRITICAL	100	77	62	x	28	MON FRI 16:00 - 18:00		
Pm	100	77	57	7	28	MON FRI 15:00 - 16:00 + 18:00 - 18:30		
EXIST								
Am	100	75	~~47~~ 42	~~15~~ 20	23	DETOUR TP		
OFF	80	62	3[illegible]	7	23			
NIGHT	70	5[illegible]	31	Y	23			
OLD								
Pm	100	7[illegible]	6[illegible]	x	28	MON FRI 15:00 18 30		

1990

City of Edmonton

C019

TIMING SHEET

Location 63 Ave - 99 St

Date Nov 19, 91

Analysed By CK
Approved
Implementation Date DEC 2/91

Design for
Evening

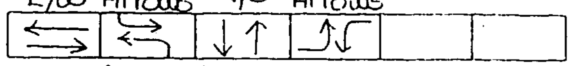
Problems
↳ MON - FRI 18:00 - 23:00
SUN 09:00 - 22:00

Recommendations (Capacity, Coordination)

Detailed Timings

Direction	E/W	N/S Arrows	N/S	E/W Arrows		
Intergreen	4+1	4+0	4+1	4+0		
Ped. Clr	11+5		13+5			

Phase



Time Plan	Cycle	Offset Ø1	Ø1	Ø2	Ø3	Ø4	Ø5	Ø6
NEW								
Evening	80	70	~~35~~ 34	×	~~37~~ 36	×		
EXIST								
Am pk	100	93	30	6	33	13		
Pm pk	100	88	30	9	28	15		
Off pk	80	70	23	7	24	8		
Saturday	90	88	30	7	28	7		
Night	70	63	33	×	27	×		

1990

City of Edmonton

Copy 1

TIMING SHEET

Location 82 Av. 109 St

Date June 15, 92

Design for

Pm peak

Analysed By CK
Approved
Implementation Date

JUL 05 1992

Problems

McKernan Traffic Plan

Recommendations (Capacity Coordination)

Implement with Stage II of 114 St + Keep in

Detailed Timings

Direction	N/S	E/W	N/S Arrows	NBD	SBD		
Phase							
Intergreen		3+2	3+2	3+0	3+0	3+0	
Ped Clr	19+5	21+5					

Time Plan	Cycle	Offset Ø1	Ø1	Ø2	Ø3	Ø4	Ø5	Ø6
NEW								
Pm Pk	100	36	47	33	7	X	X	
OLD								
Pm Pk	100	48	42	36	X	X	9	
EXIST								
Am Pk	100	85	37	36	X	14	X	
OFF Pk	80	7	30	30	7	X	X	
NIGHT	70	25	30	30	X	X	X	

1990

City of Edmonton

C.106

TIMING SHEET

Location 82 AVE – 75 ST

Date OCT 2/91
Design for

Analysed By
Approved
Implementation Date OCT. 9/91

Problems:

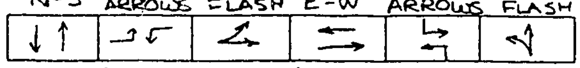
OFF-PEAK CONGESTION N-S, OK E-W

Recommendations: (Capacity, Coordination)

INCREASE GREEN N-S ; DECREASE E-W GREEN
TO EQUALIZE V/C'S.

Detailed Timings:

	N-S	E-W ARROWS	EBD FLASH	E-W	N-S ARROWS	NBD FLASH
Direction Phase						
Intergreen	4+1	4+0	4+0	4+1	4+0	4+0
Ped. Clr.	17+5			13+5		



Time Plan	Cycle	Offset Ø1	Ø1	Ø2	Ø3	Ø4	Ø5	Ø6
NEW OFF-PEAK	90	54	31	7	X	27	7	X
OLD OFF-PEAK	90	56	27	7	X	31	7	X (TP3)
EXISTING AM	100	52	44	X	X	35	7	X (TP1)
PM	100	54	37	X	10	28	X	7
NIGHT	60	10	26	X	X	24	X	X (TP6)
HOCKEY INBOUND	100	54	37	5X	5/10	28	X	7 (TP5)
OUTBOUND	110	20	54	6	X	24	8	X (TP10)

1990 City of Edmonton

TIMING SHEET

Location WHITEMUD EBD - CALGARY TR. EB

Date NOV 6, 92

Design for

AM

Analysed By C.I.

Approved

Implementation Date Nov. 6/92

Problems.

Recommendations: (Capacity, Coordination)

Detailed Timings:

	EBD	SBD				
Direction / Phase	→	↓				
Intergreen	4+1	4+1				
Ped. Clr.	11+5	10+5				

Time Plan	Cycle	Offset Ø1	Ø1	Ø2	Ø3	Ø4	Ø5	Ø6
TEMP								
AM	100	36	70	20				
EXIST								
AM	100	36	65	25				
PM	100	45	45	45				
OFF	80	65	35	35				
SAT.	90	12	33	47				
NIGHT	70	15	29	31				

1990

City of Edmonton

TIMING SHEET

Location 87 AVE 170 ST

Date AUG 19.92

Design for

Analysed By CK

Approved

Implementation Date SEPT 15/92

Problems

INSUFFICIENT PED CLEARANCE

Recommendations: (Capacity, Coordination)

USE V_{PED} = 1.20 m/s

Detailed Timings:

	Direction	N/S	E/W LT	E/W	N/S LT	NBD	SBD
	Phase	↓↑	↑↓	⇆	⇆	↰	↳
	Intergreen	4+1	4+0	4+2	4+0	4+0	4+0
	Ped Clr	14+5 (NEW) / 12+5 (OLD)		19+6 ← NEW / 17+6 ← OLD			

Time Plan	Cycle	Offset Ø1	Ø1	Ø2	Ø3	Ø4	Ø5	Ø6
NEW								
OFF PK	86	83	25	7	26	5max	X	X
NIGHT	66	42	29	X	26	X	X	X
EXIST								
Am PK	90	54	52	X	27	X	X	X
Pm PK	100	79	42	6	26	7max	X	X
TP9 SAT IN	96	67	32	7	26	7	5max	X
TP19 SAT OUT	96	67	32	7	26	7	X	5max
OLD								
OFF PK	86	83	21	7	24	9max	X	X
NIGHT	66	42	30	X	25	X	X	X

1990

City of Edmonton

TIMING SHEET

Location: ARGYLL RD – 86 ST

Date: MAY 26, 93

Analysed By: CK

Approved: [signature]

Design for: PM peak

Implementation Date: MAY 31/93

Problems: WBLT congested

Recommendations: (Capacity, Coordination)

Detailed Timings:

	ø1	ø2	ø3	ø4	ø5	ø6
Direction	E/W	NB	N/S	WB		
Phase	⇆	↰↑	↓↑	↰↱		
Intergreen	4+1	4+0	4+1	4+0		
Ped. Clr.	12+5		15+5			

	Time Plan	Cycle	Offset ø1	ø1	ø2	ø3	ø4	ø5	ø6
NEW									
	PM	100	4	42	7	15	18		
EXIST									
	AM	100	90	35	7	15	25		
	OFF	80	2	36	7	12	7		
	SAT.	90	82	42	7	12	11		
	NIGHT	70	35	40	X	20	X		
OLD									
	PM	100	4	45	7	15	15		

TIMING SHEET

Location: 82 Ave - 99 street

Date: Dec 21-93

Analysed By: M/C
Approved: [signature]
Implementation Date: June 30/94

Design for

AM, Off Pk, Saturday, (PM)

Problems

Relieve WBLT volumes at 82 Ave-96 street.

Recommendations: (Capacity, Coordination)

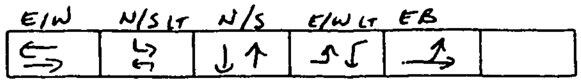
E/W LT phase in AM, Off Peak, Saturday

PM EB Trail phase to become advance phase.

Detailed Timings:

	E/W	N/S LT	N/S	E/W LT	EB	
Direction	E/W	N/S LT	N/S	E/W LT	EB	

Phase



Intergreen		3+1	3+0	3+2	3+0	3+0
Ped. Clr.	15+4		16+5			

	Time Plan	Cycle	Offset Ø1	Ø1	Ø2	Ø3	Ø4	Ø5	Ø6
New	AM	80	48	27	6	26	6	x	
	PM	100	10	~~33~~ 34	6	39	x	6	
	Off	80	77	~~24~~ 25	6	28	6	x	
	Sat	100	18	~~38~~ 39	8	32	6	x	
	Night.	70	34	27	x	34	x	x	

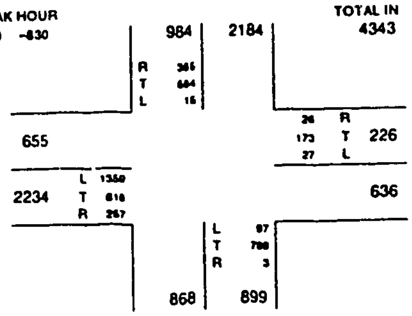
1990 City of Edmonton

PAGE 1 TRANSPORTATION DEPARTMENT - INTERSECTION FLOW ANALYSIS

LOCATION 72 AV & 114 ST DATE 09-MAR-93

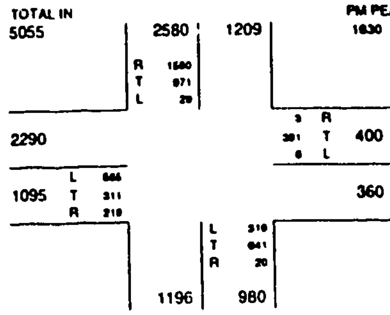
AM PEAK HOUR
730 -830

TOTAL IN
4343



TOTAL IN
5055

PM PEAK HOUR
1630 -1730



	CV	PED
N	50	1
S	27	13
E	7	4
W	54	12
T	147	30

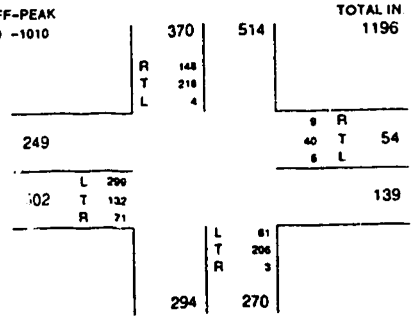
PEAK HOUR VOLUMES

	CV	PED
N	50	0
S	26	6
E	6	3
W	33	8
T	118	20

OFF-PEAK VOLUMES

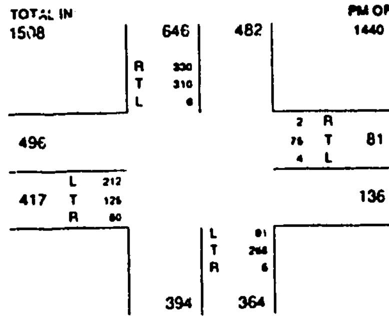
AM OFF-PEAK
940 -1010

TOTAL IN
1196



TOTAL IN
1508

PM OFF-PEAK
1440 -1610



	CV	PED
N	24	0
S	11	0
E	4	0
W	17	0
T	56	0

	CV	PED
N	34	0
S	17	1
E	1	0
W	16	0
T	68	1

COMMENTS

WEATHER: CLEAR +2C

SURVEYED BY: RANDY CARL GRAHAM PROCESSED BY: CHECKED BY:

LOCATION: 82 AVE & 75 STR DATE:1989 05 24 TR120 PAGE: 1

TOTAL IN: 5016

1640 | 1167

R 149
T 1400
L 91

1446

AM PEAK HOUR

720 -820

85 R
1099 T 1268
84 L

L 82
874 T 672
R 120

799

CV PEDS
N 28 15
S 46 1
E 51 5
W 54 7
T 179 28

L 198
T 1000
R 36

1604 | 1234

1484 | 1898

TOTAL IN: 5815

R 195
T 1205
L 84

1163

PM PEAK HOUR

1620 -1720

183 R
791 T 1106
132 L

L 238
1477 T 1070
R 169

1248

L 177
T 1477
R 94

1506 | 1748

CV PEDS
N 34 22
S 41 10
E 33 5
W 37 7
T 145 44

PEAK HOUR VOLUMES

OFF-PEAK VOLUMES

TOTAL IN: 1555

488 | 406

R 75
T 373
L 40

476

AM OFF-PEAK

930 -1000

42 R
324 T 401
35 L

L 57
260 T 169
R 34

231

CV PEDS
N 28 10
S 23 0
E 21 3
W 16 0
T 88 13

L 77
T 307
R 22

442 | 406

521 | 622

TOTAL IN: 2012

R 78
T 392
L 51

446

PM OFF-PEAK

1440 -1510

58 R
293 T 396
45 L

L 117
543 T 354
R 72

435

L 75
T 447
R 30

509 | 552

CV PEDS
N 17 7
S 33 6
E 19 1
W 31 8
T 100 22

COMMENTS:

SURVEYED BY: [illegible handwriting]

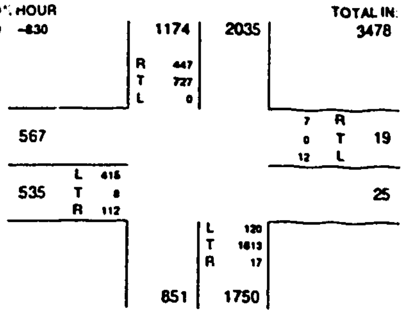
ANALYSIS BY: [illegible handwriting] CHECKED BY: [illegible handwriting]

PAGE 1 TRANSPORTATION DEPARTMENT – I[illegible]N FLOW ANALYSIS

LOCATION 87 AV & 109 ST DATE 15-OCT-91 [illegible]

AM PEAK HOUR 730 -830

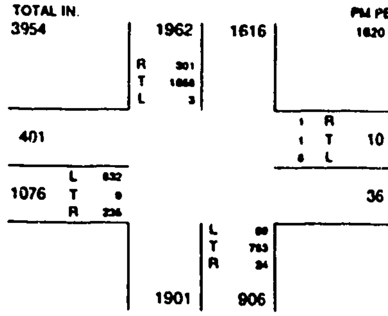
TOTAL IN: 3478



	CV	PED
N	48	3
S	62	99
E	0	48
W	29	26
T	139	176

TOTAL IN: 3954

PM PEAK HOUR 1620 -1720



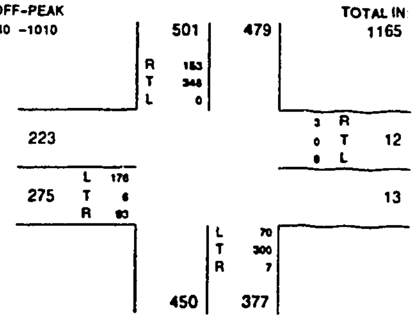
	CV	PED
N	66	0
S	36	120
E	1	33
W	[illegible]	[illegible]
T	127	[illegible]

PEAK HOUR VOLUMES

OFF-PEAK VOLUMES

AM OFF-PEAK 940 -1010

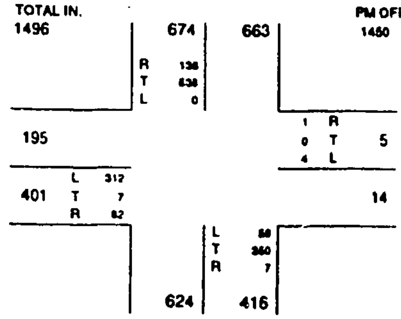
TOTAL IN: 1165



	CV	PED
N	19	0
S	9	31
E	3	11
W	11	18
T	42	60

TOTAL IN: 1496

PM OFF-PEAK 1450 -1520



	CV	PED
N	23	0
S	18	45
E	0	11
W	18	21
T	59	77

COMMENTS

SURVEYED BY *Field Staff* PROCESSED BY *[illegible]* CHECKED BY *[illegible]*

LOCATION: 63 AVE & 99 STR   DATE: 1988 06 08   TR63   PAGE: 1

TOTAL IN: 4284

1113 : 1045

R 218
T 731
L 164

196 R
838 T 1202
168 L

1139

AM PEAK HOUR

730 -830

L 238
1208 T 745
R 225

	CV	PEDS
N	74	8
S	49	9
E	73	6
W	58	4
T	254	27

L 83
T 611
R 67

1124 : 761

1440 : 1333

TOTAL IN: 5568

R 368
T 838
L 234

1766

187 R
1171 T 1505
147 L

PM PEAK HOUR

1620 -1720

L 358
1443 T 915
R 170

1314

L 227
T 788
R 165

1155 : 1180

	CV	PEDS
N	63	4
S	63	7
E	42	6
W	46	3
T	214	20

PEAK HOUR VOLUMES

OFF-PEAK VOLUMES

TOTAL IN: 1551

424 : 396

R 86
T 251
L 87

68 R
280 T 405
57 L

447

AM OFF-PEAK

940 -1010

L 86
359 T 223
R 50

350

	CV	PEDS
N	42	4
S	38	1
E	37	3
W	24	0
T	141	8

L 81
T 242
R 40

358 : 363

589 : 467

TOTAL IN: 2028

R 121
T 371
L 97

555

75 R
367 T 491
54 L

PM OFF-PEAK

1440 -1510

L 126
532 T 351
R 55

526

L 72
T 266
R 78

480 : 416

	CV	PEDS
N	55	15
S	35	1
E	45	5
W	30	4
T	165	25

COMMENTS:

SURVEYED BY: Roni, Vesa, Marty, Fraser

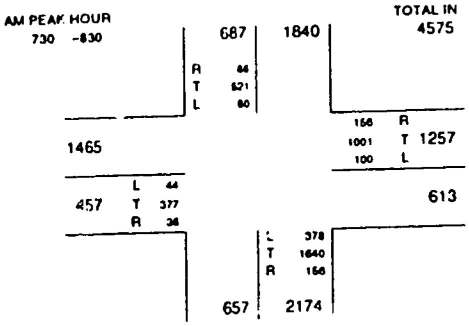
ANALYSIS BY: JQ   CHECKED BY: D.L.

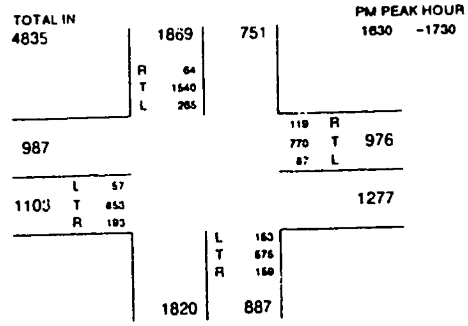
PAGE 1

TRANSPORTATION DEPARTMENT - INTERSECTION FLOW ANALYSIS

LOCATION 82 AV & 109 ST

DATE 10-MAR-93 INT938



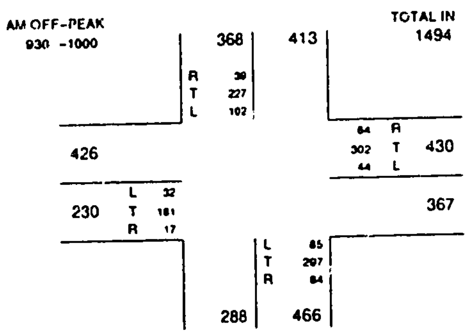


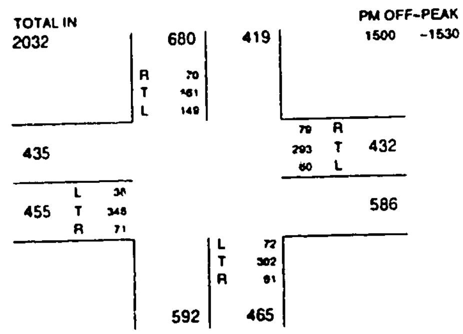
	CV	PED
N	32	122
S	62	61
E	53	166
W	35	44
T	172	373

	CV	PED
N	44	117
S	27	133
E	23	86
W	26	134
T	119	470

PEAK HOUR VOLUMES

OFF-PEAK VOLUMES





	CV	PED
	19	57
	15	
E	[illegible]	
W	12	44
T	68	167

	CV	PED
N	18	66
S	11	73
E	18	57
W	16	69
	63	265

COMMENTS

WEATHER CLEAR +1C

SURVEYED BY: RANDY CARL GRAHAM

PROCESSED BY

CHECKED BY:

LOCATION: 82 AVE & 75 STR   DATE:1989 05 24   TR120   PAGE: 1

```
 TOTAL IN:          |  1640 |   1167 |                 |          |  1484 |   1898 |    TOTAL IN:
   5016             |       |        |                 |          |       |        |        5815
                    | R  149 |       |                 |          | R  195 |       |
                    | T 1400 |       |                 |          | T 1205 |       |
                    | L   91 |       |                 |          | L   84 |       |
  ------------------+                +---------------  |  --------+                +-------------
                                       85   R          |                             183  R
   1446                              1099   T   1268   |  1163                       791  T   1106
                     AM PEAK HOUR      84   L          |             PM PEAK HOUR    132  L
  --------------                     ----------------  |  -------------              -------------
          L   82     720 -820                          |       L  238   1620 -1720
    874   T  672                                 799   |  1477 T 1070                          1248
          R  120                                       |       R  169
  ------------------+                +---------------  |  --------+                +-------------
       CV  PEDS     |        | L   198 |               |          |      | L   177 |    CV  PEDS
 N     28   15      |        | T  1000 |               |          |      | T  1477 |  N  34   22
 S     46    1      |        | R    ?? |               |          |      | R    94 |  S  41   10
 E     51    5      |        |         |               |          |      |         |  E  33    5
 W     54    7      |  1604  |    1234 |               |          | 1506 |    1748 |  W  37    7
 T    179   28                                                                        T 145   44
```

PEAK HOUR VOLUMES

OFF-PEAK VOLUMES

```
 TOTAL IN:          |   488 |    406 |                 |          |   521 |    622 |    TOTAL IN:
   1555             |       |        |                 |          |       |        |        2012
                    | R   75 |       |                 |          | R   78 |       |
                    | T  373 |       |                 |          | T  392 |       |
                    | L   40 |       |                 |          | L   51 |       |
  ------------------+                +---------------  |  --------+                +-------------
                                       42   R          |                              58  R
   476                                324   T    401   |  446                        293  T    396
                     AM OFF-PEAK       35   L          |             PM OFF-PEAK      45  L
  --------------                     ----------------  |  -------------              -------------
          L   57     930 -1000                         |       L  117   1440 -1510
    260   T  169                                 231   |   543 T  354                           435
          R   34                                       |       R   72
  ------------------+                +---------------  |  --------+                +-------------
       CV  PEDS     |        | L    77 |               |          |      | L    75 |    CV  PEDS
 N     28   10      |        | T   307 |               |          |      | T   447 |  N  17    7
 S     23    0      |        | R    22 |               |          |      | R    30 |  S  33    6
 E     21    3      |        |         |               |          |      |         |  E  19    1
 W     16    0      |   442  |     406 |               |          |  509 |         |  W  31    8
 T     88   13                                                                        T 100   22
```

COMMENTS: ____________________

SURVEYED BY: [illegible]

ANALYSIS BY: [illegible]   CHECKED BY: [illegible]

LOCATION: WHIT DRIVE & CALG TRASD   DATE:1990 01 23   TR51   PAGE: 1

PEAK HOUR VOLUMES

AM PEAK HOUR 730 -830

TOTAL IN: 3060

North leg: 1109 in; R 196, T 913, L 0; 0 out

East leg: 1786 in; 0, R; 1786 T; 165 L; T 1951

West leg: 1982; L 0, T 0, R 0; 0

South leg: L 0, T 0, R 0; 1076; 0; 0

	CV	PEDS
N	68	8
S	0	0
E	178	1
W	0	0
T	246	9

PM PEAK HOUR 1630 -1730

TOTAL IN: 6015

North leg: 3302 in; R 669, T 2633, L 0; 0 out

East leg: 0, R; 2390 T 2713; 323 L

West leg: 3059; L 0, T 0, R 0; 0

South leg: L 0, T 0, R 0; 2956; 0; 0

	CV	PEDS
N	44	11
S	0	0
E	95	5
W	0	0
T	139	16

OFF-PEAK VOLUMES

AM OFF-PEAK 940 -1010

TOTAL IN: 1124

North leg: 565 in; R 118, T 387, L 0; 0 out

East leg: 0 R; 537 T 619; 87 L

West leg: 655; L 0, T 0, R 0; 0

South leg: L 0, T 0, R 0; 469; 0; 0

	CV	PEDS
N	28	1
S	0	0
E	83	1
W	0	0
T	111	2

PM OFF-PEAK 1440 -1510

TOTAL IN: 1796

North leg: 1059 in; R 200, T 859, L 0; 0 out

East leg: 0 R; 623 T 737; 114 L

West leg: 823; L 0, T 0, R 0; 0

South leg: L 0, T 0, R 0; 973; 0; 0

	CV	PEDS
N	48	3
S	0	0
E	72	0
W	0	0
T	120	3

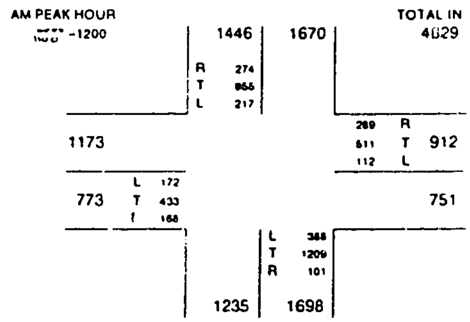
COMMENTS:

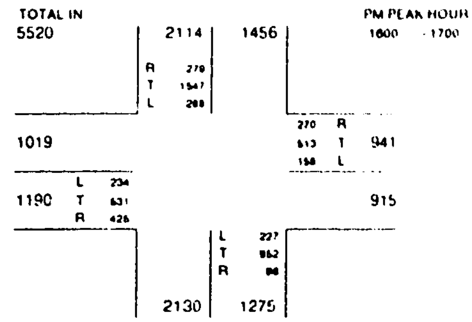
SURVEYED BY: Del & Bill

ANALYSIS BY: SHAV ?   CHECKED BY: [illegible]

TRANSPORTATION DEPARTMENT - INTERSECTION FLOW ANALYSIS

LOCATION 87 AV & 170 ST DATE 12-JUN-93 INTBKD



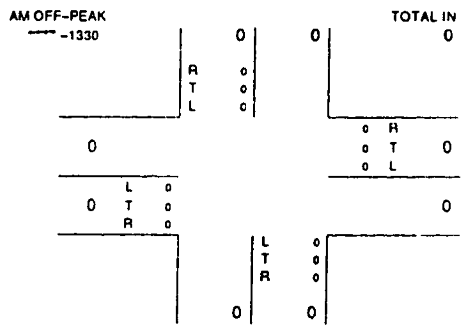


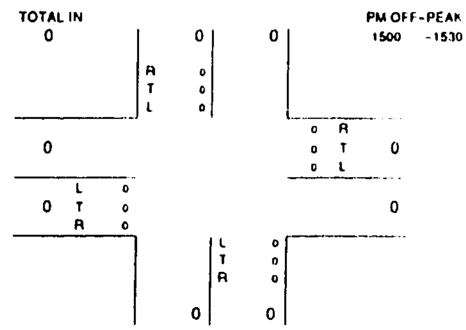
	CV	PED
N	42	31
S	60	4
E	19	10
W	21	2
T	142	

	CV	PED
N	28	45
S	26	13
E	16	16
W	23	18
T	92	92

PEAK HOUR VOLUMES

OFF-PEAK VOLUMES





	CV	PED
N	0	0
S	0	0
E	0	0
W	0	0
T	0	0

	CV	PED
N	0	0
S	0	0
E	0	0
W	0	0
T	0	0

COMMENTS *Saturday count only — surveyed 10^00 - 12^00 and 16^00 - 18^00*

WEATHER: OVERCAST +15C

SURVEYED BY: SARAH KAREN BRIAN ANGIE   PROCESSED BY: *[signature]*   CHECKED BY *[signature]*

```
LOCATION:  ARGY ROA  &  086  STR                 DATE:1989 10 16   1R38       PAGE:  1

TOTAL IN:            :  205 :    92 :             :  131 :    210 :   TOTAL IN:
  3262               :      :       :             :      :        :     3909
                     : R 39 :       :             : R 19 :        :
                     : T 107:       :             : T 103:        :
                     : L 59 :       :             : L 59 :        :

                                25  R                                  87  R
  1323                        1202  T  1640   1156                    986  T  1531
              AM PEAK HOUR     412  L                PM PEAK HOUR     458  L

         L    5     720 -820                        L   15   1620 -1720
  786    T  645                    1192      1509   T 1388                1876
         R  136                                     R  106

     CV  PEDS                : L  82 :                   : L  151 :     CV  PEDS
N     6    0                 : T  61 :                   : T  108 :  N  10    0
S    60    8                 : R 488 :                   : R  429 :  S  41    4
E    75    8                 :       :                   :        :  E  74    3
W    42    1           655   :   631                567  :    688 :  W  47    0
T   183   17                                                         T 172    7

PEAK HOUR VOLUMES

OFF-PEAK VOLUMES

TOTAL IN:            :  41 :    35 :              :  61 :     53 :   TOTAL IN:
  994                :     :       :              :     :        :     1361
                     : R 6 :       :              : R 11:        :
                     : T 23:       :              : T 29:        :
                     : L 12:       :              : L 21:        :

                                10  R                                  24  R
  375                          312  T  418     493                    387  T  561
              AM OFF-PEAK       96  L                PM OFF-PEAK      150  L

         L    6     940 -1010                       L   10   1430 -1500
  356    T  301                    418        485   T  401                562
         R   49                                     R   74

     CV  PEDS                : L  57 :                   : L   95 :     CV  PEDS
N     3    0                 : T  17 :                   : T   19 :  N   5    0
S    19    0                 : R 105 :                   : R  140 :  S  36    1
E    36    0                 :       :                   :        :  E  55    2
W    29    0           168   :   179 :              253  :    254 :  W  36    0
T    87    0                                                         T 132    3

COMMENTS:

SURVEYED BY: Vera Nuck 11321
ANALYSIS BY: LOJ                         CHECKED BY: GJA
```

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LOCATION: 82 AVE & 99 STR DATE: 1989 05 19 TR120 PAGE: 1

PEAK HOUR VOLUMES

AM PEAK HOUR 730 -830

```
TOTAL IN:          |   978 |   1050 |
  3729             |       |        |
                   | R  62 |        |
                   | T 834 |        |
                   | L 102 |        |
 ------------->                     <-----------
                                     72  R
  1101                              905  T   977
                                      0  L
 -------------                      ------------
       L   58      730 -830
  678  T  562                                684
       R   58
 ------------->                     <-----------
    CV  PEDS      |        | L  134 |
 N  58   28       |        | T  920 |
 S  44   47       |        | R   22 |
 E  36   27       |        |        |
 W  37   49       |    892 |   1076 |
 T  175  151
```

PM PEAK HOUR 1620 -1720

```
                   |  1334 |   1066 |    TOTAL IN:
                   |       |        |         5041
                   | R 120 |        |
                   | T 1052|        |
                   | L 16. .        |
 ------------->                     <-----------
                                     134  R
  1269                               987  T   1121
                                       0  L
 -------------                      ------------
       L  119      1620 -1720
 1519  T 1262                                1516
       R  138
 ------------->                     <-----------
                  |        | L  162 |     CV  PEDS
                  |        | T  813 |  N  65   47
                  |        | R   92 |  S  50   75
                  |        |        |  E  20   58
                  |   1190 |   1067 |  W  39   52
                                       T  174  232
```

OFF-PEAK VOLUMES

AM OFF-PEAK 940 -1010

```
TOTAL IN:          |   330 |    286 |
  1347             |       |        |
                   | R  44 |        |
                   | T 237 |        |
                   | L  49 |        |
 ------------->                     <-----------
                                     27  R
  449                               335  T   362
                                      0  L
 -------------                      ------------
       L   36      940 -1010
  340  T  259                                330
       R   45
 ------------->                     <-----------
    CV  PEDS      |        | L   70 |
 N  36    8       |        | T  223 |
 S  32   10       |        | R   22 |
 E  16    7       |        |        |
 W  23   12       |    282 |    315 |
 T  107  37
```

PM OFF-PEAK 1440 -1510

```
                   |   565 |    389 |    TOTAL IN:
                   |       |        |         2045
                   | R  75 |        |
                   | T 425 |        |
                   | L  65 |        |
 ------------->                     <-----------
                                     33  R
  579                               417  T   450
                                      0  L
 -------------                      ------------
       L   57      1440 -1510
  611  T  476                                574
       R   78
 ------------->                     <-----------
                  |        | L   87 |     CV  PEDS
                  |        | T  299 |  N  61   59
                  |        | R   33 |  S  32   35
                  |        |        |  E  20   28
                  |    503 |    419 |  W  42   34
                                       T  155  156
```

COMMENTS: – WBD left turns not permitted but 3 made in am peak, 1 in pm peak

- [illegible] (rain, cold, poor visibility)

SURVEYED BY: [illegible]

ANALYSIS BY: [illegible] CHECKED BY: [illegible]

Appendix B

Table B-3.1 Arrival Data Analysis Spreadsheet (Sample - Survey No. 2)

Arrivals	Observed				Poisson				Sum Squares (* 10^4)	Chi-Square	Difference
	Number	Cumulative	Frequency	Cumulative	Number	Cumulative	Frequency	Cumulative			
0	0	0	0.000	0.000	0.0	0.0	0.000	0.000			0.000
1	0	0	0.000	0.000	0.0	0.0	0.000	0.000			0.000
2	0	0	0.000	0.000	0.0	0.0	0.000	0.000			0.000
3	0	0	0.000	0.000	0.0	0.0	0.000	0.000	0.00		0.000
4	0	0	0.000	0.000	0.1	0.1	0.001	0.001	0.01		0.001
5	0	0	0.000	0.000	0.2	0.3	0.003	0.004	0.09		0.004
6	2	2	0.028	0.028	0.4	0.7	0.006	0.010	4.74		0.016
7	0	2	0.000	0.028	0.9	1.7	0.013	0.024	1.69		0.004
8	0	2	0.000	0.028	1.7	3.4	0.024	0.048	5.76		0.020
9	4	6	0.056	0.083	2.8	6.2	0.039	0.087	2.74	0.006	0.004
10	2	8	0.028	0.111	4.1	10.3	0.057	0.144	8.54		0.033
11	4	12	0.056	0.167	5.4	15.7	0.075	0.219	3.78	1.289	0.052
12	8	20	0.111	0.278	6.6	22.3	0.091	0.310	4.04	0.321	0.032
13	11	31	0.153	0.431	7.3	29.5	[illegible]	0.411	26.81	1.914	0.020
14	12	43	0.167	0.597	7.6	37.2	[illegible]	0.516	38.03	2.608	0.081
15	5	48	0.069	0.667	7.3	44.5	[illegible]	[illegible]	10.60	0.746	0.049
16	5	53	0.069	0.736	6.6	[illegible]	0.092	[illegible]	5.09	0.396	0.026
17	4	57	0.056	0.792	5.7	56.9	[illegible]	[illegible]	5.50	0.502	0.003
18	4	61	0.056	0.847	4.5	61.4	0.06	[illegible]	0.55	0.500	0.005
19	2	63	0.028	0.875	3.5	64.9	[illegible]	[illegible]	4.09		0.026
20	3	66	0.042	0.917	2.5	67.4	[illegible]	[illegible]	0.44	0.496	[illegible]
21	2	68	0.028	0.944	1.7	69.1	0.024	0.960	0.14		0.016
22	2	70	0.028	0.972	1.2	70.3	0.016	0.976	1.39		[illegible]
23	1	71	0.014	0.986	0.7	71.0	0.010	0.986	0.15		0.000
24	1	72	0.014	1.000	[illegible]	71.4	0.006	0.992	0.62		0.008
25	0	72	0.000	1.000	0.3	71.7	0.004	0.996	0.16		0.004
26	0	72	0.000	1.000	0.1	71.8	0.002	0.998	0.04		0.002
27	0	72	0.000	1.000	0.1	71.9	0.001	0.999	0.01		0.001
28	0	72	0.000	1.000	0.1	72.0	0.001	0.999	0.01		0.001
29	0	72	0.000	1.000	0.0	72.0	0.000	1.000	0.00		0.000
30	0	72	0.000	1.000	0.0	72.0	0.000	1.000			0.000
									$\Sigma = 125.0$ $\mu = 4.63$	$\Sigma = 8.779$ $\nu = 10$	Max = 0.081 n = 72

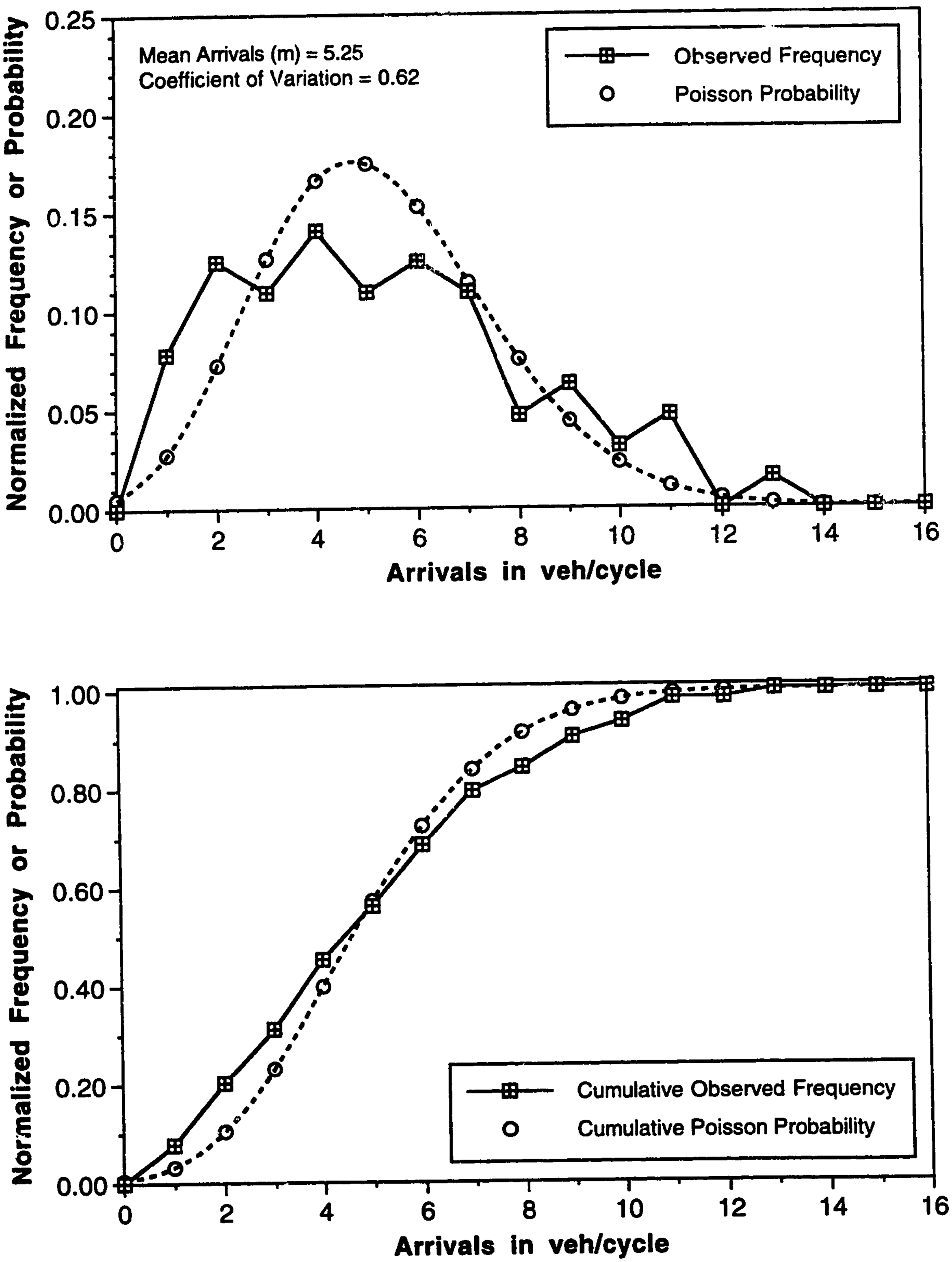
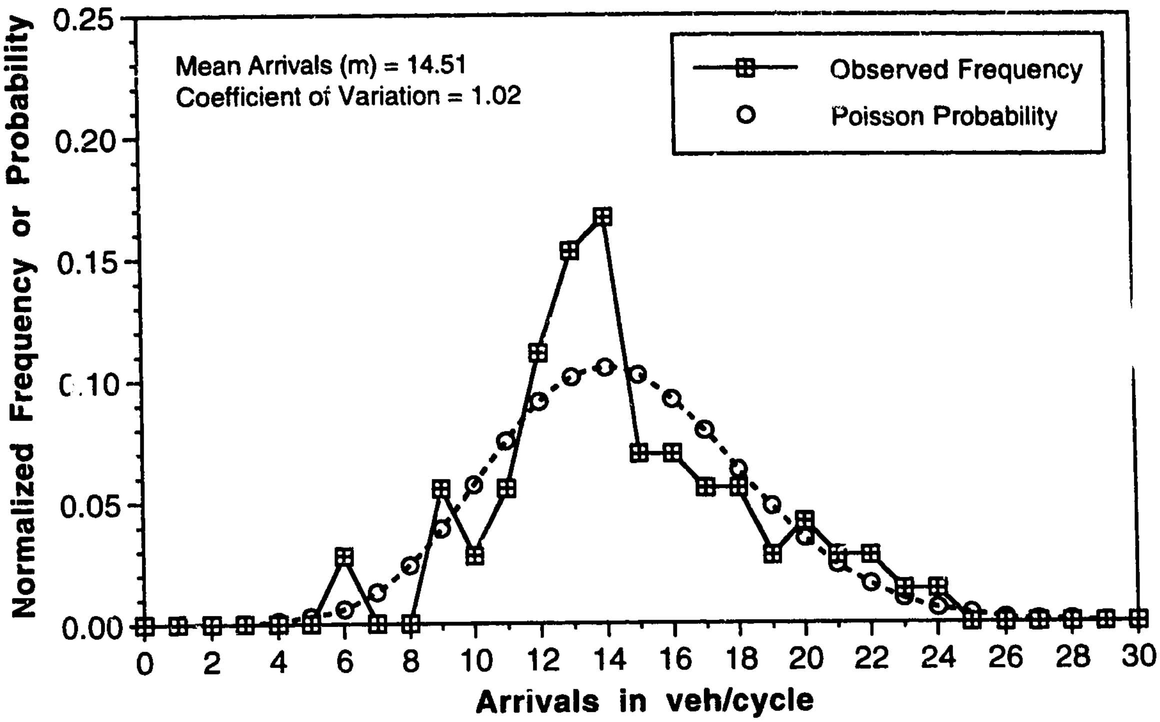


Figure B-3.1 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 1



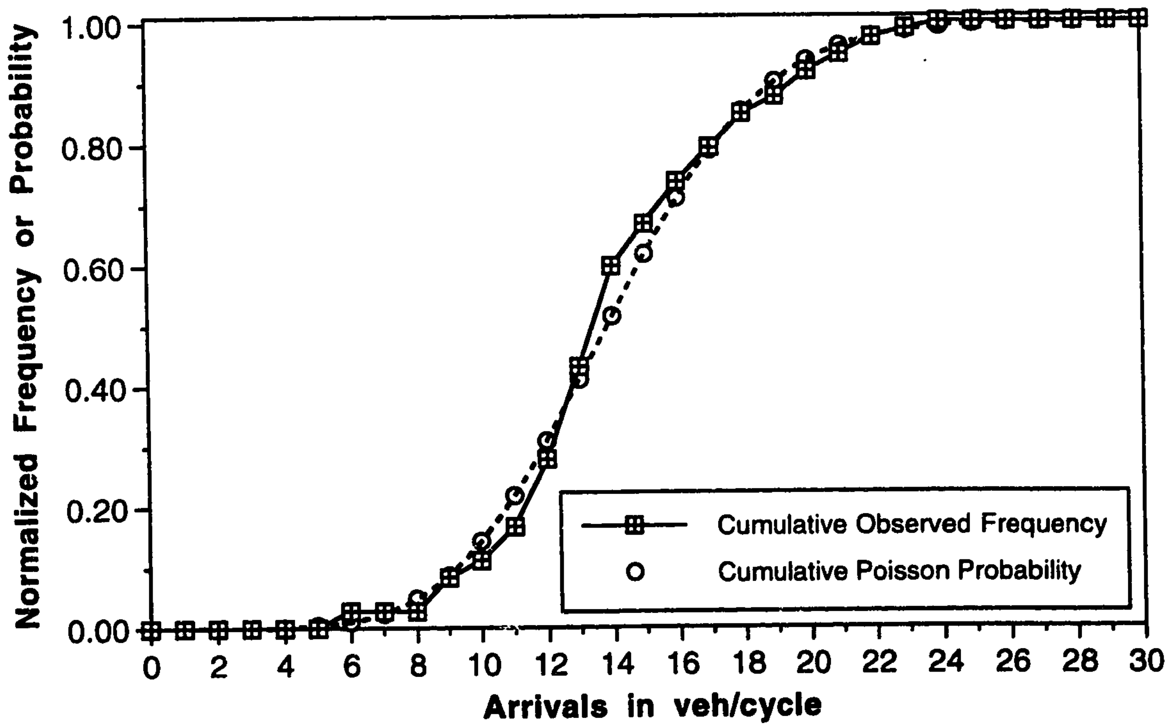
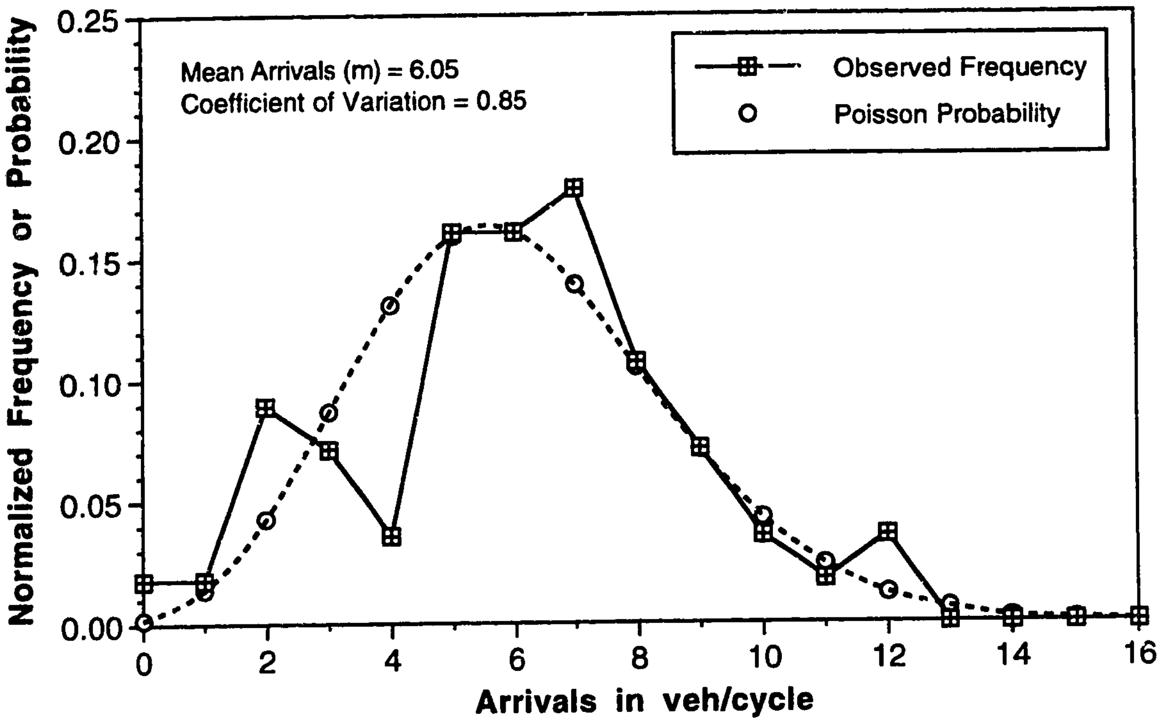


Figure B-3.2 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 2



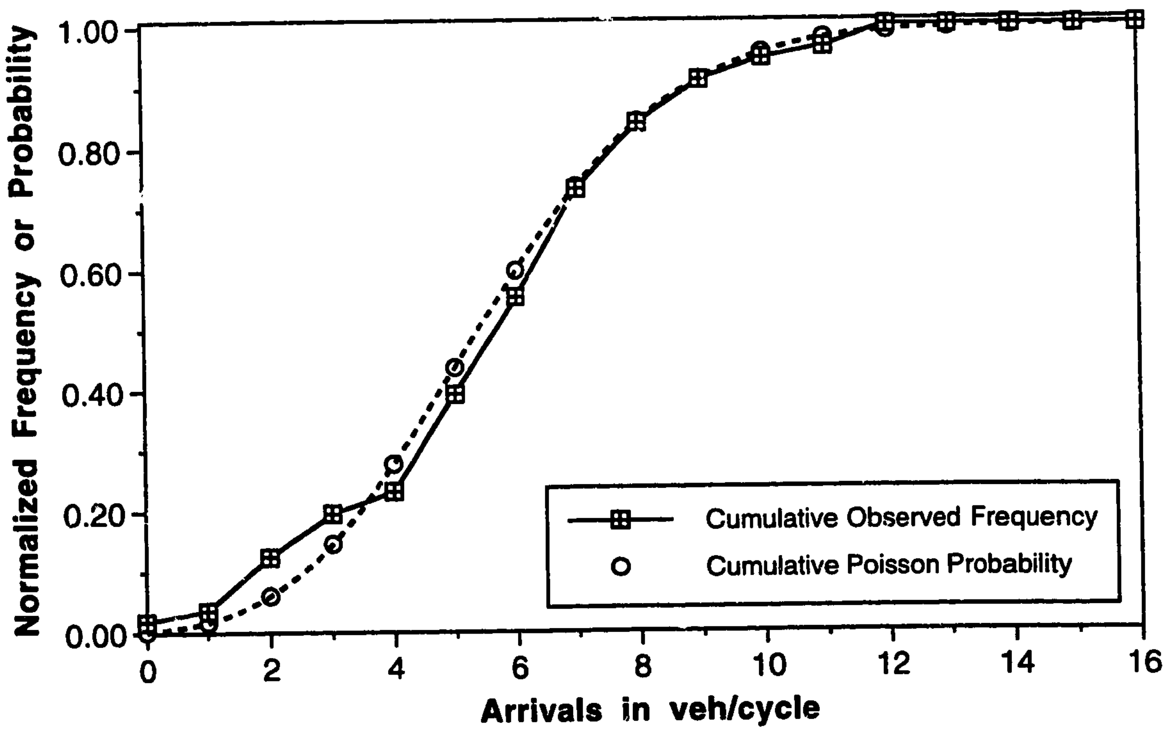


Figure B-3.3 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 3

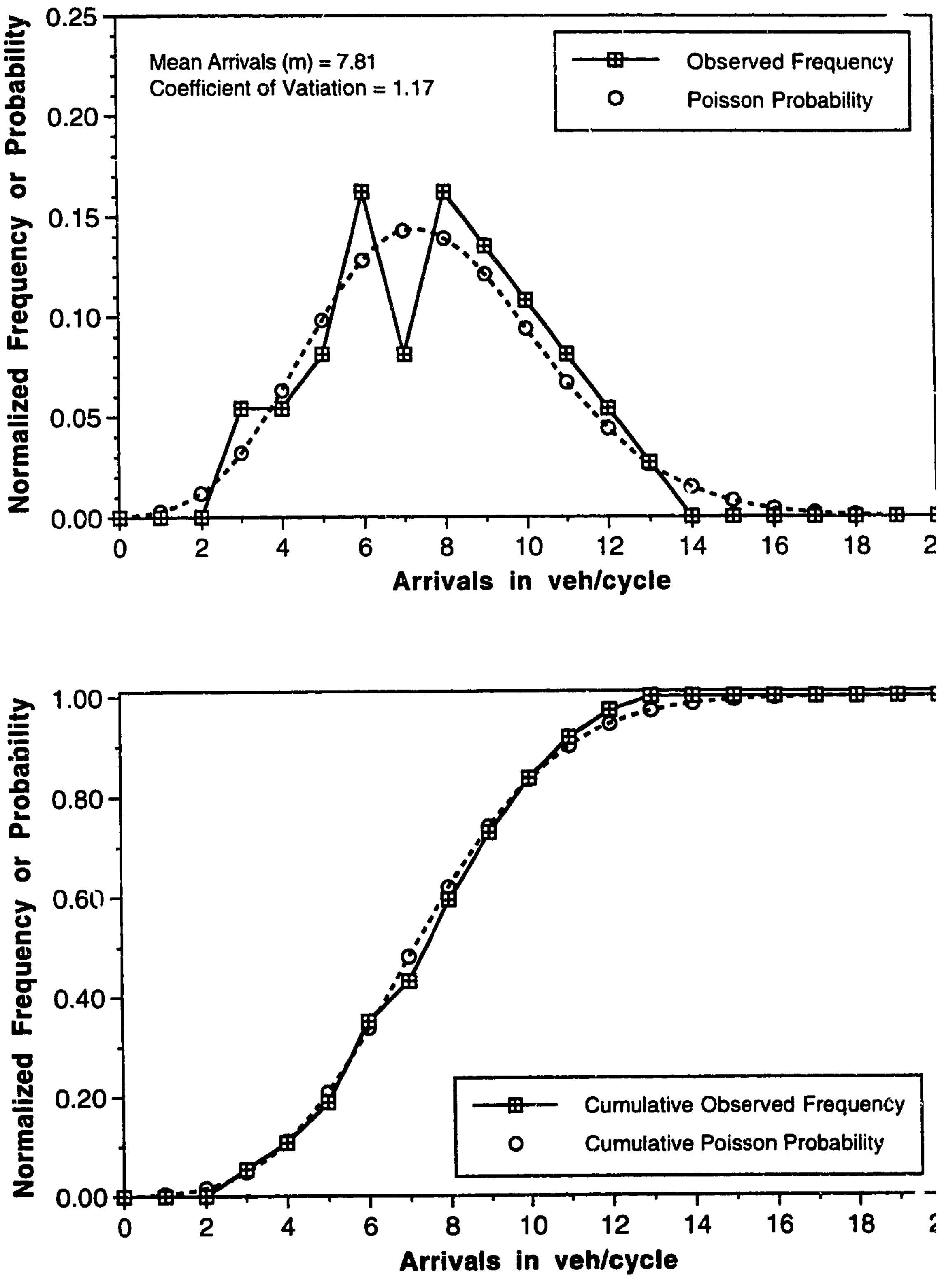
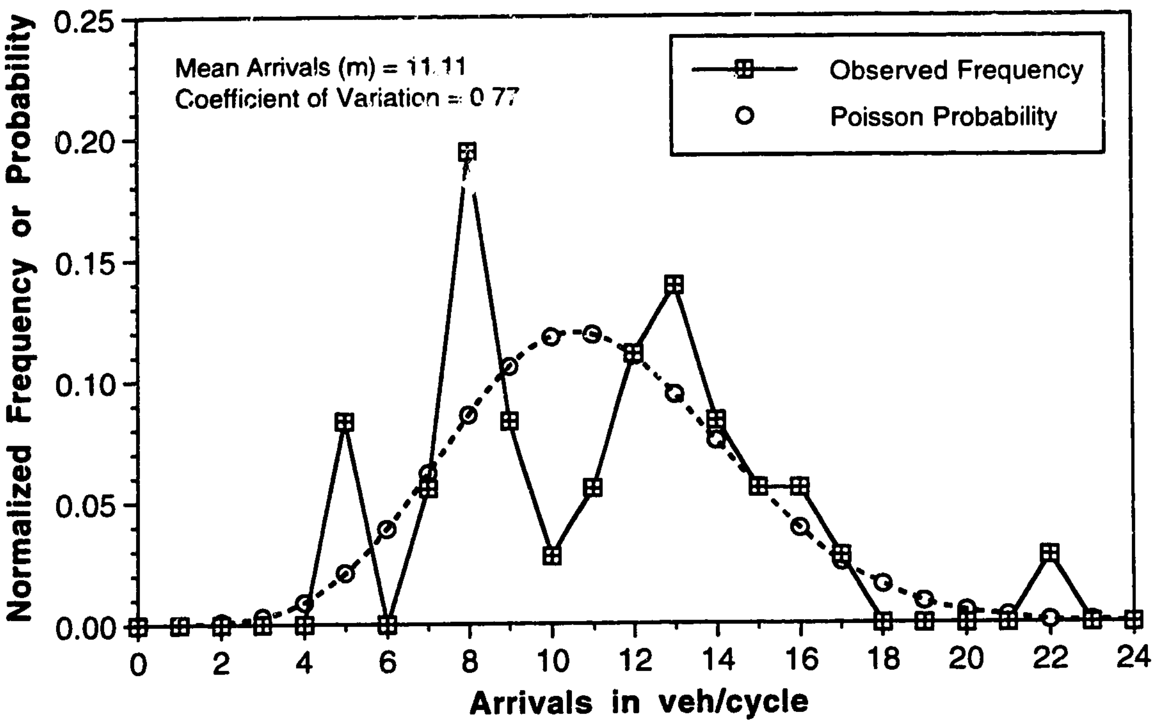


Figure B-3.4 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 4



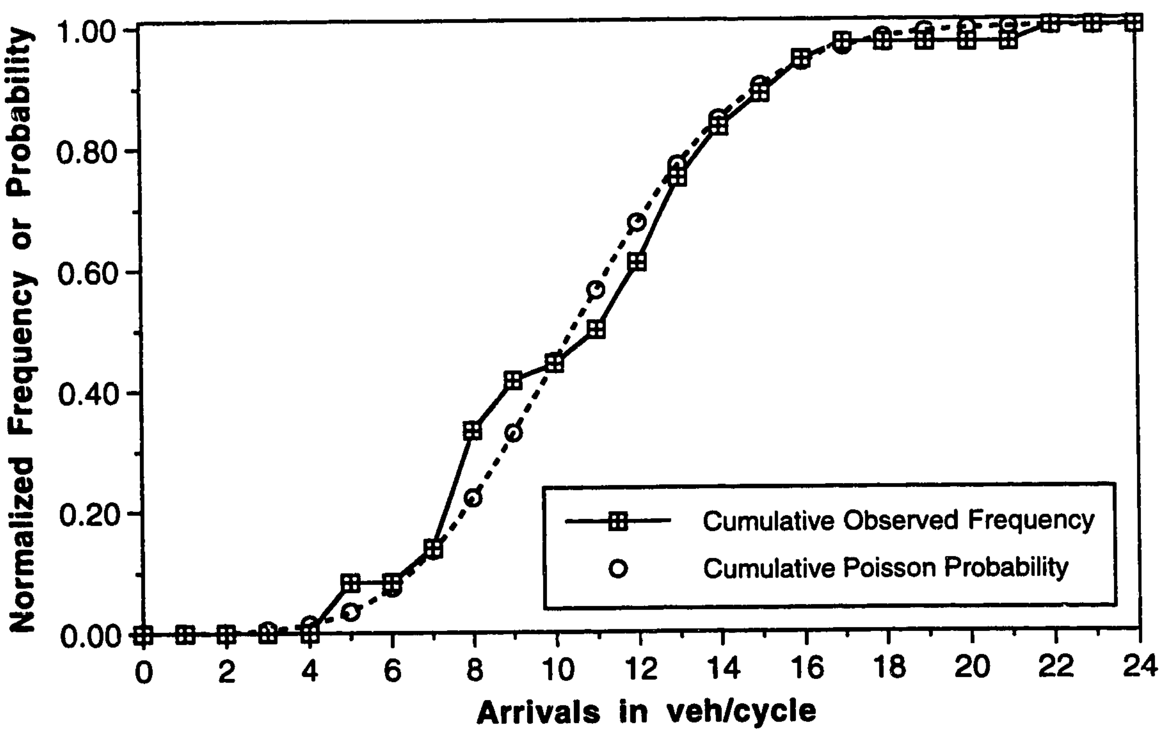
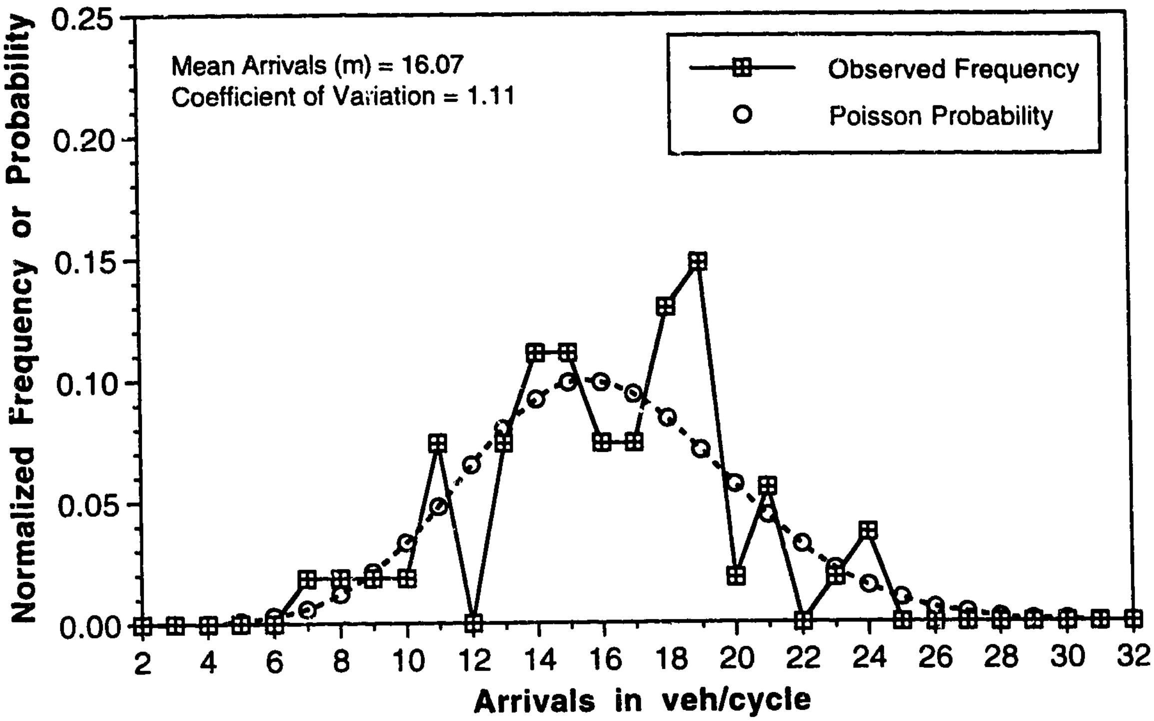


Figure B-3.5 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 6



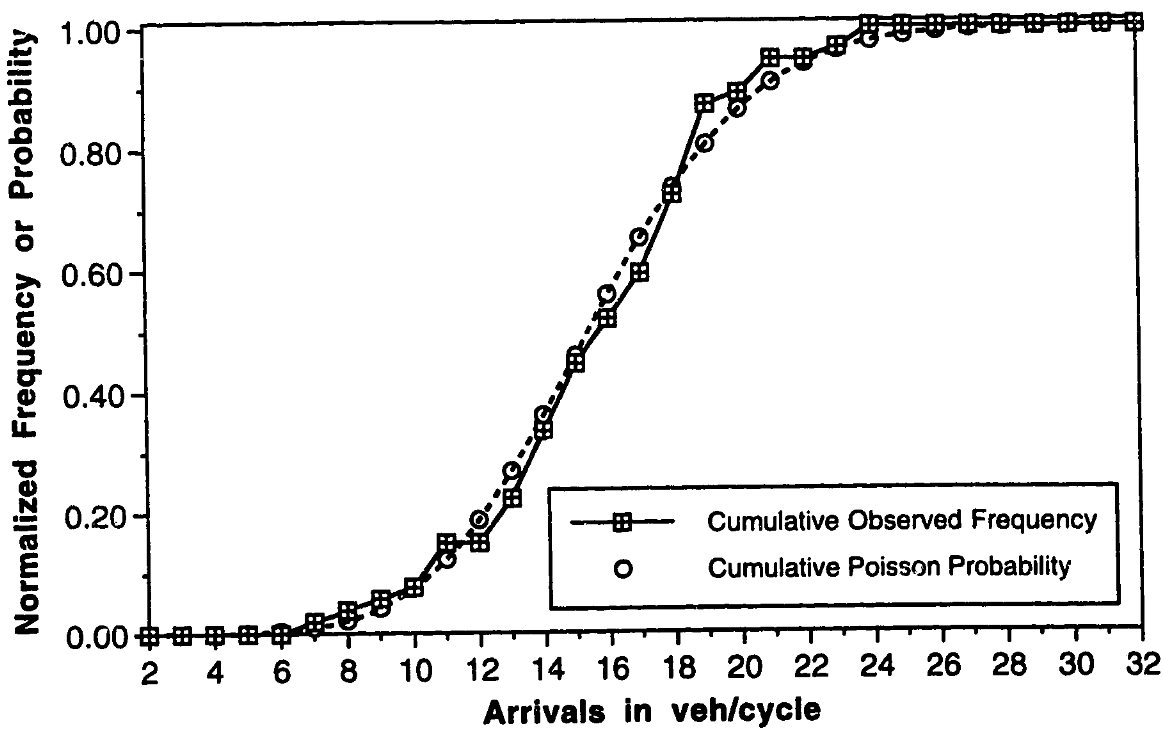
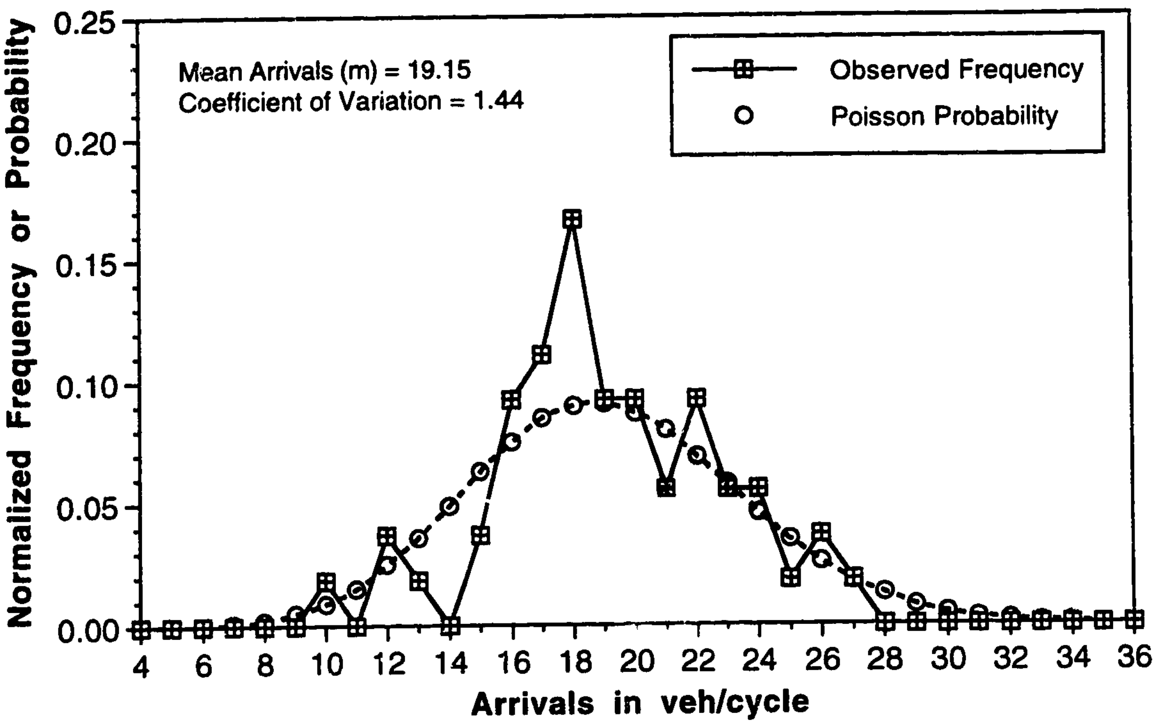


Figure B-3.6 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 7



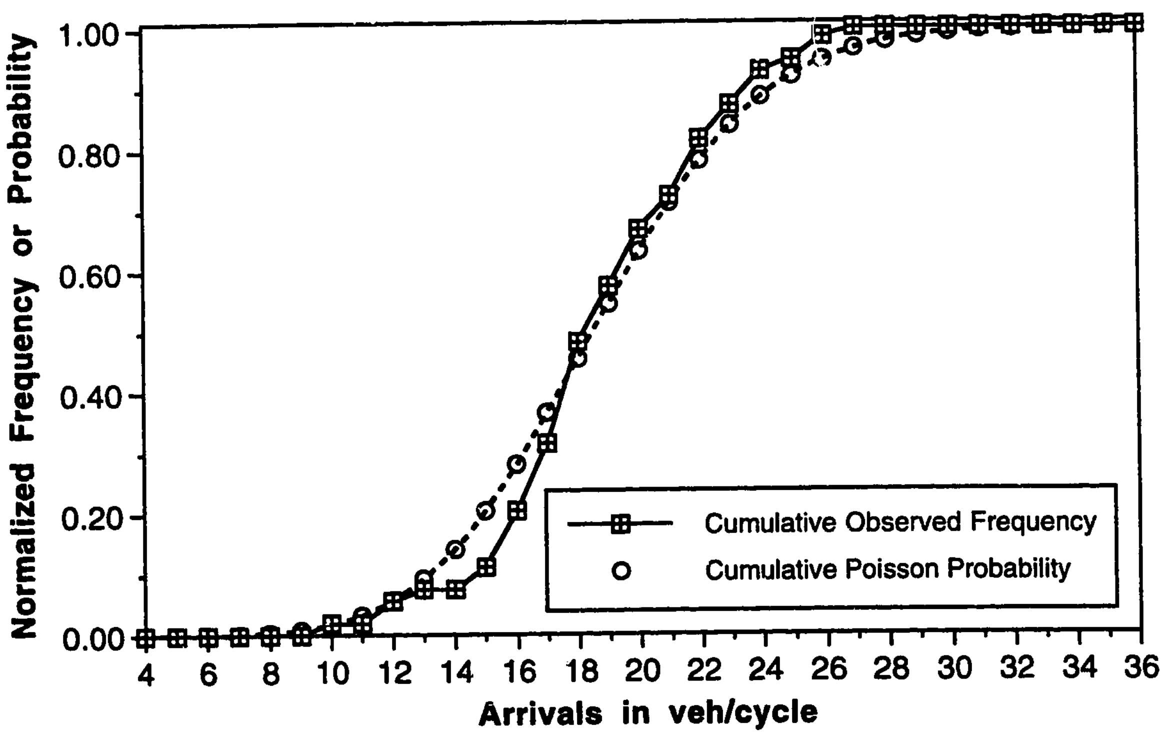
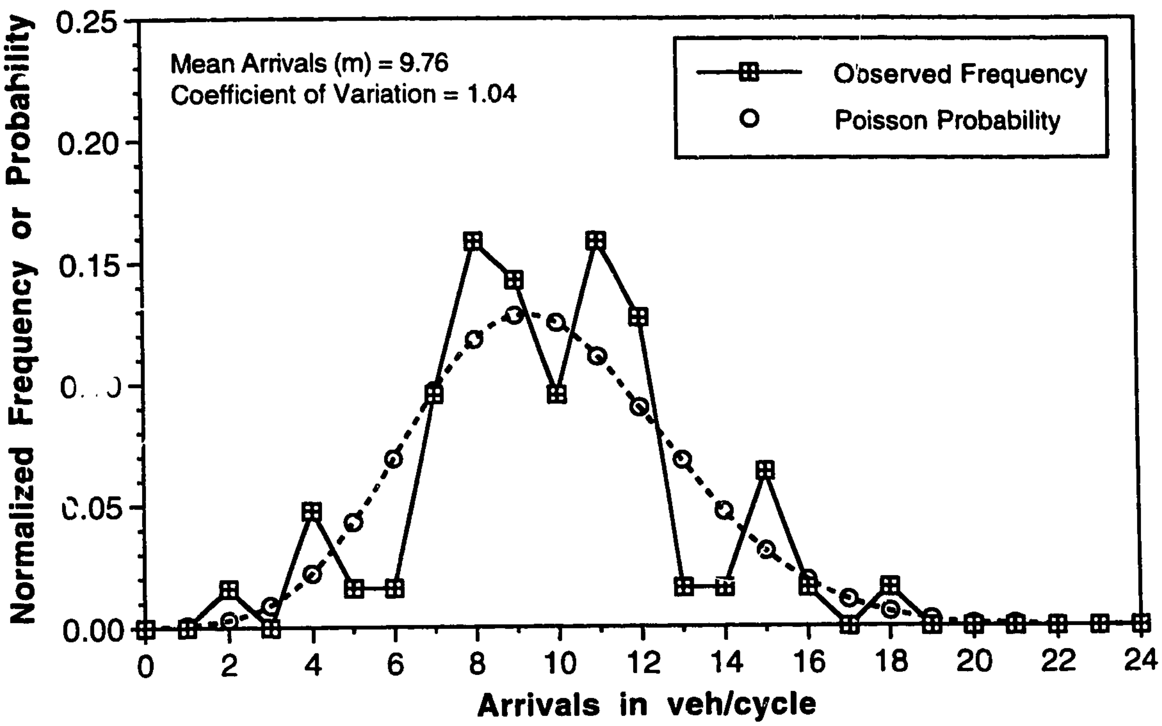


Figure B-3.7 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 8



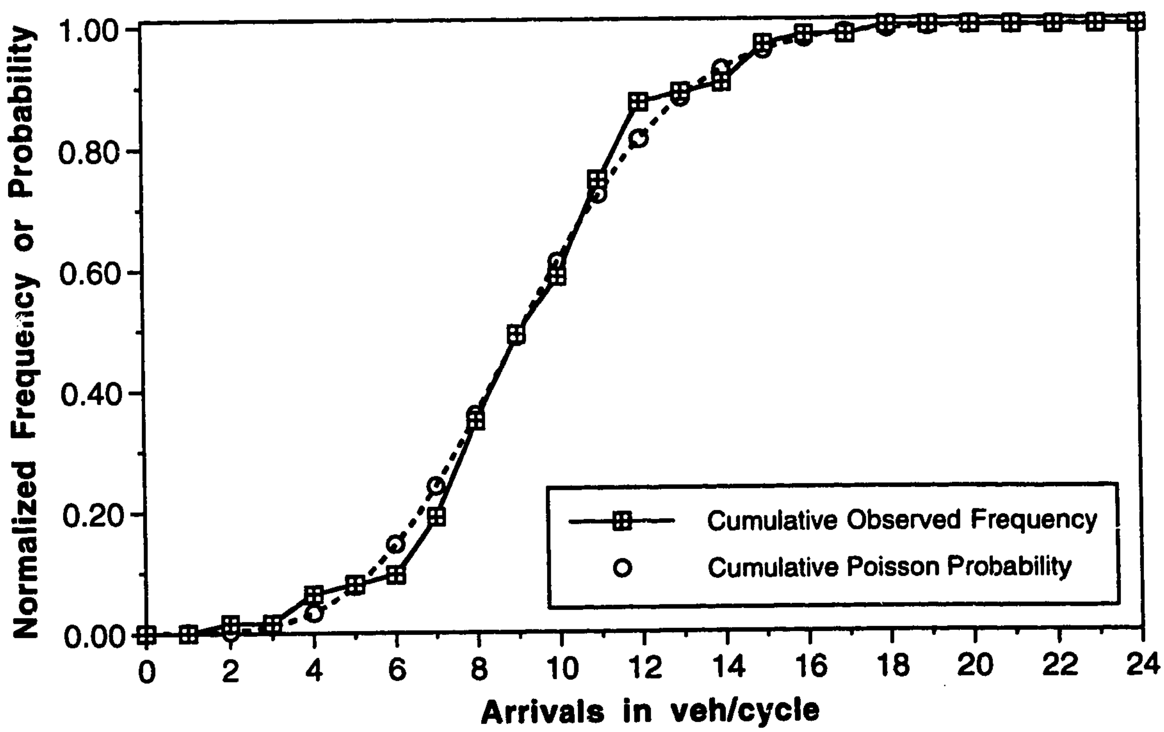
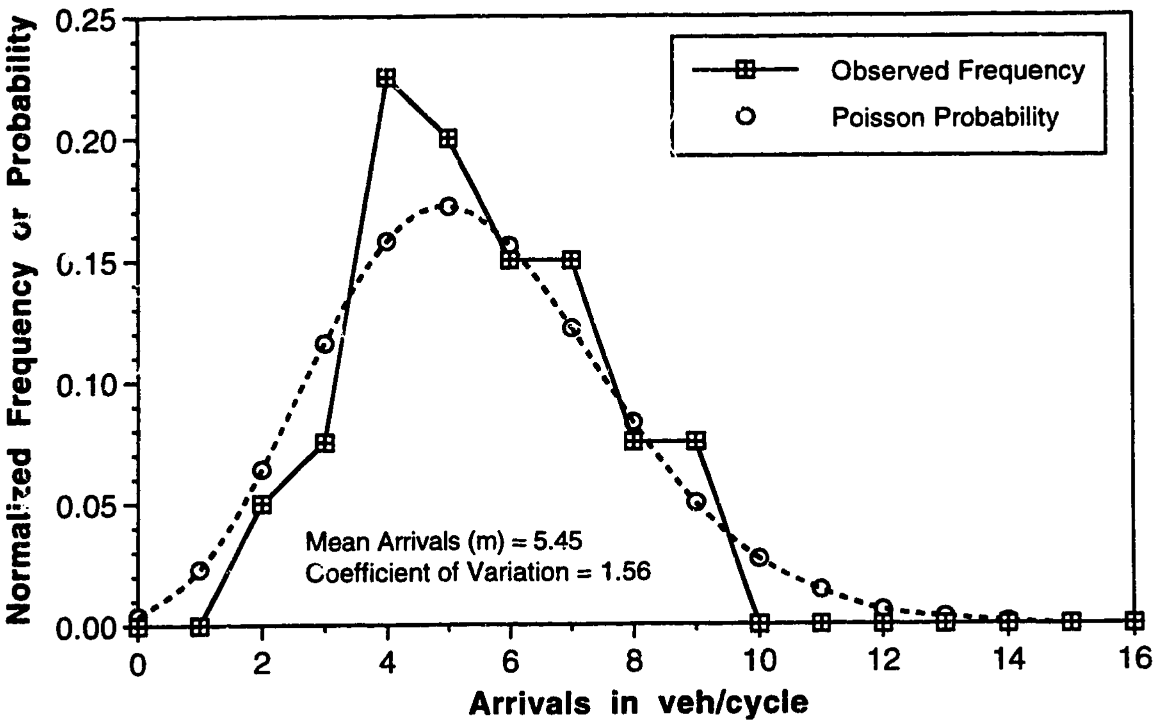


Figure B-3.8 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 9



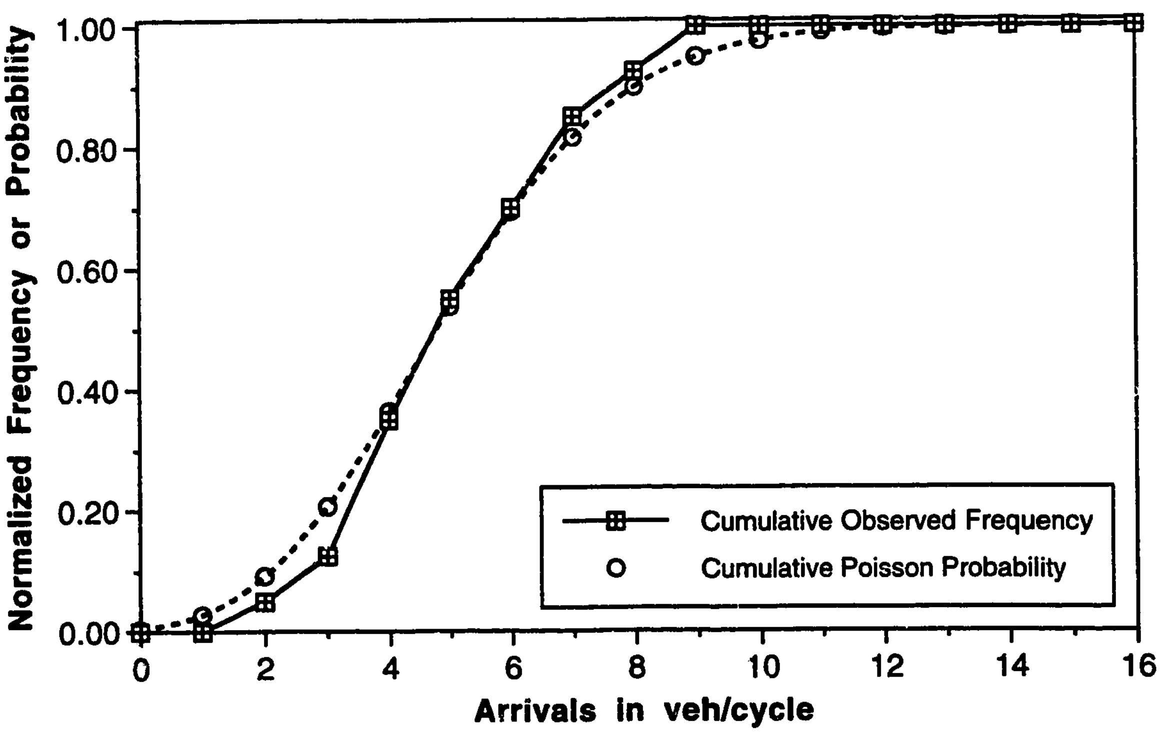


Figure B-3.9 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 10

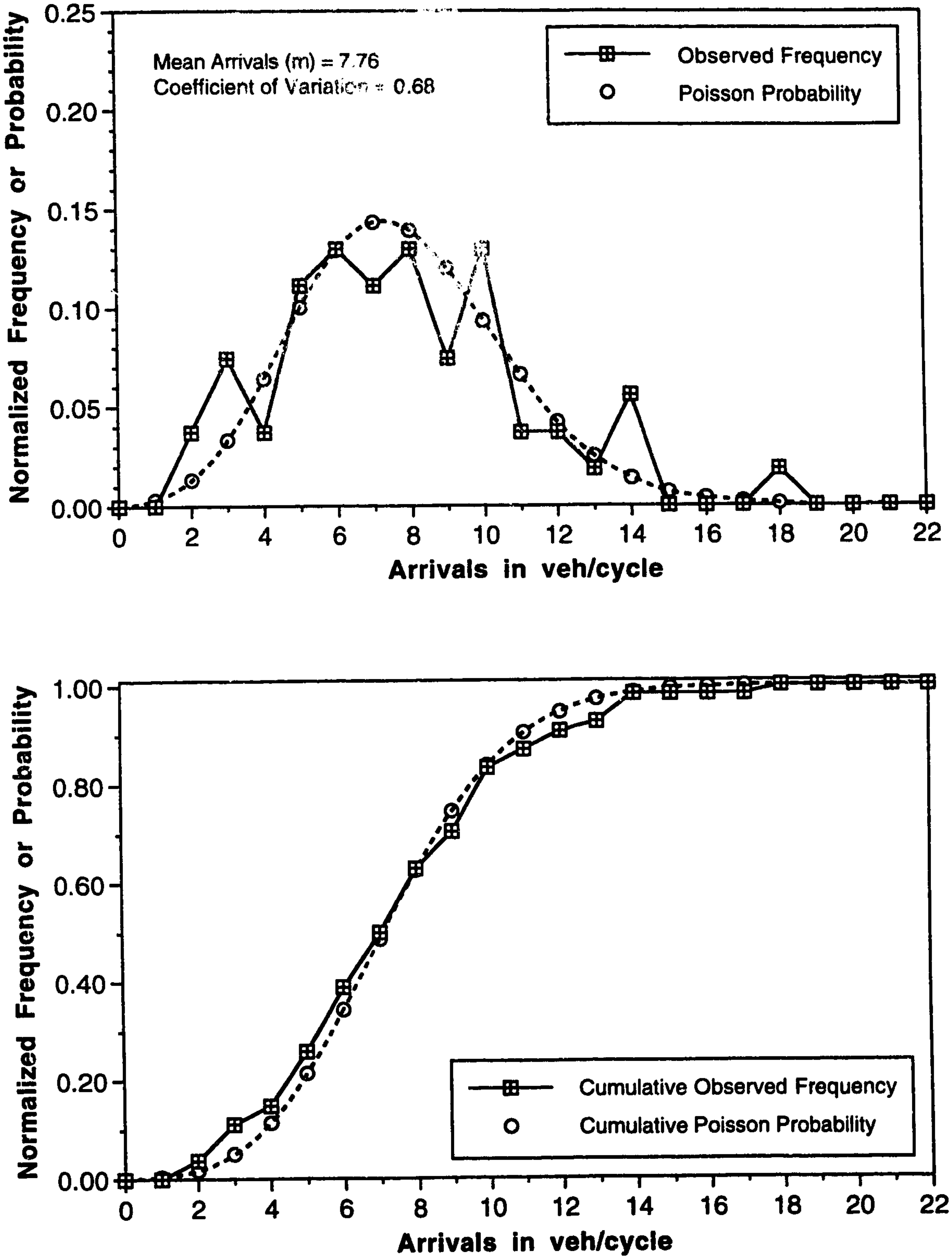
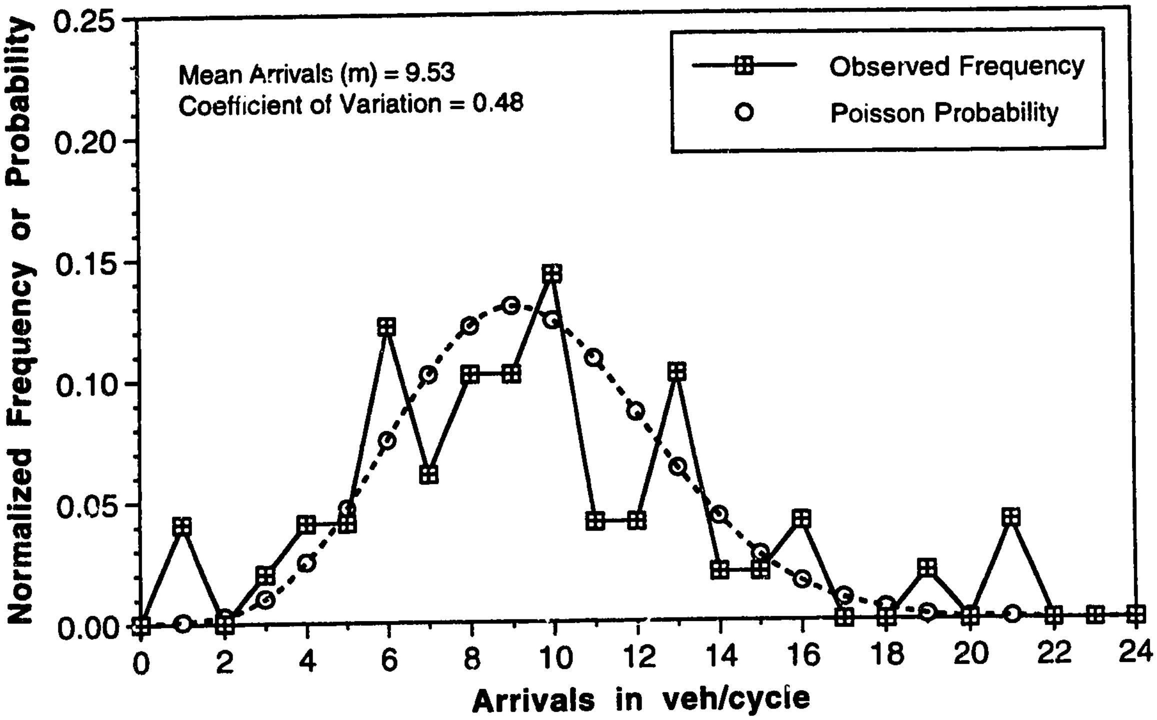


Figure B-3.10 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 11



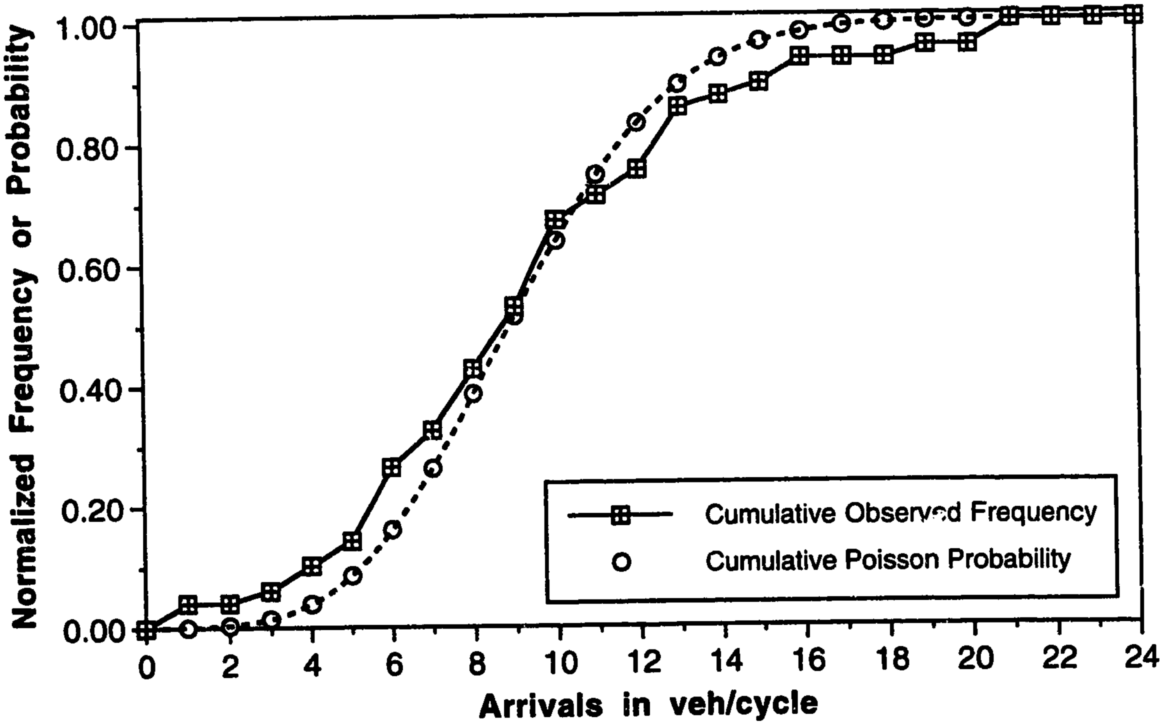
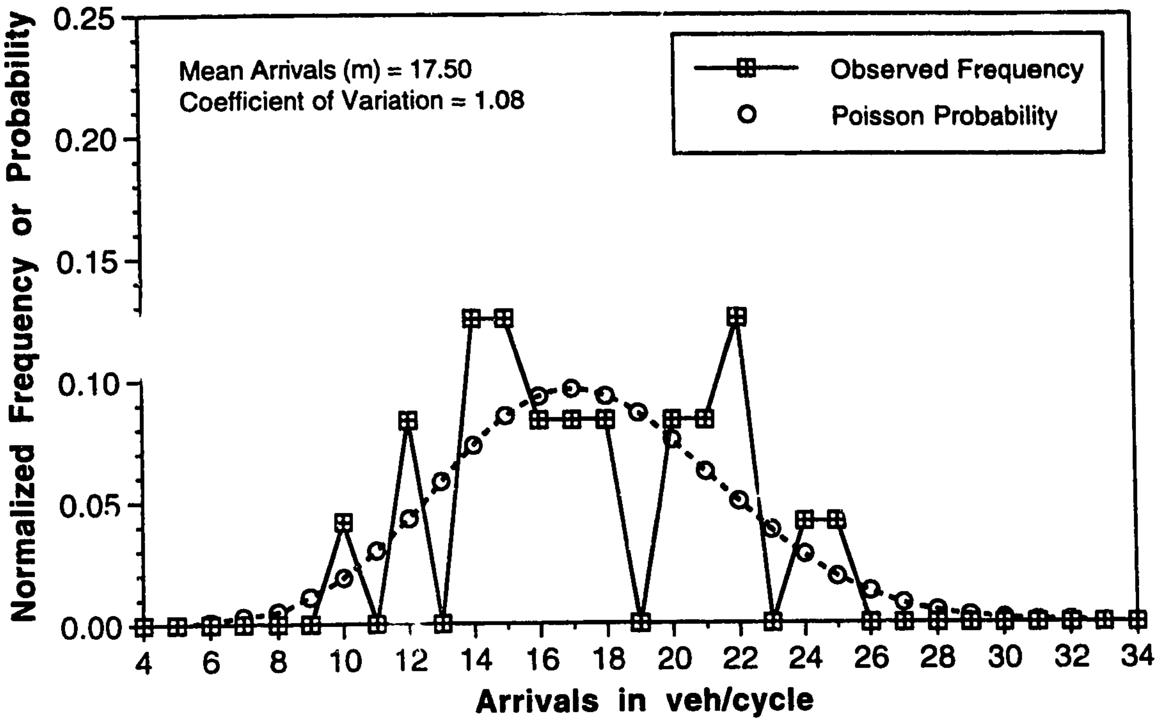


Figure B-3.11 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 12



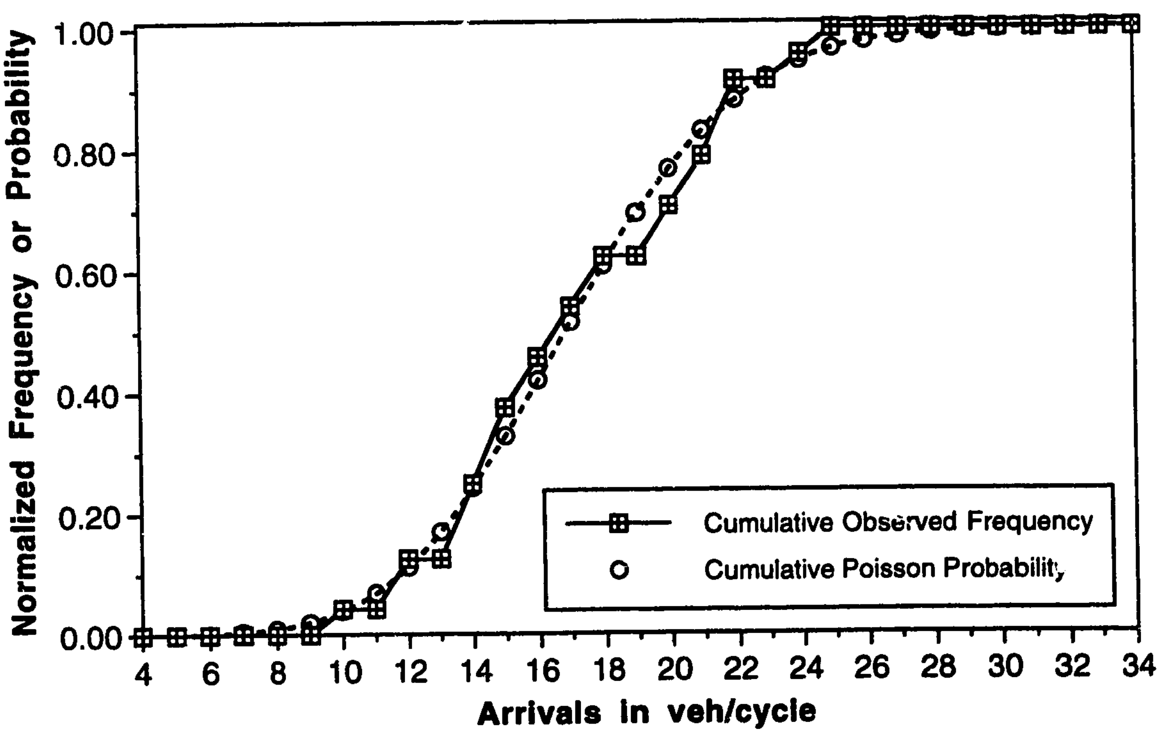
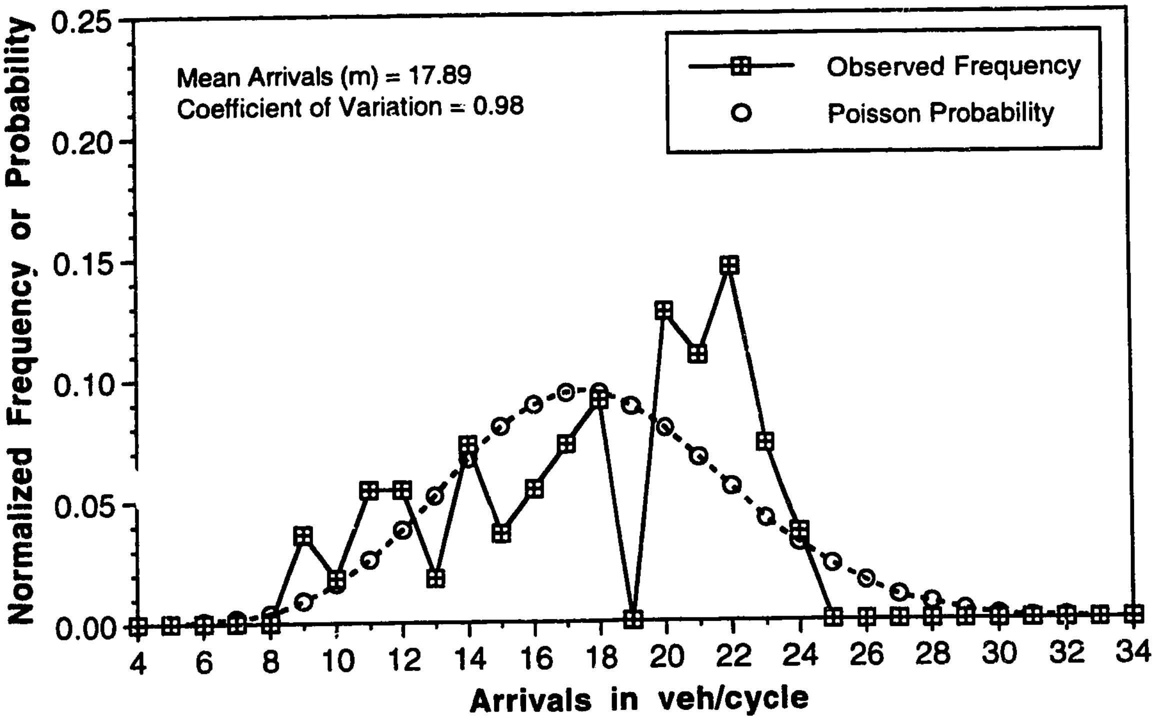


Figure B-3.12 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 13



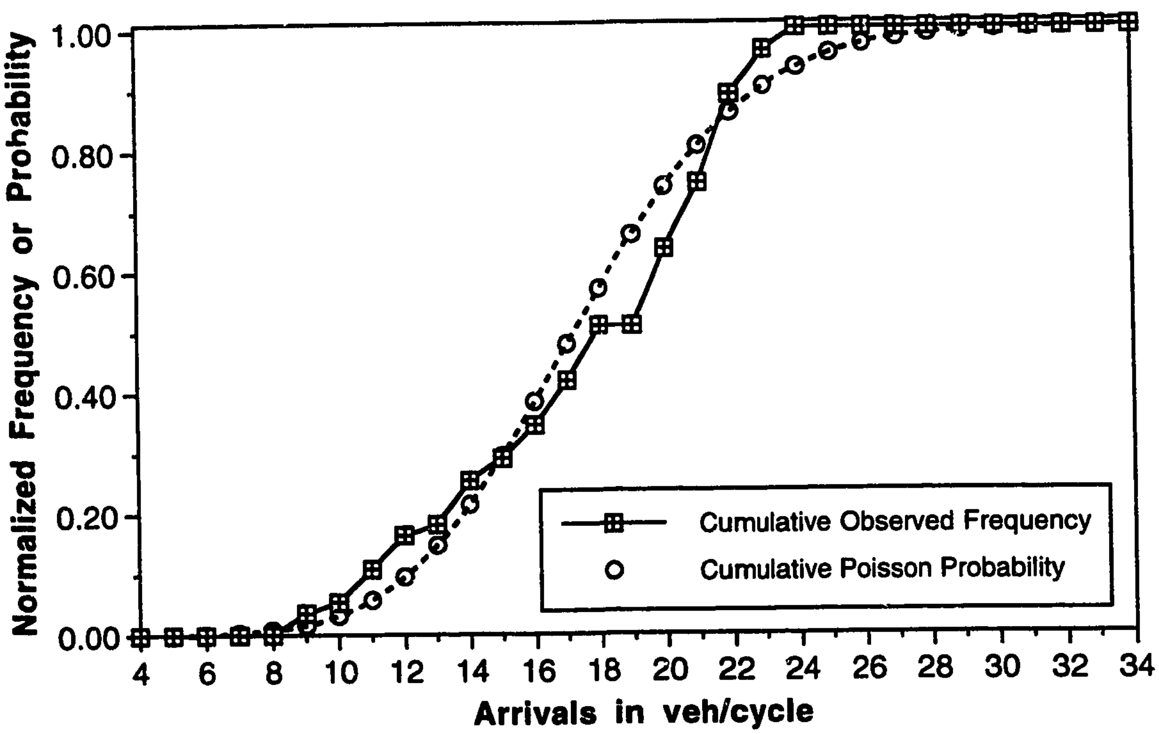


Figure B-3.13 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 14

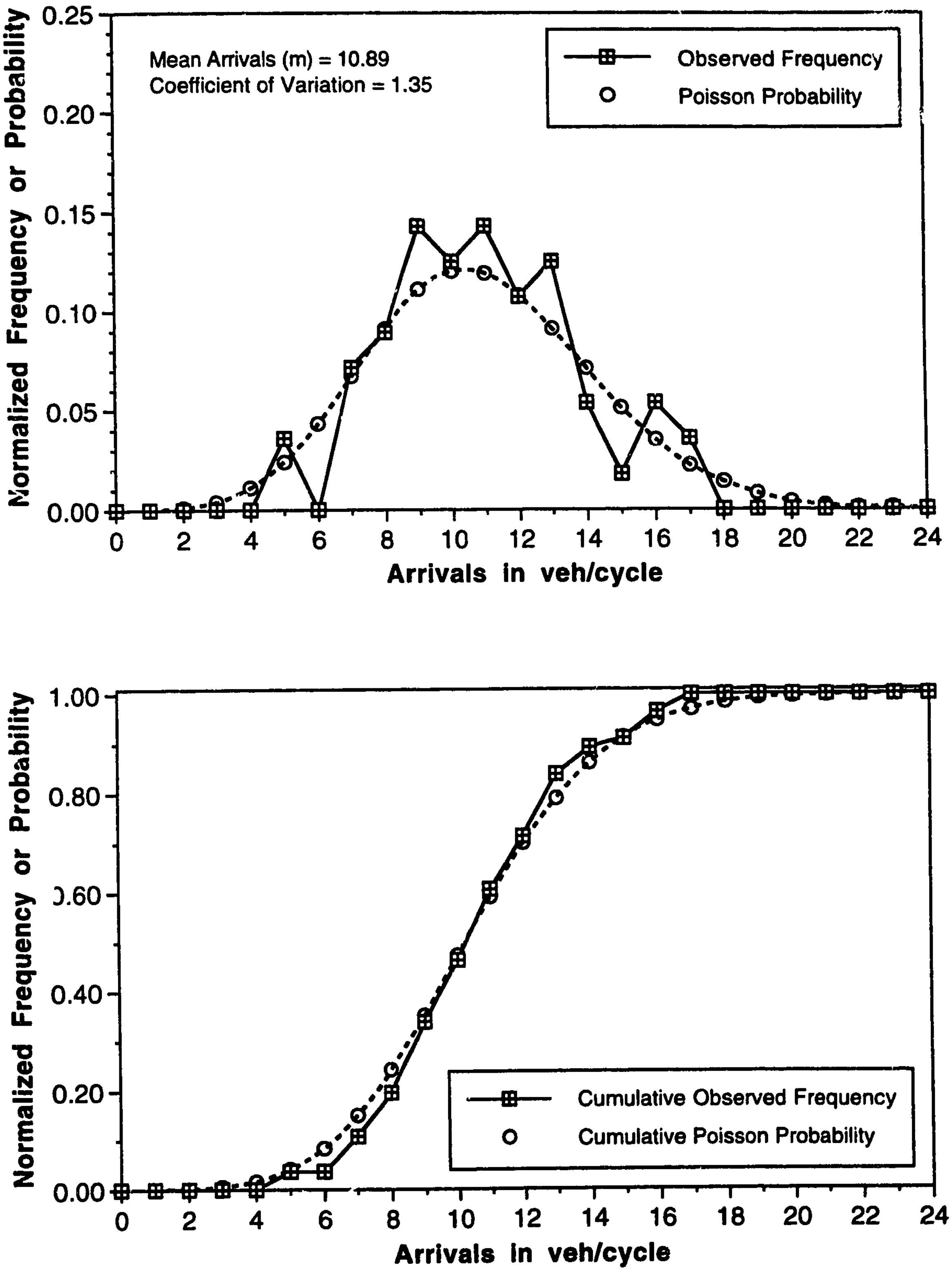


Figure B-3.14 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 15

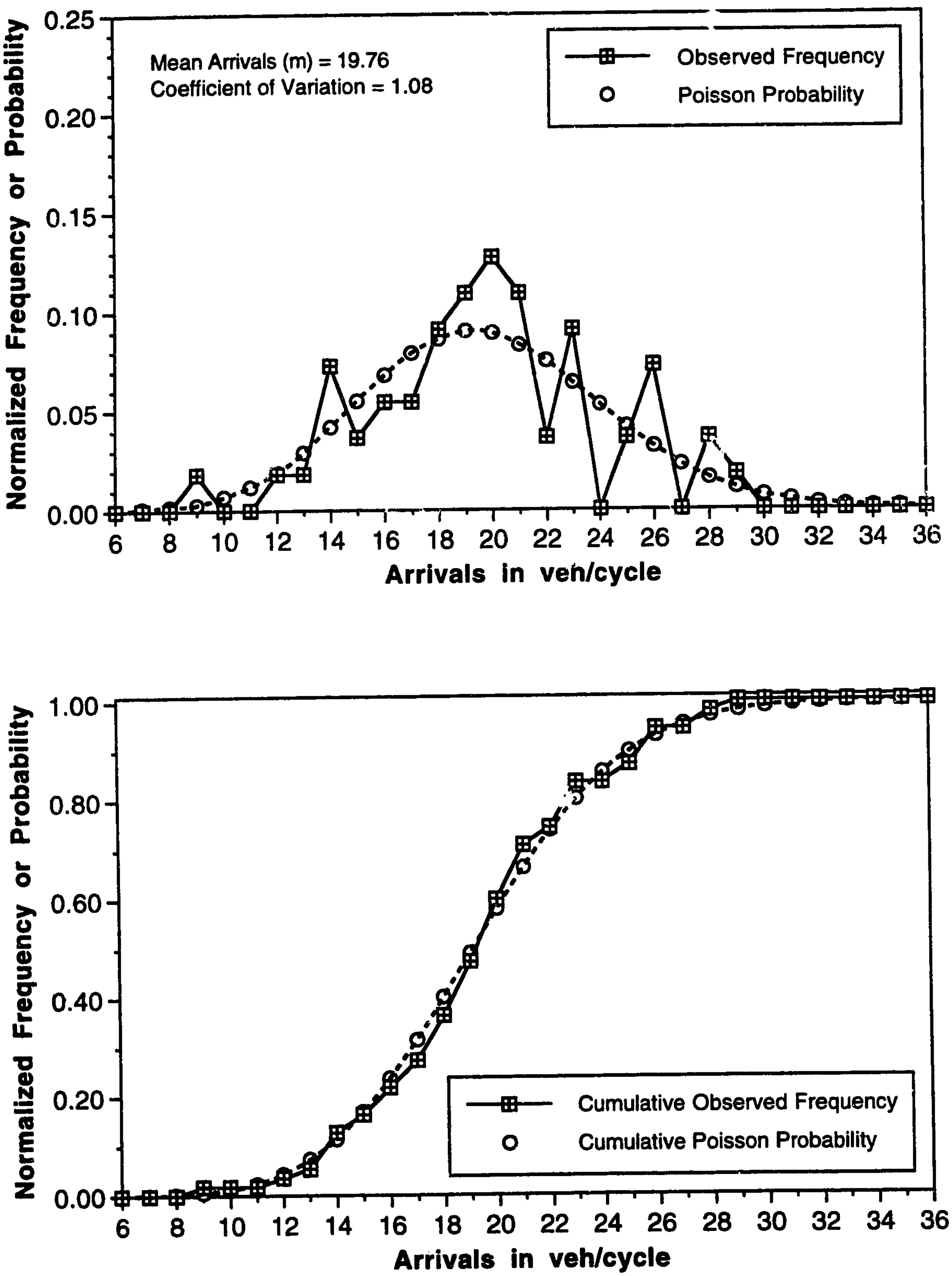
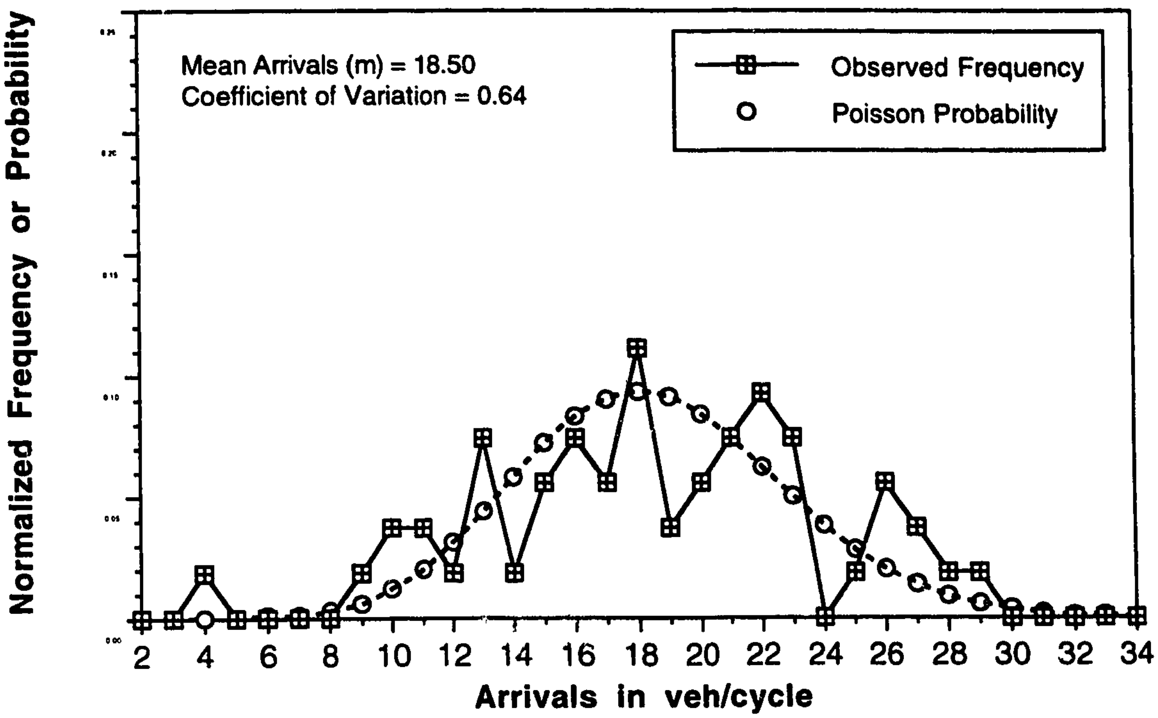


Figure B-3.15 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 17



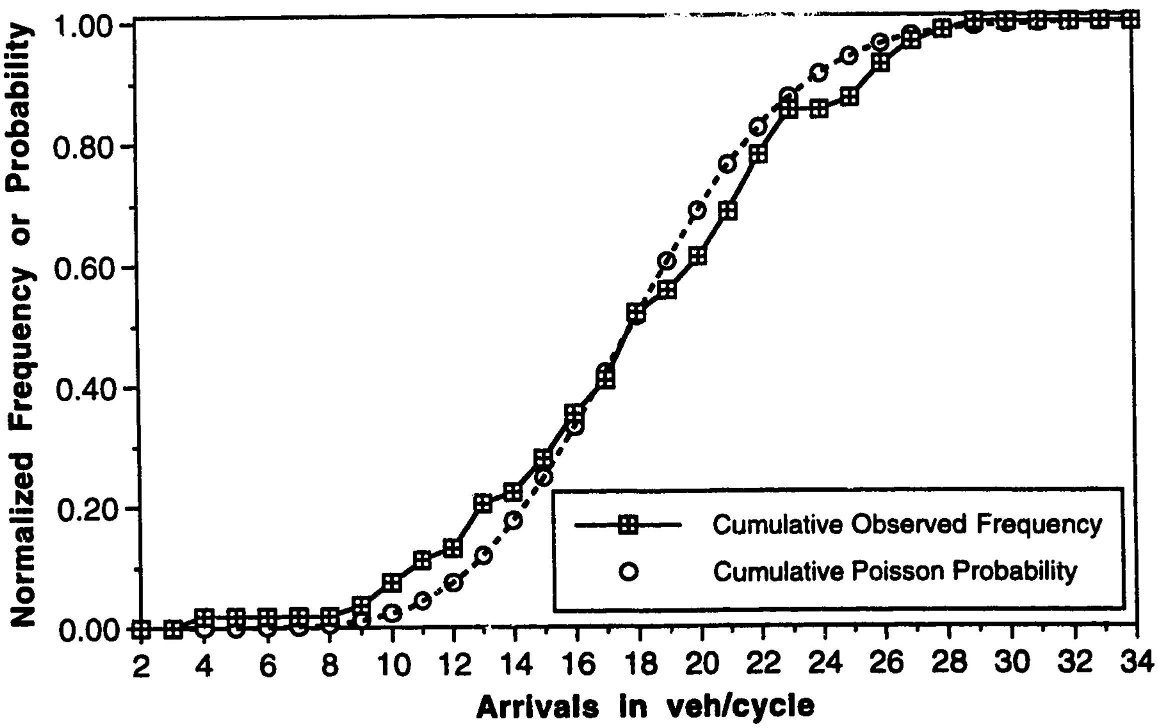
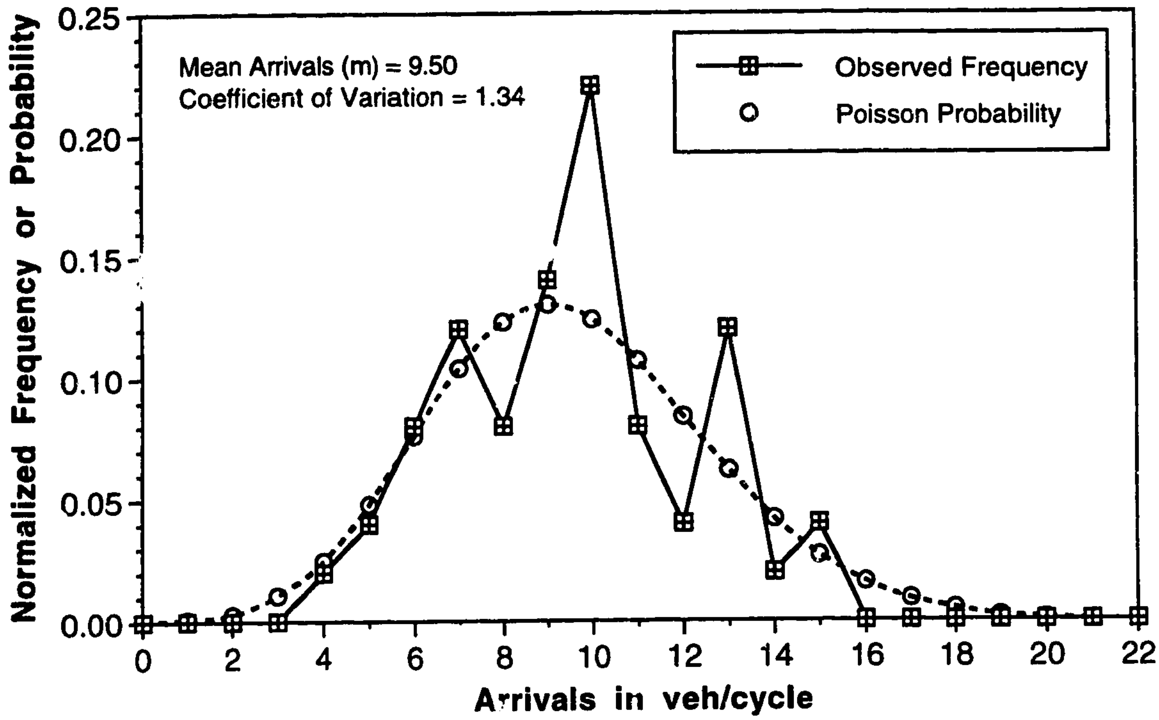


Figure B-3.16 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 18



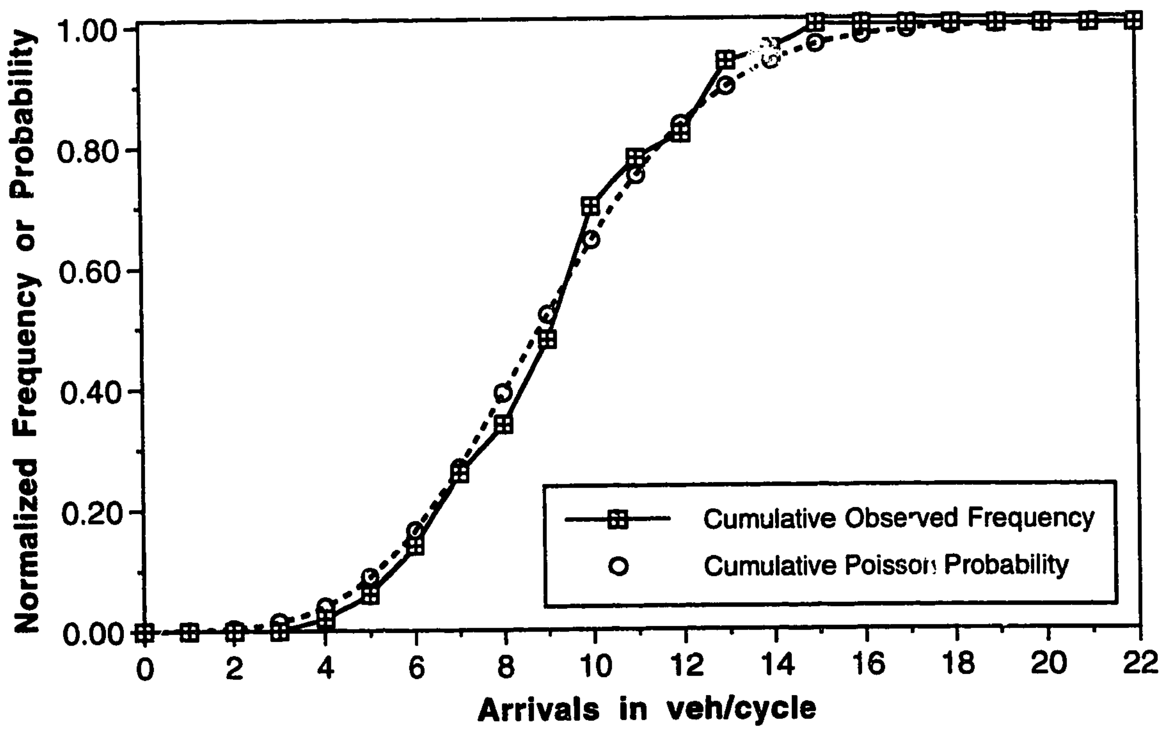
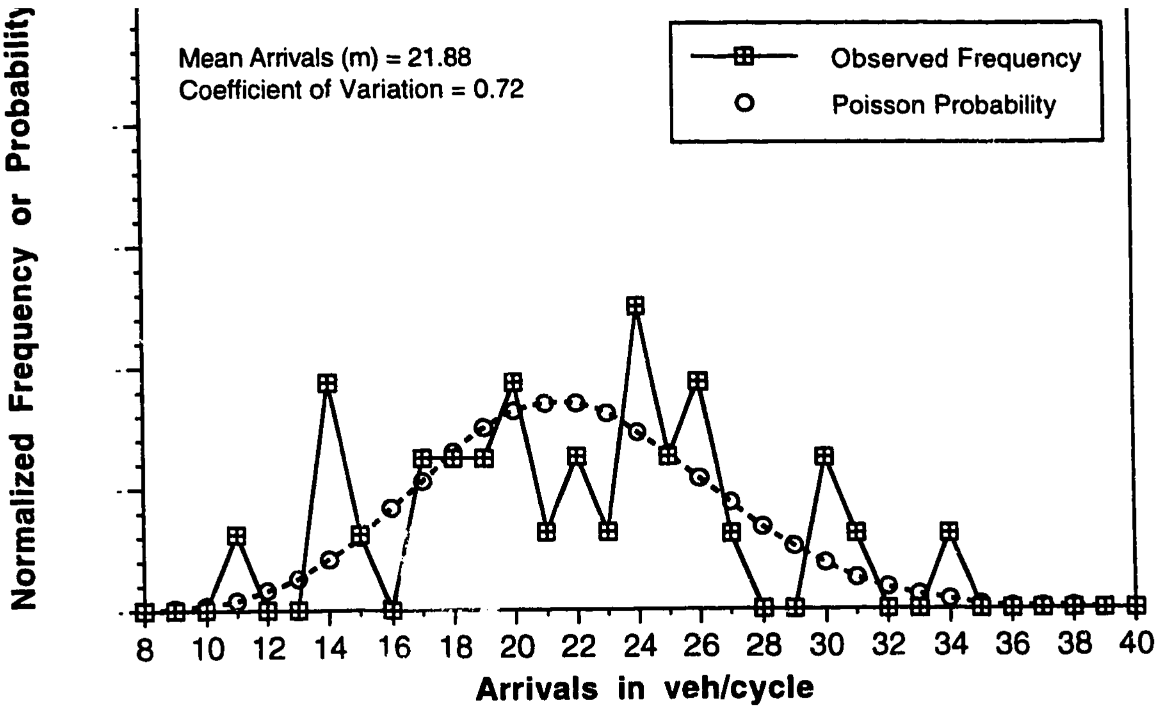


Figure B-3.17 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 19



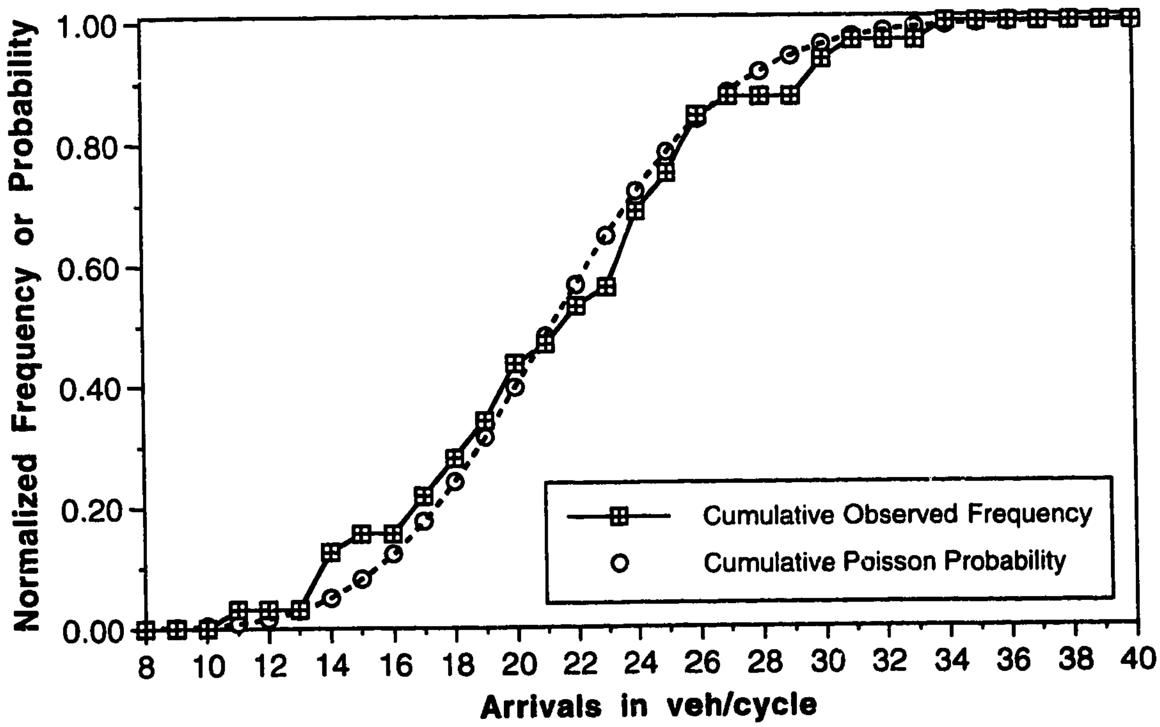
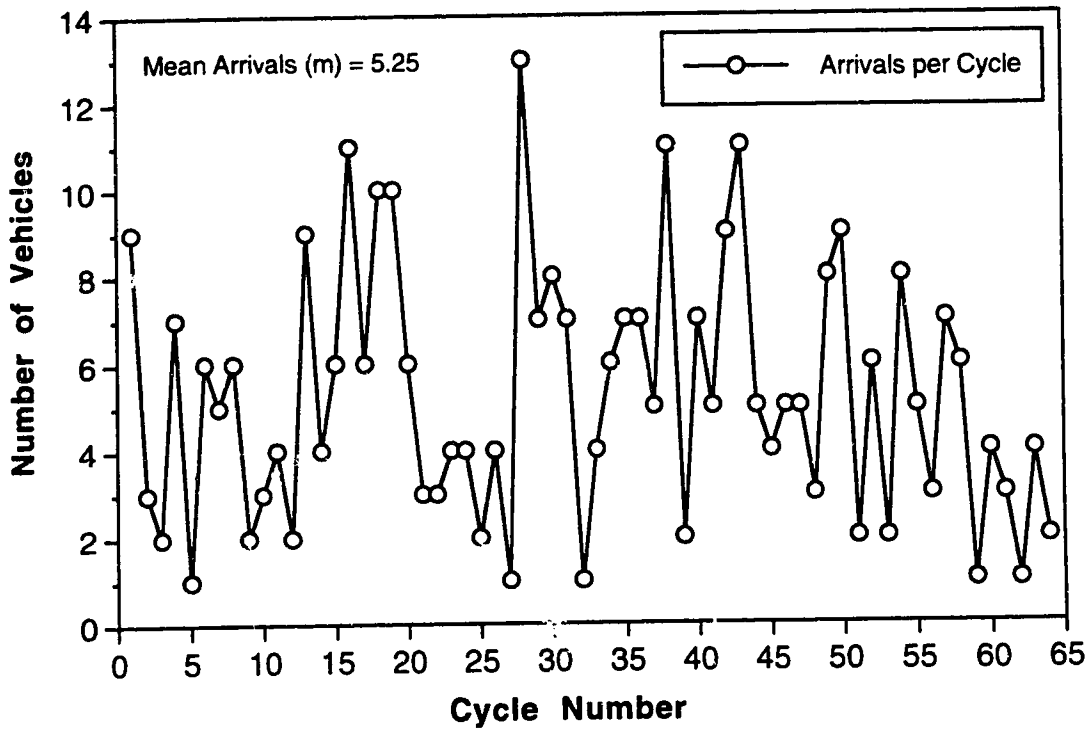


Figure B-3.18 Comparison between Observed Arrival Frequencies and Poisson Probabilities for Survey No. 20



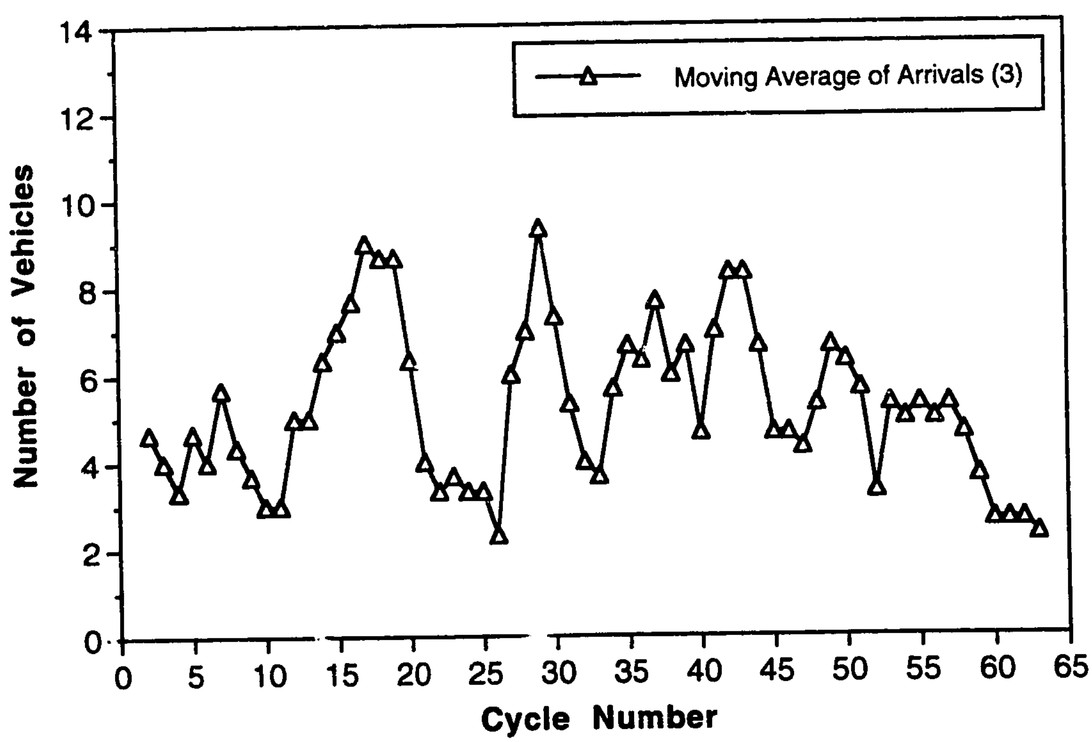
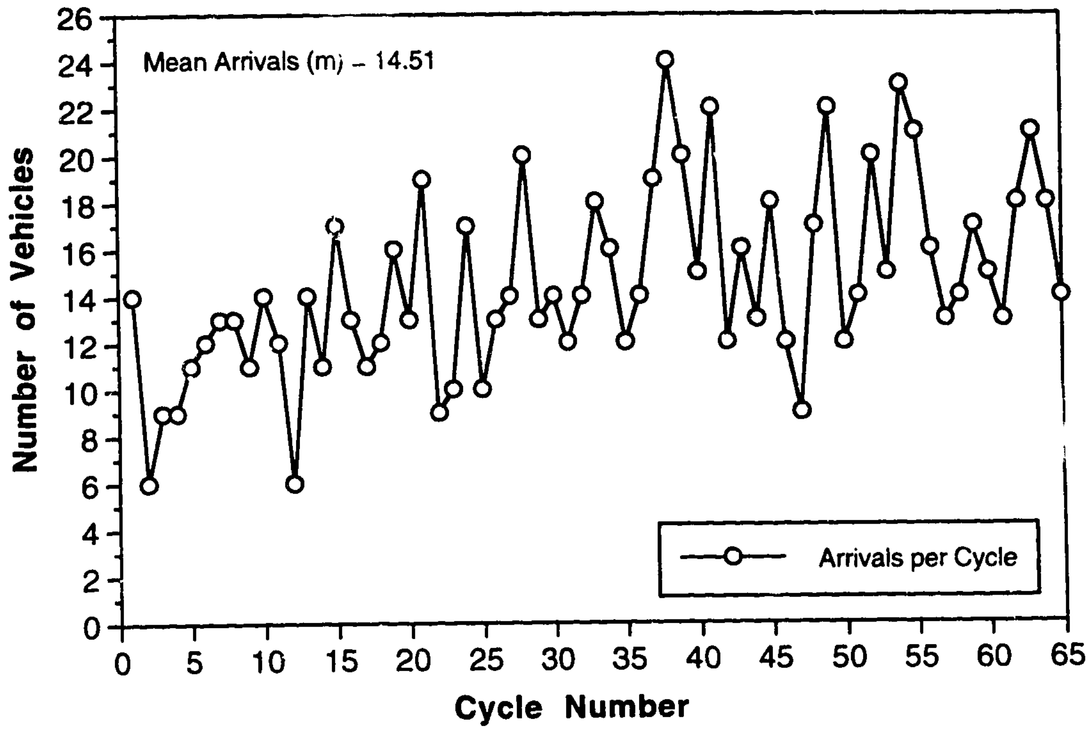


Figure B-3.19 Arrivals per Cycle for Survey No. 1



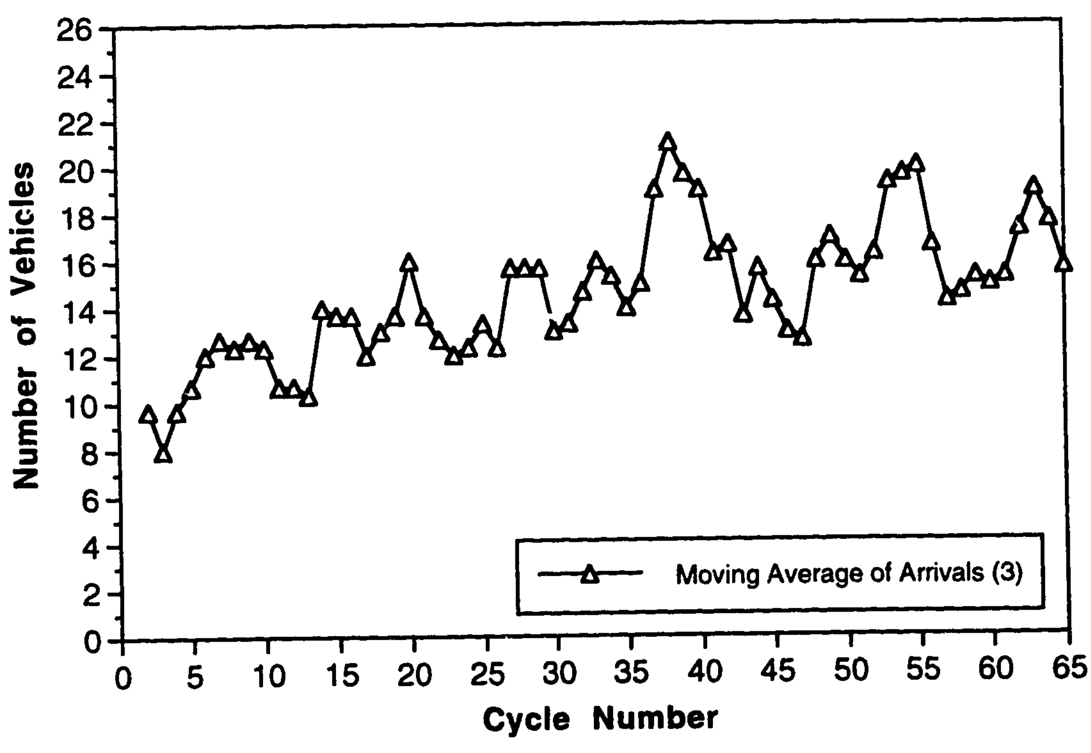
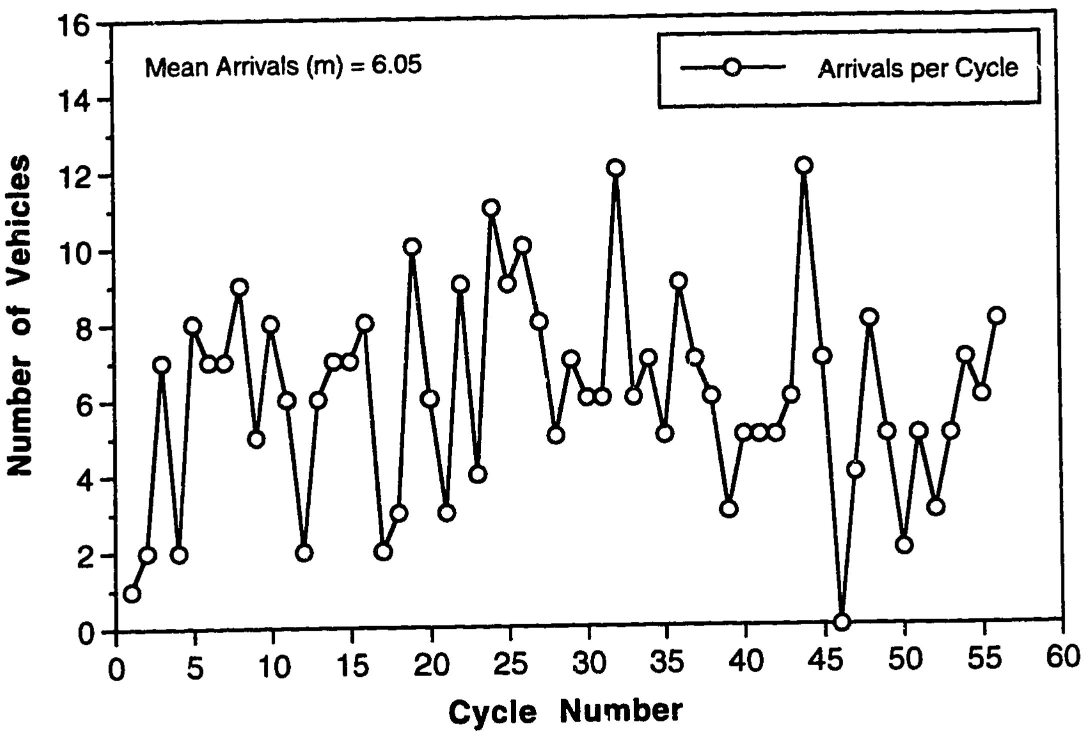


Figure B-3.20 Arrivals per Cycle for Survey No. 2



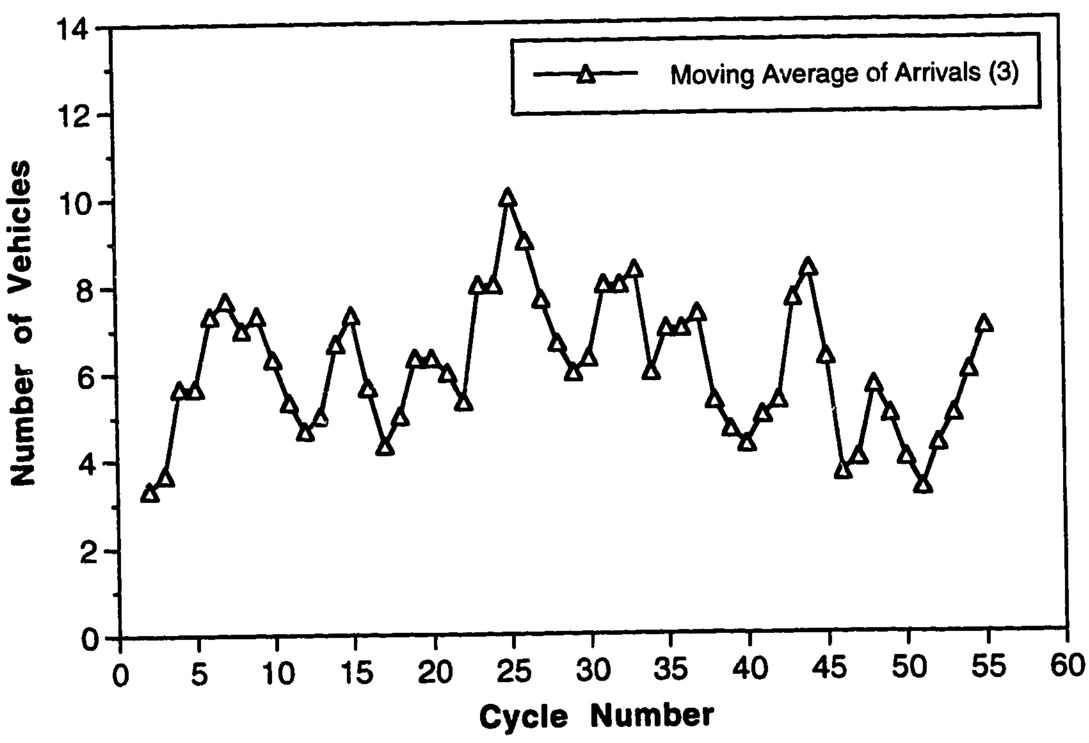
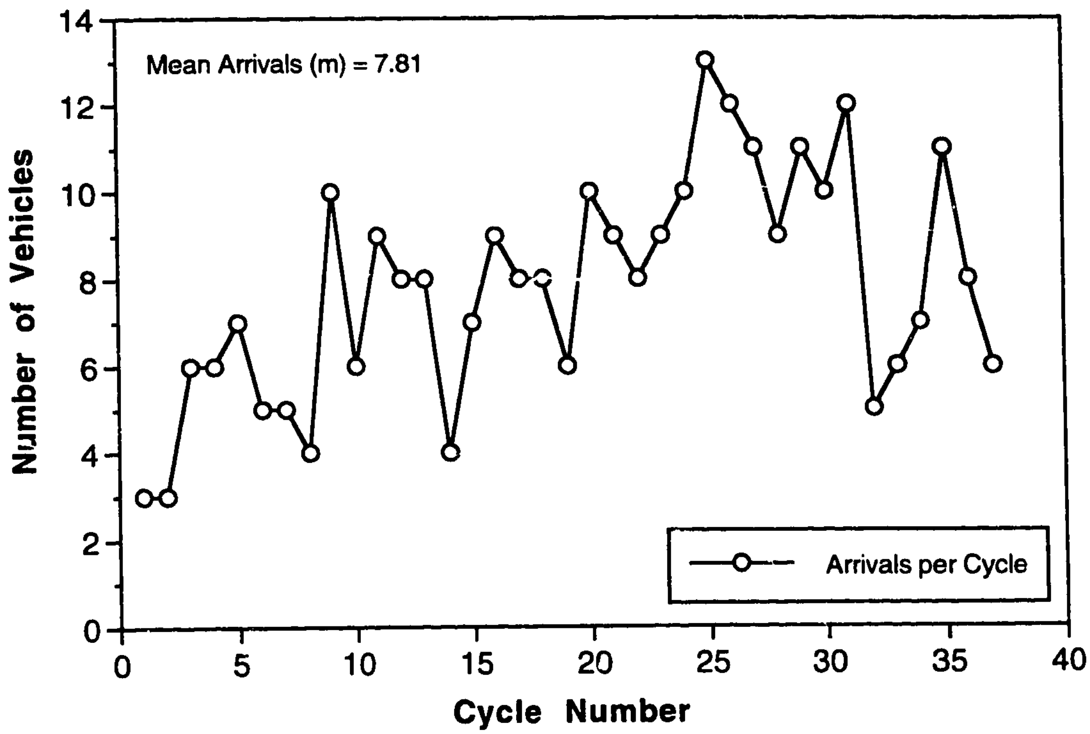


Figure B-3.21 Arrivals per Cycle for Survey No. 3



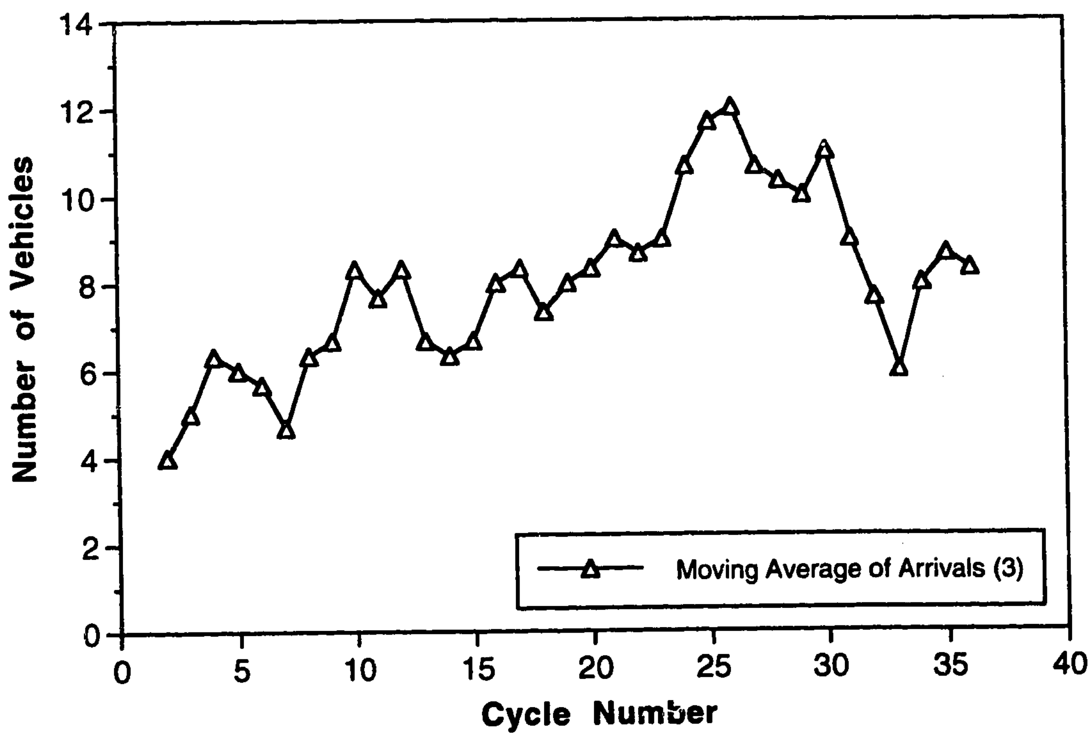
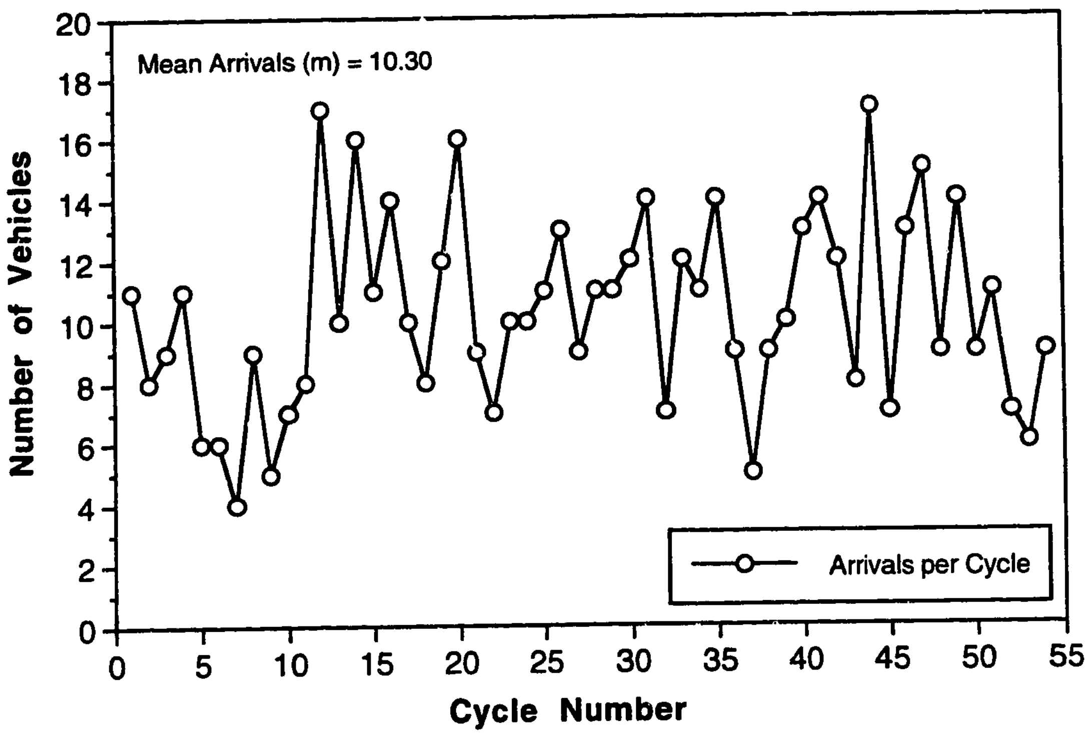


Figure B-3.22 Arrivals per Cycle for Survey No. 4



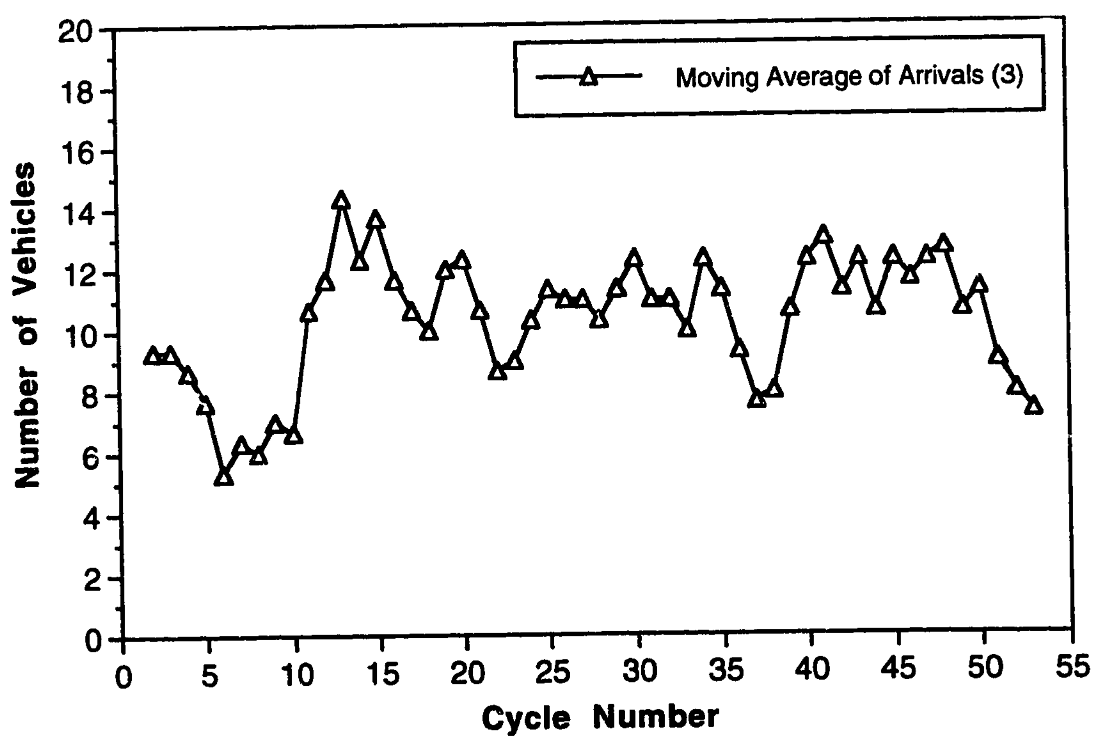
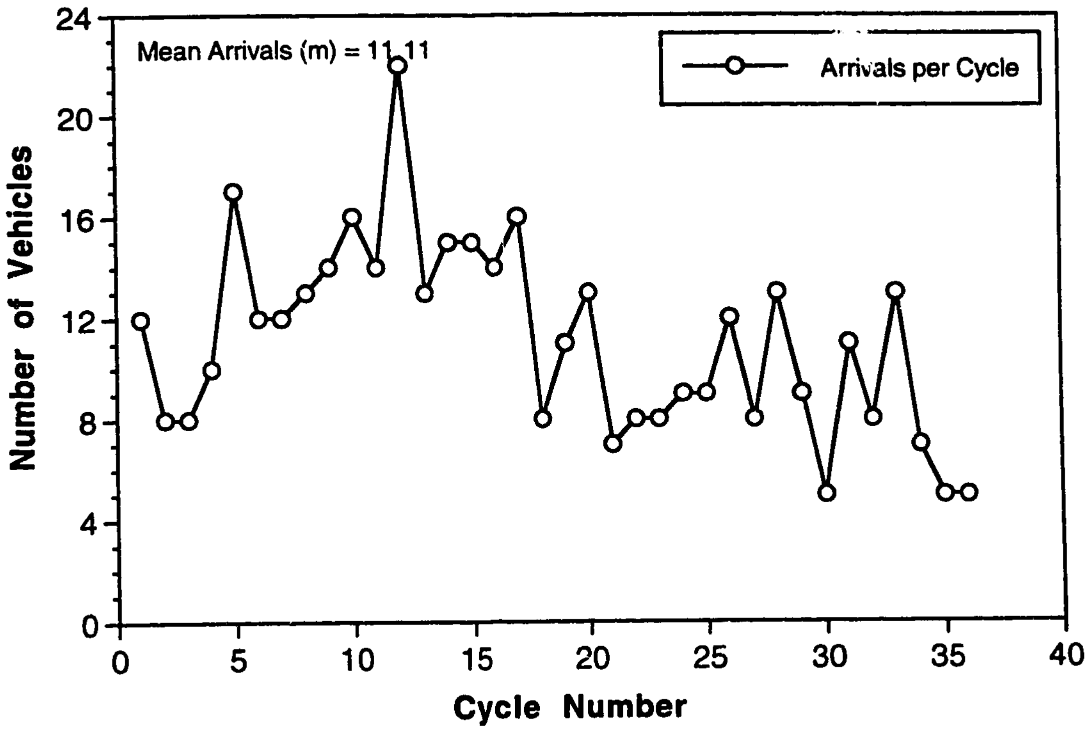


Figure B-3.23 Arrivals per Cycle for Survey No. 5



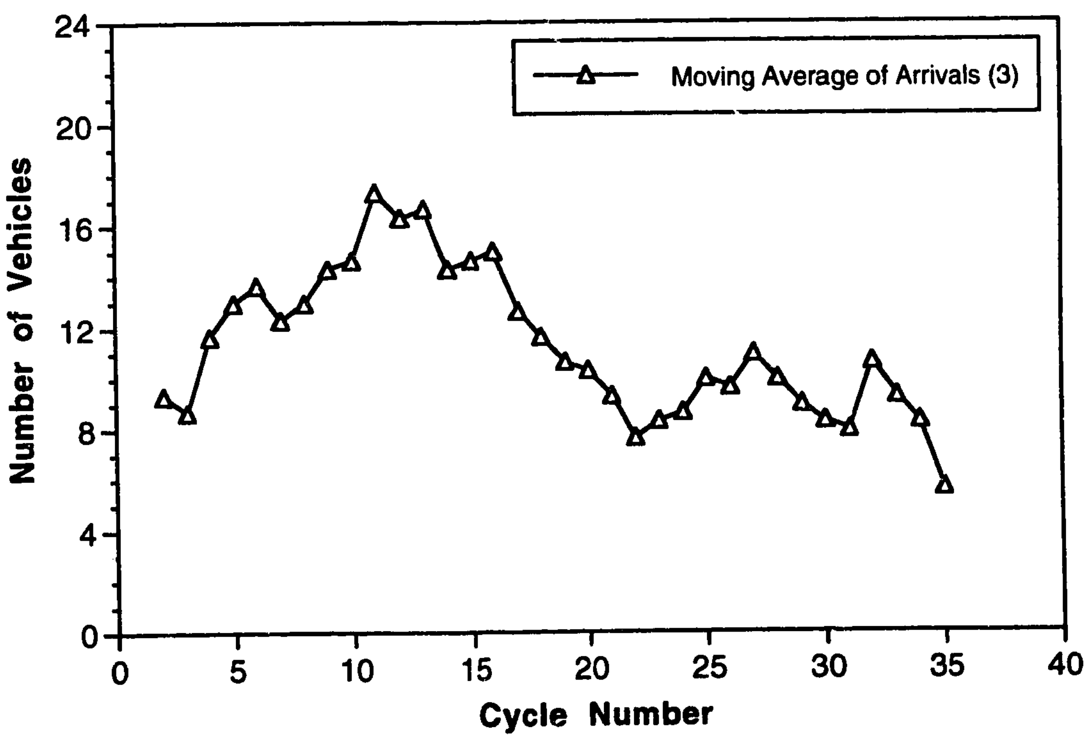


Figure B-3.24 Arrivals per Cycle for Survey No. 6

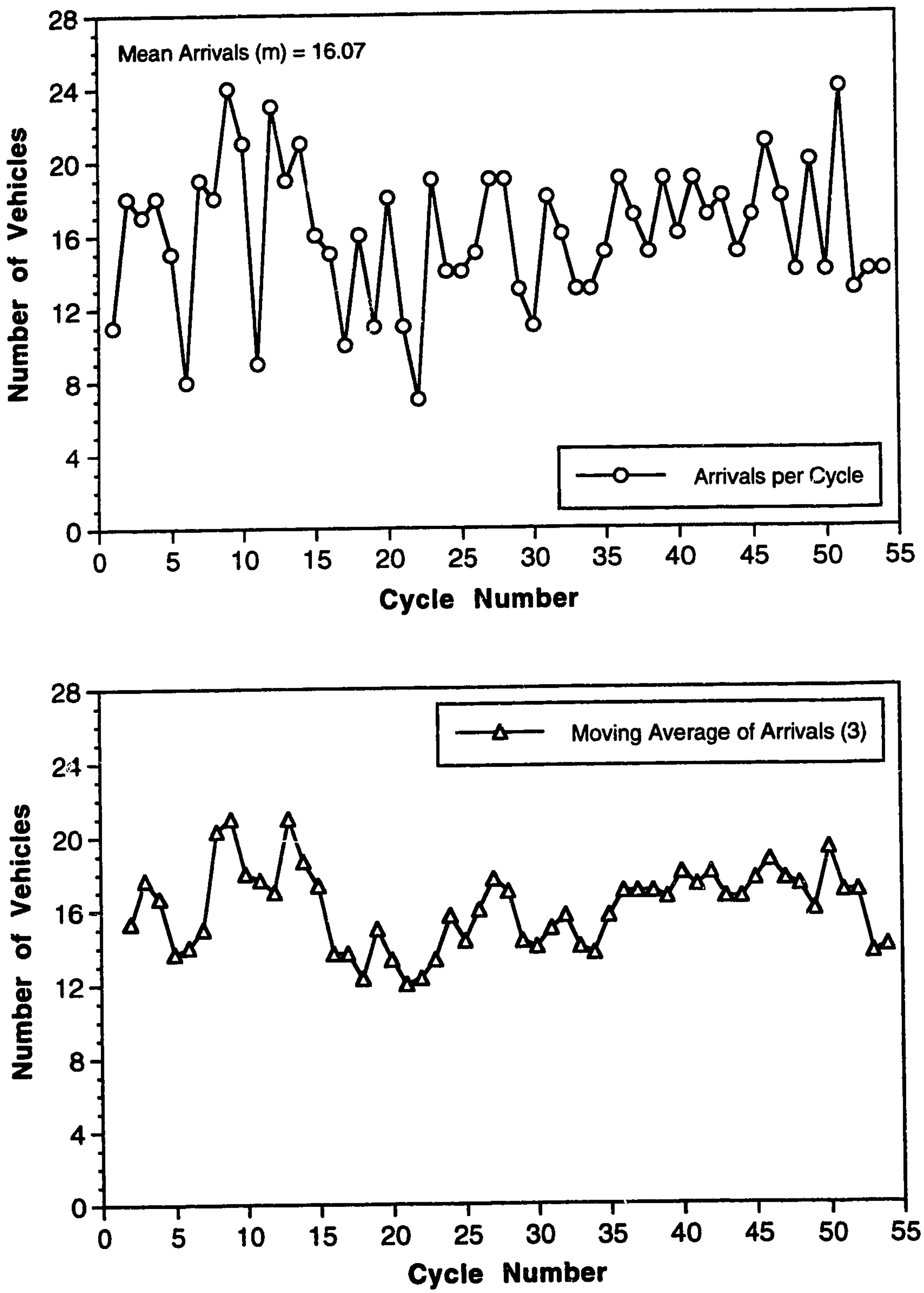
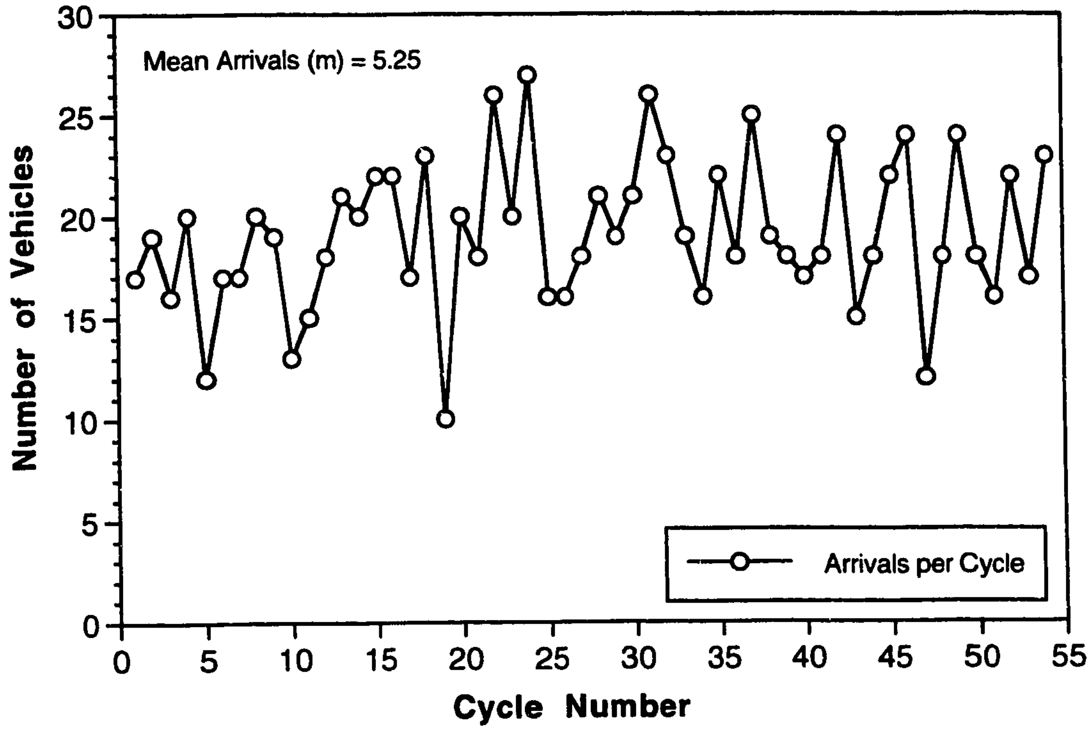


Figure B-3.25 Arrivals per Cycle for Survey No. 7



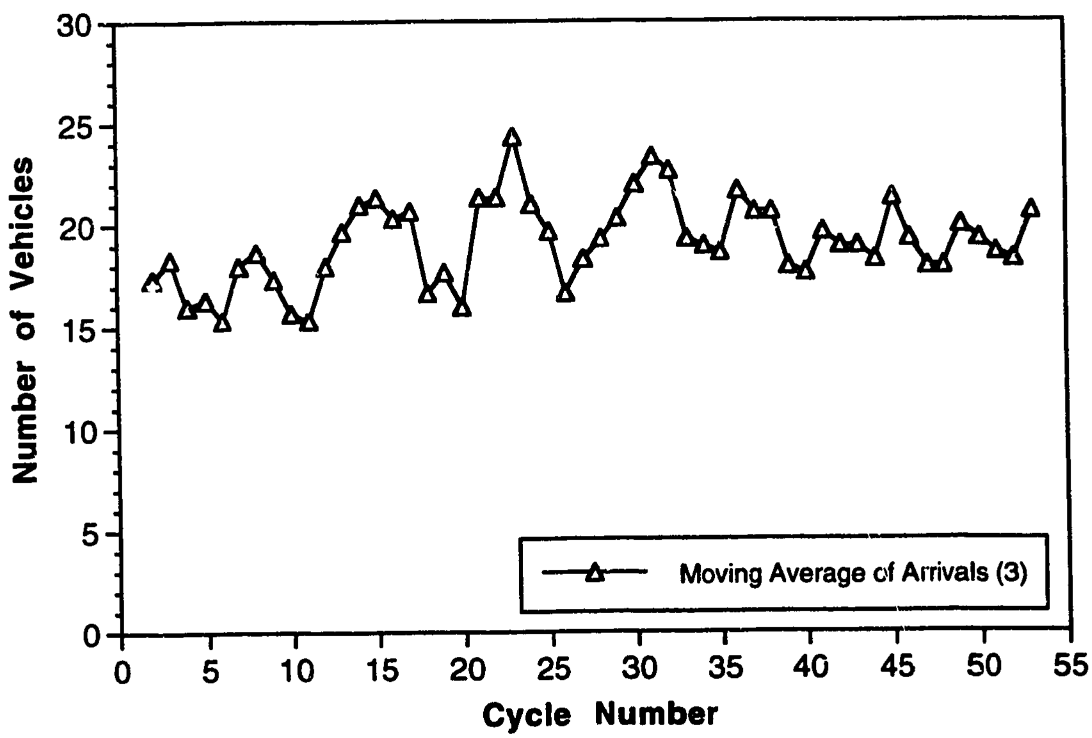


Figure B-3.26 Arrivals per Cycle for Survey No. 8

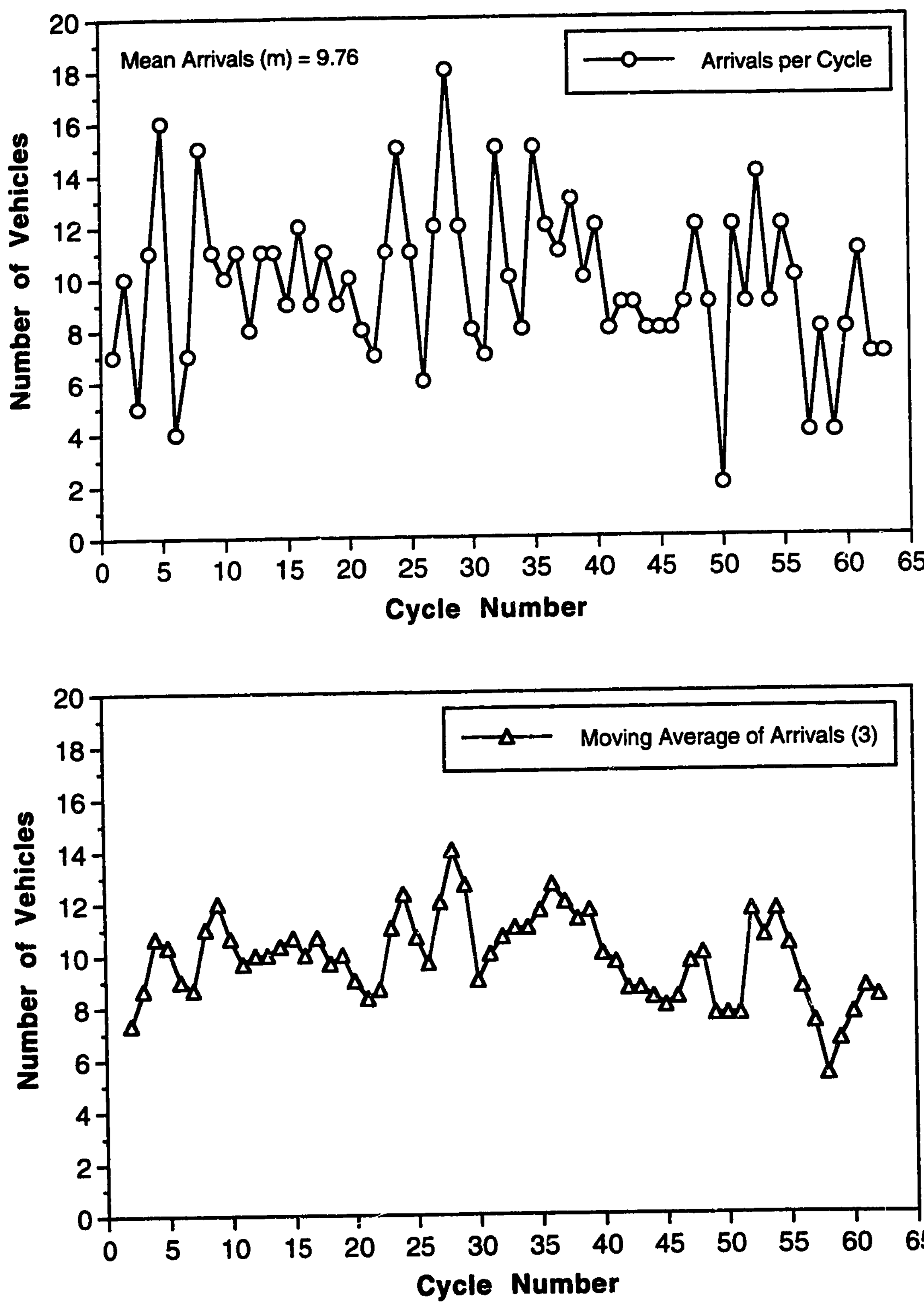


Figure B-3.27 Arrivals per Cycle for Survey No. 9

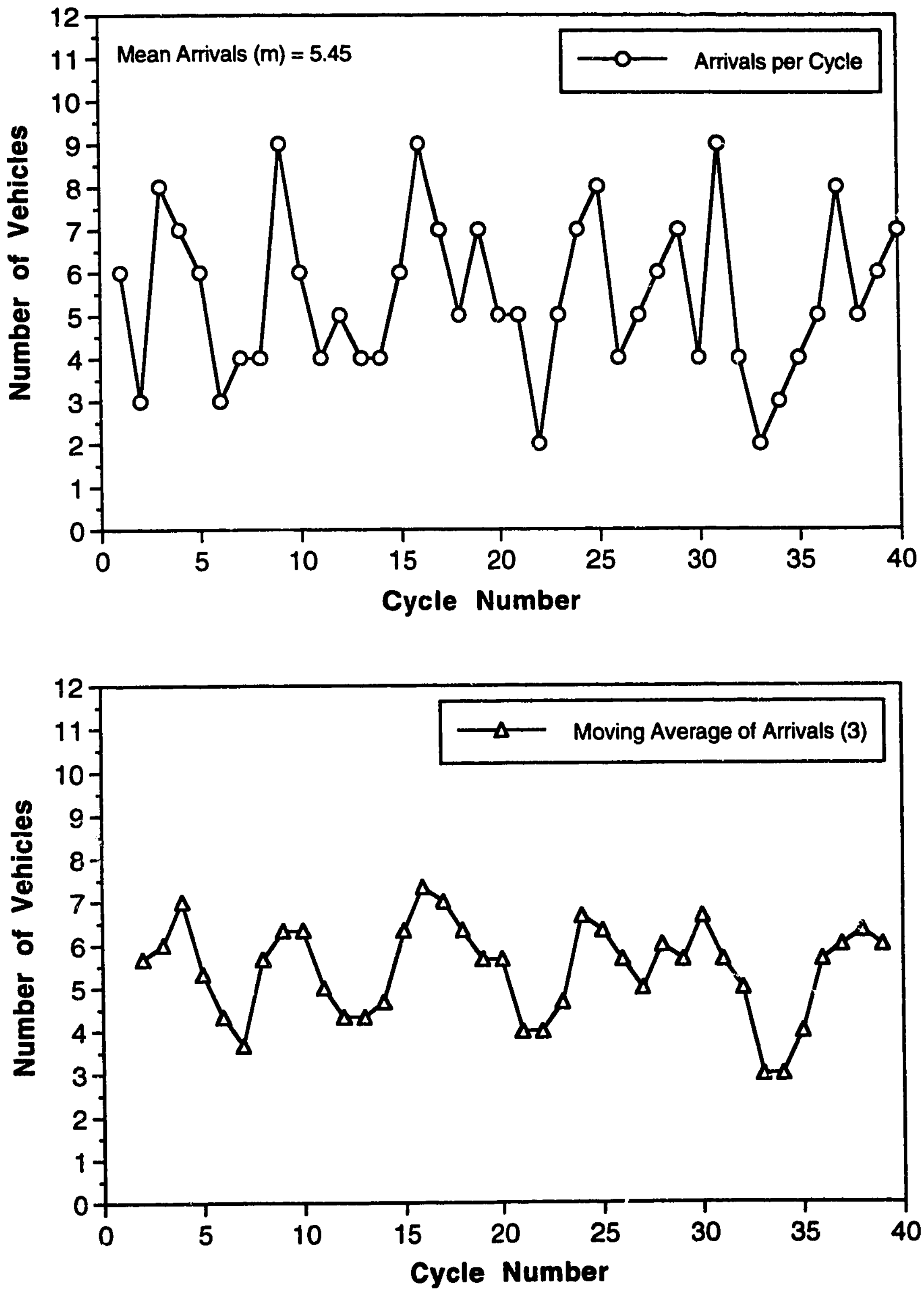
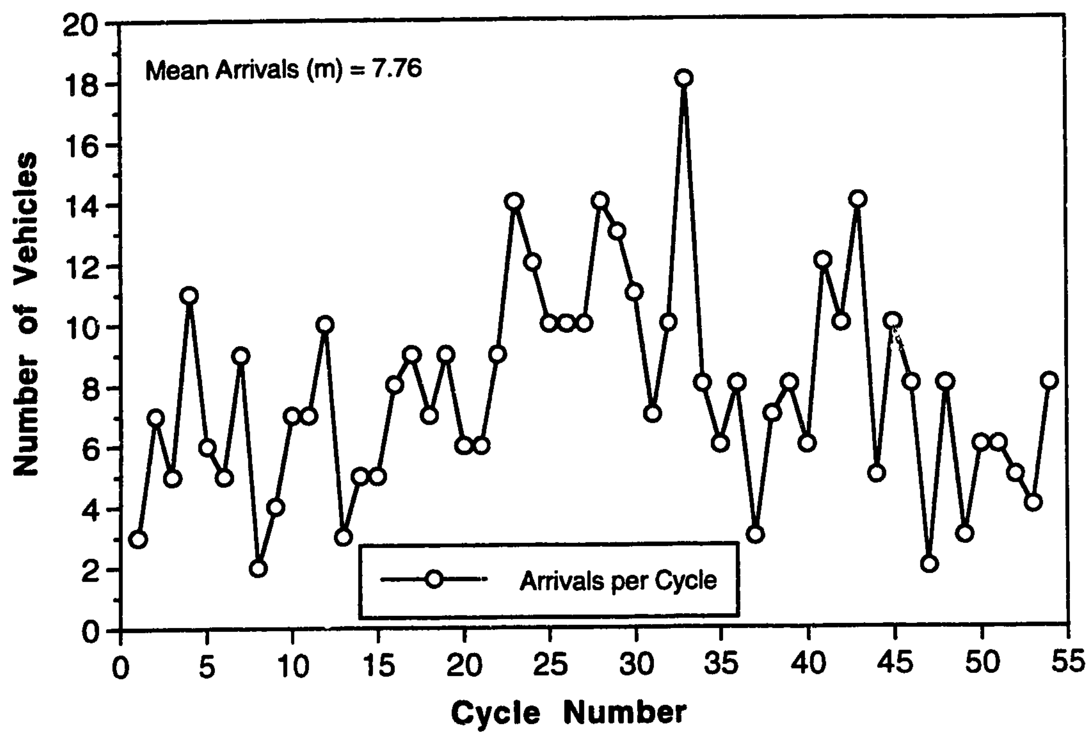


Figure B-3.28 Arrivals per Cycle for Survey No. 10



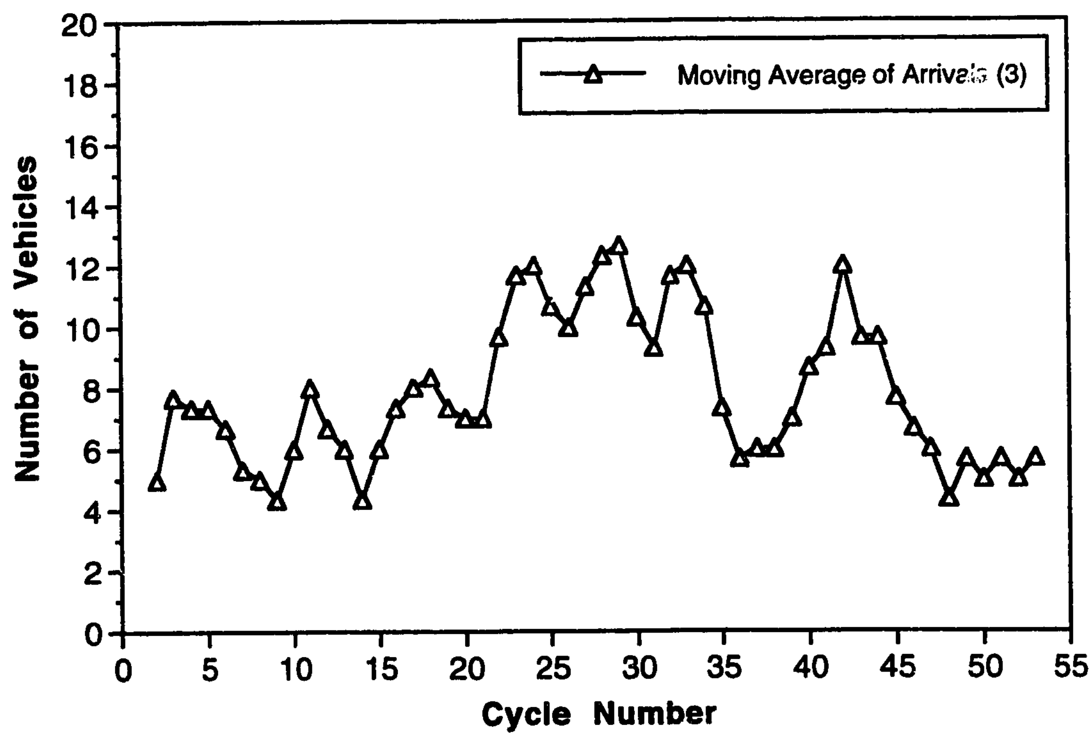
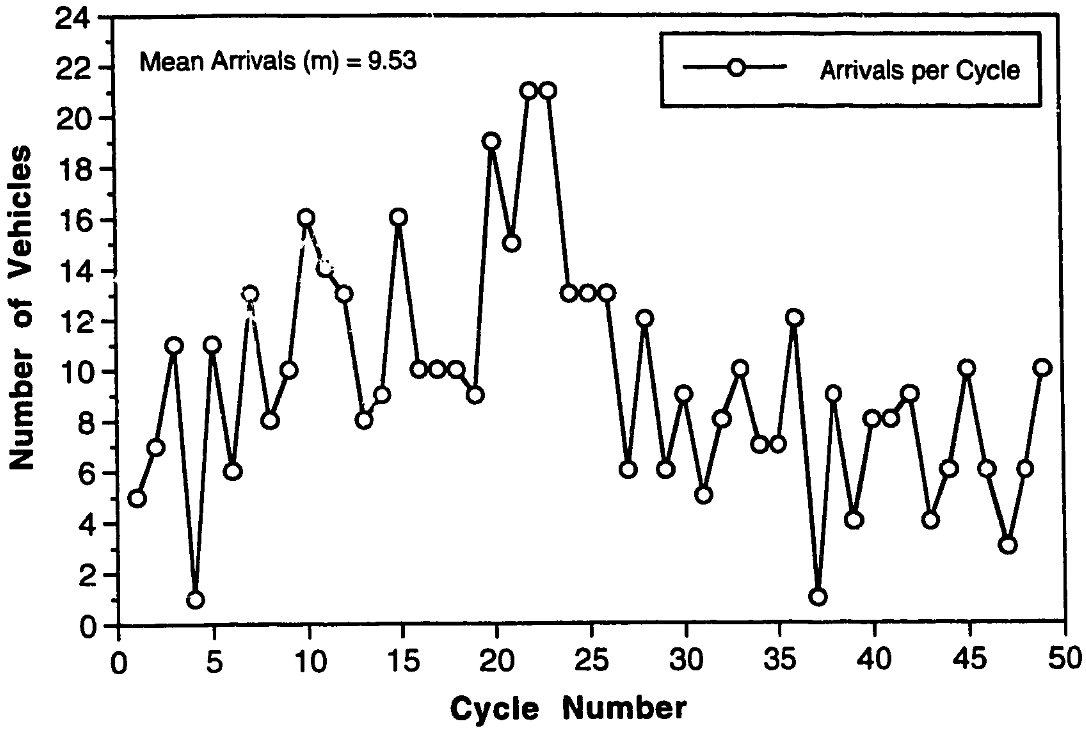


Figure B-3.29 Arrivals per Cycle for Survey No. 11



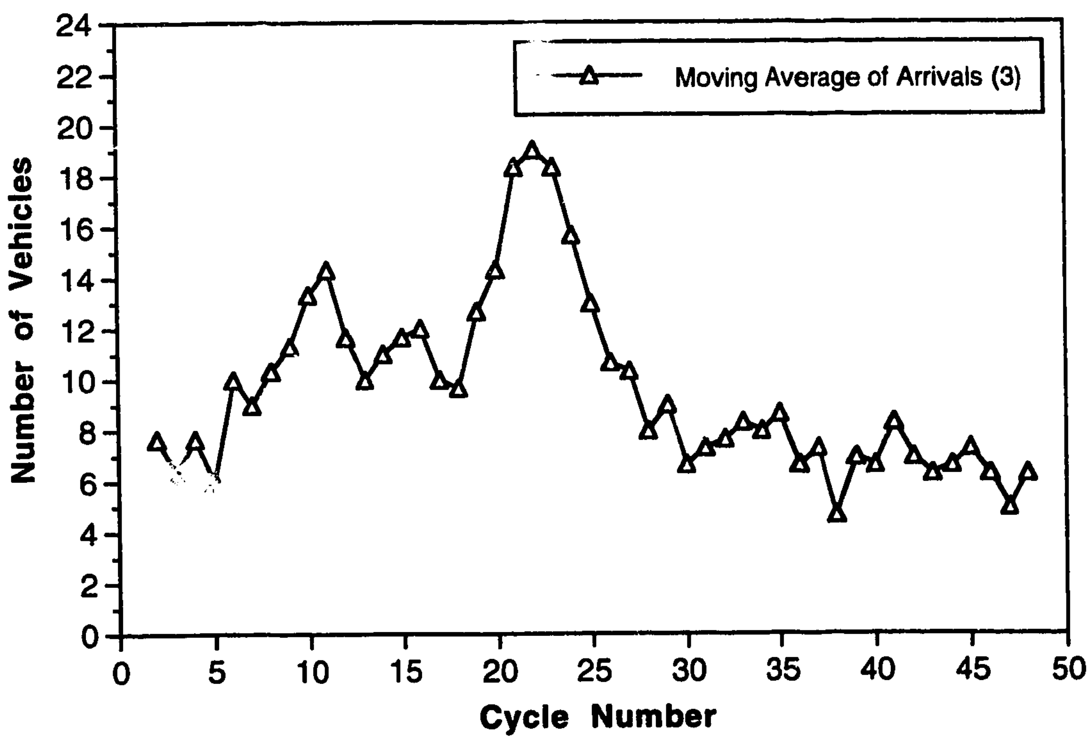


Figure B-3.30 Arrivals per Cycle for Survey No. 12

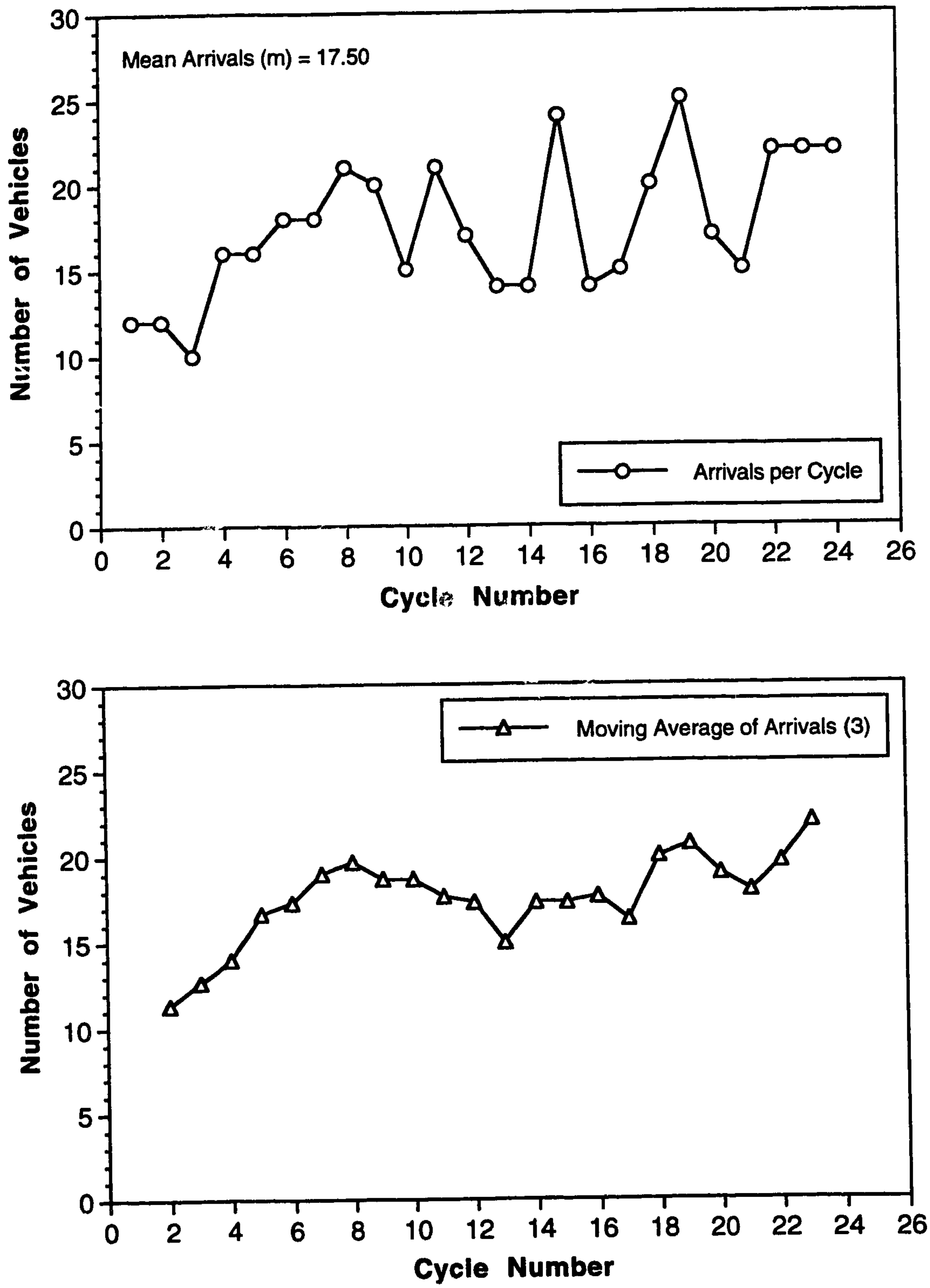
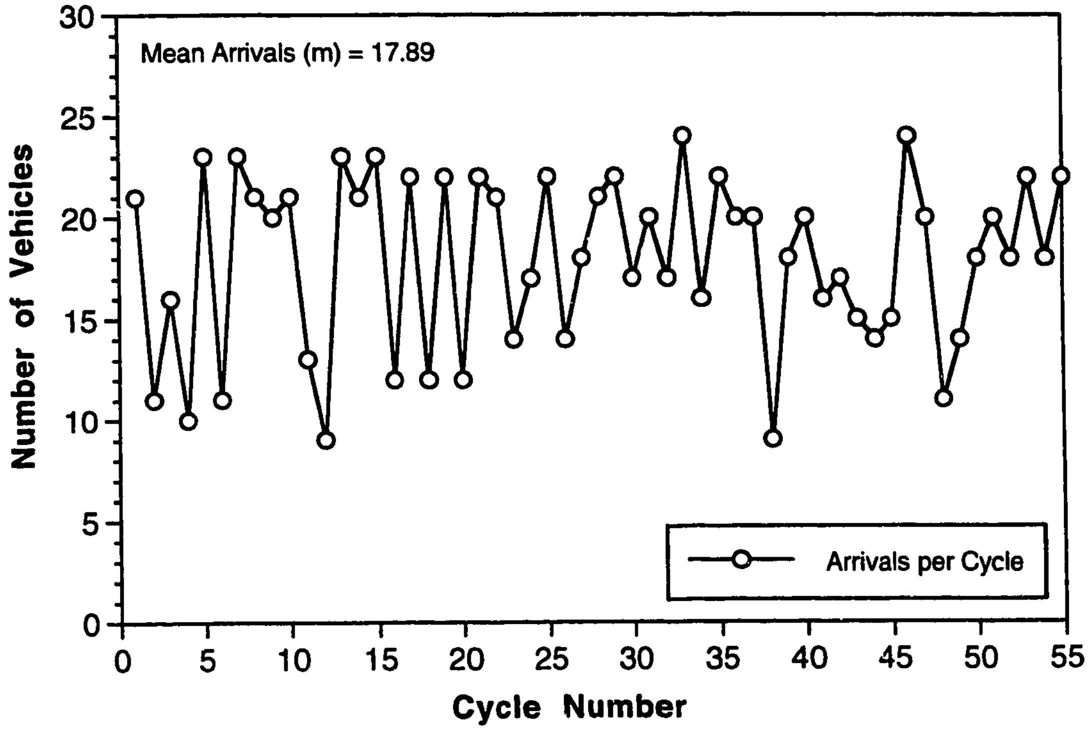


Figure B-3.31 Arrivals per Cycle for Survey No. 13



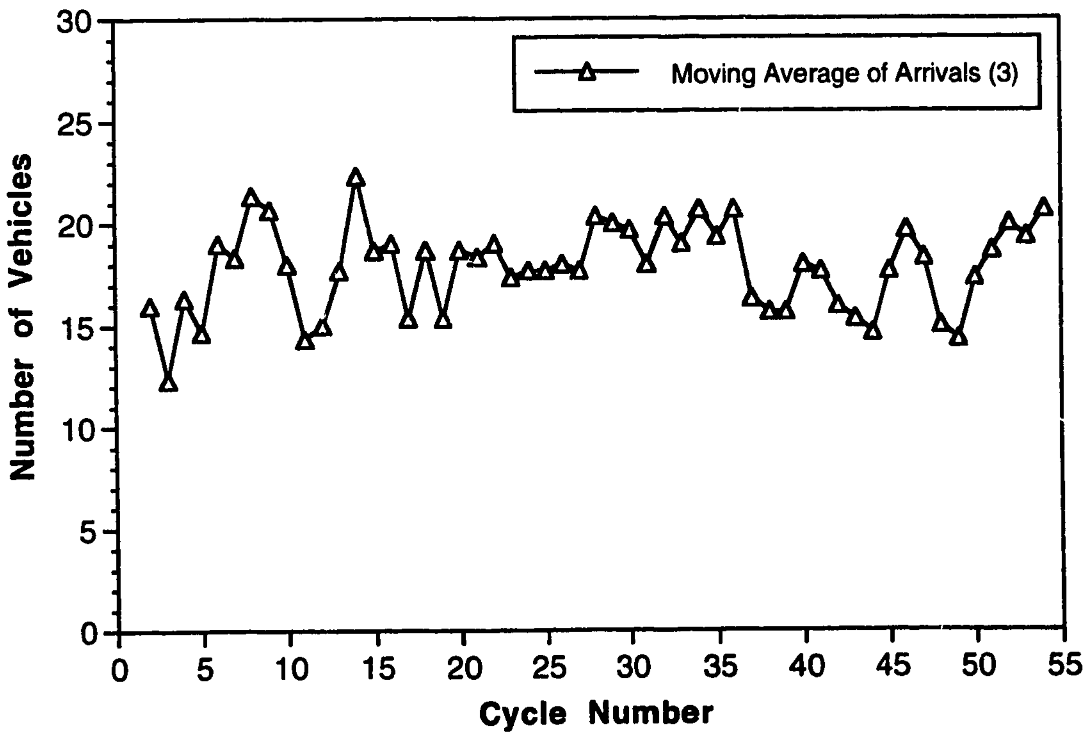
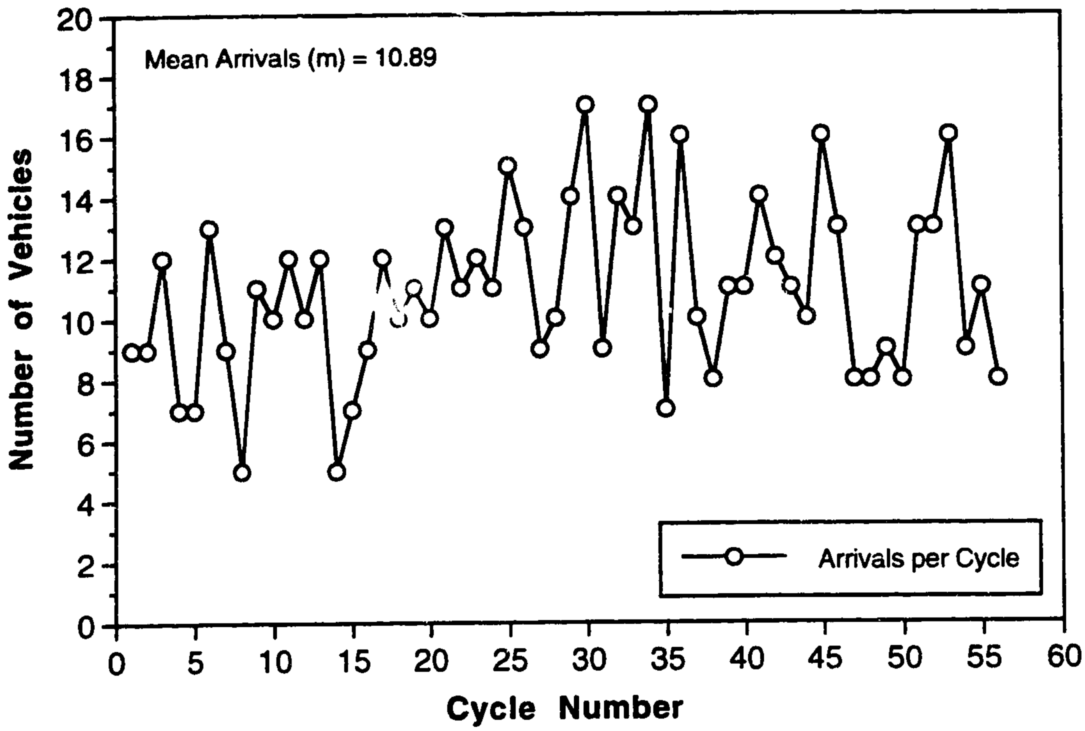


Figure B-3.32 Arrivals per Cycle for Survey No. 14



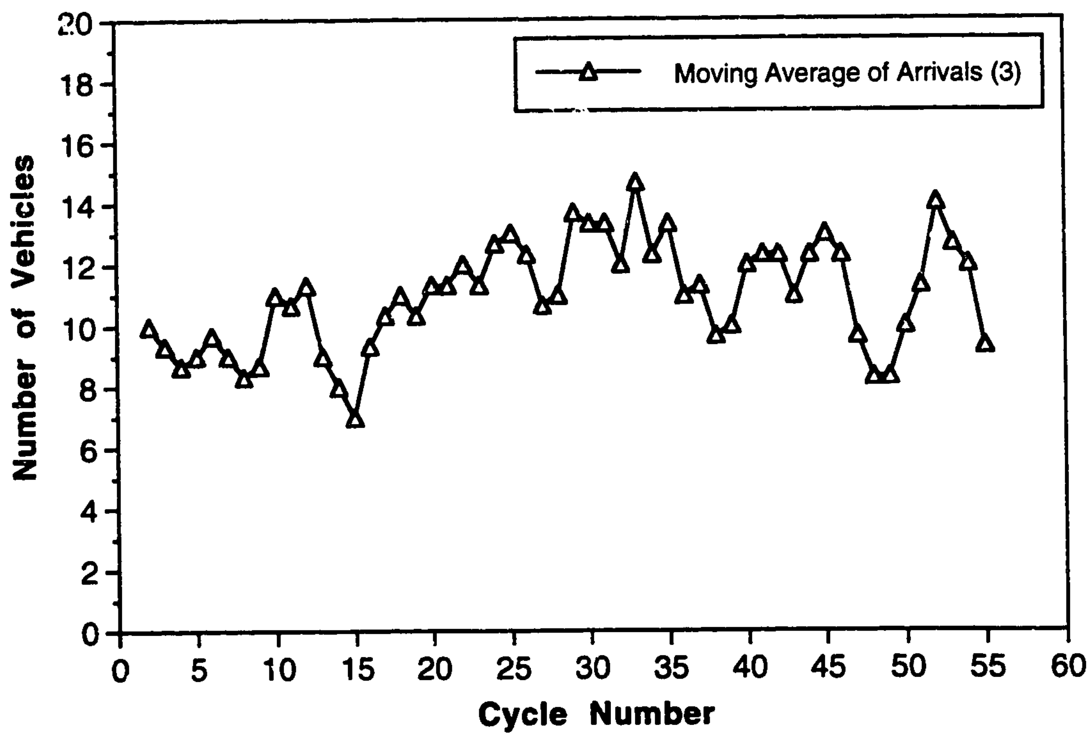
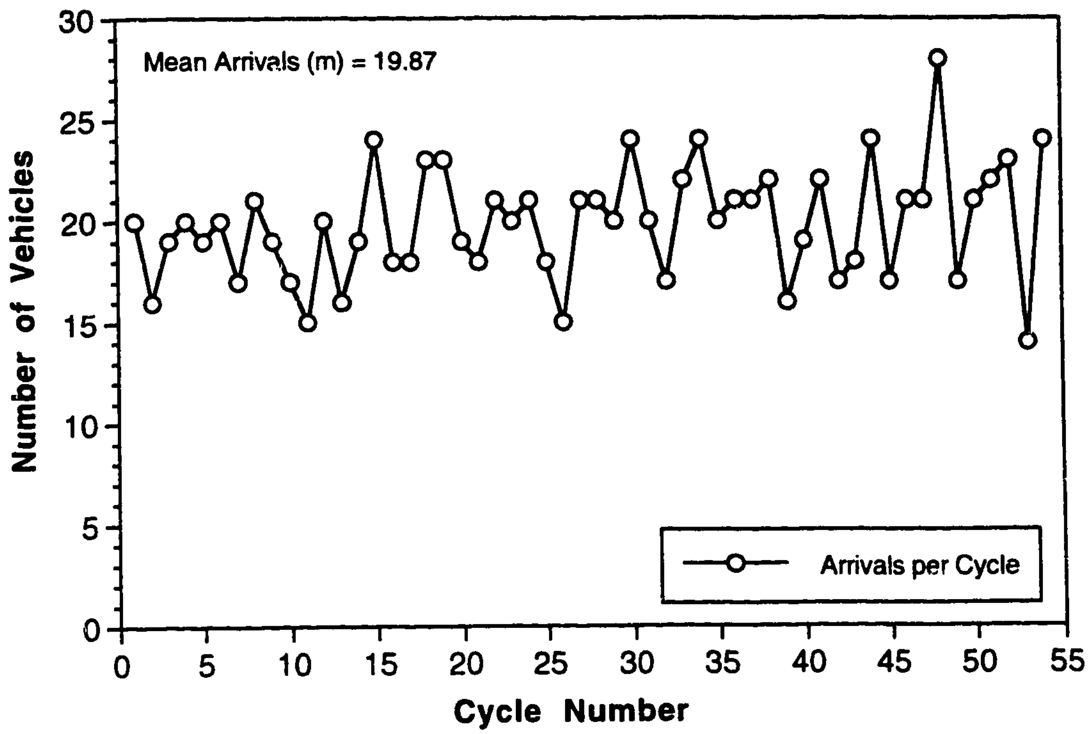


Figure B-3.33 Arrivals per Cycle for Survey No. 15



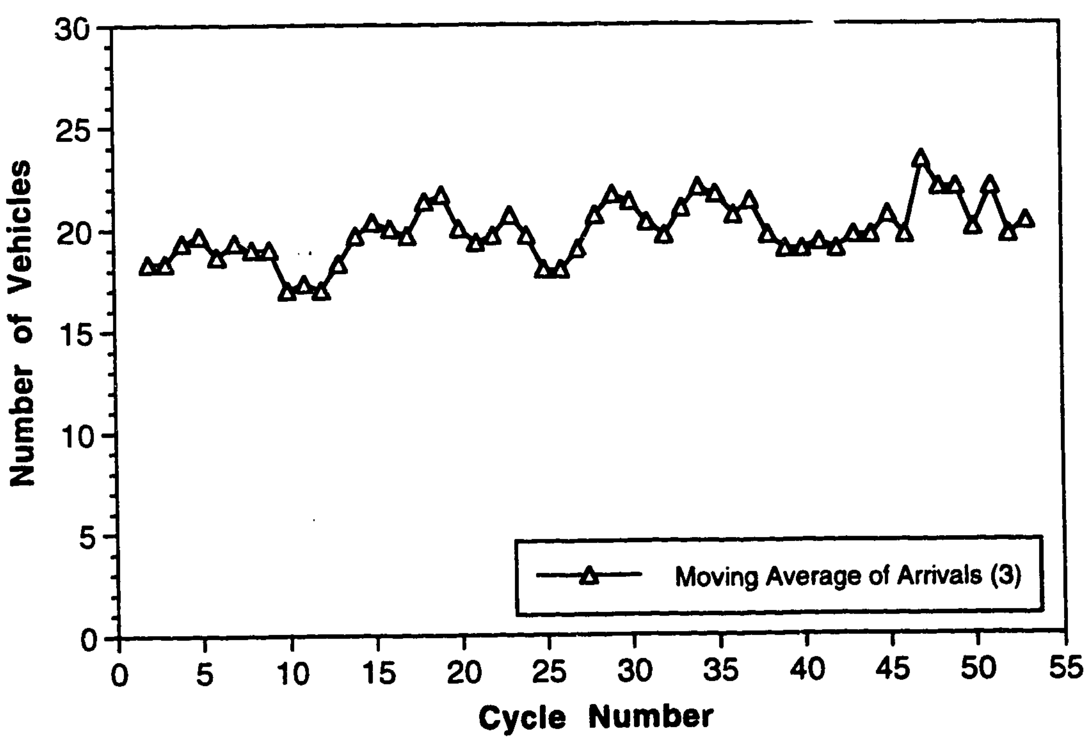
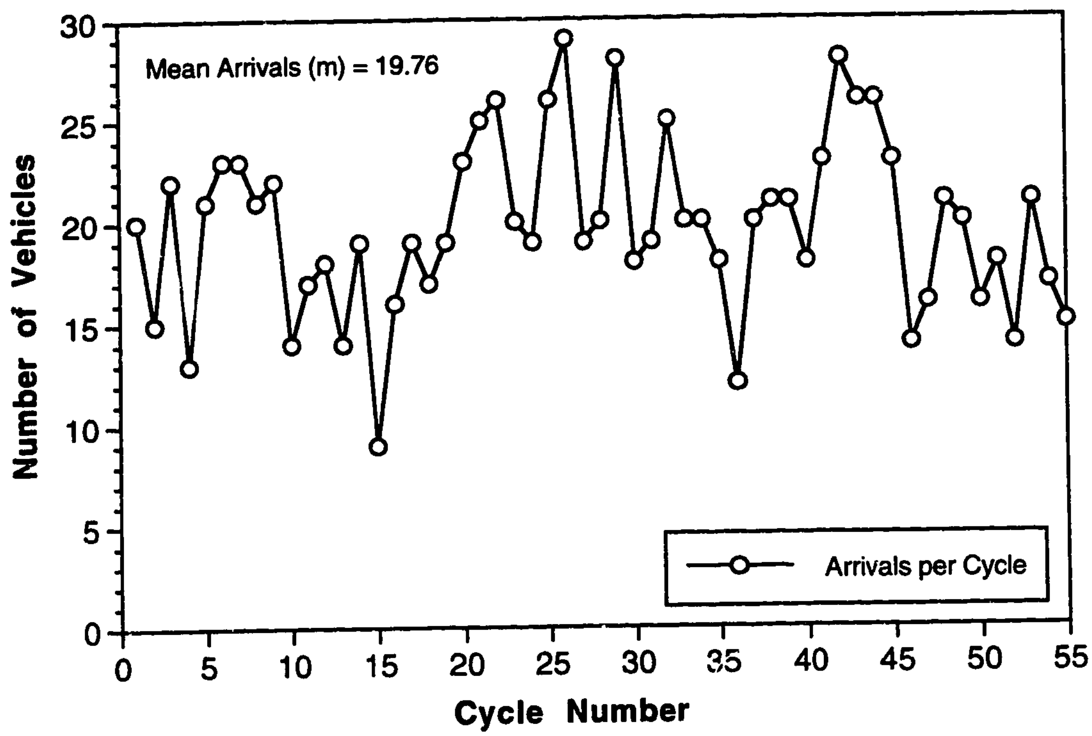


Figure B-3.34 Arrivals per Cycle for Survey No. 16



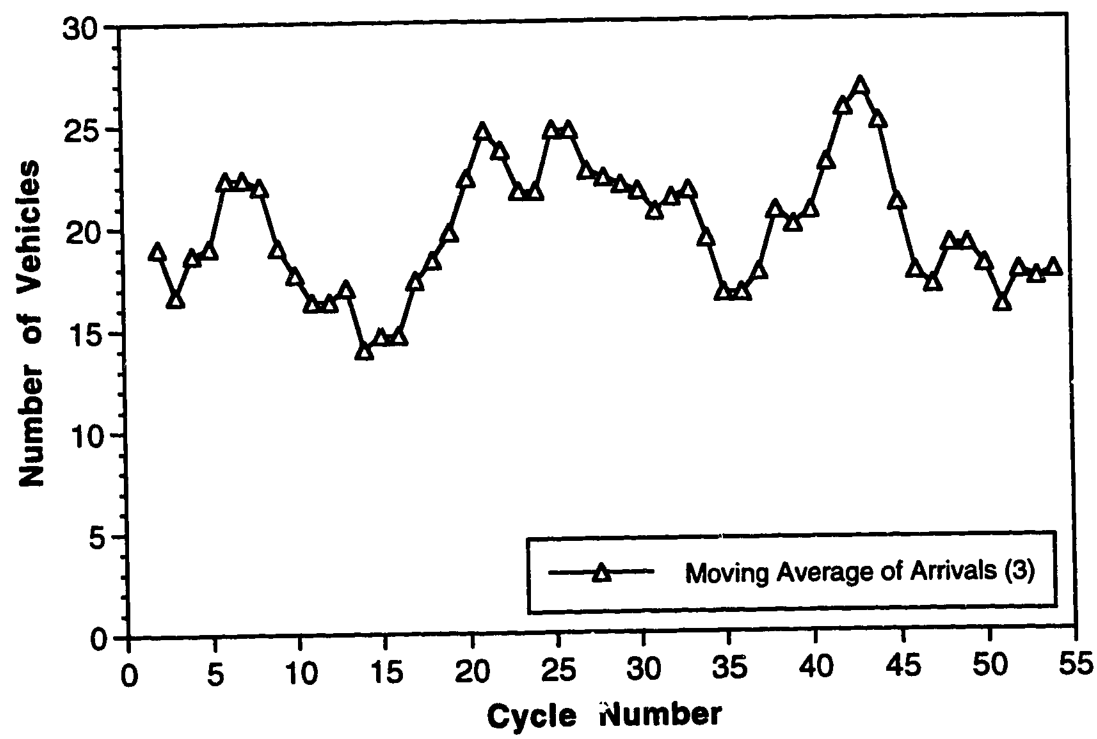
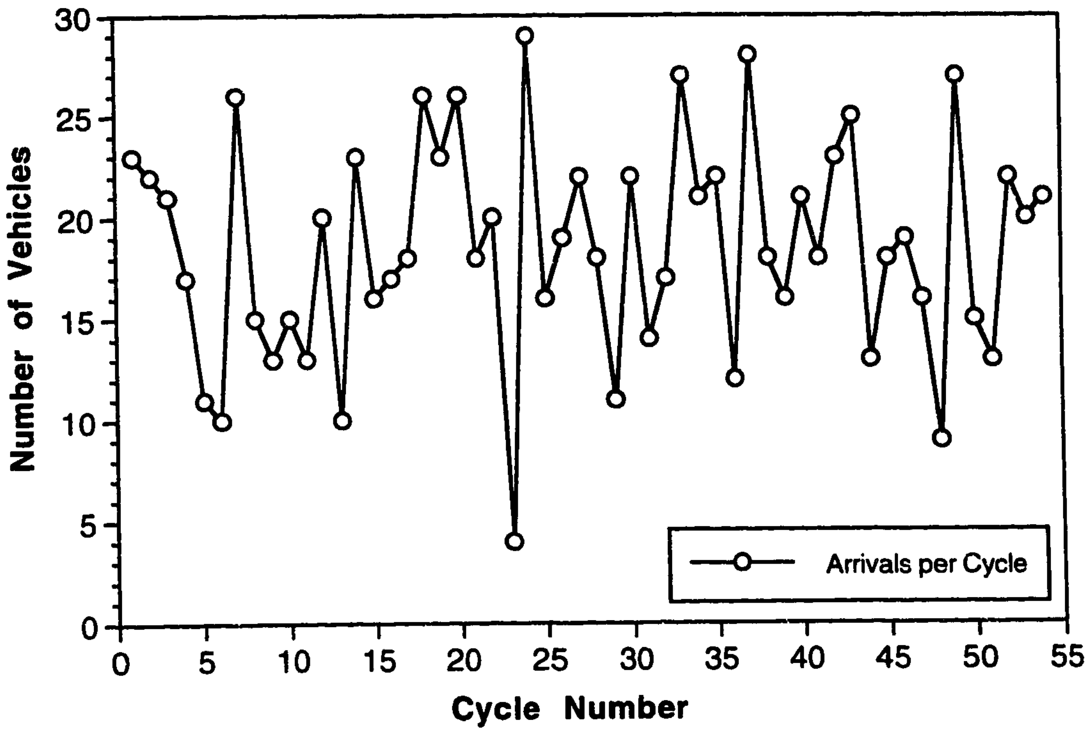


Figure B-3.35 Arrivals per Cycle for Survey No. 17



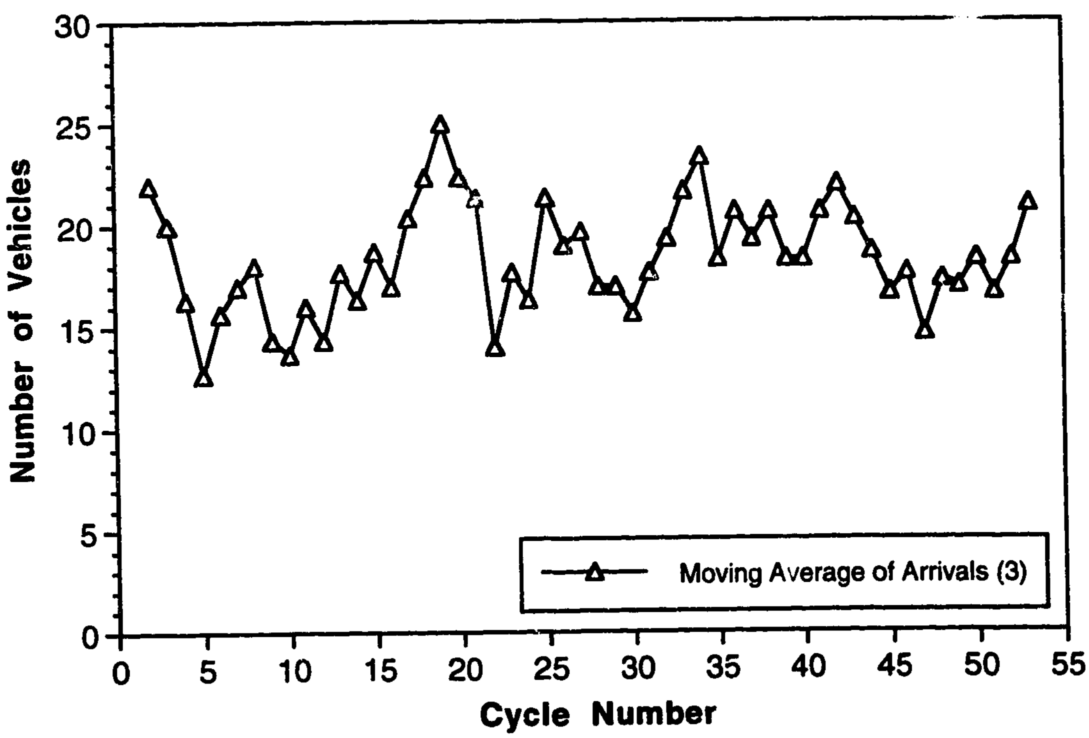
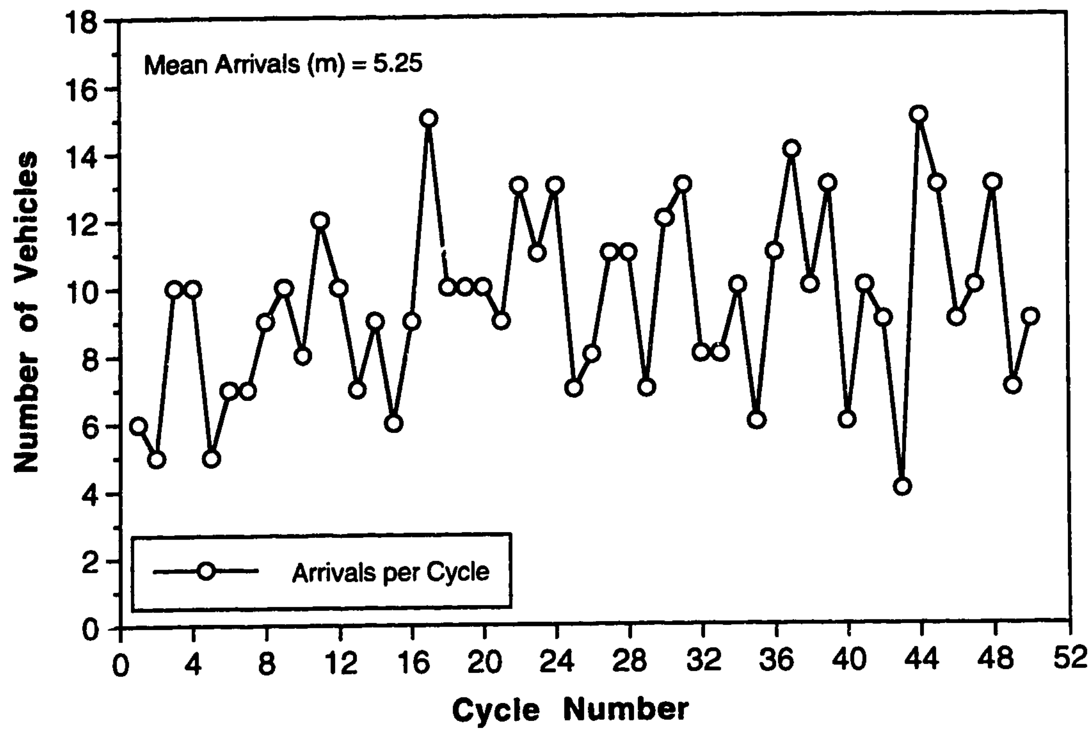


Figure B-3.36 Arrivals per Cycle for Survey No. 18



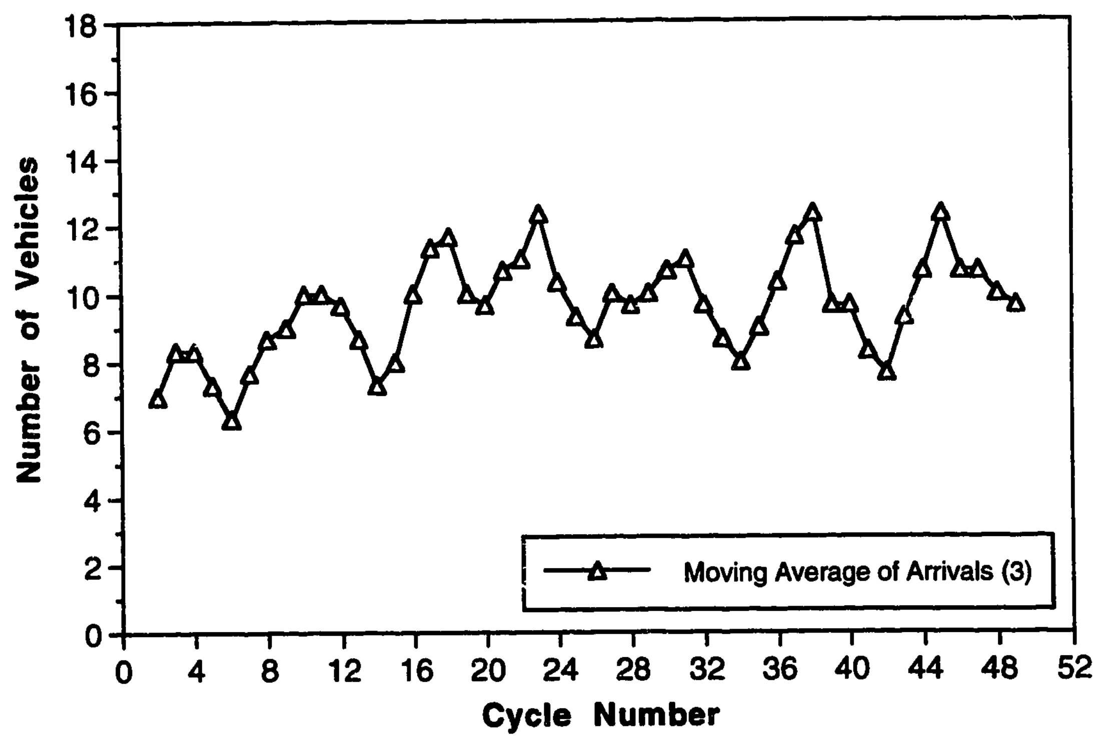
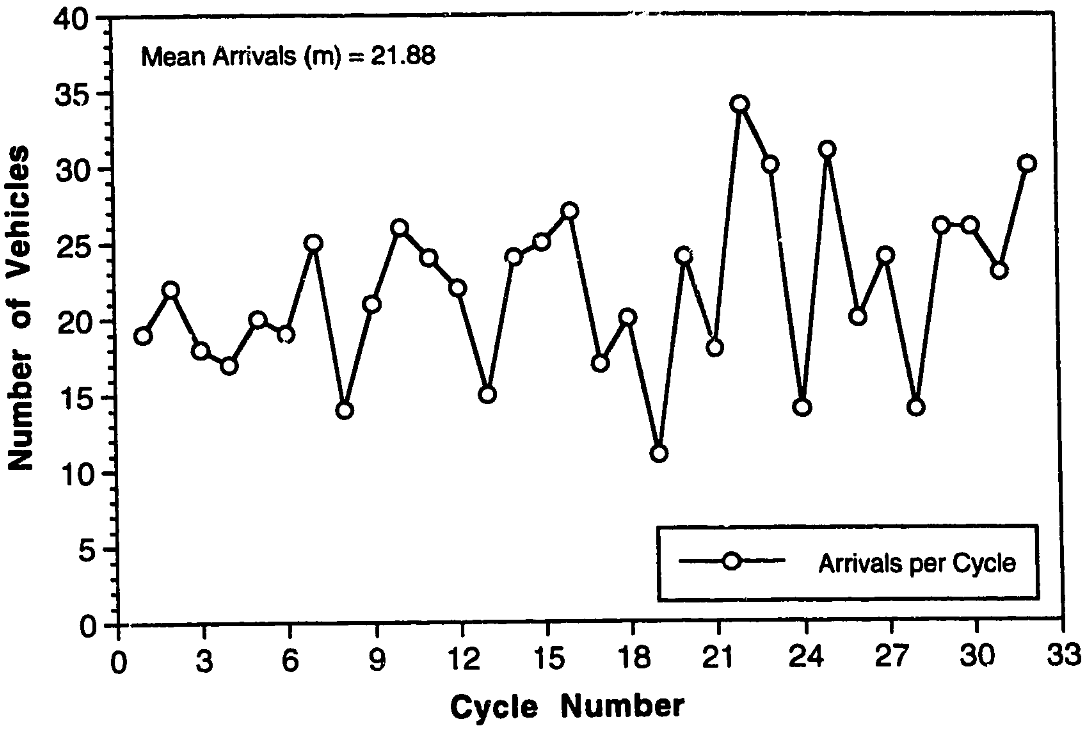


Figure B-3.37 Arrivals per Cycle for Survey No. 19



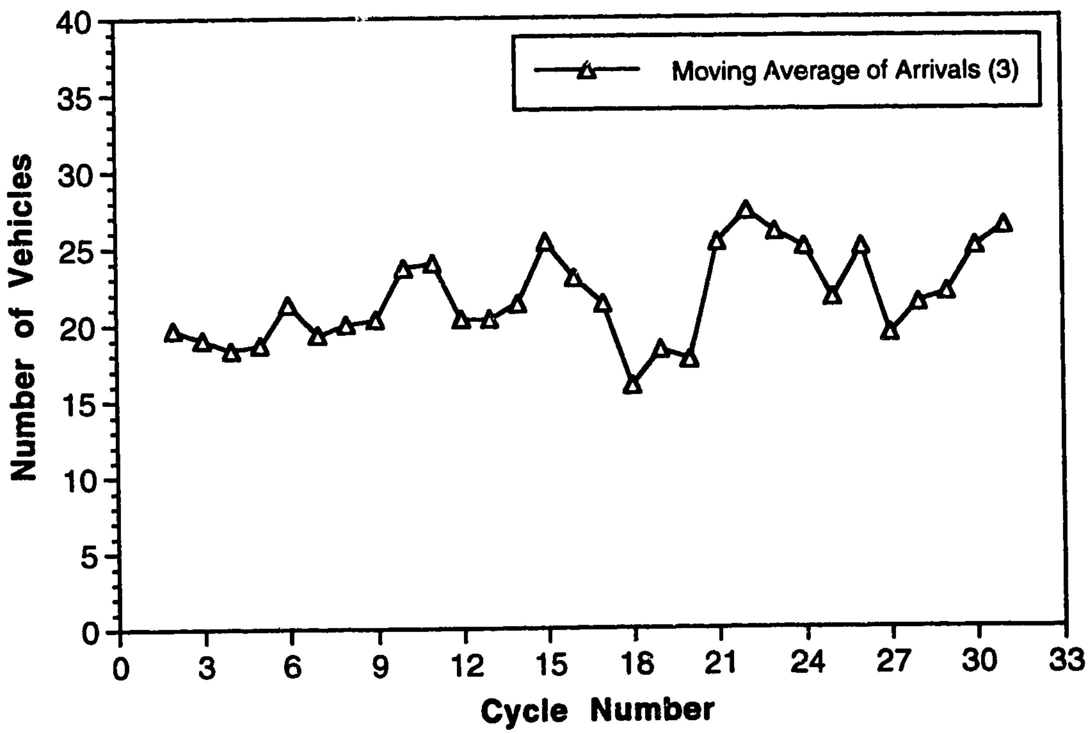


Figure B-3.38 Arrivals per Cycle for Survey No. 20

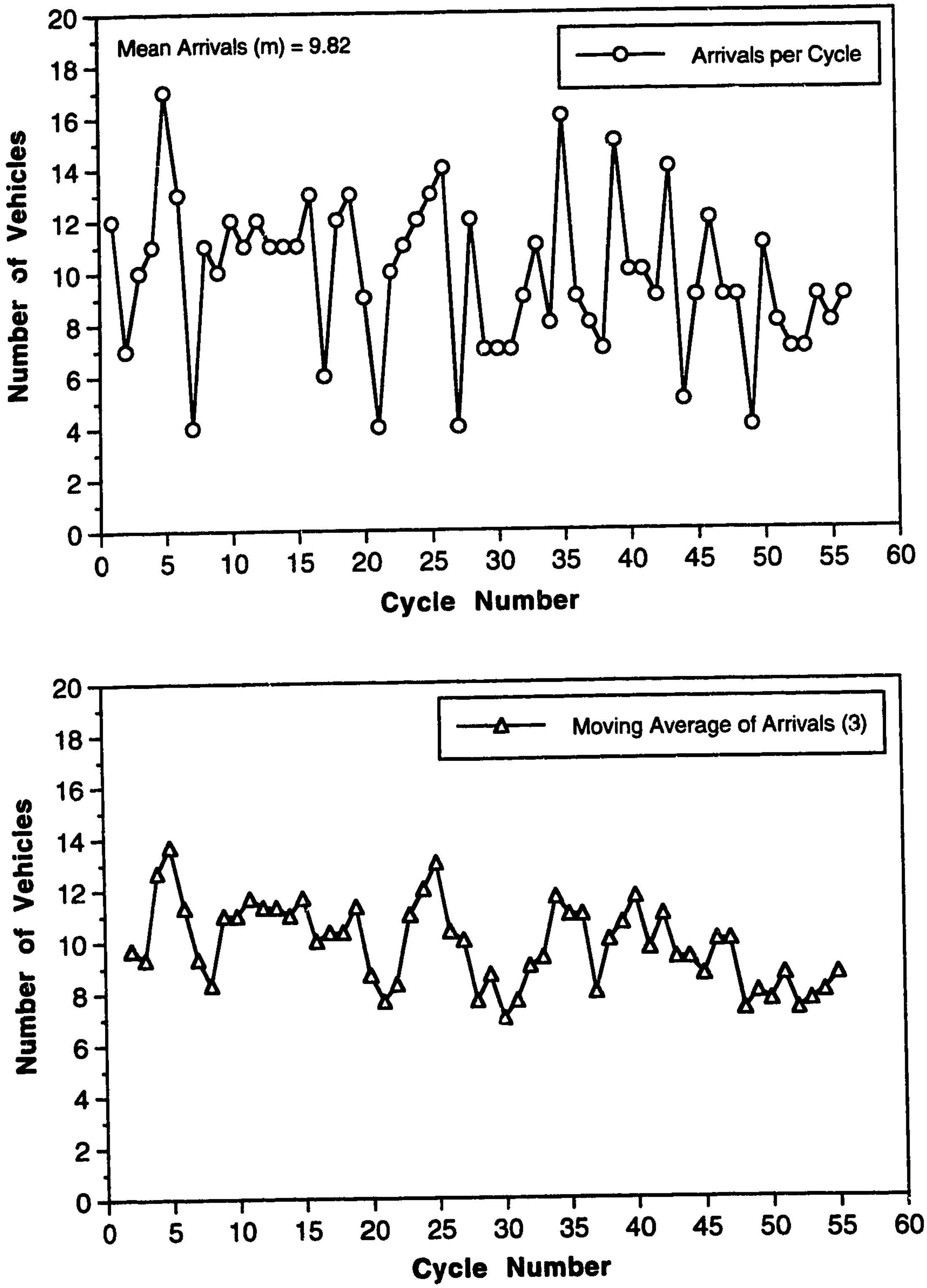
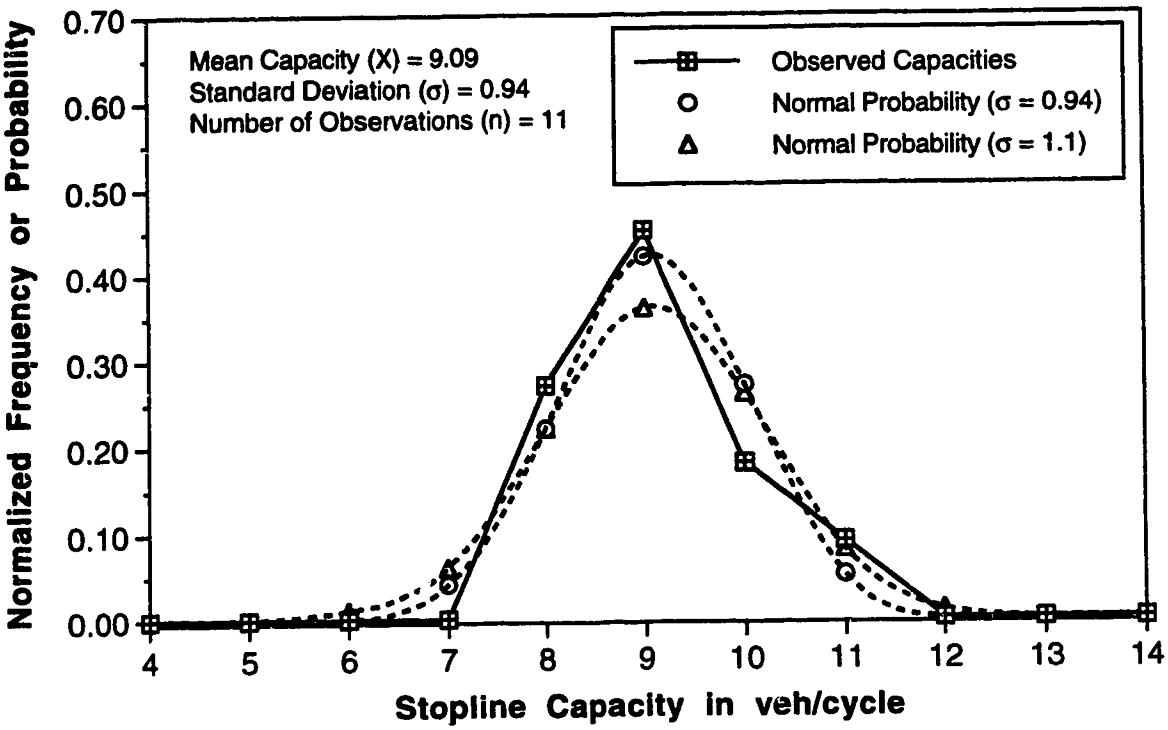


Figure B-3.39 Arrivals per Cycle for Survey No. 21

Appendix C



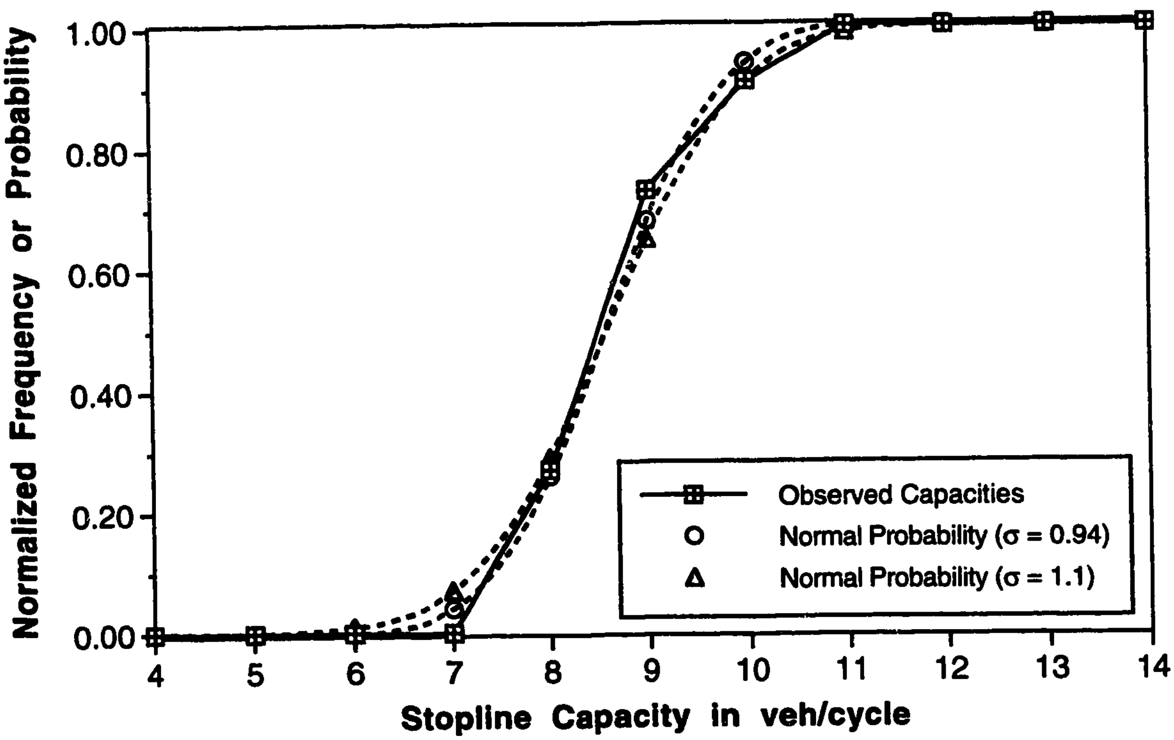
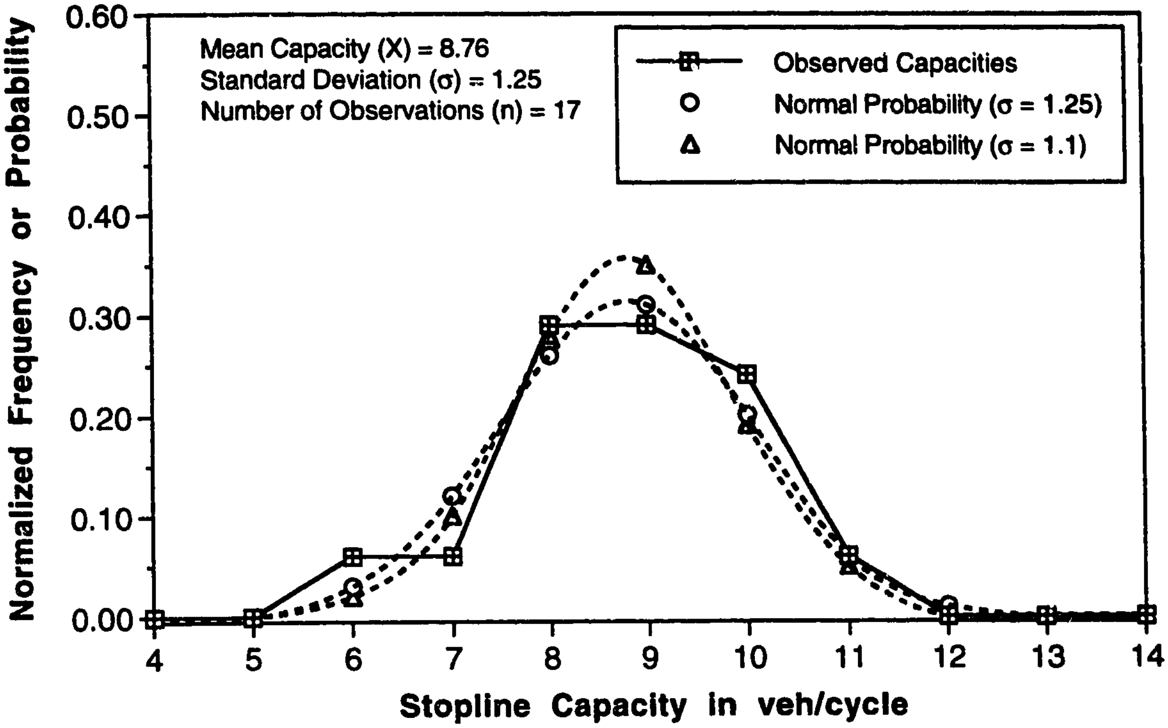


Figure C-4.1 Comparison between Observed Cycle Capacities and Normally Distributed Capacities for Survey No. 1



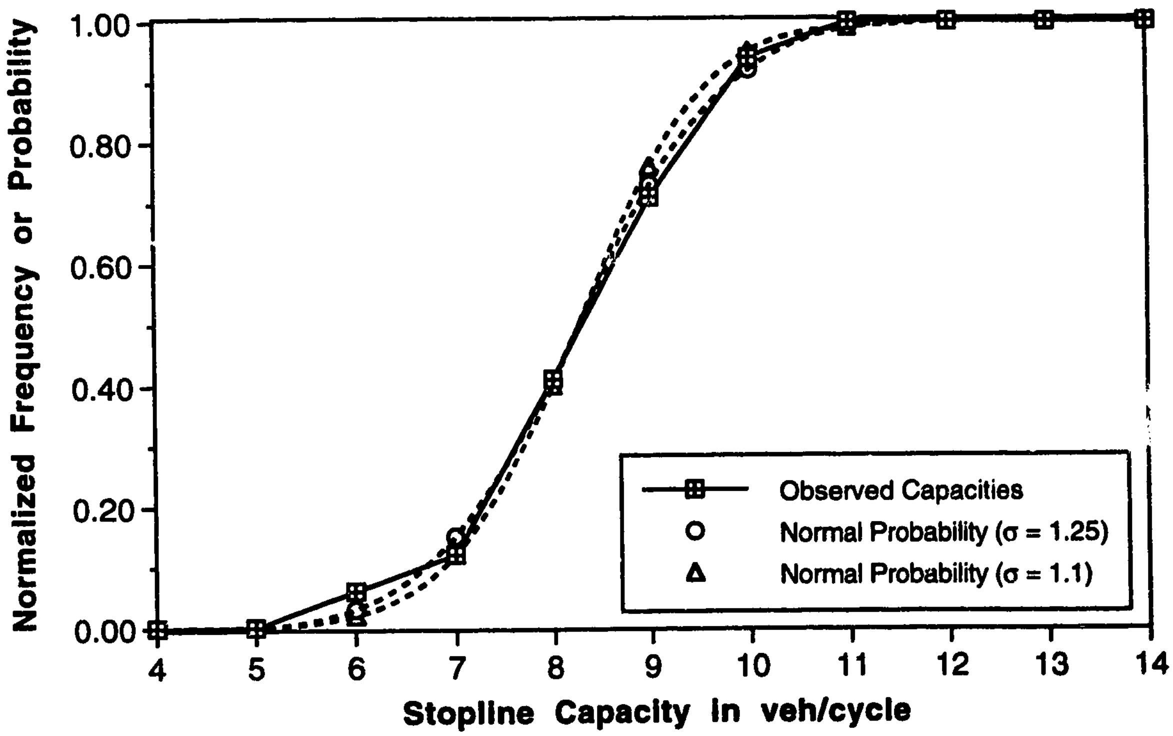
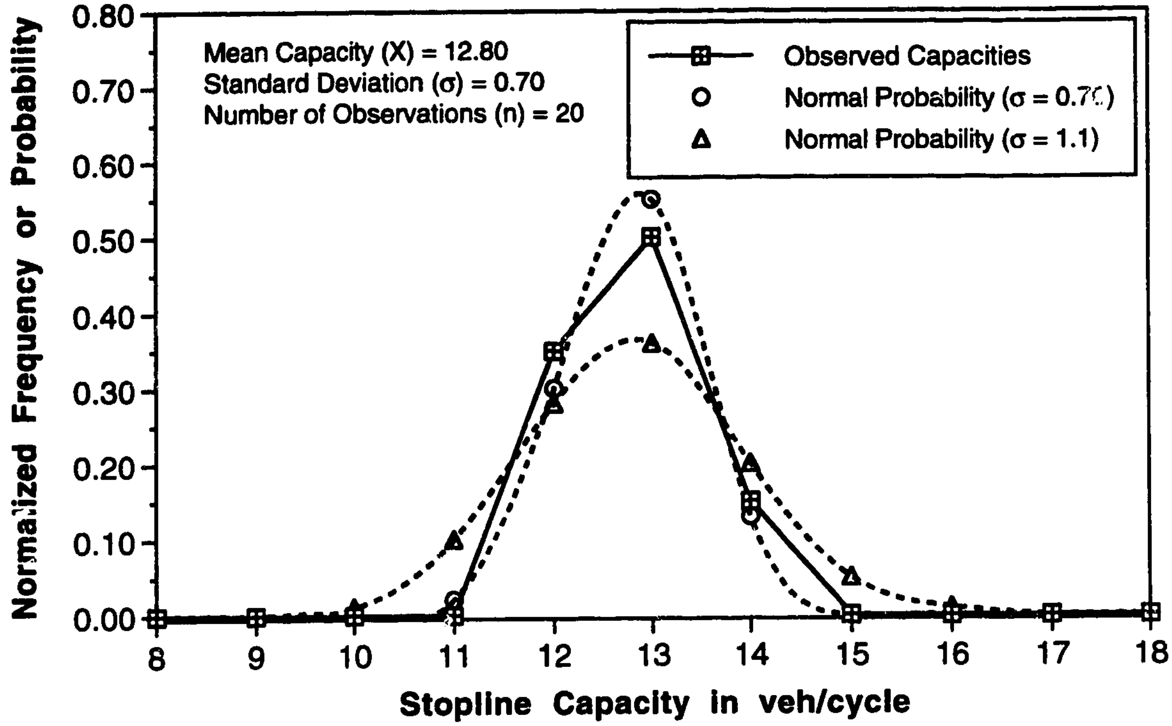


Figure C-4.2 Comparison between Observed Cycle Capacities and Normally Distributed Capacities for Survey No. 3



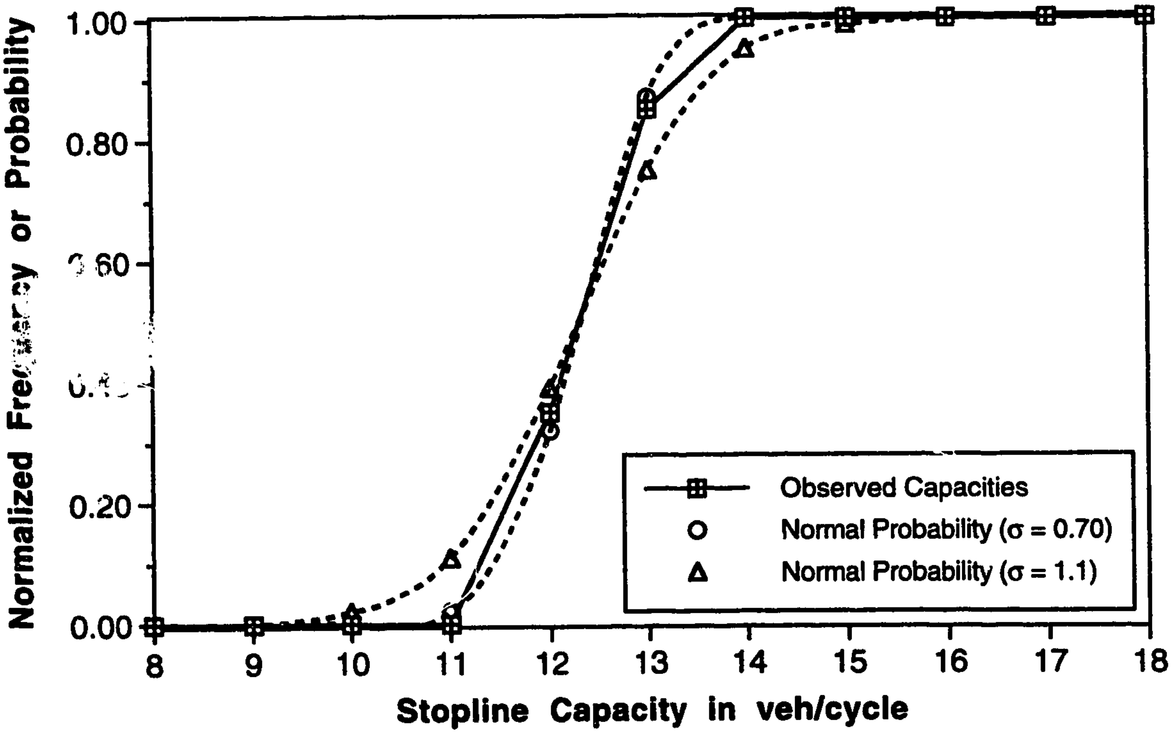
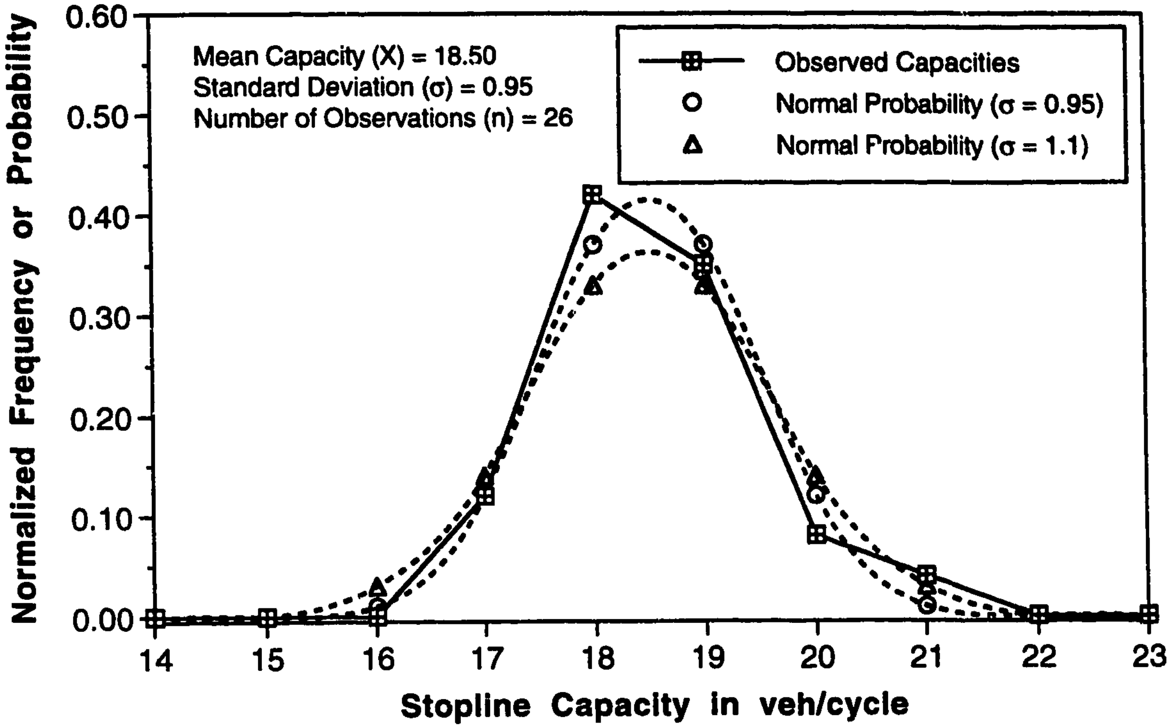


Figure C-4.3 Comparison between Observed Cycle Capacities and Normally Distributed Capacities for Survey No. 5



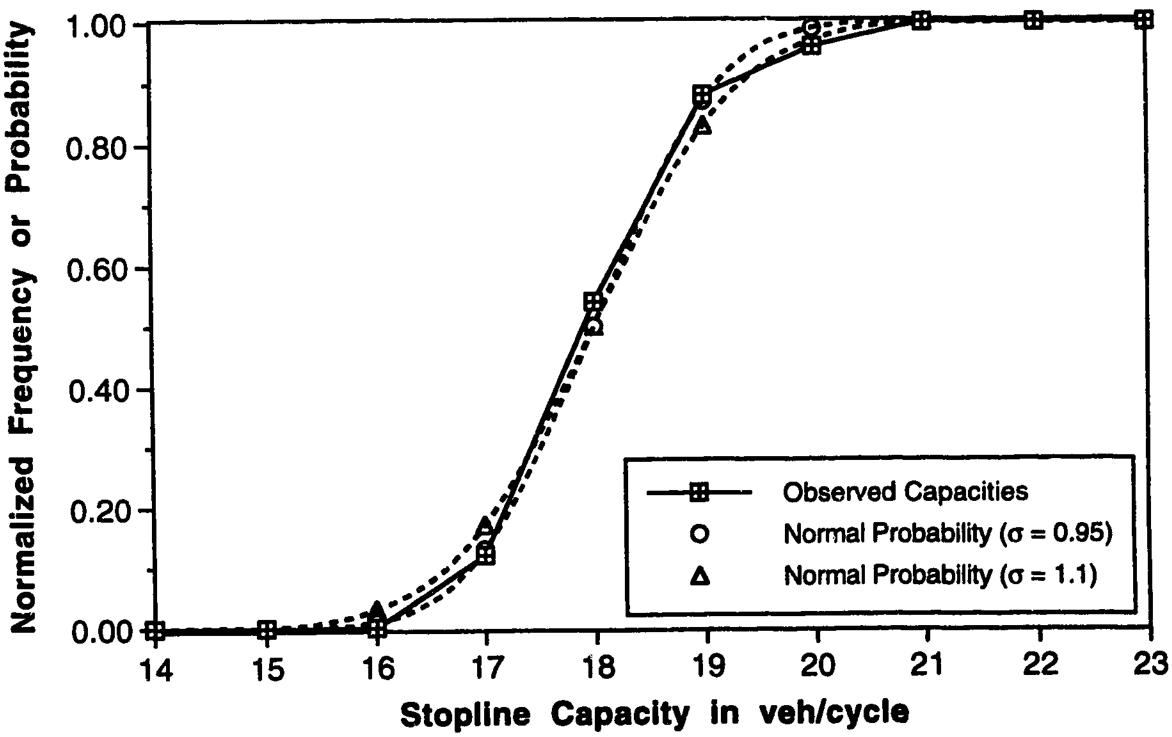


Figure C-4.4 Comparison between Observed Cycle Capacities and Normally Distributed Capacities for Survey No. 7

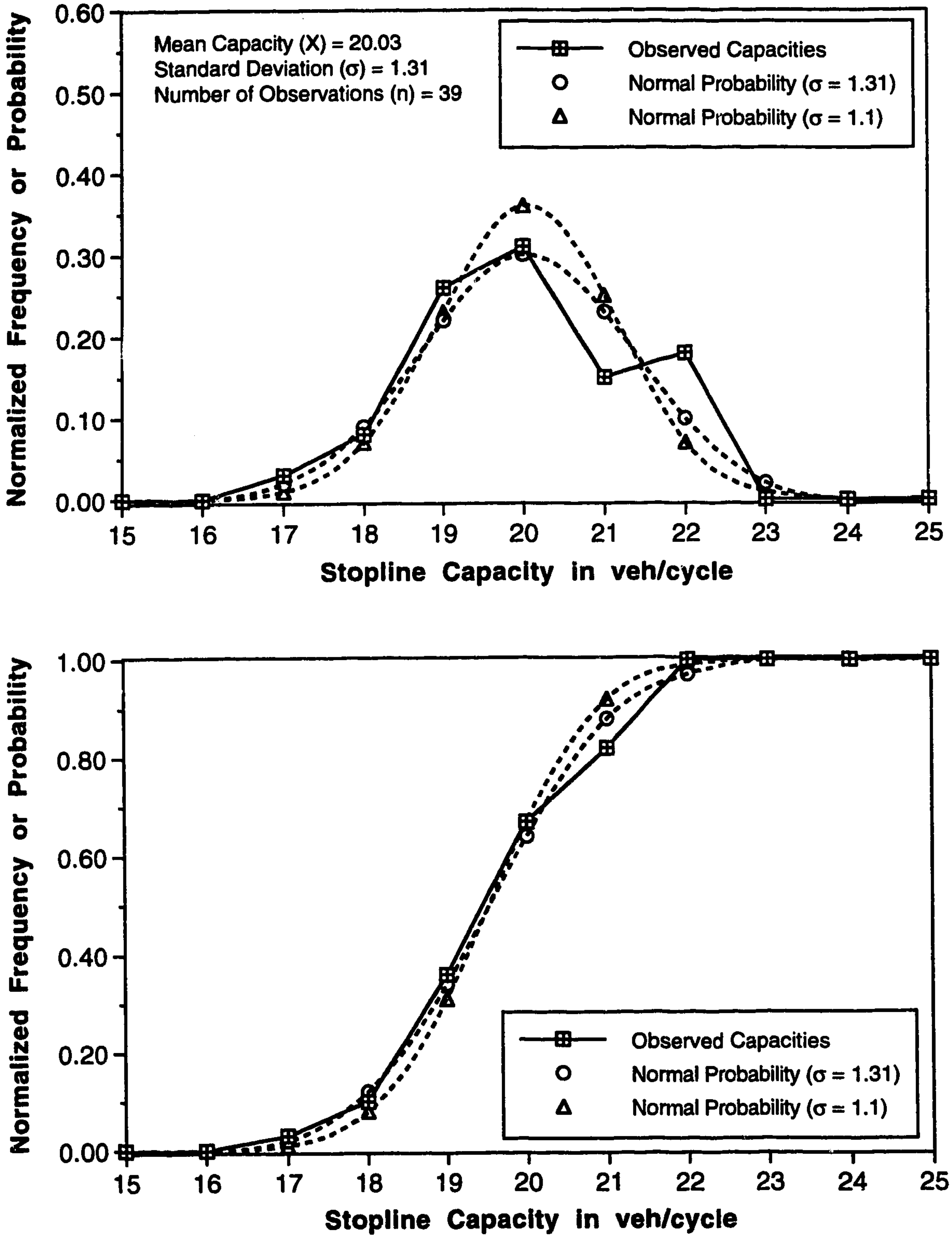
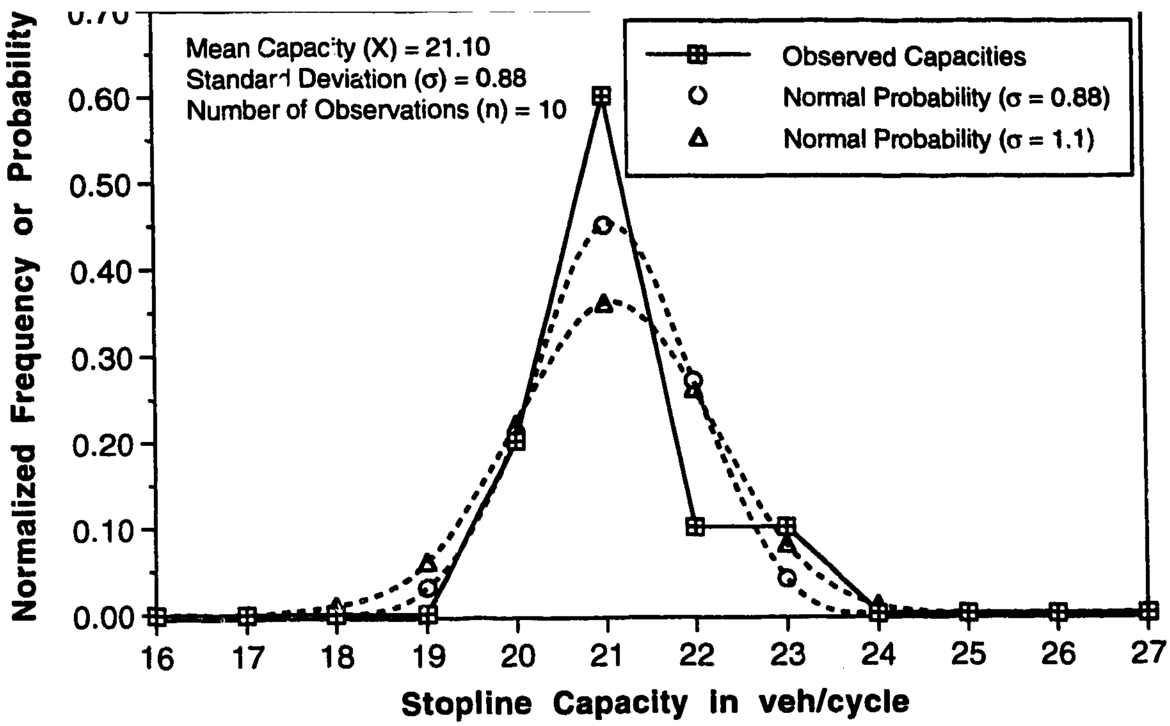


Figure C-4.5 Comparison between Observed Cycle Capacities and Normally Distributed Capacities for Survey No. 8



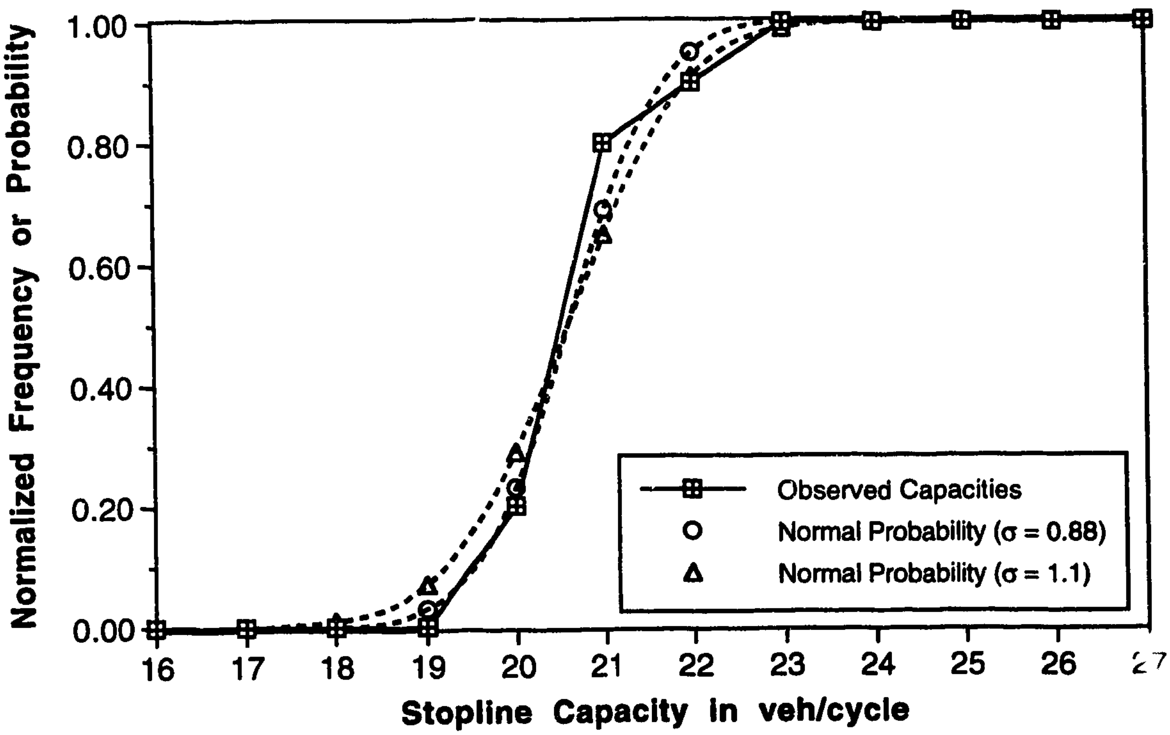
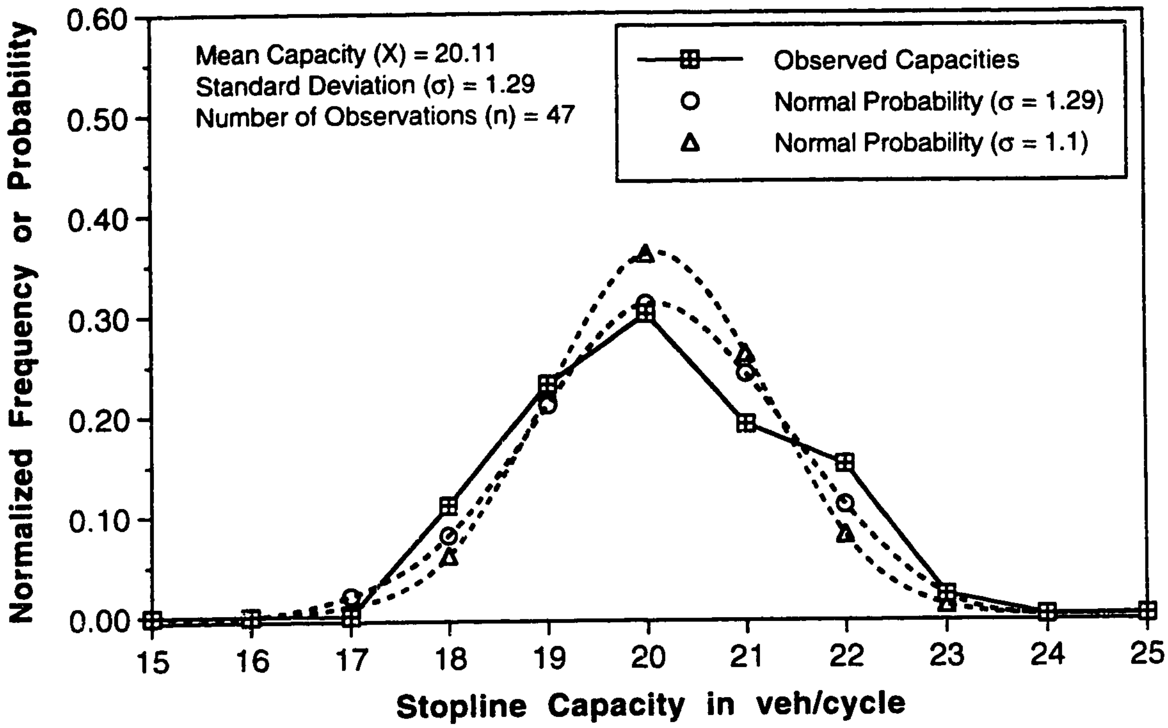


Figure C-4.6 Comparison between Observed Cycle Capacities and Normally Distributed Capacities for Survey No. 13



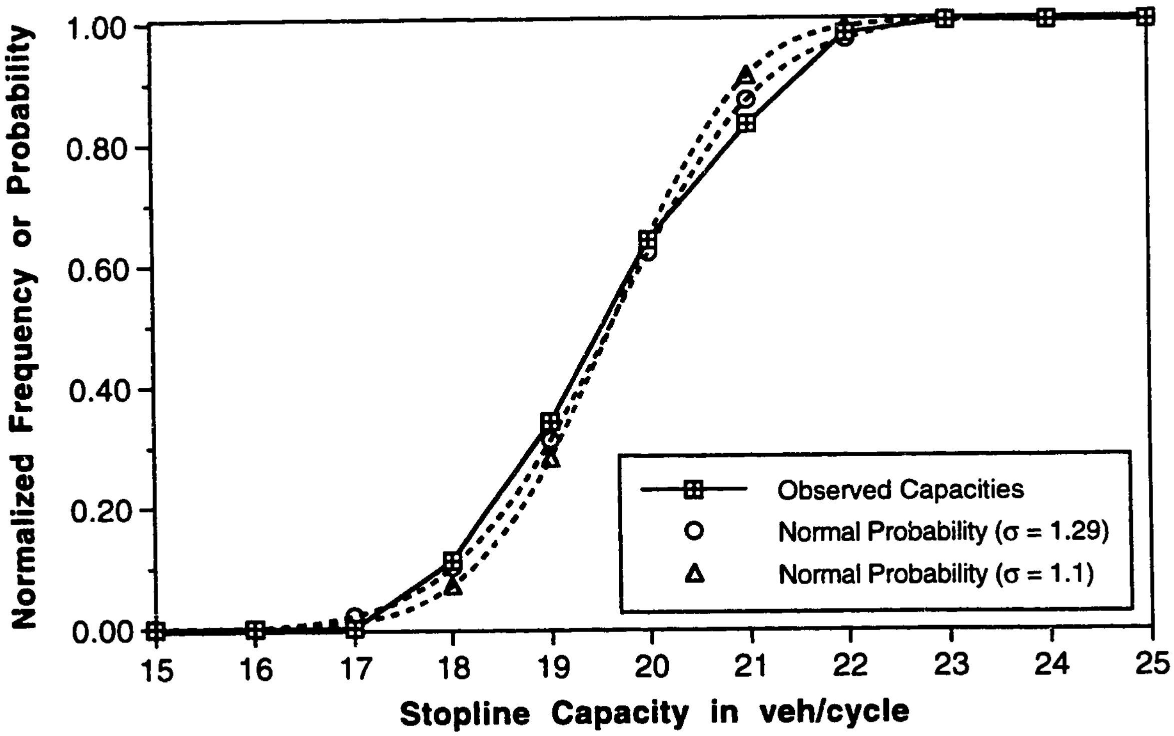


Figure C-4.7 Comparison between Observed Cycle Capacities and Normally Distributed Capacities for Survey No. 16

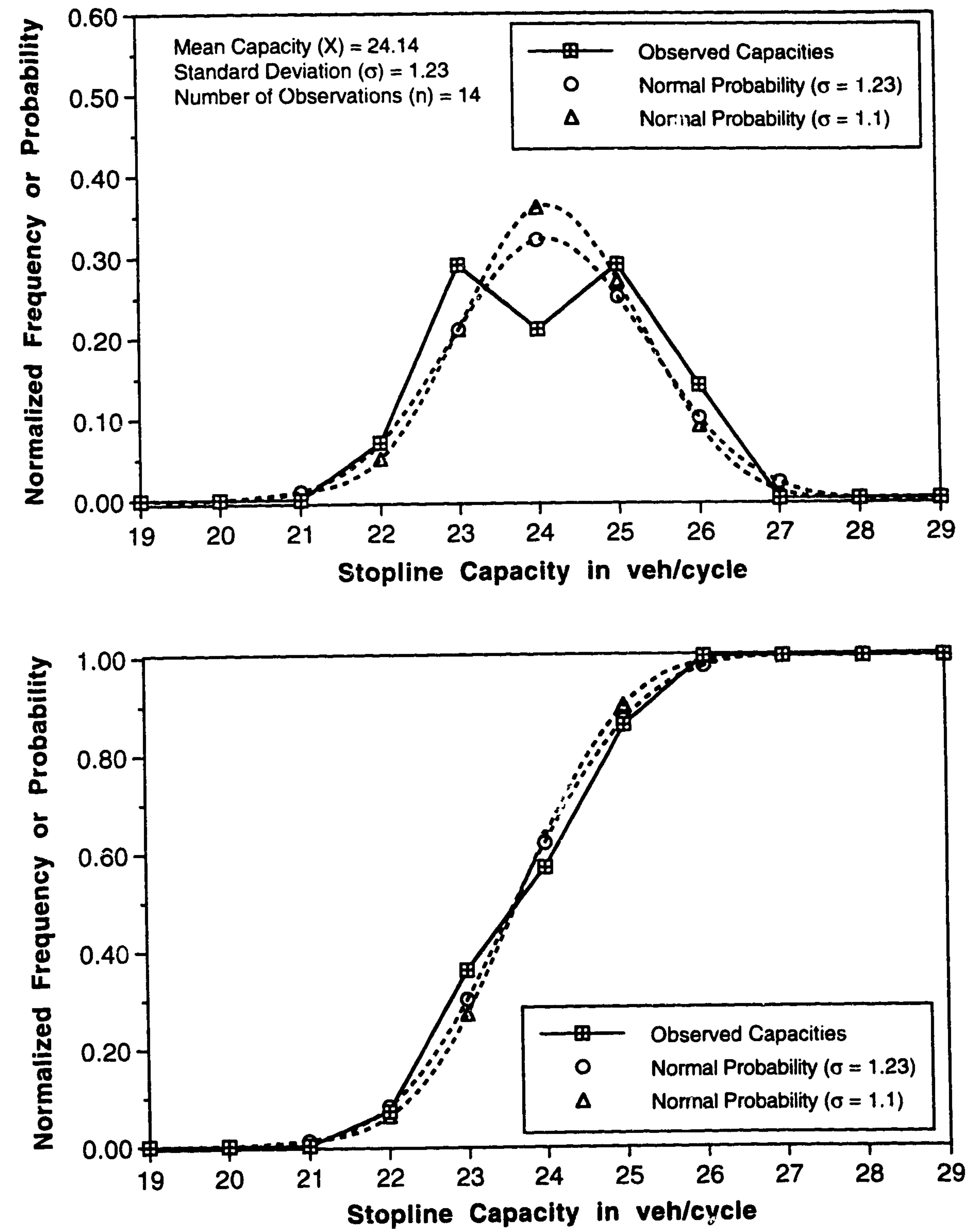


Figure C-4.8 Comparison between Observed Cycle Capacities and Normally Distributed Capacities for Survey No. 17

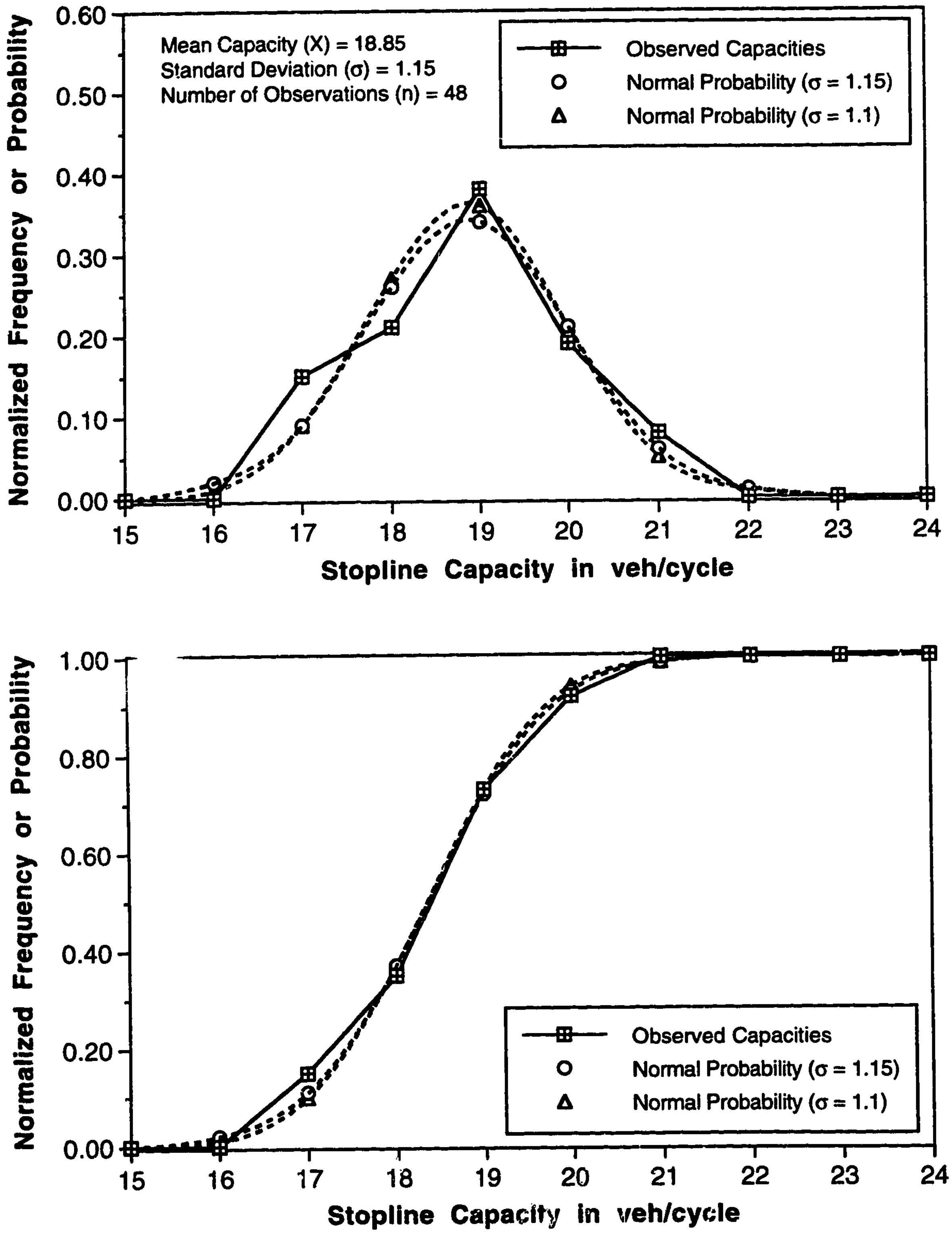
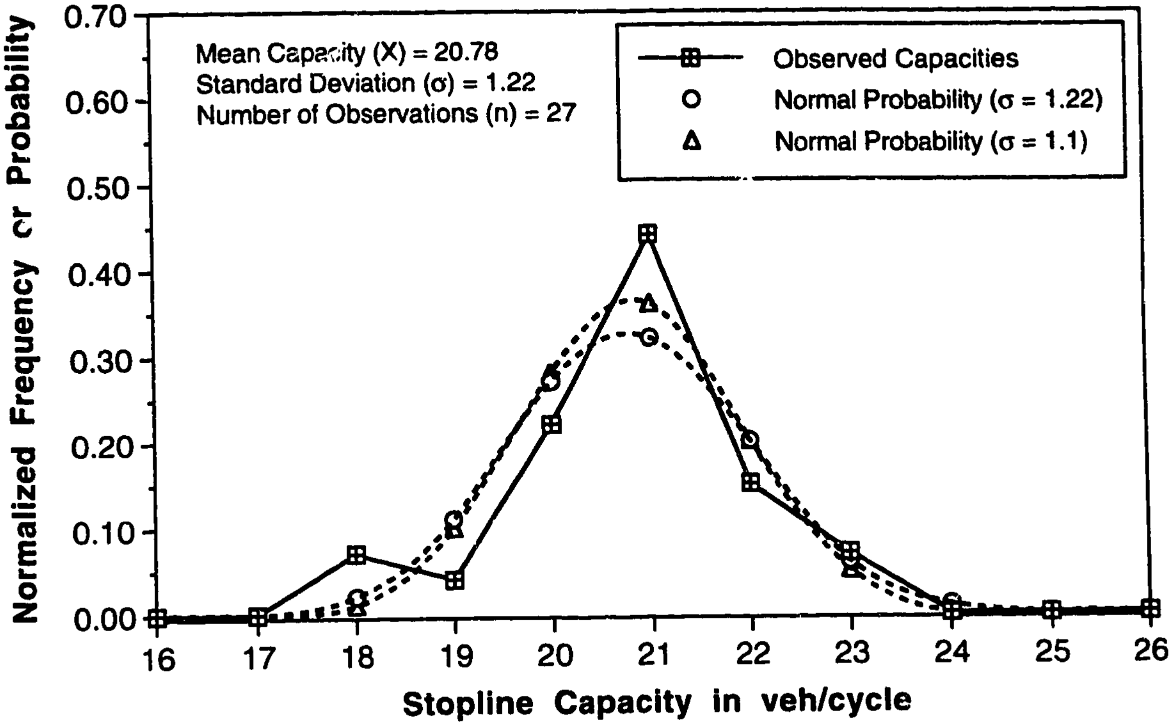


Figure C-4.9 Comparison between Observed Cycle Capacities and Normally Distributed Capacities for Survey No. 18



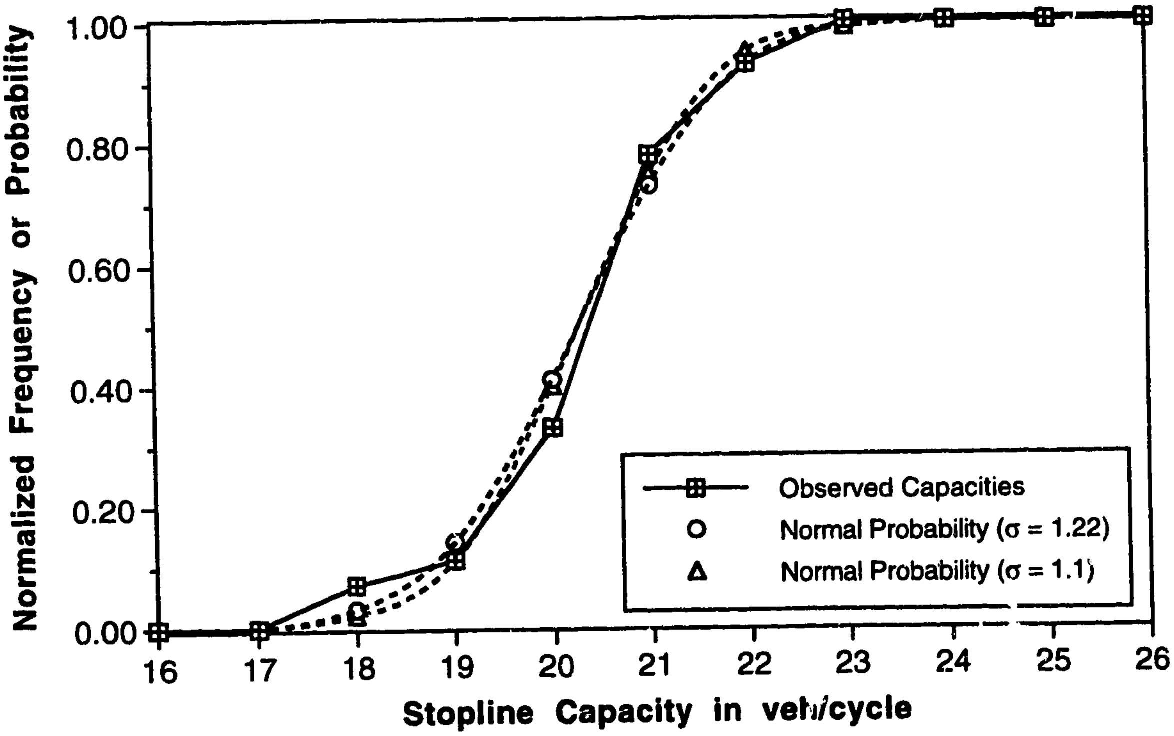


Figure C-4.10 Comparison between Observed Cycle Capacities and Normally Distributed Capacities for Survey No. 20

Appendix D

DISCAPOS - Source Code Listing

```
program MainProgram;

    uses
        SubSubPrograms, SubPrograms;

    var
        I, J, Arrivals, Capacity, ECap, OLcycle, OLveh, Temp: integer;
        Series, Cycle, Rerun, Reset, Disp: integer;
        MeanCap, MeanArr, RandNum, SumOL, AveOLF: real;
        NC, NS, StDev, OnePlus, OneMinus, OLF, Save: real;
        fullScreen: Rect;

begin
    SetRect(fullScreen, 0, 16, 640, 480);
    SetTextRect(fullScreen);
    Rerun := 1;
    Reset := 1;

    writeln('Welcome to DISCAPOS - The Distributed Capacity Overload Factor
Simulation Program');
    writeln('                    © Randall Sonnenberg - 1993');
    writeln;



    repeat

        GetCap(MeanCap);
        GetMArr(MeanArr);
        GetCycle;
        CalcMax(MeanCap, MeanArr);
        CalcADist(MeanArr, ArrDist);
        CalcCDist(MeanCap, CapDist);

        repeat
            Series := 1;
            Cycle := 1;
            OLcycle := 0;
            OLveh := 0;
            SumOL := 0;

            writeln;
            randSeed := integer(TickCount);

            writeln('||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||');

            while Series <= NumSeries do
                begin
                    while Cycle <= NumCycle do
                        begin
                            RandNum := (abs(Random) / 32767);
```

```
                    CalcArr(RandNum, ArrDist, Arrivals);
                    RandNum := (abs(Random) / 32767);
                    CalcCap(RandNum, CapDist, Capacity);
                    ECap := Capacity - OLVeh;

                    if Arrivals > ECap then
                        begin
                            OLcycle := OLcycle + 1;
                            OLveh := Arrivals - ECap;
                        end {true if}
                    else
                        OLveh := 0; {false if}

                    Cycle := Cycle + 1;

                end; {Cycle while loop}

            OLF := OLcycle / NumCycle;
            OLFVect(Series) := OLF;
            NumOL(Series) := OLcycle;
            SumOL := SumOL + OLcycle;

            OLveh := 0;
            OLcycle := 0;
            Cycle := 1;
            Series := Series + 1;

            if Series mod 10 = 0 then
                write('I');

        end; {Series while loop}

    NC := NumCycle;
    NS := NumSeries;
    AveOLF := SumOL / (NC * NS);
    CalcStDev(NumOL, StDev);
    writeln;
    writeln;
    writeln(NumSeries : 5, ' series of', NumCycle : 3, ' cycles were simulated');
    writeln;
    writeln('Average Overload Factor = ', AveOLF : 5 : 2, '        Standard Deviation =
', StDev : 5 : 2);

    OneMinus := AveOLF - StDev;
    OnePlus := AveOLF + StDev;
    writeln('  Average OLF minus 1 Standard Deviation = ', OneMinus : 5 : 2);
    writeln('  Average OLF plus 1 Standard Deviation = ', OnePlus : 5 : 2);

    for J := NumSeries downto 2 do
        for I := 1 to J - 1 do
            if OLFVect(I) > OLFVect(I + 1) then
                begin
                    Save := OLFVect(I + 1);
                    OLFVect(I + 1) := OLFVect(I);
```

```
                OLFVect(I) := Save;
            end;  {True if}

for I := 1 to 20 do
     DistVect(I) := 0;

writeln;
writeln('Distribution of Overload Factors in groups of 0.05');
for I := 1 to NumSeries do
     begin
          if OLFVect(I) < 0.05 then
               DistVect(1) := DistVect(1) + 1
          else if OLFVect(I) < 0.10 then
               DistVect(2) := DistVect(2) + 1
          else if OLFVect(I) < 0.15 then
               DistVect(3) := DistVect(3) + 1
          else if OLFVect(I) < 0.20 then
               DistVect(4) := DistVect(4) + 1
          else if OLFVect(I) < 0.25 then
               DistVect(5) := DistVect(5) + 1
          else if OLFVect(I) < 0.30 then
               DistVect(6) := DistVect(6) + 1
          else if OLFVect(I) < 0.35 then
               DistVect(7) := DistVect(7) + 1
          else if OLFVect(I) < 0.40 then
               DistVect(8) := DistVect(8) + 1
          else if OLFVect(I) < 0.45 then
               DistVect(9) := DistVect(9) + 1
          else if OLFVect(I) < 0.50 then
               DistVect(10) := DistVect(10) + 1
          else if OLFVect(I) < 0.55 then
               DistVect(11) := DistVect(11) + 1
          else if OLFVect(I) < 0.60 then
               DistVect(12) := DistVect(12) + 1
          else if OLFVect(I) < 0.65 then
               DistVect(13) := DistVect(13) + 1
          else if OLFVect(I) < 0.70 then
               DistVect(14) := DistVect(14) + 1
          else if OLFVect(I) < 0.75 then
               DistVect(15) := DistVect(15) + 1
          else if OLFVect(I) < 0.80 then
               DistVect(16) := DistVect(16) + 1
          else if OLFVect(I) < 0.85 then
               DistVect(17) := DistVect(17) + 1
          else if OLFVect(I) < 0.90 then
               DistVect(18) := DistVect(18) + 1
          else if OLFVect(I) < 0.95 then
               DistVect(19) := DistVect(19) + 1
          else if OLFVect(I) <= 1.00 then
               DistVect(20) := DistVect(20) + 1
     end;  {OLF Bins}

  for I := 1 to 20 do
     write(DistVect(I) : 4);
```

```
            writeln;
            writeln;
            writeln('Percentiles of Overload Factor Distribution');
            writeln('90th Percentiles = ', OLFVect(50) : 5 : 2, OLFVect(950) : 7 : 2);
            writeln('67th Percentiles = ', OLFVect(166) : 5 : 2, OLFVect(844) : 7 : 2);
            writeln('50th Percentiles = ', OLFVect(250) : 5 : 2, OLFVect(750) : 7 : 2);

            sysbeep(1);

            writeln;
            writeln('Enter 1 to rerun simulation with same input data, or any other number
to continue');
            readln(rerun);

        until rerun <> 1;

        writeln;
        writeln('Enter 1 to continue with new input data, or any other number to quit');
        readln(reset);

    until reset <> 1;

end. {MainProgram}
```

DISCAPOS - Source Code Listing

```
unit SubPrograms;

interface
    uses
        SubSubPrograms;

    procedure GetCap (var MeanCap: real);
    procedure GetMArr (var MeanArr: real);
    procedure GetCycle;
    procedure CalcADist (MeanArr: real; var ArrDist: DVect);
    procedure CalcCDist (MeanCap: real; var CapDist: DVect);
    procedure CalcArr (RandNum: real; ArrDist: DVect; var Arrivals: integer);
    procedure CalcCap (RandNum: real; CapDist: DVect; var Capacity: integer);
    procedure CalcStDev (NumOL: IVect; var StDev: real);


implementation

    procedure GetCap (var MeanCap: real);
        var
            Valid: boolean;

    begin
        repeat
            Valid := true;
            writeln;
            writeln('Enter STOPLINE CAPACITY of Lane, in veh/cycle:');
            readln(MeanCap);

            if MeanCap <= 0 then
                begin
                    writeln('Stopline Capacity must be greater than zero!!');
                    Valid := false;
                end;

            if MeanCap > 60 then
                begin
                    writeln('Stopline Capacity must not be more than 60!!');
                    Valid := false;
                end;

        until valid = true;
    end;  {GetCap procedure}

    procedure GetMArr (var MeanArr: real);
        var
            Valid: boolean;

    begin
        repeat
            Valid := true;
```

```
        writeln;
        writeln('Enter MEAN ARRIVALS for Lane, in veh/cycle:');
        readln(MeanArr);

        if MeanArr <= 0 then
            begin
                writeln('Average arrivals must be greater than zero!!');
                Valid := false;
            end;

        if MeanArr > 60 then
            begin
                writeln('Average arrivals must not be more than 60!!');
                Valid := false;
            end;

    until valid = true;
end;  {GetMArr procedure}

procedure GetCycle;
    var
        Data: real;
        Valid: boolean;

begin
    repeat
        Valid := True;
        writeln;
        writeln('Enter number of consecutive cycles to be simulated:');
        readln(Data);
        NumCycle := Round(Data);

        if NumCycle <= 5 then
            begin
                writeln('A' least five consecutive cycles must be simulated!!');
                Valid := false;
            end;

        if NumCycle > 250 then
            begin
                writeln('Chose fewer consecutive cycles for simulation!!');
                Valid := false;
            end;

    until Valid = True;
end;  {GetCycle procedure}

procedure CalcADist (MeanArr: real; var ArrDist: DVect);
    var
        I: integer;
        Pcurrent, Factorial: double;
        done: boolean;
        ProbVect: DVect;
```

```
begin
    I := 0;

    repeat
        Fact(I, Factorial);
        Pcurrent := EXP(-MeanArr) * EXP(I * LN(MeanArr)) / Factorial;
        ProbVect(I) := Pcurrent;
        I := I + 1;
    until I = Max;

    ArrDist(0) := ProbVect(0);
    I := 1;

    repeat
        ArrDist(I) := ArrDist(I - 1) + ProbVect(I);
        I := I + 1;
    until I = Max;

    ArrDist(Max) := 1.0;

end; {CalcADist procedure}

procedure CalcCDist (MeanCap: real; var CapDist: DVect);
    var
        I: integer;
        Pcurrent: double;
        done: boolean;
        ProbVect: DVect;

begin
    I := 0;

    repeat
        Pcurrent := 0.3626748 * EXP(-((SQR(I - MeanCap)) / 2.42));
        ProbVect(I) := Pcurrent;
        I := I + 1;
    until I = Max;

    CapDist(0) := ProbVect(0);
    I := 1;

    repeat
        CapDist(I) := CapDist(I - 1) + ProbVect(I);
        I := I + 1;
    until I = Max;

    CapDist(Max) := 1.0;

end; {CalcCDist procedure}

procedure CalcArr (RandNum: real; ArrDist: DVect; var Arrivals: integer);
    var
        I: integer;
        done: boolean;
```

```
begin

    I := 0;
    Done := false;


    repeat
        if I = Max then
            begin
                Arrivals := Max;
                Done := true;
            end;
        if RandNum <= ArrDist(I) then
            begin
                Arrivals := I;
                Done := true;
            end;
        I := I + 1;
    until Done = true;

end; {CalcArr procedure}

procedure CalcCap (RandNum: real; CapDist: DVect; var Capacity: integer);
    var
        I: integer;
        done: boolean;

begin

    I := 0;
    Done := false;


    repeat
        if I = Max then
            begin
                Capacity := Max;
                Done := true;
            end;
        if RandNum <= CapDist(I) then
            begin
                Capacity := I;
                Done := true;
            end;
        I := I + 1;
    until Done = true;

end; {CalcCap procedure}

procedure CalcStDev (NumOL: IVect; var StDev: real);
    var
        I: integer;
        Sumx, Sumx2, Variance, NS: real;
```

```
begin

    I := 0;
    Sumx := 0.0;
    Sumx2 := 0.0;

    repeat
        Sumx := Sumx + (NumOL(I) / NumCycle);
        Sumx2 := Sumx2 + SQR(NumOL(I) / NumCycle);
        I := I + 1;
    until I = NumSeries + 1;

    NS := NumSeries;
    Variance := ((NumSeries * Sumx2) - SQR(Sumx)) / (NS * (NS - 1));
    StDev := SQRT(Variance);

end; {CalcStDev procedure}

end. {SubPrograms}
```

DISCAPOS - Source Code Listing

```
unit SubSubPrograms;

interface
    const
        NumSeries = 1000;

    type
        DVect = array(0..125) of double;
        RVect = array(0..1000) of real;
        IVect = array(0..1000) of integer;

    var
        NumCycle, Max: integer;
        ArrDist, CapDist: DVect;
        NumOL, DistVect: IVect;
        OLFVect: RVect;


    procedure CalcMax (MeanCap, MeanArr: real);
    procedure Fact (I: integer; var Factorial: double);
    procedure Wait (x: integer);

implementation

    procedure CalcMax (MeanCap, MeanArr: real);

        var
            Temp: integer;

    begin

        if (MeanCap >= MeanArr) then
            Temp := Round(MeanCap)
        else
            Temp := Round(MeanArr);

        if (Temp >= 0) and (Temp <= 6) then
            Max := 25;
        if (Temp >= 7) and (Temp <= 13) then
            Max := 40;
        if (Temp >= 14) and (Temp <= 20) then
            Max := 50;
        if (Temp >= 21) and (Temp <= 30) then
            Max := 65;
        if (Temp >= 31) and (Temp <= 45) then
            Max := 90;
        if (Temp >= 46) and (Temp <= 61) then
            Max := 110;

    end;  {CalcMax Procedure}
```

```
procedure Fact (I: integer; var Factorial: double);
    var
        J: integer;
begin
    if I > 2 then
        begin
            J := I - 1;
            Factorial := J * I;
            repeat
                J := J - 1;
                Factorial := J * Factorial;
            until J = 1;
        end {true if}
    else if I = 2 then
        begin
            Factorial := 2;
        end {true if}
    else
        Factorial := 1;
end;  {Fact procedure}

procedure Wait (x: integer);
    var
        dummy: longint;
begin
    delay(x,  dummy);
end;   {Wait procedure}


end. {SubSubPrograms}
```

PRADOL - Source Code Listing

```
program MainProgram;

    uses
        SubSubPrograms, SubPrograms;

    var
        CapLow, CapHigh, Capacity, Cycle, Max, Done, OK: integer;
        Percent, P1e, P2e, P2a, P2o, P3e, P3a, P3o, P4e, P4a, P4o, P5e, P5a, P5o: real;
        MeanArr: double;

        ProbVect: DVect;
        fullScreen: Rect;

begin
    SetRect(fullScreen, 10, 25, 750, 475);
    SetTextRect(fullScreen);
    Done := 1;

    writeln('Welcome to PRADOL - the Probability of Arrival and Discharge Overload
Calculation Program');
    writeln('                © Randall Sonnenberg - 1993');
    writeln;

    while (Done = 1) do
        begin
            GetCap(CapLow, CapHigh, Percent);
            GetMArr(MeanArr);
            GetCycle(Cycle);
            OK := 1;

            if (((CapHigh > 5) or (MeanArr > 5)) and (Cycle = 4)) then
                begin
                    writeln('Execution time may exceed 1 minute on many computers,
enter "1" to continue or "2" to abort');
                    readln(OK);
                end;

            if (Cycle = 5) then
                begin
                    writeln('Execution time may be greater than 5 minutes on many
computers, enter "1" to continue or "2" to abort');
                    readln(OK);
                end;

            if (OK = 1) then
                begin
                    CalcPVect(MeanArr, ProbVect);

                    if (CapHigh >= 1) and (CapHigh <= 6) then
                        Max := 25;
                    if (CapHigh >= 7) and (CapHigh <= 13) then
```

```
        Max := 40;
    if (CapHigh >= 14) and (CapHigh <= 20) then
        Max := 50;
    if (CapHigh >= 21) and (CapHigh <= 30) then
        Max := 65;
    if (CapHigh >= 31) and (CapHigh <= 45) then
        Max := 90;
    if (CapHigh >= 46) and (CapHigh <= 61) then
        Max := 110;

    case Cycle of
        1:
            begin
                CycleOne(ProbVect, CapLow, Max);
                P1L := P1;

                CycleOne(ProbVect, CapHigh, Max);
                P1H := P1;

                P1e := ((P1H - P1L) * Percent) + P1L;

                writeln;
                writeln('Probability of an Overload in cycle 1 is', P1e : 7 : 4);
            end;
        2:
            begin
                CycleOne(ProbVect, CapLow, Max);
                P1L := P1;
                CycleTwo(ProbVect, CapLow, Max);
                P2L := P2;
                P1a2L := P1a2;
                P1o2L := P1o2;

                CycleOne(ProbVect, CapHigh, Max);
                P1H := P1;
                CycleTwo(ProbVect, CapHigh, Max);
                P2H := P2;
                P1a2H := P1a2;
                P1o2H := P1o2;

                P1e := ((P1H - P1L) * Percent) + P1L;
                P2e := ((P2H - P2L) * Percent) + P2L;
                P2a := ((P1a2H - P1a2L) * Percent) + P1a2L;
                P2o := ((P1o2H - P1o2L) * Percent) + P1o2L;

                writeln;
                writeln('Probability of an Overload in cycle 1 is', P1e : 7 : 4);
                writeln;
                writeln('Probability of an Overload in cycle 2 is', P2e : 7 : 4);
                writeln('Probability of an Overload in cycles 1 and 2 is', P2a
: 7 : 4);
                writeln('Probability of an Overload in cycles 1 or 2 is', P2o : 7
: 4);
            end;
```

```
3:
  begin
    CycleOne(ProbVect, CapLow, Max);
    P1L := P1;
    CycleTwo(ProbVect, CapLow, Max);
    P2L := P2;
    P1a2L := P1a2;
    P1o2L := P1o2;
    CycleThree(ProbVect, CapLow, Max);
    P3L := P3;
    P1a2a3L := P1a2a3;
    P1o2o3L := P1o2o3;

    CycleOne(ProbVect, CapHigh, Max);
    P1H := P1;
    CycleTwo(ProbVect, CapHigh, Max);
    P2H := P2;
    P1a2H := P1a2;
    P1o2H := P1o2;
    CycleThree(ProbVect, CapHigh, Max);
    P3H := P3;
    P1a2a3H := P1a2a3;
    P1o2o3H := P1o2o3;

    P1e := ((P1H - P1L) * Percent) + P1L;
    P2e := ((P2H - P2L) * Percent) + P2L;
    P2a := ((P1a2H - P1a2L) * Percent) + P1a2L;
    P2o := ((P1o2H - P1o2L) * Percent) + P1o2L;
    P3e := ((P3H - P3L) * Percent) + P3L;
    P3a := ((P1a2a3H - P1a2a3L) * Percent) + P1a2a3L;
    P3o := ((P1o2o3H - P1o2o3L) * Percent) + P1o2o3L;

    writeln;
    writeln('Probability of an Overload in cycle 1 is', P1e : 7 : 4);
    writeln;
    writeln('Probability of an Overload in cycle 2 is', P2e : 7 : 4);
    writeln('Probability of an Overload in cycles 1 and 2 is', P2a
: 7 : 4);
    writeln('Probability of an Overload in cycles 1 or 2 is', P2o : 7
: 4);
    writeln;
    writeln('Probability of an Overload in cycle 3 is', P3e : 7 : 4);
    writeln('Probability of an Overload in cycles 1 and 2 and 3
is', P3a : 7 : 4);
    writeln('Probability of an Overload in cycles 1 or 2 or 3 is',
P3o : 7 : 4);
  end;
4:
  begin
    CycleOne(ProbVect, CapLow, Max);
    P1L := P1;
    CycleTwo(ProbVect, CapLow, Max);
    P2L := P2;
    P1a2L := P1a2;
```

```
P1o2L := P1o2;
CycleThree(ProbVect, CapLow, Max);
P3L := P3;
P1a2a3L := P1a2a3;
P1o2o3L := P1o2o3;
CycleFour(ProbVect, CapLow, Max);
P4L := P4;
P1a2a3a4L := P1a2a3a4;
P1o2o3o4L := P1o2o3o4;

CycleOne(ProbVect, CapHigh, Max);
P1H := P1;
CycleTwo(ProbVect, CapHigh, Max);
P2H := P2;
P1a2H := P1a2;
P1o2H := P1o2;
CycleThree(ProbVect, CapHigh, Max);
P3H := P3;
P1a2a3H := P1a2a3;
P1o2o3H := P1o2o3;
CycleFour(ProbVect, CapHigh, Max);
P4H := P4;
P1a2a3a4H := P1a2a3a4;
P1o2o3o4H := P1o2o3o4;

P1e := ((P1H - P1L) * Percent) + P1L;
P2e := ((P2H - P2L) * Percent) + P2L;
P2a := ((P1a2H - P1a2L) * Percent) + P1a2L;
P2o := ((P1o2H - P1o2L) * Percent) + P1o2L;
P3e := ((P3H - P3L) * Percent) + P3L;
P3a := ((P1a2a3H - P1a2a3L) * Percent) + P1a2a3L;
P3o := ((P1o2o3H - P1o2o3L) * Percent) + P1o2o3L;
P4e := ((P4H - P4L) * Percent) + P4L;
P4a := ((P1a2a3a4H - P1a2a3a4L) * Percent) + P1a2a3a4L;
P4o := ((P1o2o3o4H - P1o2o3o4L) * Percent) + P1o2o3o4L;

writeln;
writeln('Probability of an Overload in cycle 1 is', P1e : 7 : 4);
writeln;
writeln('Probability of an Overload in cycle 2 is', P2e : 7 : 4);
writeln('Probability of an Overload in cycles 1 and 2 is', P2a
: 7 : 4);
writeln('Probability of an Overload in cycles 1 or 2 is', P2o : 7
: 4);
writeln;
writeln('Probability of an Overload in cycle 3 is', P3e : 7 : 4);
writeln('Probability of an Overload in cycles 1 and 2 and 3
is', P3a : 7 : 4);
writeln('Probability of an Overload in cycles 1 or 2 or 3 is',
P3o : 7 : 4);
writeln;
writeln('Probability of an Overload in cycle 4 is', P4e : 7 : 4);
writeln('Probability of an Overload in cycles 1 and 2 and 3
and 4 is', P4a : 7 : 4);
```

```
                writeln('Probability of an Overload in cycles 1 or 2 or 3 or 4
is', P4o : 7 : 4);
            end;
        5:
            begin
                CycleOne(ProbVect, CapLow, Max);
                P1L := P1;
                CycleTwo(ProbVect, CapLow, Max);
                P2L := P2;
                P1a2L := P1a2;
                P1o2L := P1o2;
                CycleThree(ProbVect, CapLow, Max);
                P3L := P3;
                P1a2a3L := P1a2a3;
                P1o2o3L := P1o2o3;
                CycleFour(ProbVect, CapLow, Max);
                P4L := P4;
                P1a2a3a4L := P1a2a3a4;
                P1o2o3o4L := P1o2o3o4;
                CycleFive(ProbVect, CapLow, Max);
                P5L := P5;
                P1a2a3a4a5L := P1a2a3a4a5;
                P1o2o3o4o5L := P1o2o3o4o5;

                CycleOne(ProbVect, CapHigh, Max);
                P1H := P1;
                CycleTwo(ProbVect, CapHigh, Max);
                P2H := P2;
                P1a2H := P1a2;
                P1o2H := P1o2;
                CycleThree(ProbVect, CapHigh, Max);
                P3H := P3;
                P1a2a3H := P1a2a3;
                P1o2o3H := P1o2o3;
                CycleFour(ProbVect, CapHigh, Max);
                P4H := P4;
                P1a2a3a4H := P1a2a3a4;
                P1o2o3o4H := P1o2o3o4;
                CycleFive(ProbVect, CapHigh, Max);
                P5H := P5;
                P1a2a3a4a5H := P1a2a3a4a5;
                P1o2o3o4o5H := P1o2o3o4o5;

                P1e := ((P1H - P1L) * Percent) + P1L;
                P2e := ((P2H - P2L) * Percent) + P2L;
                P2a := ((P1a2H - P1a2L) * Percent) + P1a2L;
                P2o := ((P1o2H - P1o2L) * Percent) + P1o2L;
                P3e := ((P3H - P3L) * Percent) + P3L;
                P3a := ((P1a2a3H - P1a2a3L) * Percent) + P1a2a3L;
                P3o := ((P1o2o3H - P1o2o3L) * Percent) + P1o2o3L;
                P4e := ((P4H - P4L) * Percent) + P4L;
                P4a := ((P1a2a3a4H - P1a2a3a4L) * Percent) + P1a2a3a4L;
                P4o := ((P1o2o3o4H - P1o2o3o4L) * Percent) + P1o2o3o4L;
                P5e := ((P5H - P5L) * Percent) + P5L;
```

```
                              P5a := ((P1a2a3a4a5H - P1a2a3a4a5L) * Percent) +
P1a2a3a4a5L;
                              P5o := ((P1o2o3o4o5H - P1o2o3o4o5L) * Percent) +
P1o2o3o4o5L;

                              writeln;
                              writeln('Probability of an Overload in cycle 1 is', P1e : 6 : 3);
                              writeln;
                              writeln('Probability of an Overload in cycle 2 is', P2e : 6 : 3);
                              writeln('Probability of an Overload in cycles 1 and 2 is', P2a
: 6 : 3);
                              writeln('Probability of an Overload in cycles 1 or 2 is', P2o : 6
: 3);
                              writeln;
                              writeln('Probability of an Overload in cycle 3 is', P3e : 6 : 3);
                              writeln('Probability of an Overload in cycles 1 and 2 and 3
is', P3a : 6 : 3);
                              writeln('Probability of an Overload in cycles 1 or 2 or 3 is',
P3o : 6 : 3);
                              writeln;
                              writeln('Probability of an Overload in cycle 4 is', P4e : 6 : 3);
                              writeln('Probability of an Overload in cycles 1 and 2 and 3
and 4 is', P4a : 6 : 3);
                              writeln('Probability of an Overload in cycles 1 or 2 or 3 or 4
is', P4o : 6 : 3);
                              writeln;
                              writeln('Probability of an Overload in cycle 5 is', P5e : 6 : 3);
                              writeln('Probability of an Overload in cycles 1 and 2 and 3
and 4 and 5 is', P5a : 6 : 3);
                              writeln('Probability of an Overload in cycles 1 or 2 or 3 or 4
or 5 is', P5o : 6 : 3);
                          end;
                    end; {Case Statement}

                 end; {OK if}

              writeln;
              writeln('Enter "1" for further calculations with new input values, or "2" to quit
PRADOL');
              readln(done);


           end; {Done while Loop}

        sysbeep(1);

    end. {MainProgram}
```

```
unit SubPrograms;

interface
    uses
        SubSubPrograms;


    type
        DVect = array(0..125) of double;
        IVect = array(0..125) of integer;

    procedure GetCap (var CapLow, CapHigh: integer; var Percent: real);
    procedure GetMArr (var Arrivals: double);
    procedure GetCycle (var Cycle: integer);
    procedure CalcPVect (MeanArr: double; var ProbVect: DVect);
    procedure CycleOne (ProbVect: DVect; Capacity, Max: integer);
    procedure CycleTwo (ProbVect: DVect; Capacity, Max: integer);
    procedure CycleThree (ProbVect: DVect; Capacity, Max: integer);
    procedure CycleFour (ProbVect: DVect; Capacity, Max: integer);
    procedure CycleFive (ProbVect: DVect; Capacity, Max: integer);



implementation

    procedure GetCap (var CapLow, CapHigh: integer; var Percent: real);
        var
            Capacity: integer;
            Data: real;
            Valid: boolean;

    begin
        repeat
            Valid := true;
            writeln;
            writeln('Enter CAPACITY of Lane, in veh/cycle:');
            readln(Data);

            Capacity := Round(Data);

            if Capacity <= 0 then
                begin
                    writeln('Capacity must be greater than zero!!');
                    Valid := false;
                end;

            if Capacity > 60 then
                begin
                    writeln('Capacity must not be more than 60!!');
                    Valid := false;
                end;
```

```
    until Valid = true;

    CapLow := Trunc(Data);
    CapHigh := CapLow + 1;
    Percent := Data - CapLow;

end; {GetCap procedure}


procedure GetMArr (var Arrivals: double);
    var
        Valid: boolean;
begin

    repeat
        Valid := True;
        writeln;
        writeln('Enter MEAN ARRIVALS, in veh/cycle:');
        readln(Arrivals);

        if Arrivals <= 0 then
            begin
                writeln('Average arrivals must be greater than zero!!');
                Valid := false;
            end;

        if Arrivals > 60 then
            begin
                writeln('Average arrivals must not be more than 60!!');
                Valid := false;
            end;

    until Valid = true;
end; {GetMArr procedure}


procedure GetCycle (var Cycle: integer);
    var
        Data: real;
        Valid: boolean;
begin

    repeat
        Valid := True;
        writeln;
        writeln('Enter number of consecutive cycles to be evaluated (1 to 5):');
        readln(Data);
        Cycle := Round(Data);

        if Cycle <= 0 then
            begin
                writeln('At least one cycle must be chosen for evaluation !!');
                Valid := false;
```

```
        end;

      if Cycle > 5 then
        begin
          writeln('A maximum of five consecutive cycles can be evaluated!!');
          Valid := false;
        end;

    until Valid = True;
end; {GetCycle procedure}


procedure CalcPVect (MeanArr: double; var ProbVect: DVect);

    var
      I, Temp, Max: integer;
      Factorial: double;
      done: boolean;

begin

    Temp := Round(MeanArr);

    if (Temp >= 0) and (Temp <= 6) then
      Max := 25;
    if (Temp >= 7) and (Temp <= 13) then
      Max := 40;
    if (Temp >= 14) and (Temp <= 20) then
      Max := 50;
    if (Temp >= 21) and (Temp <= 30) then
      Max := 65;
    if (Temp >= 31) and (Temp <= 45) then
      Max := 90;
    if (Temp >= 46) and (Temp <= 61) then
      Max := 110;

    I := 0;
    repeat
      Fact(I, Factorial);
      ProbVect(I) := EXP(-MeanArr) * EXP(I * LN(MeanArr)) / Factorial;
      I := I + 1;
    until I = Max;

end; {CalcPVect procedure}


procedure CycleOne (ProbVect: DVect; Capacity, Max: integer);

    var
      veh: integer;

begin

    ANOL := 0.0;
```

```
    Veh := 0;
    repeat
        ANOL := ANOL + ProbVect(Veh);
        Veh := Veh + 1;
    until Veh = Capacity + 1;
    AOL := 1 - ANOL;
    P1 := AOL;

end; {CycleOne procedure}

procedure CycleTwo (ProbVect: DVect; Capacity, Max: integer);

    var
        Temp: double;
        Veh, RemVeh1: integer;

begin

    BNOL := 0.0;
    RemVeh1 := 0;
    repeat
        Veh := 0;
        Temp := 0.0;
        RemVeh1 := RemVeh1 + 1;
        if RemVeh1 >= Capacity + 1 then
            begin
                Temp := 1.0E-100;
            end
        else
            begin
                repeat
                    Temp := Temp + ProbVect(Veh);
                    Veh := Veh + 1;
                until Veh = Capacity - RemVeh1 + 1;
            end;
        BNOL := BNOL + (Temp * ProbVect(Capacity + RemVeh1));
    until RemVeh1 = Max - Capacity;
    BOL := AOL - BNOL;

    BOL := BOL / AOL;
    BNOL := BNOL / AOL;

    P2 := (AOL * BOL) + (ANOL * AOL);
    P1o2 := (AOL * BOL) + (AOL * BNOL) + (ANOL * AOL);
    P1a2 := AOL * BOL;

end; {CycleTwo procedure}

procedure CycleThree (ProbVect: DVect; Capacity, Max: integer);

    var
        Temp: double;
        Veh, RemVeh1, RemVeh2: integer;
```

```
begin

    CNOL := 0.0;
    RemVeh1 := 0;
    RemVeh2 := 0;

    repeat
        RemVeh1 := RemVeh1 + 1;
        RemVeh2 := 0;
        repeat
            Veh := 0;
            Temp := 0.0;
            RemVeh2 := RemVeh2 + 1;
            If RemVeh2 >= Capacity + 1 then
                begin
                    Temp := 1.0E-100;
                end
            else
                begin
                    repeat
                        Temp := Temp + ProbVect(Veh);
                        Veh := Veh + 1;
                    until Veh = Capacity - RemVeh2 + 1;
                end;
            CNOL := CNOL + (Temp * ProbVect(Capacity + RemVeh1) *
ProbVect(Capacity + RemVeh2));
        until RemVeh2 = Max - Capacity;
    until RemVeh1 = Max - Capacity;
    COL := BOL - CNOL;

    COL := COL / BOL;
    CNOL := CNOL / BOL;

    P3 := (AOL * BOL * COL) + (AOL * BNOL * AOL) + (ANOL * AOL * BOL) + (ANOL *
ANOL * AOL);
    P1o2o3 := (AOL * BOL * COL) + (AOL * BOL * CNOL) + (AOL * BNOL * AOL) + (AOL *
BNOL * ANOL) + (ANOL * AOL * BOL) + (ANOL * AOL * BNOL) + (ANOL * ANOL * AOL);
    P1a2a3 := AOL * BOL * COL;

end; {CycleThree procedure}


procedure CycleFour (ProbVect: DVect; Capacity, Max: integer);

    var
        Temp: double;
        Veh, RemVeh1, RemVeh2, RemVeh3: integer;

begin

    DNOL := 0.0;
    RemVeh1 := 0;
    RemVeh2 := 0;
    RemVeh3 := 0;
```

```
        repeat
            RemVeh1 := RemVeh1 + 1;
            RemVeh2 := 0;
            repeat
                RemVeh2 := RemVeh2 + 1;
                RemVeh3 := 0;
                repeat
                    Veh := 0;
                    Temp := 0.0;
                    RemVeh3 := RemVeh3 + 1;
                    if RemVeh3 >= Capacity + 1 then
                        begin
                            Temp := 1.0E-100;
                        end
                    else
                        begin
                            repeat
                                Temp := Temp + ProbVect(Veh);
                                Veh := Veh + 1;
                            until Veh = Capacity - RemVeh3 + 1;
                        end;
                    DNOL := DNOL + (Temp * ProbVect(Capacity + RemVeh1) *
ProbVect(Capacity + RemVeh2) * ProbVect(Capacity + RemVeh3));
                until RemVeh3 = Max - Capacity;
            until RemVeh2 = Max - Capacity;
        until RemVeh1 = Max - Capacity;
        DOL := COL - DNOL;

        DOL := DOL / COL;
        DNOL := DNOL / COL;

        P4 := (AOL * BOL * COL * DOL) + (AOL * BOL * CNOL * AOL) + (AOL * BNOL * AOL *
BOL) + (AOL * BNOL * ANOL * AOL);
        P4 := P4 + (ANOL * AOL * BOL * COL) + (ANOL * AOL * BNOL * AOL) + (ANOL * ANOL
* AOL * BOL) + (ANOL * ANOL * ANOL * AOL);
        P1o2o3o4 := (AOL * BOL * COL * DOL) + (AOL * BOL * COL * DNOL) + (AOL * BOL *
CNOL * AOL) + (AOL * BOL * CNOL * ANOL) + (AOL * BNOL * AOL * BOL) + (AOL * BNOL *
AOL * BNOL) + (AOL * BNOL * ANOL * AOL) + (AOL * BNOL * ANOL * ANOL);
        P1o2o3o4 := P1o2o3o4 + (ANOL * AOL * BOL * COL) + (ANOL * AOL * BOL * CNOL) +
(ANOL * AOL * BNOL * AOL) + (ANOL * AOL * BNOL * ANOL) + (ANOL * ANOL * AOL * BOL)
+ (ANOL * ANOL * AOL * BNOL) + (ANOL * ANOL * ANOL * AOL);
        P1a2a3a4 := AOL * BOL * COL * DOL;

    end; {CycleFour procedure}


    procedure CycleFive (ProbVect: DVect; Capacity, Max: integer);

        var
            Temp: double;
            Veh, RemVeh1, RemVeh2, RemVeh3, RemVeh4: integer;

    begin
```

```
ENOL := 0.0;
RemVeh1 := 0;
RemVeh2 := 0;
RemVeh3 := 0;
RemVeh4 := 0;

repeat
    RemVeh1 := RemVeh1 + 1;
    RemVeh2 := 0;
    repeat
        RemVeh2 := RemVeh2 + 1;
        RemVeh3 := 0;
        repeat
            RemVeh3 := RemVeh3 + 1;
            RemVeh4 := 0;
            repeat
                Veh := 0;
                Temp := 0.0;
                RemVeh4 := RemVeh4 + 1;
                if RemVeh4 >= Capacity + 1 then
                    begin
                        Temp := 1.0E-100;
                    end
                else
                    begin
                        repeat
                            Temp := Temp + ProbVect(Veh);
                            Veh := Veh + 1;
                        until Veh = Capacity - RemVeh4 + 1;
                    end;
                ENOL := ENOL + (Temp * ProbVect(Capacity + RemVeh1) *
ProbVect(Capacity + RemVeh2) * ProbVect(Capacity + RemVeh3) *
ProbVect(Capacity + RemVeh4));
            until RemVeh4 = Max - Capacity;
        until RemVeh3 = Max - Capacity;
    until RemVeh2 = Max - Capacity;
until RemVeh1 = Max - Capacity;
EOL := DOL - ENOL;

EOL := EOL / DOL;
ENOL := ENOL / DOL;
```

```
        P5 := (AOL * BOL * COL * DOL * EOL) + (AOL * BOL * COL * DNOL * AOL) + (AOL *
BOL * CNOL * AOL * BOL) + (AOL * BOL * CNOL * AOL * BOL);
        P5 := P5 + (AOL * BNOL * AOL * BOL * COL) + (AOL * BNOL * AOL * BNOL * AOL) +
(AOL * BNOL * ANOL * AOL * BOL) + (AOL * BNOL * ANOL * ANOL * AOL);
        P5 := P5 + (ANOL * AOL * BOL * COL * DOL) + (ANOL * AOL * BOL * CNOL * AOL) +
(ANOL * AOL * BNOL * AOL * BOL) + (ANOL * AOL * BNOL * ANOL * AOL);
        P5 := P5 + (ANOL * ANOL * AOL * BOL * COL) + (ANOL * ANOL * AOL * BNOL * AOL)
+ (ANOL * ANOL * ANOL * AOL * BOL) + (ANOL * ANOL * ANOL * ANOL * AOL);
        P1o2o3o4o5 := 1 - (ANOL * ANOL * ANOL * ANOL * ANOL);
        P1a2a3a4a5 := AOL * BOL * COL * DOL * EOL;

    end; {CycleFive procedure}

end. {SubPrograms}
```

PRADOL - Source Code Listing

```
unit SubSubPrograms;

interface
    var
        P1, P1L, P1H: real;
        P2, P2L, P2H, P1a2, P1a2L, P1a2H, P1o2, P1o2L, P1o2H: real;
        P3, P3L, P3H, P1a2a3, P1a2a3L, P1a2a3H, P1o2o3, P1o2o3L, P1o2o3H: real;
        P4, P4L, P4H, P1a2a3a4, P1a2a3a4L, P1a2a3a4H, P1o2o3o4, P1o2o3o4L, P1o2o3o4H:
real;
        P5, P5L, P5H, P1a2a3a4a5, P1a2a3a4a5L, P1a2a3a4a5H, P1o2o3o4o5, P1o2o3o4o5L,
P1o2o3o4o5H: real;
        AOL, BOL, COL, DOL, EOL: double;
        ANOL, BNOL, CNOL, DNOL, ENOL: double;

    procedure Fact (Capacity: integer; var Factorial: double);
    procedure Wait (x: integer);

implementation

    procedure Fact (Capacity: integer; var Factorial: double);
        var
            J: integer;
    begin
        if Capacity > 2 then
            begin
                J := Capacity - 1;
                Factorial := J * Capacity;
                repeat
                    J := J - 1;
                    Factorial := J * Factorial;
                until J = 1;
            end {true if}
        else if Capacity = 2 then
            begin
                Factorial := 2;
            end {true if}
        else
            Factorial := 1;
    end;  {Fact procedure}

    procedure Wait (x: integer);
        var
            dummy: longint;
    begin
        delay(x, dummy);
    end;  {Wait procedure}

end. {SubSubPrograms}
```

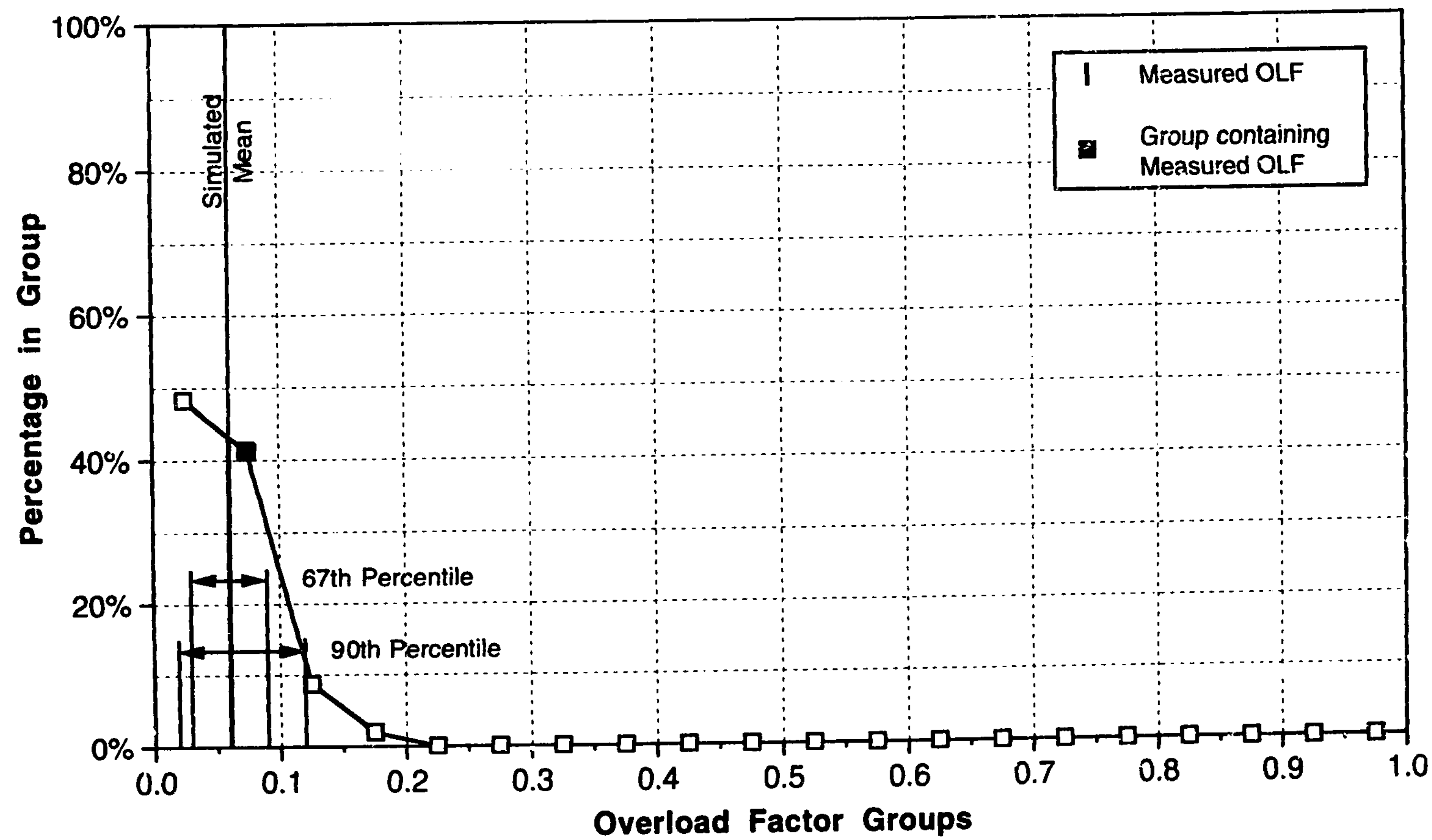


Figure D-3.2 Frequency Plot of Simulated Overload Factors for Survey No. 1

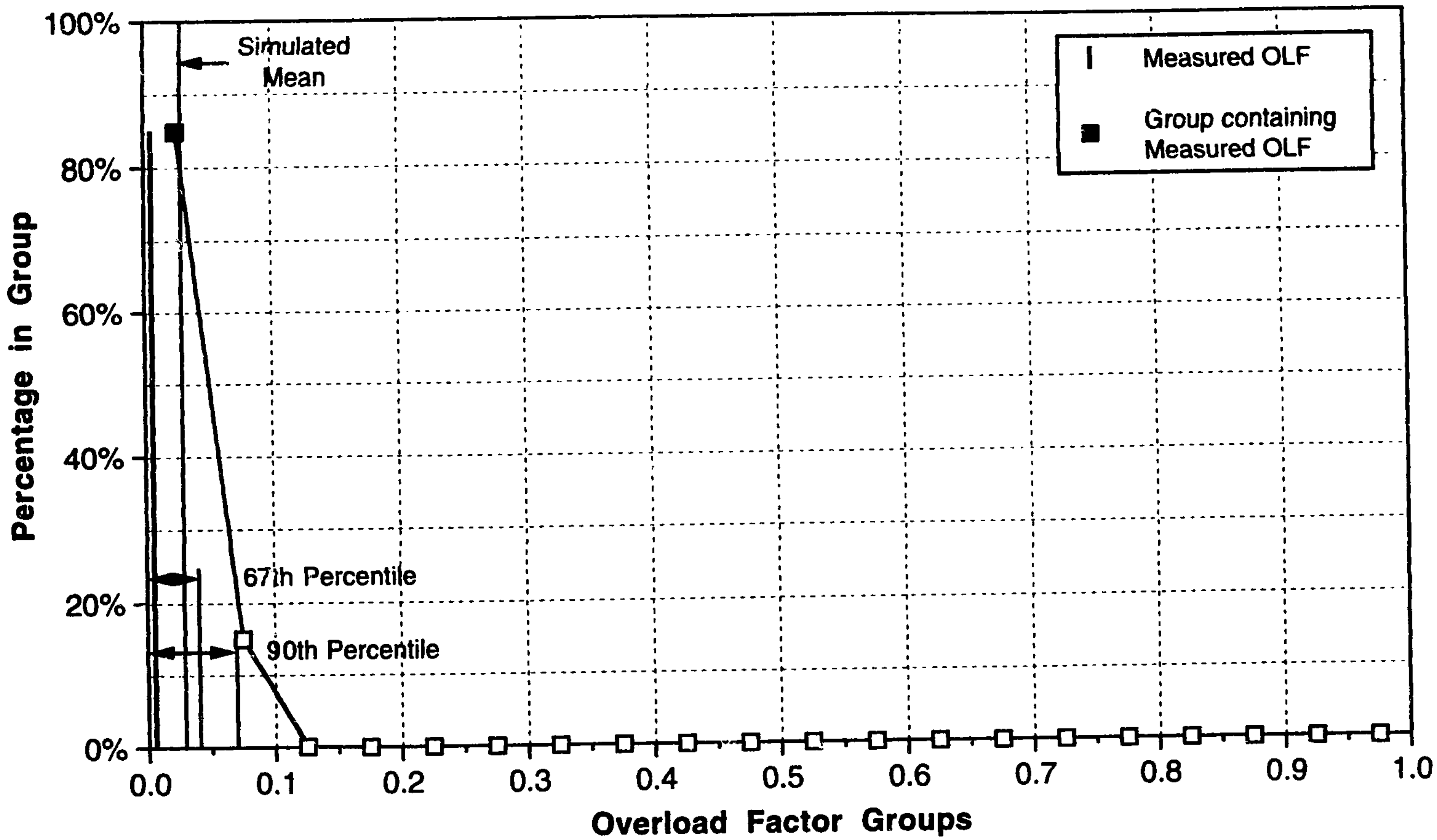


Figure D-3.3 Frequency Plot of Simulated Overload Factors for Survey No. 2

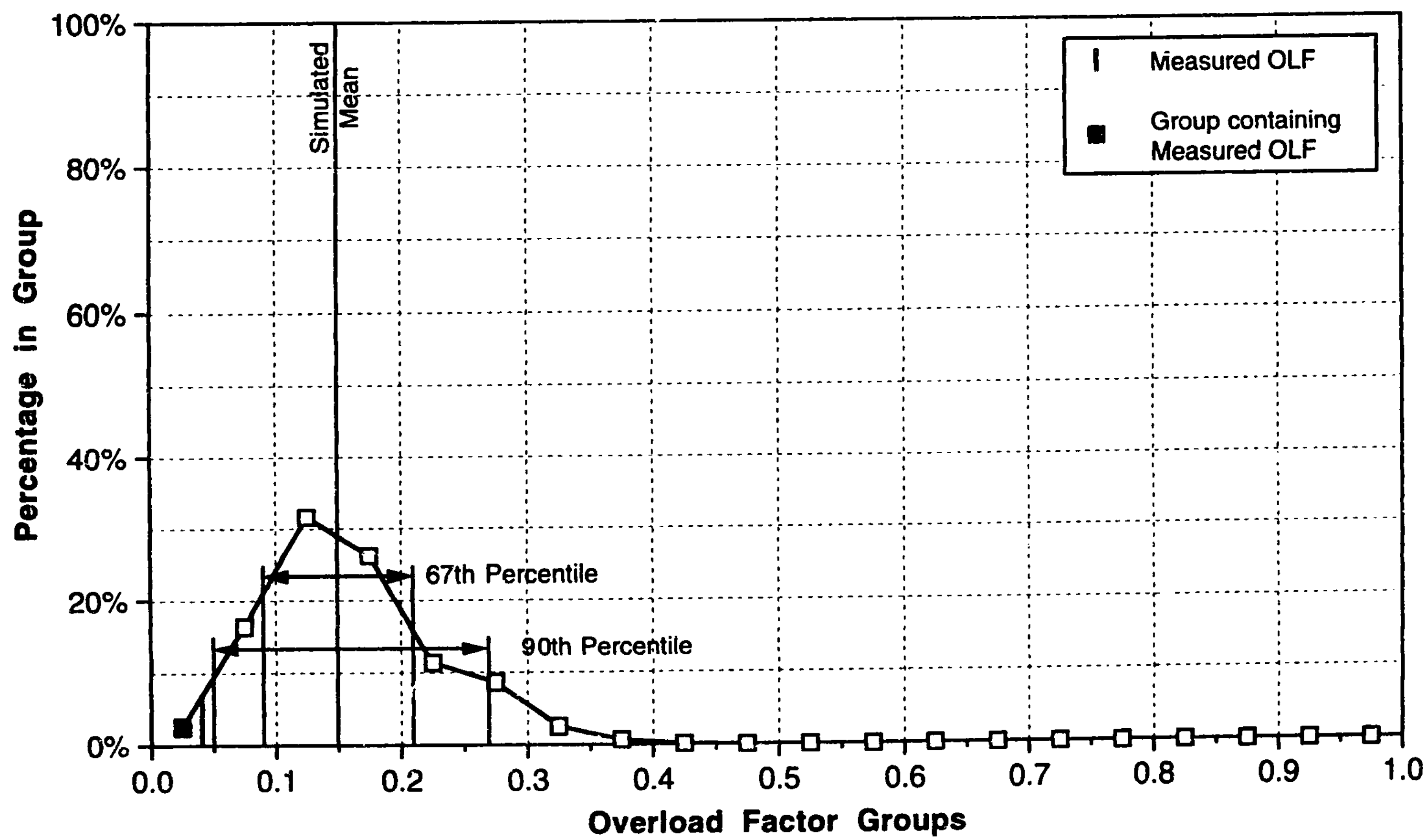


Figure D-3.4 Frequency Plot of Simulated Overload Factors for Survey No. 3

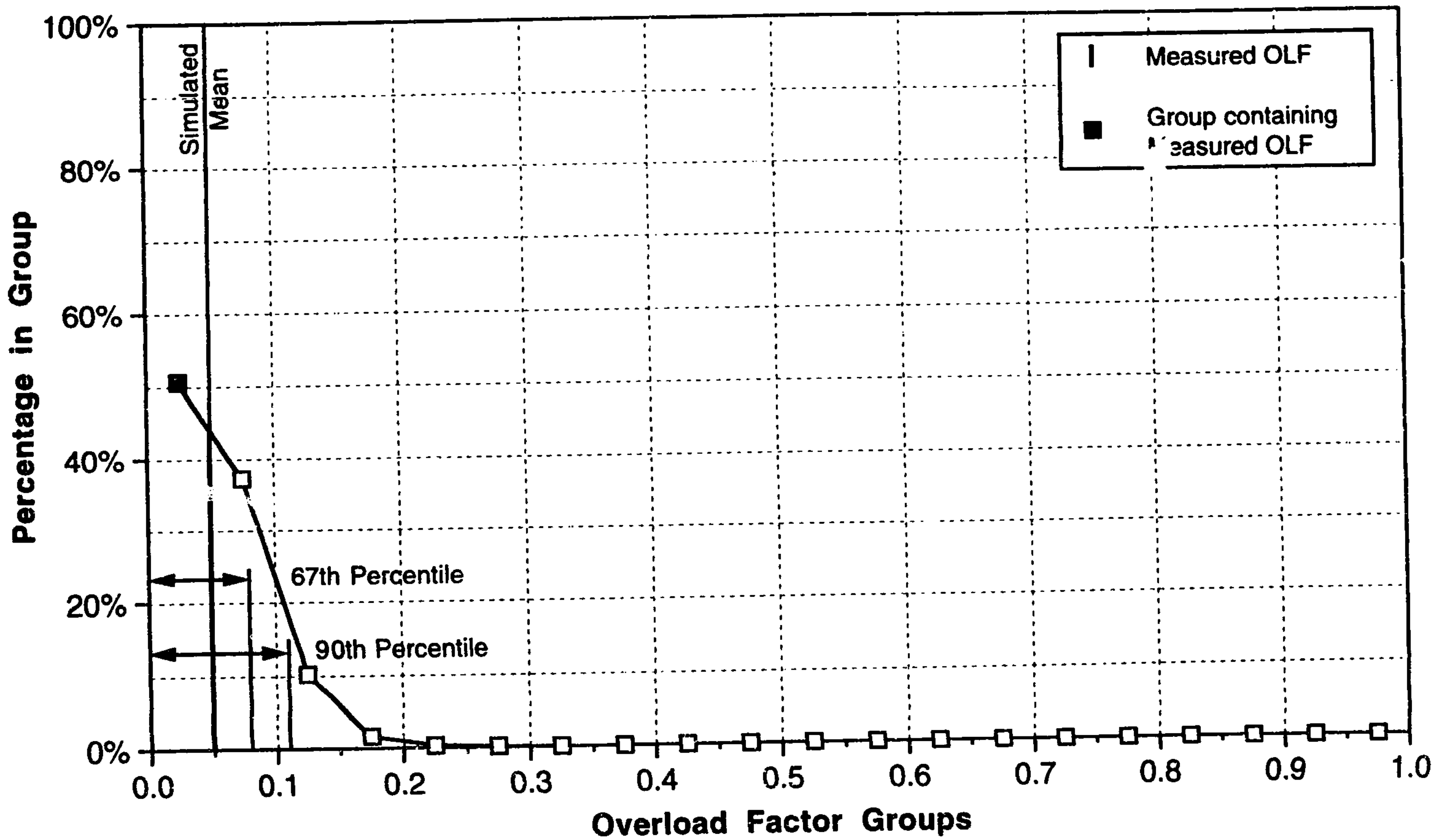


Figure D-3.5 Frequency Plot of Simulated Overload Factors for Survey No. 4

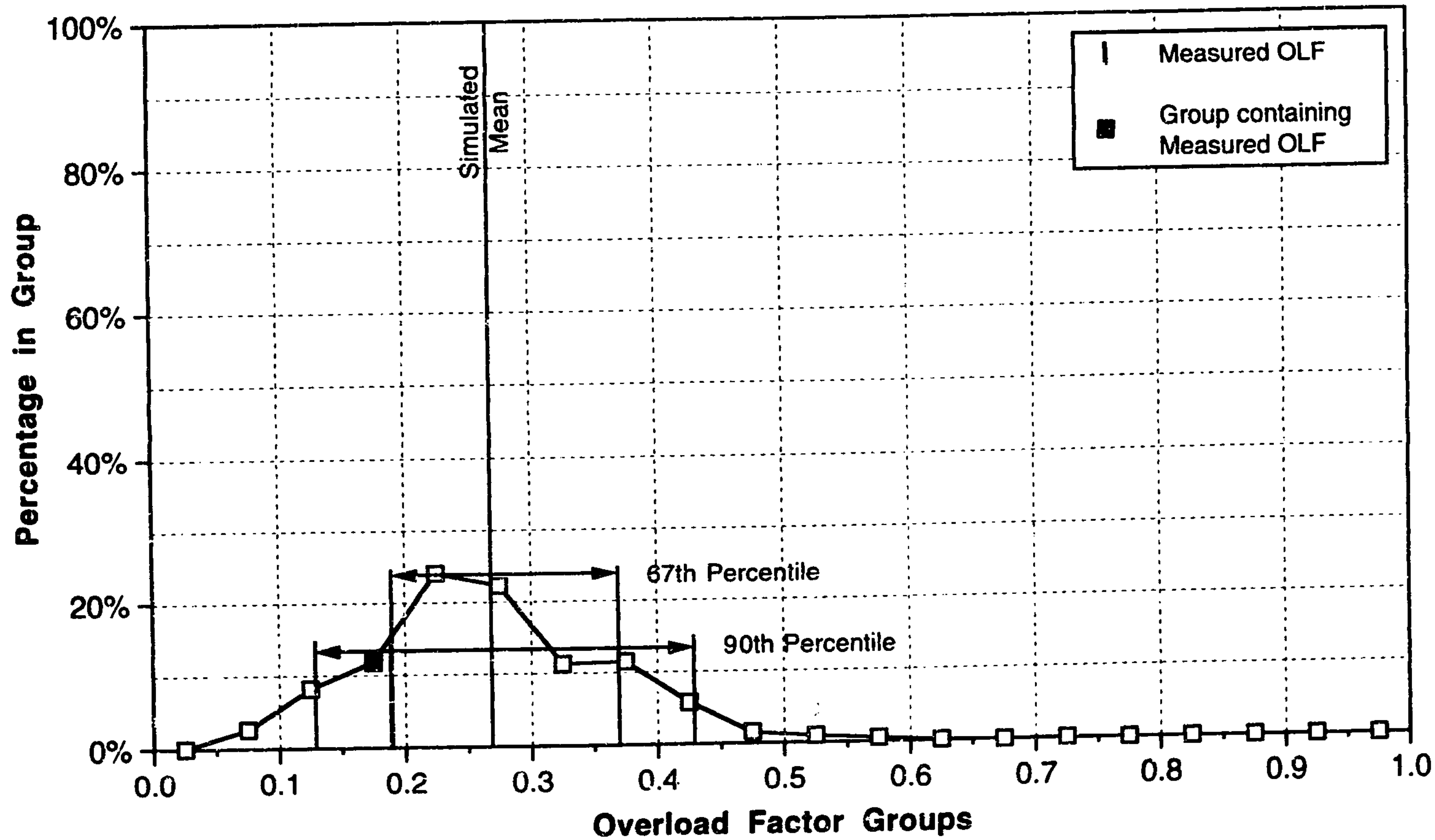


Figure D-3.6 Frequency Plot of Simulated Overload Factors for Survey No. 5

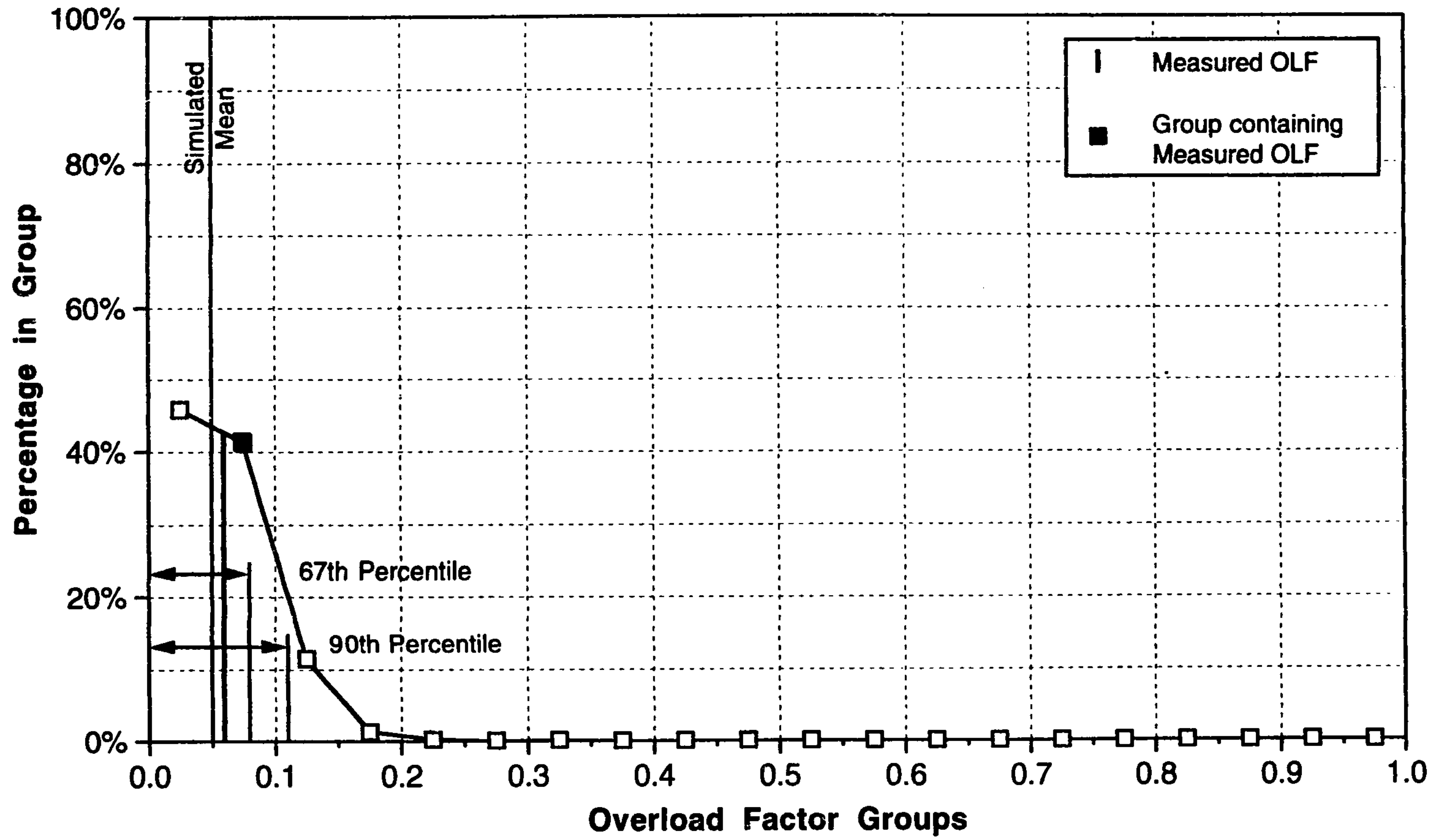


Figure D-3.7 Frequency Plot of Simulated Overload Factors for Survey No. 6

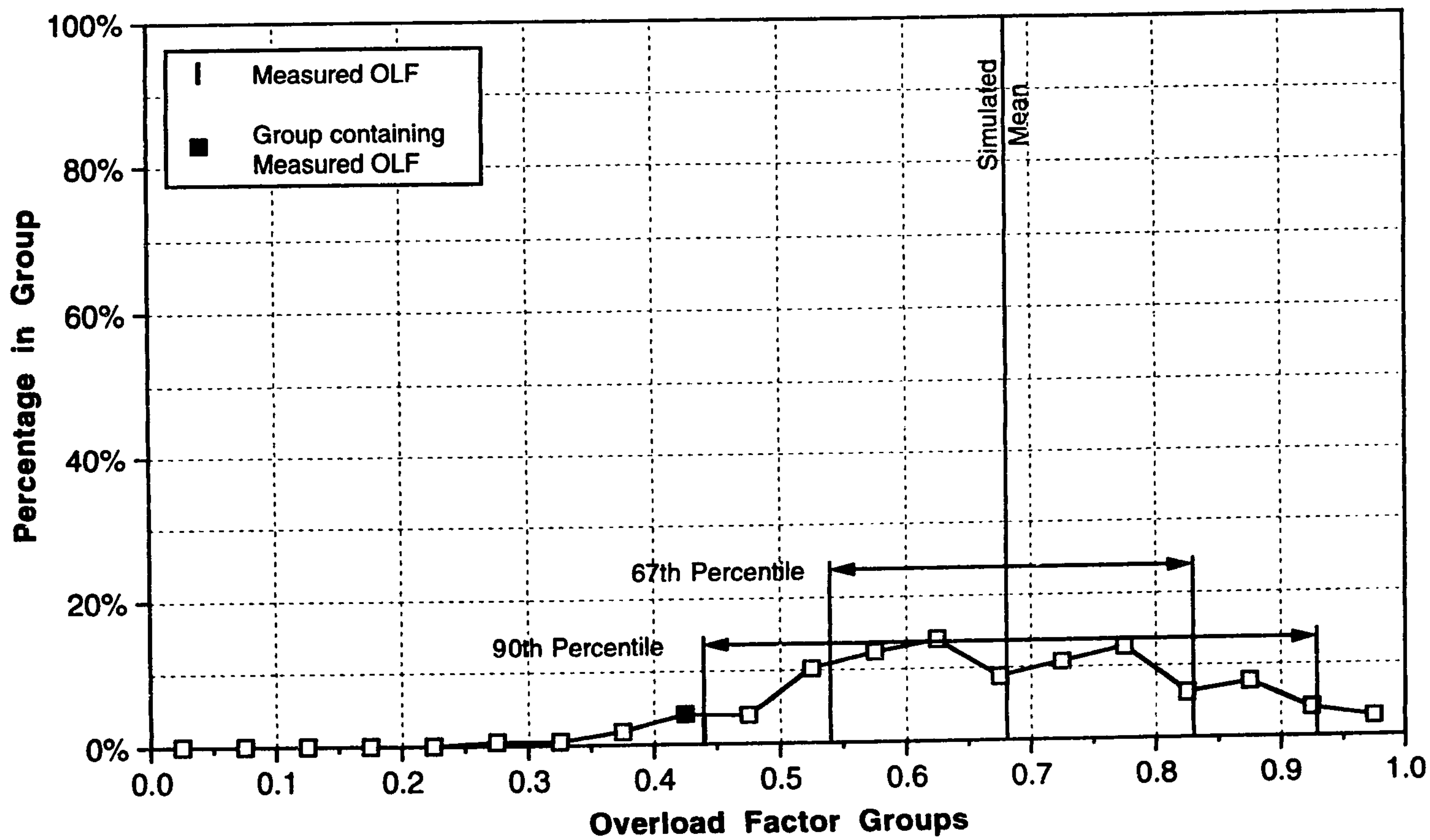


Figure D-3.8 Frequency Plot of Simulated Overload Factors for Survey No. 8

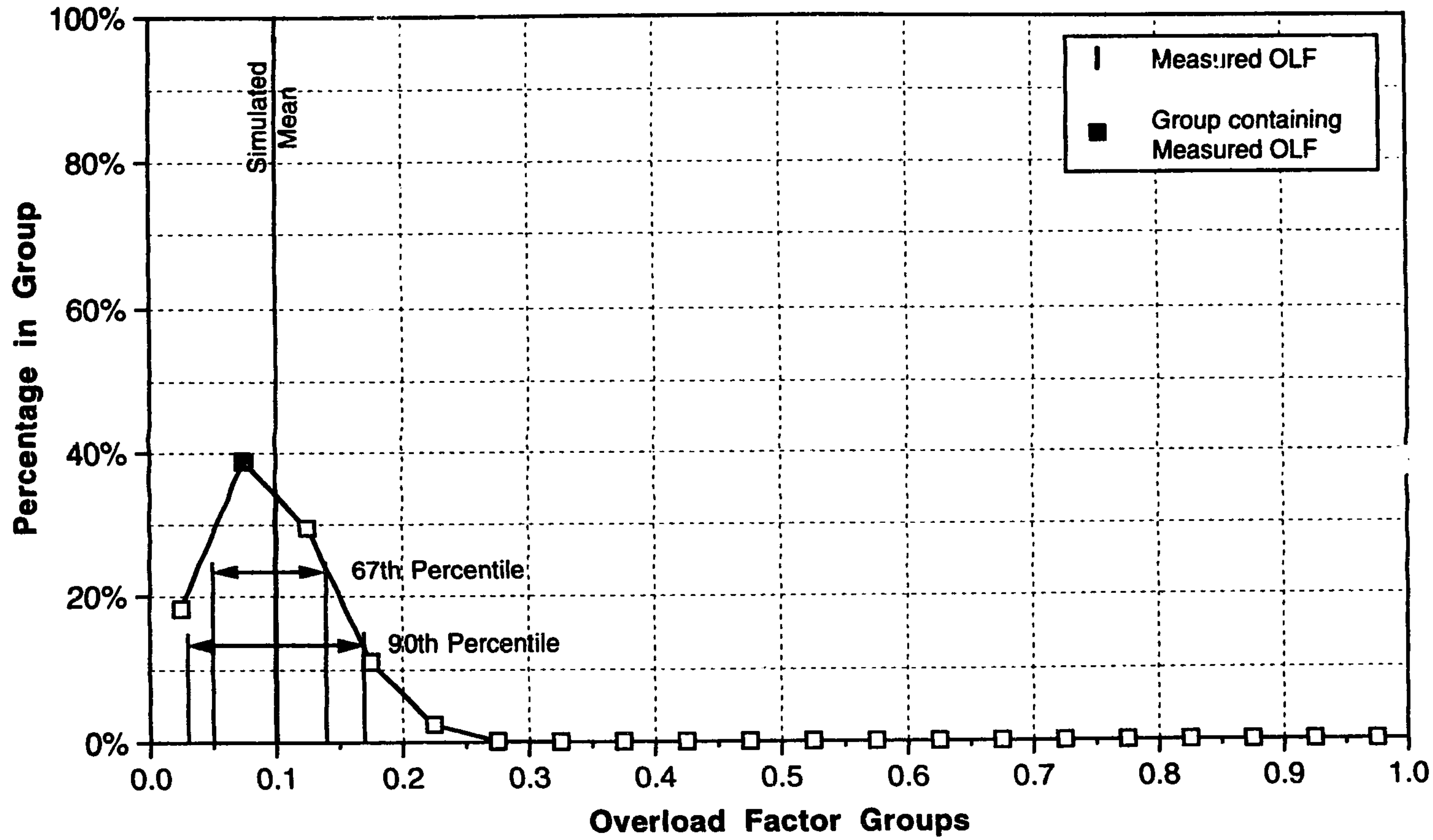


Figure D-3.9 **Frequency Plot of Simulated Overload Factors for Survey No. 9**

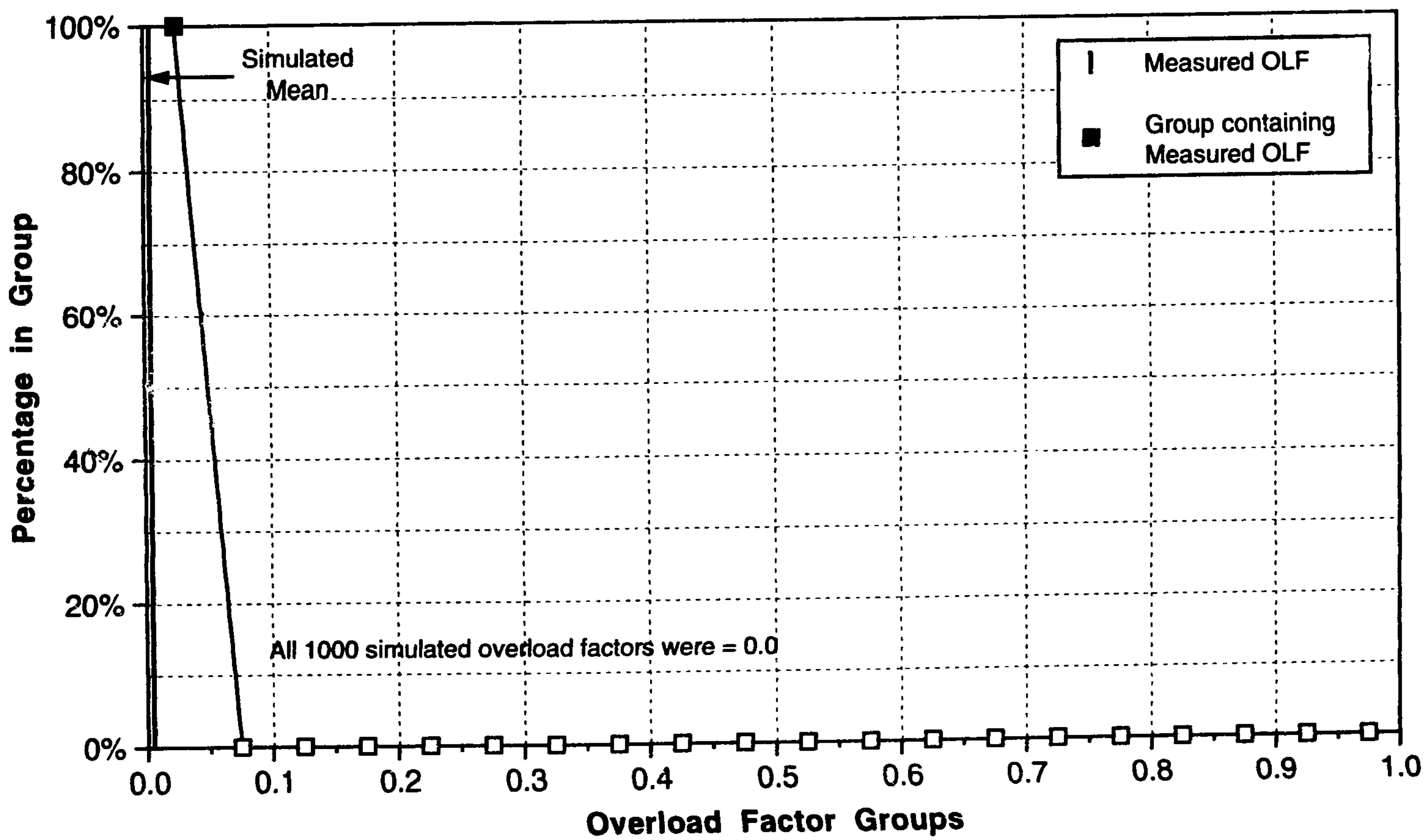


Figure D-3.10 Frequency Plot of Simulated Overload Factors for Survey No. 10

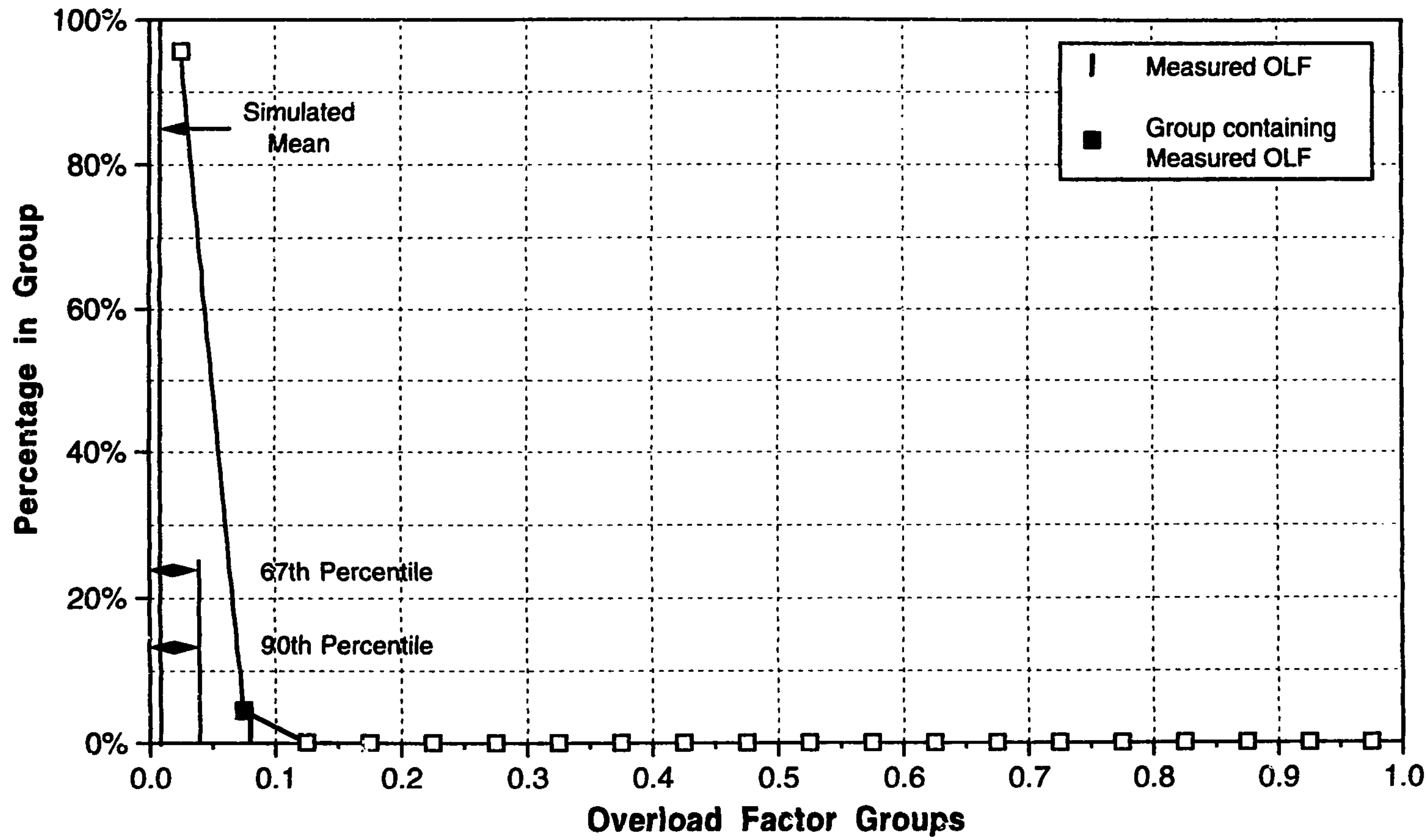


Figure D-3.11 Frequency Plot of Simulated Overload Factors for Survey No. 12

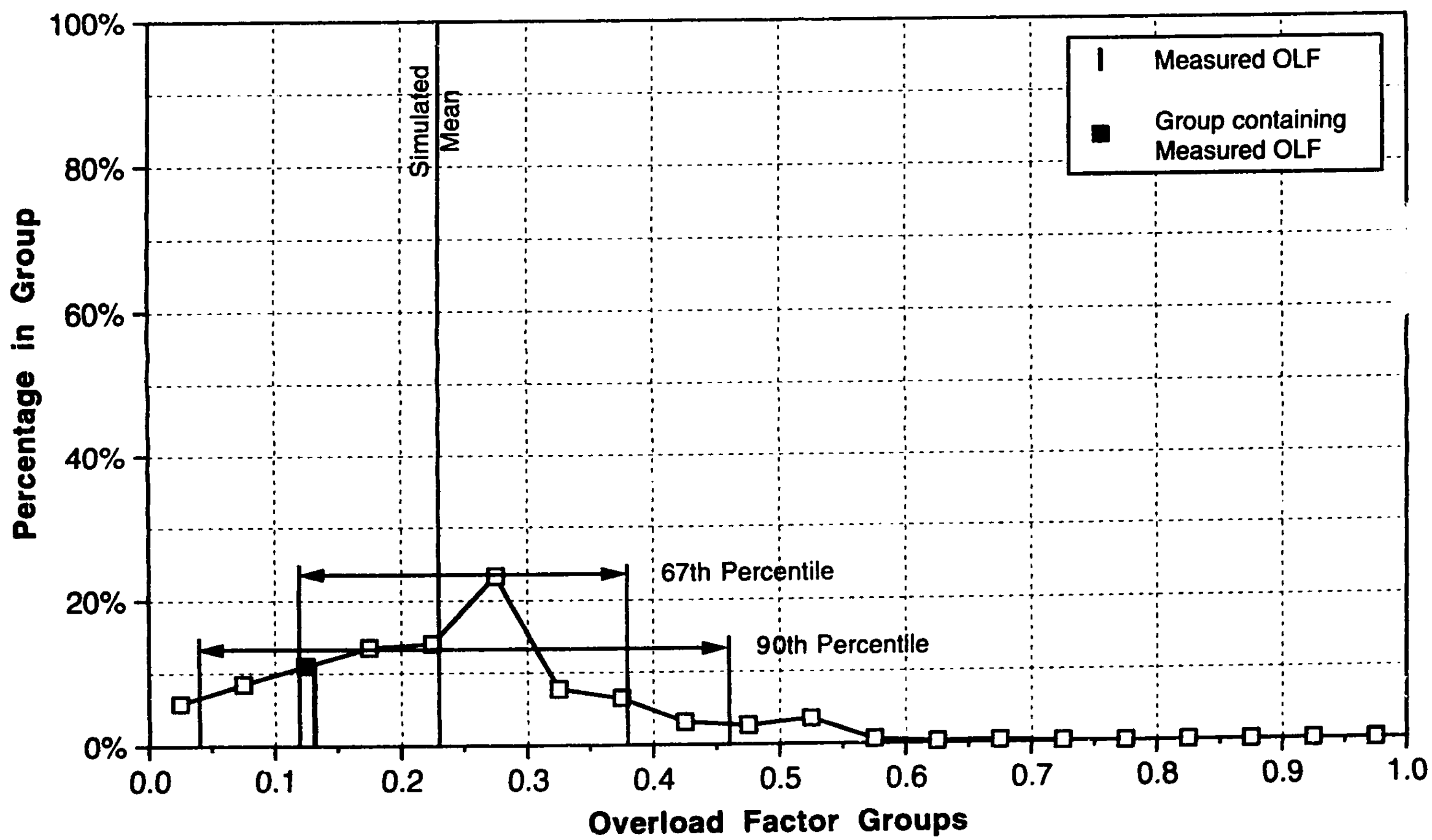


Figure D-3.12 Frequency Plot of Simulated Overload Factors for Survey No. 13

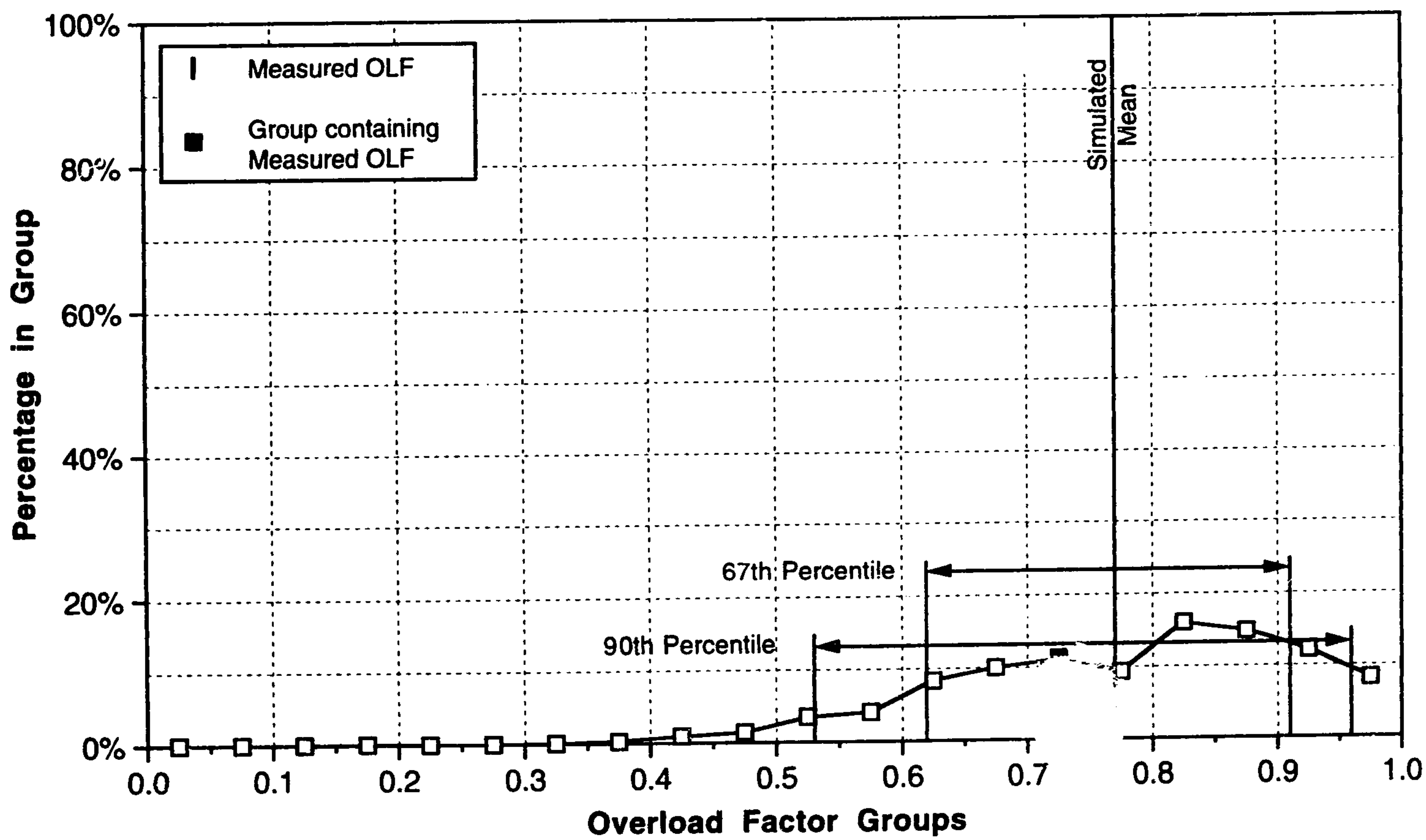


Figure D-3.13 Frequency Plot of Simulated Overload Factors for Survey No. 14

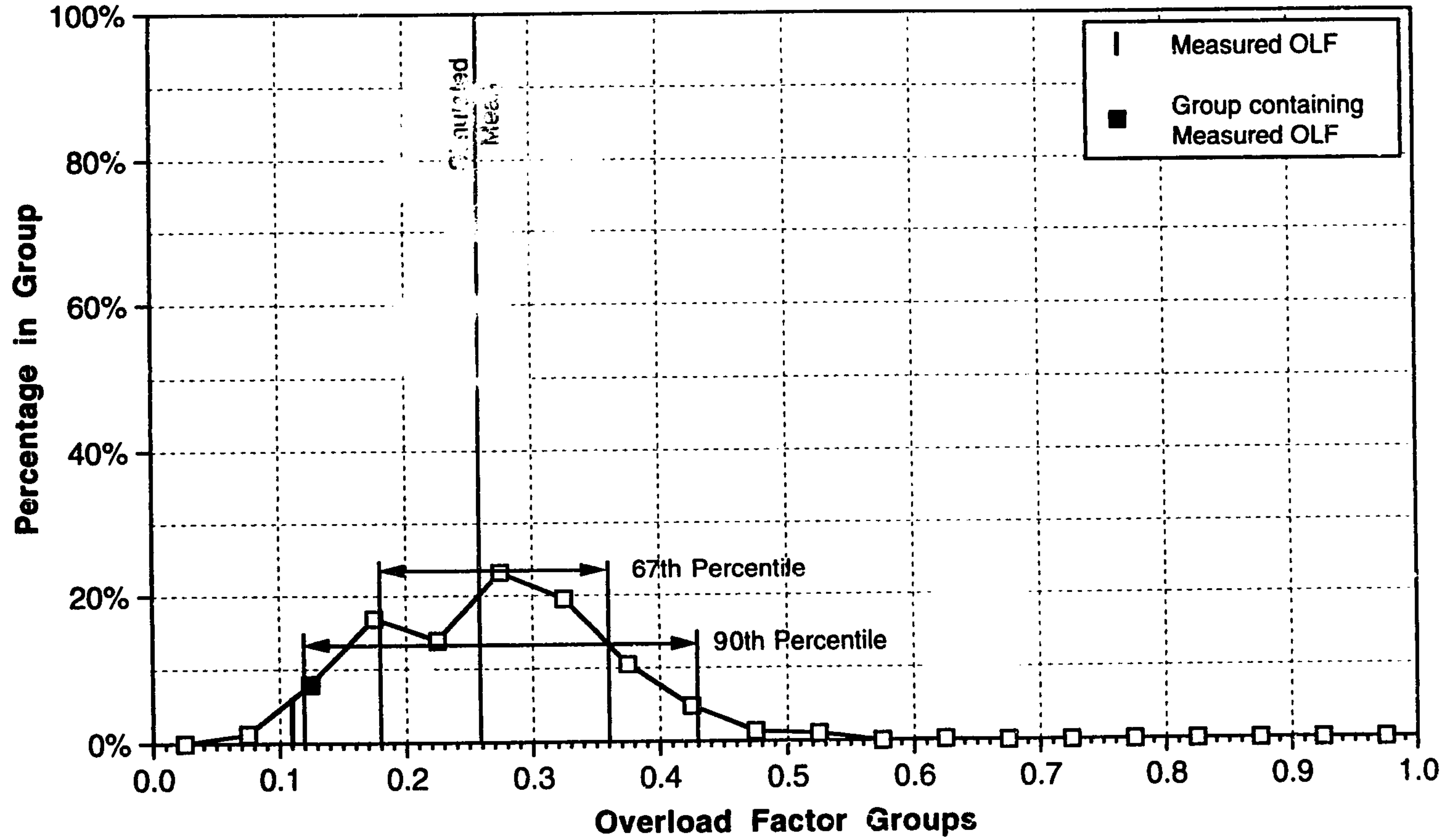


Figure D-3.14 Frequency Plot of Simulated Overload Factors for Survey No. 15

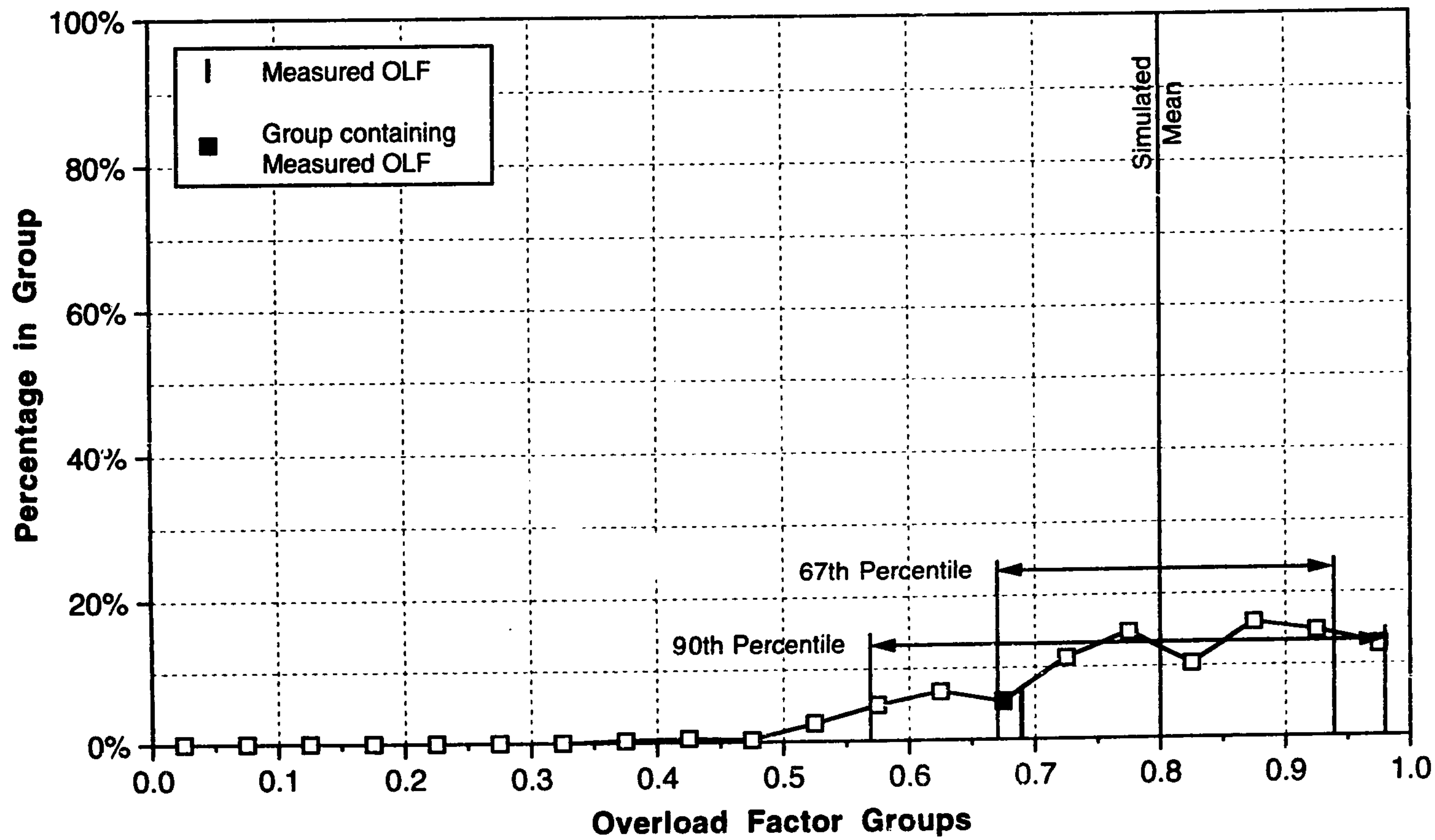


Figure D-3.15 Frequency Plot of Simulated Overload Factors for Survey No. 16

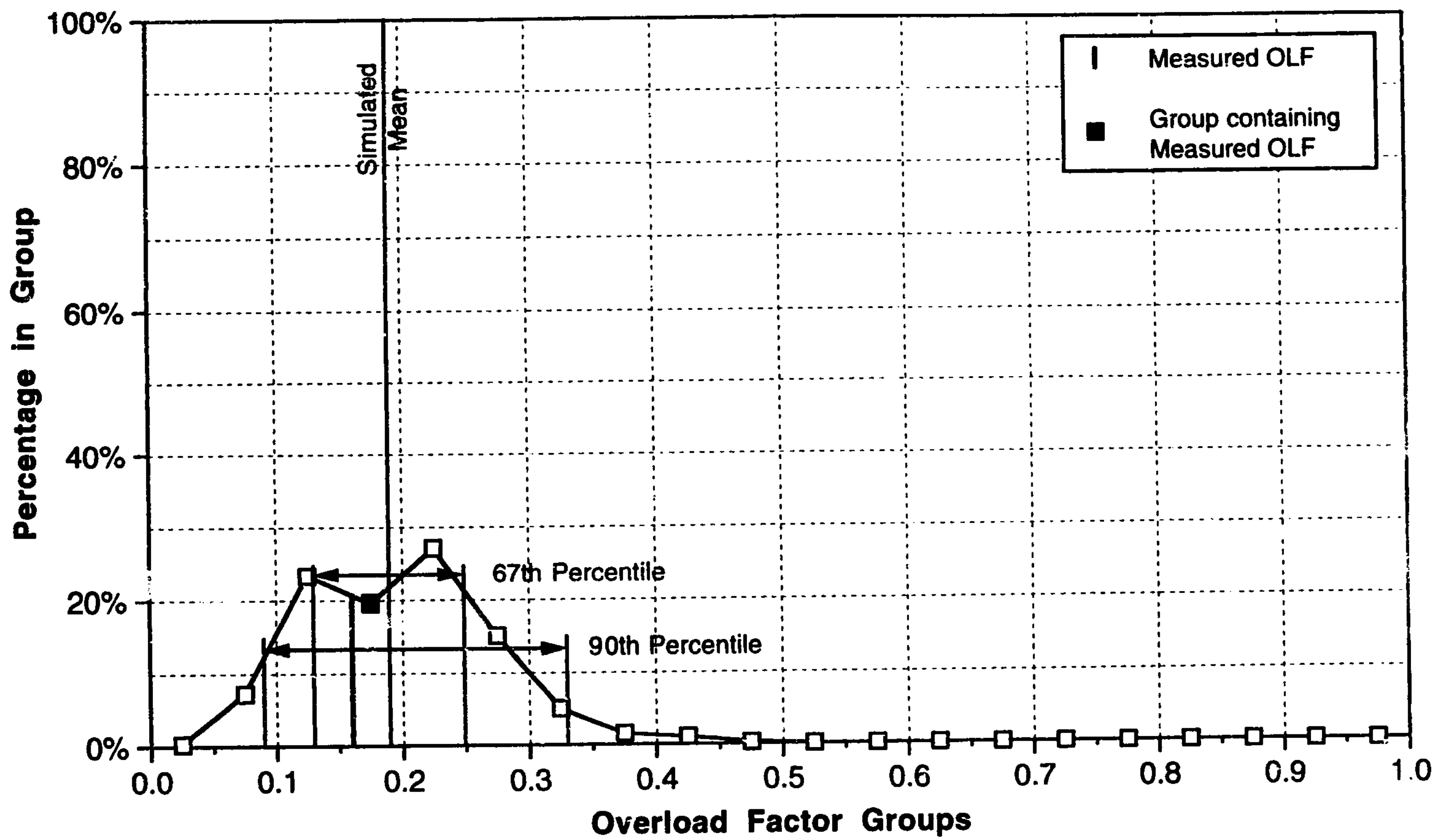


Figure D-3.16 Frequency Plot of Simulated Overload Factors for Survey No. 17

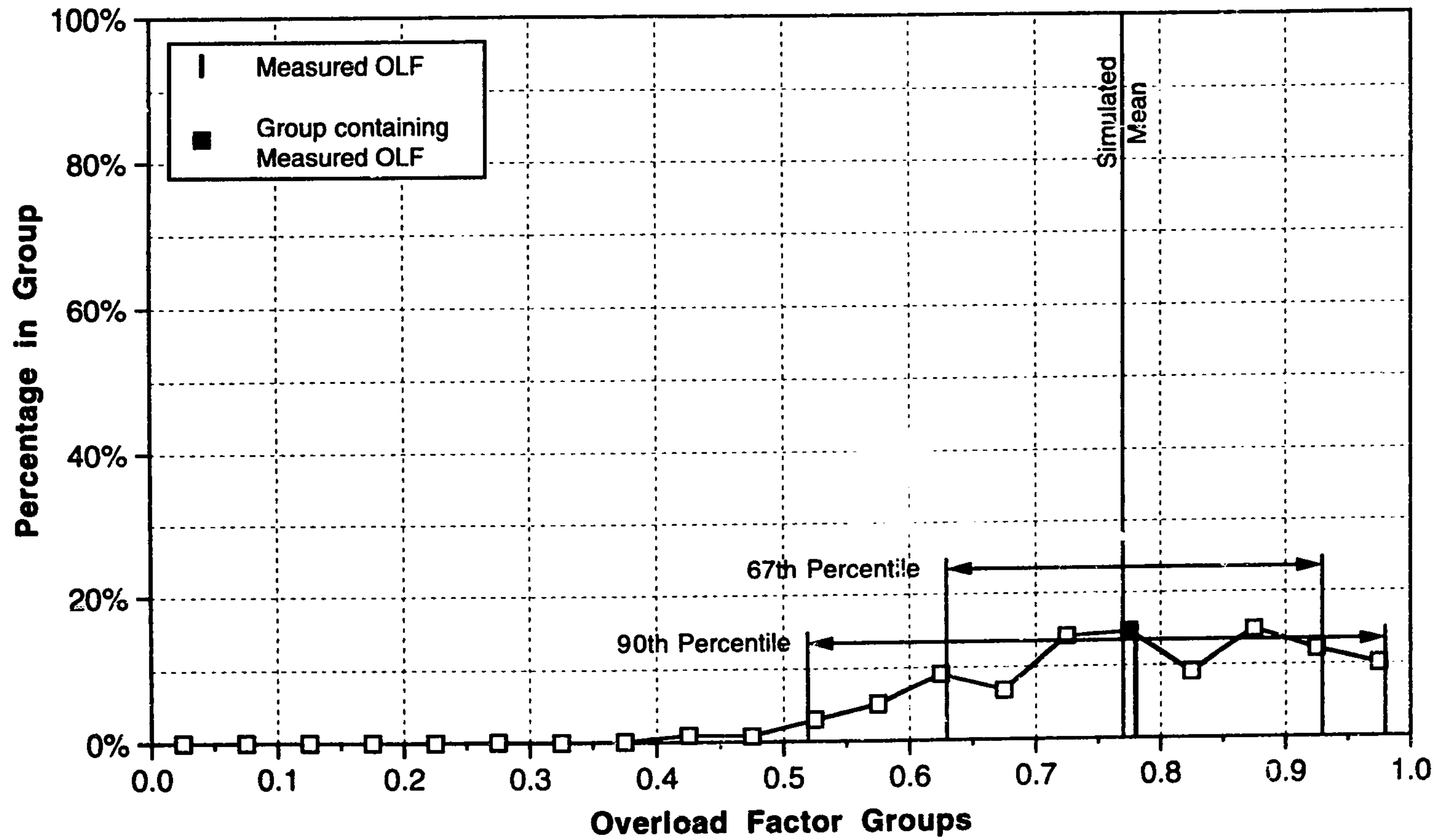


Figure D-3.17 Frequency Plot of Simulated Overload Factors for Survey No. 18

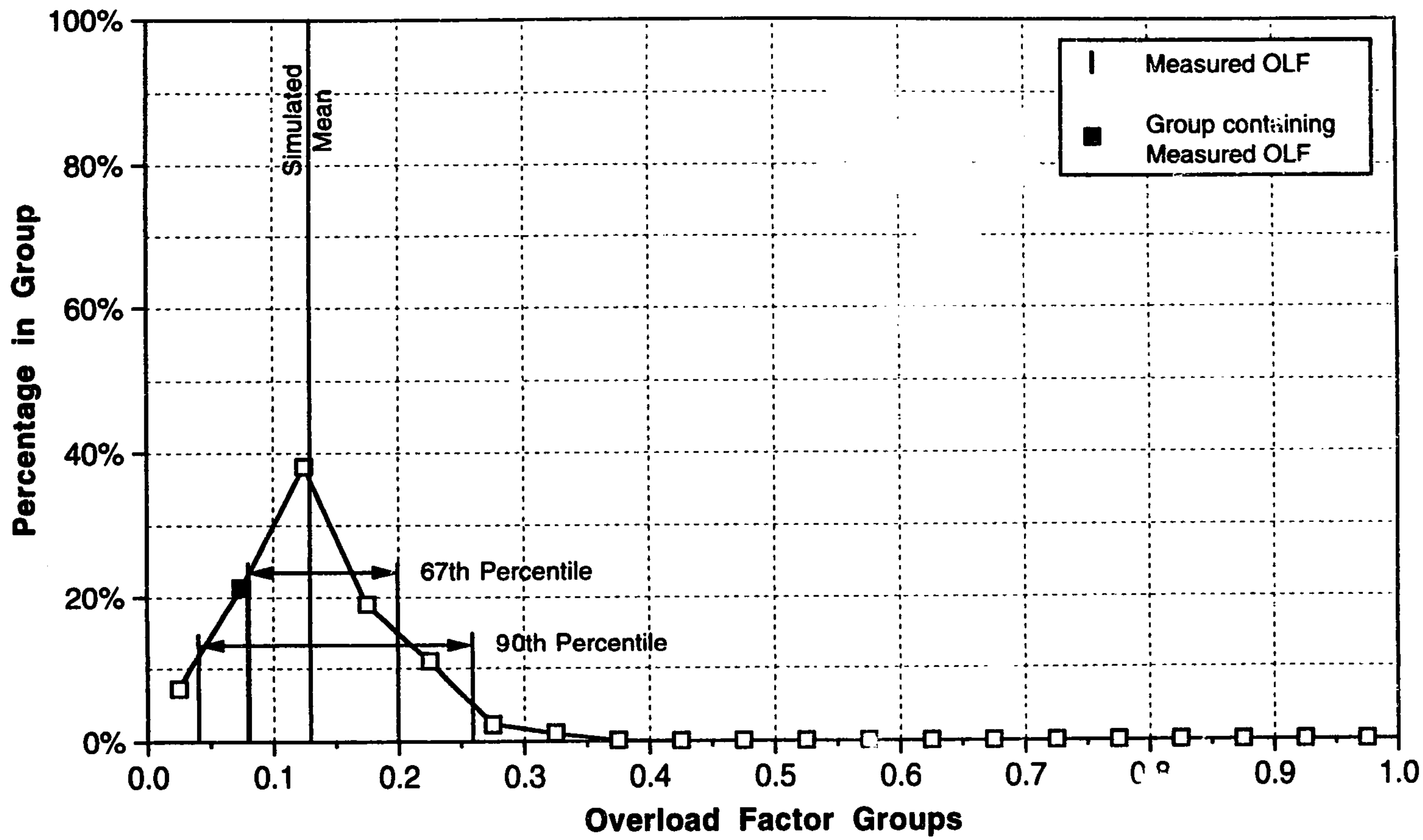


Figure D-3.18 Frequency Plot of Simulated Overload Factors for Survey No. 19

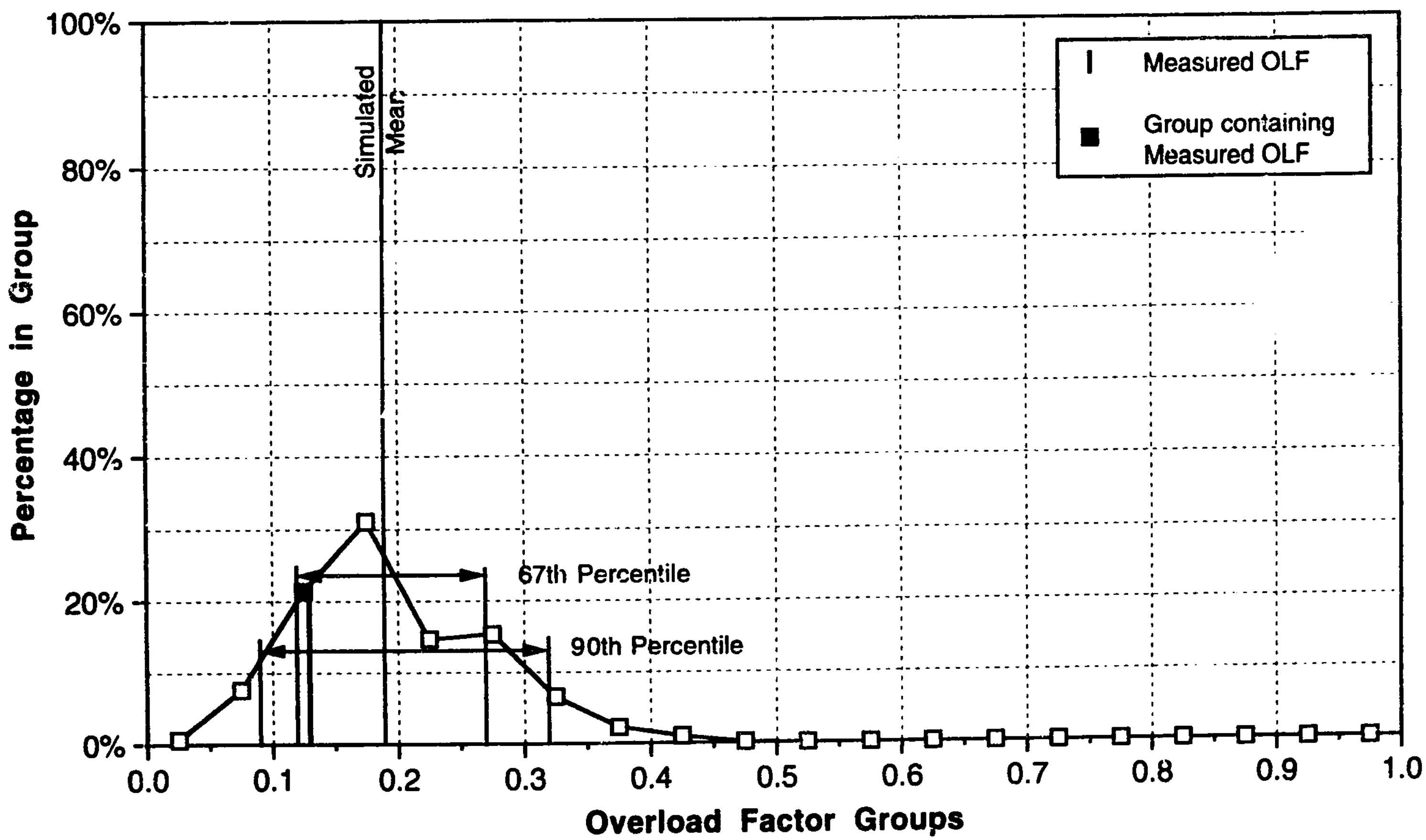


Figure D-3.19 Frequency Plot of Simulated Overload Factors for Survey No. 21

RANDOM NUMBER GENERATION CHECK PROGRAM

The first three random numbers are: 13925 4246 4982

The first random number was repeated after 15439 random numbers were generated.
The next two random numbers are: 5360 23294 - The random numbers are not repeating.

The first random number was repeated after 27580 random numbers were generated.
The next two random numbers are: 25100 7968 - The random numbers are not repeating.

The first random number was repeated after 45394 random numbers were generated.
The next two random numbers are: 15322 25118 - The random numbers are not repeating.

The first random number was repeated after 60358 random numbers were generated.
The next two random numbers are: 2909 8118 - The random numbers are not repeating.

The first random number was repeated after 84125 random numbers were generated.
The next two random numbers are: 2281 8266 - The random numbers are not repeating.

The first random number was repeated after 112749 random numbers were generated.
The next two random numbers are: 7953 27442 - The random numbers are not repeating.

The first random number was repeated after 136754 random numbers were generated.
The next two random numbers are: 19500 523 - The random numbers are not repeating.

The first random number was repeated after 142634 random numbers were generated.
The next two random numbers are: 7309 31992 - The random numbers are not repeating.

The first random number was repeated after 150409 random numbers were generated.
The next two random numbers are: 732 32651 - The random numbers are not repeating.

The first random number was repeated after 162174 random numbers were generated.
The next two random numbers are: 7056 14971 - The random numbers are not repeating.

The first random number was repeated after 172580 random numbers were generated.
The next two random numbers are: 2389 24357 - The random numbers are not repeating.

The first random number was repeated after 251549 random numbers were generated.
The next two random numbers are: 4201 32723 - The random numbers are not repeating.

The first random number was repeated after 267034 random numbers were generated.
The next two random numbers are: 1639 22145 - The random numbers are not repeating.

The first random number was repeated after 283227 random numbers were generated.
The next two random numbers are: 4764 23049 - The random numbers are not repeating.

The first random number was repeated after 284389 random numbers were generated.
The next two random numbers are: 7885 13441 - The random numbers are not repeating.

The first random number was repeated after 285067 random numbers were generated.
The next two random numbers are: 2127 18415 - The random numbers are not repeating.

The first random number was repeated after 312851 random numbers were generated.
The next two random numbers are: 3436 6355 - The random numbers are not repeating.

The first random number was repeated after 383889 random numbers were generated.
The next two random numbers are: 12765 15118 - The random numbers are not repeating.

The first random number was repeated after 413476 random numbers were generated.
The next two random numbers are: 16999 25312 - The random numbers are not repeating.

The first random number was repeated after 518412 random numbers were generated.
The next two random numbers are: 7562 22039 - The random numbers are not repeating.

The first random number was repeated after 563803 random numbers were generated.
The next two random numbers are: 1958 8952 - The random numbers are not repeating.

The first random number was repeated after 637184 random numbers were generated.
The next two random numbers are: 122 24947 - The random numbers are not repeating.

The first random number was repeated after 645627 random numbers were generated.
The next two random numbers are: 14658 9421 - The random numbers are not repeating.

The first random number was repeated after 678357 random numbers were generated.
The next two random numbers are: 12035 26801 - The random numbers are not repeating.

The first random number was repeated after 761216 random numbers were generated.
The next two random numbers are: 1473 19539 - The random numbers are not repeating.

The first random number was repeated after 764797 random numbers were generated.
The next two random numbers are: 23223 20101 - The random numbers are not repeating.

The first random number was repeated after 810819 random numbers were generated.
The next two random numbers are: 15569 16065 - The random numbers are not repeating.

The first random number was repeated after 850285 random numbers were generated.
The next two random numbers are: 24648 6898 - The random numbers are not repeating.

The first random number was repeated after 851669 random numbers were generated.
The next two random numbers are: 10731 5928 - The random numbers are not repeating.

The first random number was repeated after 880857 random numbers were generated.
The next two random numbers are: 13025 30080 - The random numbers are not repeating.

The first random number was repeated after 940422 random numbers were generated.
The next two random numbers are: 3482 4235 - The random numbers are not repeating.

The first random number was repeated after 946975 random numbers were generated.
The next two random numbers are: 20529 763 - The random numbers are not repeating.

The first random number was repeated after 960450 random numbers were generated.
The next two random numbers are: 11925 20344 - The random numbers are not repeating.

The first random number was repeated after 975904 random numbers were generated.
The next two random numbers are: 10836 3650 - The random numbers are not repeating.

The first random number was repeated after 985970 random numbers were generated.
The next two random numbers are: 18117 15375 - The random numbers are not repeating.

No in Bin	% in Bin	Low Bound	Up Bound	Cumulative
20077	2.008	0.00	0.02	2.008
20263	2.026	0.02	0.04	4.034
20279	2.028	0.04	0.06	6.062
19947	1.995	0.06	0.08	8.057
20180	2.018	0.08	0.10	10.075
20095	2.010	0.10	0.12	12.084
19912	1.991	0.12	0.14	14.075
20265	2.026	0.14	0.16	16.102
20067	2.007	0.16	0.18	18.109
19866	1.987	0.18	0.20	20.095
19978	1.998	0.20	0.22	22.093
20019	2.002	0.22	0.24	24.095
19869	1.987	0.24	0.26	26.082
19869	1.987	0.26	0.28	28.069
20176	2.018	0.28	0.30	30.086
19893	1.989	0.30	0.32	32.075
19951	1.995	0.32	0.34	34.071
19825	1.983	0.34	0.36	36.053
20267	2.027	0.36	0.38	38.080
19786	1.979	0.38	0.40	40.058
19950	1.995	0.40	0.42	42.053
20082	2.008	0.42	0.44	44.062
19965	1.997	0.44	0.46	46.058
19984	1.998	0.46	0.48	48.057
20105	2.011	0.48	0.50	50.067
19885	1.988	0.50	0.52	52.056
19778	1.978	0.52	0.54	54.033
19835	1.984	0.54	0.56	56.017
19965	1.997	0.56	0.58	58.013
19967	1.997	0.58	0.60	60.010
19901	1.990	0.60	0.62	62.000
20225	2.022	0.62	0.64	64.023
20169	2.017	0.64	0.66	66.040
19680	1.968	0.66	0.68	68.008
20029	2.003	0.68	0.70	70.010
20202	2.020	0.70	0.72	72.031
20089	2.009	0.72	0.74	74.040
20089	2.009	0.74	0.76	76.048
19835	1.984	0.76	0.78	78.032
19980	1.998	0.78	0.80	80.030

19690	1.969	0.80	0.82	81.999
20253	2.025	0.82	0.84	84.024
20008	2.001	0.84	0.86	86.025
19878	1.988	0.86	0.88	88.013
20114	2.011	0.88	0.90	90.024
20043	2.004	0.90	0.92	92.029
19889	1.989	0.92	0.94	94.017
19856	1.986	0.94	0.96	96.003
20003	2.000	0.96	0.98	98.003
19932	1.993	0.98	1.00	99.997

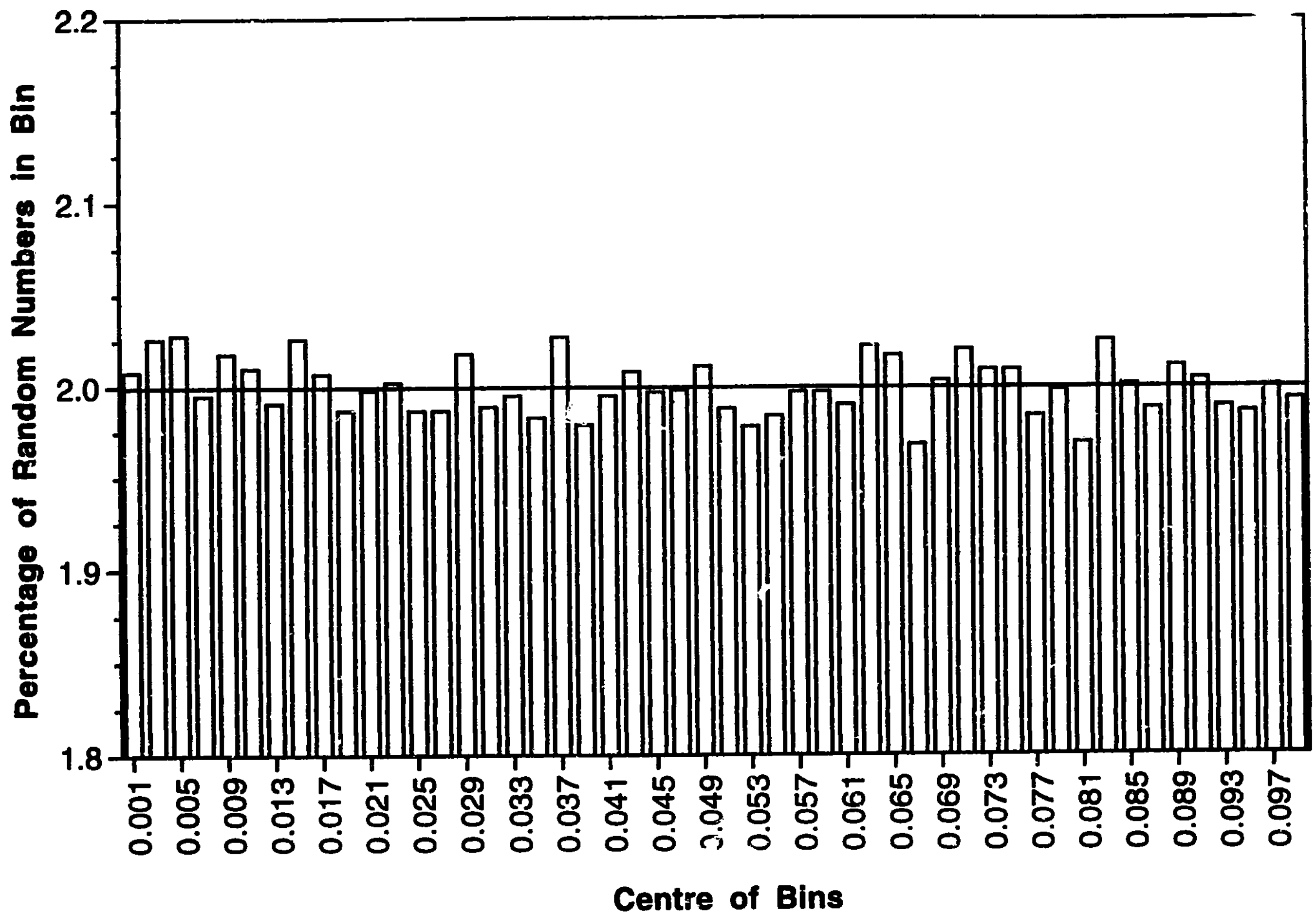


Figure D-3.1 Frequency Plot of 1,000,000 Random Numbers in Groups of 2%