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16. Abstract

The Texas Department of Transportation operates and maintains a large fleet of automotive equipment. The multi-echelon maintenance system supporting the fleet has, as primary elements, major shop facilities at each Departmental District Office. Because of the large volume of work orders and the sophistication of newer automotive systems, purchase of computerized automotive diagnostic test equipment (CDE) for these shops has been suggested.

Data describing the movement of work orders through the District shops were obtained from the EOS Repair-Order-Parts-Issue Data Base. Distributions of work order arrivals, departures, service times, and reason codes were analyzed for Fiscal Years 1988, 1989, and 1990. Of a total volume of approximately 750,000 annual work orders, approximately 5 percent were found to contain reason codes that would be significantly affected by CDE. An economic analysis of the potential benefits and costs of CDE was developed. These calculations indicate that the shops with the highest work order volumes could justify significant CDE investments, while shops with low work order demand could not.

Before-After analyses were conducted of 11 District shops in which CDE was installed between 1988 and 1990. These analyses indicated reductions in service times and increases in the number of work orders with CDE-susceptible reason codes.

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AUTOMOTIVE DIAGNOSTIC TECHNOLOGY

by

Randy B. Machemehl
John Karachepone

Research Report Number 986-1F

Research Project 3-4-90/1-986
Automotive Diagnostic Technology

conducted for

Texas Department of Transportation

by the

CENTER FOR TRANSPORTATION RESEARCH
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Randy B. Machemehl, P.E. (Texas No. 41921)
Research Supervisor

PREFACE

Research Study 3-4-90-986, "Automotive Diagnostic Technology," was an assessment of the impacts of a potential TxDOT decision to purchase and use computerized automotive diagnostic equipment in its District automotive shops. The assessment uses actual data to describe the levels of maintenance activity in the district automotive maintenance shops and attempts to characterize impacts in terms of quantifiable economic costs and benefits.

ABSTRACT

The Texas Department of Transportation operates and maintains a large fleet of automotive equipment. The multi-echelon maintenance system supporting the fleet has, as primary elements, major shop facilities at each Departmental District office. Due to the large volume of work orders and the sophistication of newer automotive systems, purchase of computerized automotive diagnostic test equipment (CDE) for these shops has been suggested.

Data describing the movement of work orders through the District shops were obtained from the EOS Repair-Order-Parts-Issue database. Distributions of work order arrivals, departures, service times, and reason codes were analyzed for FY's 1988, '89 and '90. Of a total volume of approximately 750,000 annual work orders, approximately 5 percent were found to contain reason codes that would be significantly affected by CDE. An economic analysis of the potential benefits and costs of CDE was developed. These calculations indicate that the shops with the highest work order volumes could justify significant CDE investments, while shops with low work order demand could not.

Before-after analyses were conducted of 11 District shops in which CDE was installed between 1988 and 1990. These analyses indicated reductions in service times and increases in the number of work orders with CDE-susceptible reason codes.

SUMMARY

An assessment of the potential economic impacts of the use of computerized automotive diagnostic test equipment (CDE) in the Texas Department of Transportation's District maintenance shops has been developed. The analyses indicate that only a small fraction of all work orders processed through these shops annually contain repair reason codes which would be susceptible to diagnosis with CDE. The shops with the highest volume of work orders can economically justify purchase and use of sophisticated CDE, while those with moderate or low work order volume cannot.

Before-after analyses of the 11 shops which currently have CDE capabilities indicate that the presence of these tools has reduced service times. The volume of work orders processed with CDE related repair reason codes has increased with the presence of the equipment.

All economic analyses have been based on easily quantifiable benefits and costs. Long-term benefits of CDE use in preventive maintenance and other less easily quantifiable potential benefits have been noted but not used in the basic analysis.

IMPLEMENTATION STATEMENT

Results of this study can be used immediately by personnel of the Division of Equipment and Procurement as a guide to the type and quantity of computerized diagnostic test equipment (CDE) to be purchased. The economic analyses of CDE investments have been presented in a variety of formats to facilitate their use, including several electronic spreadsheets.

ACKNOWLEDGEMENTS

The conduct of this study was supported continually by the contact individuals in the the Division of Equipment and Procurement of the Texas Department of Transportation. Mr. Glenn Hagler was particularly helpful in providing timely information and assistance.

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CHAPTER 1. INTRODUCTION

The Texas Department of Transportation (TxDOT) operates and maintains a large multifaceted vehicle fleet. Included are typical passenger cars and light trucks, large cargo trucks, and even a variety of types of construction equipment. Virtually all of these vehicles are, in some way, critical to the success of the TxDOT mission. Continuous, reliable availability of these vehicles depends upon a rather comprehensive maintenance program.

The TxDOT maintenance function is designed around a typical multilevel responsibility system. That is, vehicle operators are responsible for "operator level" maintenance such as refueling and cleaning, whereas vehicle maintenance tasks slightly beyond the operator's capability can often be handled by a small local maintenance organization such as those in remote residencies. Serious problems, or those not successfully diagnosed by lower level organizations, and many scheduled preventive maintenance actions are sent to the respective District Maintenance Shop. These shops generally possess the highest level of maintenance capability found within the Department. During the 1989-90 fiscal year, almost 740,000 maintenance requests passed through the 25 District shops.

The high volume of maintenance activity in these shops indicates that equipment or procedures that can improve efficiency are clearly worth examining. Computerized automotive diagnostic equipment (CDE) offers potential for reducing the labor time required for diagnosing many types of vehicles. Such savings can be potentially large since in some cases the majority of the total repair time is expended diagnosing the problem. However, capabilities and costs of CDE equipment vary widely, and certainly many of the 740,000 annual maintenance requests, noted earlier, would not be improved by use of even the most exotic CDE. These considerations lead to questions regarding the advisability of investing in CDE technology.

The following sections of this report present a review of techniques for describing maintenance operations in terms of their interruption of normal functions and how the impact of CDE technology might be quantified. Investment in CDE technology is examined from an economic viewpoint for each of the TxDOT District maintenance operations. Reasonable but conservative ranges of key variables are employed in a kind of sensitivity analysis of the investment decision. Finally, assuming most likely scenarios for key variables, recommendations for each District are provided.

CHAPTER 2. BACKGROUND

CONCEPTUAL PROBLEM AND ANALYSIS APPROACHES

Vehicles and in fact all types of equipment and machinery are prone to breakdowns and need regular servicing and maintenance to remain in optimum working condition. Repair crews are aided in their assessment of the problem and in repairs by a variety of tools that speed the process so that the machinery can be returned to its original working order and to performing the job it was designed to do. The longer a piece of machinery remains out of order the less useful work it does for its owner, and that translates to higher costs.

Maintenance of vehicles and any other equipment is primarily of two types:

1. Preventive maintenance and
2. Maintenance on breakdown.

Preventive maintenance involves a regular check on vehicles and servicing regardless of the operating condition of the vehicles. This policy tries to limit down time by trying to diagnose problems before they occur and take preventive measures. However this implies that the vehicle be necessarily taken out of operation on a regular basis for a short duration even if the vehicle is working satisfactorily. Preventive maintenance has been an accepted and widely used practice for some time because of its inherent quality of being able to diagnose and take preventive action before a problem occurs, thus avoiding potentially large expenses and long down time.

Maintenance after a breakdown has occurred is generally more expensive and also has the characteristic of being a totally random event. Apart from the loss in production, the possibility of having to provide a higher level of service is very real. However, the provision of this type of repair service—maintenance on breakdown—can never be completely avoided by preventive maintenance since breakdowns can still occur, and do occur, at random, despite the best preventive maintenance.

Importance of problem diagnosis needs to be emphasized at this point. It is common for repair facilities to spend almost half the total service time on making the right diagnosis of the vehicle problems. This results in the repair crew, especially higher skilled (and therefore higher paid) repair men, to be involved in comparatively unproductive diagnosis efforts. Correct diagnosis of the problem is critical and its importance is not underestimated, but rather sufficient time savings can be realized through the diagnostic tools that are now available. Subject to capital costs of these tools, computerized diagnostic tools that are now available commercially offer the best savings in automotive repair diagnosis.

HISTORICAL PERSPECTIVES

In early publications the machine maintenance or machine repair problem was referred to as a 'machine interference' problem, the interference resulting from several machines requiring the services of a repair crew at the same time. Occasionally the associated queueing model has been referred to as the 'Swedish machine' model [4] after the early work of Palm (1947). [10]

Early applications were in the textile industry; for example, on spinning machines, the repair operation involves rejoining yarn. Examples are given in work by Benson and Cox (1951) [3], Benson (1952) [2], Cox (1954) [5] and Cox and Smith (1961) [6]. Morse (1958) [9] devotes one chapter to the maintenance of equipment.

Saaty (1961) [12] considers the subject of machine interference to indicate applications of queueing theory. He deals with six different cases.

1. Poisson Input, Arbitrary-service Distribution.
2. The Exponential-service-time case for c Repairmen.
3. The Constant-service-time case for a Single Repairman.
4. Two types of Stoppages, Single Repairman
5. Each of c Repairmen specializing in One Type of Stoppage with c kinds of Stoppages in all.

6. Constant Repair Time by a Walking Repairman.

A multiserver queueing system where customers from a Poisson arrival stream require simultaneous service from a random number of independent but identical and exponential servers was introduced by Green in 1980. [7] A first come first served queue discipline governed his queueing system. This model was suggested for systems like hospital emergency rooms, loading docks, and maintenance systems. It was shown to be useful in testing certain estimation methods by Seila (1980). [14] Seila gave computational formulae along with tables of these values for selected systems as an aid to simulation methodologists who need to know the first two moments of waiting time in order to evaluate estimators of the waiting time in queue. [15]

Many queueing activities occur in a group or in batches. This is often a reflection of reality where a group of people arrive at a point at the same time and require service. Sometimes service is provided in a batch and departure may be regulated such that a minimum number of requests for service is required before service is actually provided and departure allowed. This type of a queueing regime is a 'Bulk Queue.'

The concept of bulk queues was introduced by Bailey [1] in 1954 when he considered a bulk service queue with simple Poisson arrivals, service batches of fixed size and vehicle departures independent of queue size, and derived the transform of the queue length distribution. Since then many researchers have investigated bulk arrival and bulk service queues. Bulk queueing theory has been applied to the problem of estimating delays to vehicles at intersections controlled by traffic signals by a number of authors. [11]

A queueing network is a multiple node system in which a job requires service at more than one station. If the buffer space between stations is finite and only a limited number of customers can queue in front of any intermediate node, then the phenomenon of blocking may occur. Blocking occurs when the flow of jobs through one queue is momentarily stopped owing to a capacity limitation of another queue having been reached. Queueing networks with blocking have been studied by a number of authors. The literature is extensive and covers a wide variety of assumptions regarding arrival processes, service distribution and recently, multiple job classes with priorities. [16]

In machine maintenance problems it often happens that the machinery pool which serves as the source of customers to the maintenance facility is a finite one. In this finite source queue case the probability of some machine requiring maintenance due to a breakdown during a short time period is dependent on the number of machines in service. A cyclic queue problem is one in which a set of queues in tandem serve a fixed population where on completing its job at the last phase the unit returns and waits for service again in the queue of the first phase. Finite source queues and cyclic queues have applications in vehicle breakdown and maintenance operations. Some other applications have been in estimating aircraft fleet availability and in modelling the movement of vehicles in port operations. [13]

APPLICABLE QUEUEING THEORY

Queueing models provide a very useful basis on which decisions based on scientific study and inquiry can be made. It is important to note that a queueing model in itself does not provide answers that may be required but provide the decision maker with an aid or tool by which he can make a knowledgeable decision.

In the vehicle repair case, management decisions regarding the type and number of diagnostic tools, number of repair crews, and other pertinent resources need to be made. Information required to make these decisions can be provided by a queueing model.

The analysis of queueing systems is made difficult by the inherently probabilistic ('random' or stochastic) nature of the problems. In general there is some 'randomness' associated with both the arrival of units to be serviced and the servicing of units. [4]

The entire process of vehicles entering a repair facility can be described as a 'Birth – Death process.' The repair shop facility is modelled as a queueing system with vehicles that break down and arrive at the facility similar to a 'birth process' and serviced vehicles leaving the system as a 'death process.' Thus a 'birth' refers to the arrival of a vehicle to the queueing system and 'death' refers to the departure of a serviced vehicle from the repair facility.

Some of the terminology and notations used are enumerated below.

n = number of units in the system

λ = average number of arrivals per unit time—mean rate of arrivals

μ = average number of services per unit time—mean rate of service

L = number of units in the system—expected line length

Lq = number of units waiting for service—queue length
= L – number of units being served

Pn = probability that exactly n units are in the queueing system

W = expected waiting time in the system (includes service time)

Wq = expected waiting time in the queue (excludes service time)

ρ = utilization factor—$\frac{\lambda}{\mu}$—(the expected fraction of the time the facility is busy).

Note that $\frac{1}{\lambda}$ and $\frac{1}{\mu}$ are the expected time between arrivals and the expected service time respectively.

Let us assume that arrivals to the system occur with a Poisson distribution (interarrival time is exponential with parameter $\frac{1}{\lambda}$) and that service times for units may have any probability distribution. Assume only that the service times for the respective units are independent with some common probability distribution whose mean ($\frac{1}{\mu}$) and variance (σ^2) are known. It can be shown that the basic steady state results, when the utilization factor (ρ) is less than 1, are the following.

$$Po = 1 - \rho$$

$$Lq = \frac{(\lambda^2 * \sigma^2) + \rho^2}{2(1-\rho)}$$

$$L = \rho + Lq$$

$$Wq = \frac{Lq}{\lambda}$$

$$W = Wq + \frac{1}{\mu}$$

If the service time distribution is exponential, the variance (σ^2) is replaced by the variance of an exponential distribution ($\frac{1}{\mu^2}$). [8]

Thus the problem is analyzed as a system where vehicles which are in regular operation break down and have to be serviced at a repair facility. If the repair shop is not operating at capacity then, this vehicle proceeds to be diagnosed and repaired. However, if there is already a vehicle being currently diagnosed, the vehicle that has just arrived must wait and forms a queue. It has been inherently assumed that a bottleneck occurs at the diagnosis stage and that savings in time are possible if advanced tools can be used for diagnosis thus increasing the ability of the workshop to service vehicles.

SUMMARY

Both preventive maintenance and maintenance on breakdown form an integral part of any equipment maintenance program. The use of diagnostic tools offers the possibility of a significant increase in efficiency of the service facility as a disproportionate amount of time is often spent in diagnosing the specific repairs a work order requires. Historically, the study of the machine maintenance or machine interference problem began in the late 40's in the textile industry. It has since come to incorporate a wide body of knowledge and includes a number of techniques that are specifically applicable given the special conditions of the system under study. The machine interference or equipment maintenance problem is now one of the important applications of queueing theory. The service facility is modeled as a queueing system where vehicles arrive demanding service and depart after receiving the required service. Queues may form if an arrival occurs when the facility is already operating at capacity. Conditions that indicate the analysis technique to be used include the type of arrival distribution and service distribution, and these have to be characterized.

CHAPTER 3. SERVICE HISTORY AND QUEUEING ANALYSIS

Data descriptive of TxDOT maintenance activities at the 25 District shops were made available in the form of the EOS Repair-Order-Parts-Issue database for the years 1987 to 1990. The three tapes (one for each year) were read and the relevant records identified and selected for analysis. A brief organizational description of the data on the tapes and a description of the identification and selection process of the relevant records is given below.

Each observation, which is one maintenance order, has a set of 34 fields associated with it. The record format is shown in Table 3.1. The column reference number provides a quick means of identifying the fields composing each record.

The introduction of computerized diagnostic tools in the diagnostic process will have an effect only on some repairs. For example, engine problems can be effectively diagnosed by such a tool but a problem with the trunk lock will not be helped by using the diagnostic equipment. Selection of observations for the study was based on the nature of the repairs. The relevant observations would be identified based on the 'Reason-Code' in reference column number 11 (Table 3.1). Furthermore, from the objectives of the study, it was evident that all the fields in the database were not required. The fields that were retained are those shown in Table 3.2.

The complete list of "reason codes" from TACS Table TEOS003 is provided in Appendix D. After review of typical capabilities of Computerized Diagnostic Analysis Equipment (CDE), the reason codes listed in Table 3.3 were selected as potentially being affected by CDE use. These repairs are those pertaining to vehicle inspections, engine diagnosis and analysis, the engine in general, electrical systems, hydraulic system diagnosis and analysis, and auxiliary engine and its systems, if any.

The observations that have 'reason codes' that correspond to the above repairs were saved separately for further analysis. This new database of observations consists of those repairs that could be affected by CDE if they were available. Every observation in the new database has 12 fields (corresponding to those fields retained—Table 3.2) associated with it and observations from 3 years of data are available.

Table 3.1 Format of TxDOT maintenance database

Column Reference Number	Record Description	Format
1	RO-PI-District-Number	(N2)
2	RO-Number	(A6)
3	RO-Number-Suffix	(A1)
4	RO-Line-Number	(N2)
5	RO-PI-Equipment Number	(A6)
6	RO-Date-In	(N6)
7	RO-Time-In	(N4)
8	RO-Date-Out	(N6)
9	RO-Time-Out	(N4)
10	RO-Manager-Number	(A3)
11	RO-Reason-Code	(N3)
12	RO-Work-Class	(A1)
13	RO-Owner-District	(N2)
14	RO-Odometer-Hour-Meter	(N7)
15	RO-Repair-Date	(N6)
16	RO-Mechanic-SSN	(N9)
17	RO-Repair-Manhours	(P3)
18	RO-Repair-Function	(N3)
19	RO-Repair-Status	(A1)
20	RO-Facilities-Delay	(P3)
21	RO-Personnel-Delay	(P3)
22	RO-Parts-Delay	(P3)
23	RO-Labor-Charge	(P5.2)
24	RO-Down-Time	(P5)
25	PI-Transaction-Date	(N6)
26	PI-Document-Number	(A8)
27	PI-Function-Code	(N3)
28	PI-Object-Code	(N3)
29	PI-Part-Number	(A21)
30	PI-Description	(A40)
31	PI-Stock-Item-Number	(A7)
32	PI-Quantity	(P5)
33	PI-Total-Price	(P7.2)
34	Record-Type	(A1)

Table 3.2 List of fields retained for study

Column Reference Number	Record Description	Format
1	District Number	(N2)
5	Equipment Number	(A6)
6	Date In	(N6)
7	Time In	(N4)
8	Date Out	(N6)
9	Time Out	(N4)
11	Reason Code	(N3)
12	Work Class	(A1)
20	Facilities Delay	(P3)
21	Personnel Delay	(P3)
22	Parts Delay	(P3)
24	Down Time	(P5)

Using the field corresponding to reference column 1 (District number) the observations were easily sorted and counted to give the total number of work orders processed at each District repair facility that would have been affected by diagnostic tools. The total number of repair orders, by District, serviced at each of the repair facilities without reference to the specific repair undertaken was counted from the TxDOT database. Using the reason codes of Table 3.3, those repairs susceptible to CDE use were also tabulated. The ratio of repairs that would be affected by the use of CDE to the total repairs undertaken at each District repair facility is calculated and expressed as a percentage.

These values are tabulated on a District-by-District basis for all the three years for which data is available and are presented in Tables 3.4a through 3.4c.

OBSERVATIONS

In FYs 1987-1988 and 88-89 the averages among all shops, of the number of repair orders with reason codes indicating likely benefit from CDE were 1198 and 1160. This constituted an average of about 4 percent of all services in each repair facility. The standard deviations associated with these averages were 1.285 and 1.019 percent, respectively.

The year 1989-1990 varies significantly from the previous two years in that a significantly larger number of work orders had the reason codes of Table 3.3. The average number among all shops that would have benefited from the use of diagnostic equipment was 1,726. This constituted an average of 5.83 percent of all work orders processed and had a standard deviation of 2.002 percent.

Table 3.3 Reason codes potentially affected by use of CDE

Code/ Argument Values	Equipment Operating System Repair Reason
012	Periodic Inspection
013	Annual Inspection
016	Engine Diagnosis and Analysis
020	Engine
021	Engine, Head Gasket and Above
022	Engine, Below Head Gasket
024	Engine, Ignition System
025	Engine, Cooling System
026	Engine, Air Intake System
027	Engine, Fuel System
028	Engine, Exhaust System
029	Engine, Emission System
050	Electrical System
051	Electrical Wiring
055	Starter
056	Generator/Alternator
058	Battery
059	On-Board Computer/Analysis
078	Hydraulic Diagnosis and Analysis
130	Auxiliary Engine
131	Engine, Head Gasket and Above
132	Engine, Below Head Gasket
134	Engine, Ignition System
136	Engine, Air Intake System
137	Engine, Fuel System
138	Engine, Exhaust System
139	Engine, Emission System

SERVICE HISTORY AND QUEUEING ANALYSIS

The pattern, timewise, of work order arrivals at each of the District repair shops is required for analyzing the shops as queuing systems. The arrival pattern on an hour-by-hour basis over all working days at each shop provides information regarding the time during the day that most demands for service are made.

The rate at which service is provided or the rate at which service is completed at the repair facility will be affected by CDE. In order to find the arrival and the service completion pattern, each year's data were sorted and separated by District. Every observation at each District's repair facility had 12 records corresponding to the records that were listed in Table 3.2.

SERVICE DEMAND ANALYSIS

The analysis here focuses on the field corresponding to the 'time in' of each observation

Table 3.4a Work orders benefiting from use of CDE 1987-1988

District Number	Total Number of Vehicles Serviced	Numbers of Work Orders with Reason Codes of Table 3.3	Vehicles Benefiting as a Percentage
1	20,200	553	2.74
2	48,737	1,634	3.35
3	20,235	979	4.84
4	39,973	1,014	2.54
5	35,102	1,330	3.79
6	32,423	1,170	3.61
7	34,713	1,316	3.79
8	27,107	774	2.86
9	29,020	1,356	4.67
10	25,844	1,151	4.45
11	20,262	1,112	5.49
12	61,000	2,241	3.67
13	31,401	1,626	5.18
14	23,026	1,250	5.43
15	48,475	2,598	5.36
16	32,065	1,664	5.19
17	25,154	1,136	4.52
18	40,887	1,078	2.64
19	20,522	589	2.87
20	28,885	1,233	4.27
21	33,852	1,687	4.98
23	16,066	975	6.07
24	22,452	629	2.80
25	22,532	711	3.16
29	4,424	139	3.14
50	351	1	0.28
	Total = 744,708	Total = 29,946	Avg. = 4.02

Average Number of Vehicles per District Benefiting from CDE = 1,197.84

(work order). The observations were sorted and the frequency distribution of the arrival times was plotted. A class interval of one hour was chosen to provide an accurate picture of the arrival distribution.

An example histogram for the Houston District is presented as Figure 3.1. Histograms for all 25 Districts for the 3 years 1987 to 1990 are presented in Appendices A through C. The histograms present the number of work orders and the hours of the day. The first class interval denoted by 0 hours denotes all arrivals/departures beginning from the 000 hours to 700 hours. The last interval denoted by 1800 hours corresponds to the period beginning at 1800 hours and ending at midnight. Each hour flagged on the horizontal (X) axis corresponds to the hour beginning at the flagged time. For example, the column flagged 900 represents the number of work orders that arrived at the facility, or departed the service facility on completion of service, beginning at the 900 hour and until but not including 1000 hours.

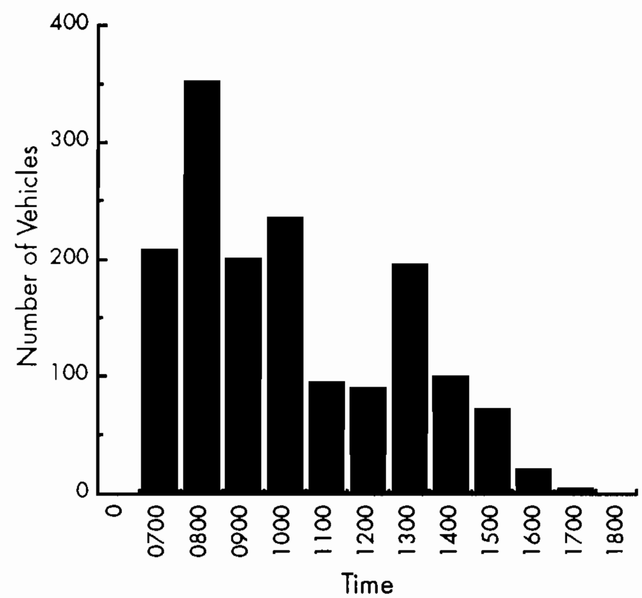

Figure 3.1 Arrival distribution 1989-90, Houston district

Table 3.4b Work orders benefiting from use of CDE 1988-1989

District Number	Total Number of Vehicles Serviced	Numbers of Work Orders with Reason Codes of Table 3.3	Vehicles Benefiting as a Percentage
1	22,830	641	2.81
2	50,065	1,591	3.18
3	20,849	1,148	5.51
4	38,336	1,169	3.05
5	39,305	1,051	2.67
6	32,962	1,310	3.97
7	38,237	1,202	3.14
8	28,240	890	3.15
9	27,901	995	3.57
10	26,039	1,093	4.20
11	18,802	1,025	5.45
12	61,214	1,923	3.14
13	33,475	1,378	4.12
14	25,025	1,190	4.76
15	49,863	2,652	5.32
16	35,748	1,509	4.22
17	25,727	1,101	4.28
18	42,253	1,054	2.49
19	24,686	986	3.99
20	30,838	1,297	4.21
21	32,183	1,555	4.83
23	18,871	896	4.75
24	20,636	642	3.11
.25	26,140	559	2.14
29	7,190	134	1.86
50	53	0	0.00
	Total = 777,468	Total = 28,991	Avg. = 3.73

Average Number of Vehicles per District Benefiting from CDE = 1,159.64

Some trends that can be generalized to all Districts are easily observable from the plots of the District frequency distributions. A very high proportion of the vehicles arrive in the hour immediately following the opening of the service facility. The number of arriving work orders drops towards noon. The noon hour or the hour beginning at 1300 hours again shows increased arrivals. The number of arrivals then falls steadily until the repair facility closes. This behavior is not surprising as most vehicles are expected to arrive at the service facility when it opens in the morning. The rise in arrivals at noon or 1300 hour is due to the fact that vehicles are processed more slowly or not processed at midday since personnel are at lunch, causing arriving vehicles to accumulate during this period. These are processed when personnel return giving a second peak of arrivals during the noon hour or the 1300 hour, depending on the time the lunch break is taken.

SERVICE COMPLETION ANALYSIS

The analysis here focuses on the field corresponding to the 'time out' of each observation (work order). The observations are sorted and a frequency distribution of the departure times is plotted. The same class interval of one hour, chosen for the service demand analysis, in the previous section, is used for this analysis. An example histogram for the Houston District is presented as Figure 3.2, with the complete 25 District set for the 3 years 1987 to 1990 presented in Appendices A through C.

The trend for service completion and for vehicles to leave the service facility is a more uniform distribution with peaks towards the end of the day and in the morning just before 'lunch.' In most cases it is only the first hour of the working day and the hour beginning 1300 hours that have a significantly lower departure rate.

Table 3.4c Work orders benefiting from use of CDE 1989-1990

District Number	Total Number of Vehicles Serviced	Numbers of Work Orders with Reason Codes of Table 3.3	Vehicles Benefiting as a Percentage
1	25,410	1,892	7.45
2	47,277	3,588	7.59
3	20,810	1,709	8.21
4	44,722	2,158	4.83
5	35,449	1,156	3.26
6	30,118	1,988	6.60
7	33,652	2,646	7.86
8	25,206	2,399	9.52
9	24,831	1,680	6.77
10	23,006	784	3.41
11	17,520	732	4.18
12	53,174	1,542	2.90
13	34,471	1,755	5.09
14	24,573	1,363	5.55
15	48,836	2,997	6.14
16	32,541	1,067	3.28
17	23,713	1,331	5.61
18	44,468	3,389	7.62
19	24,523	2,010	8.20
20	27,549	1,412	5.13
21	28,154	2,128	7.56
23	16,927	679	4.01
24	22,386	916	4.09
25	23,490	1,670	7.11
29	6,891	150	2.18
50	4	0	0.00
	Total = 739,701	Total = 43,141	Avg. = 5.83

Average Number of Vehicles per District Benefiting from CDE = 1,725.64

This is consistent with the fact that vehicles depart from the service facility as soon as service is completed and the first hour of operation of the facility each day does not see many work orders completed. The hour just after 'lunch' again sees a steep drop in service orders completed. During the 'lunch' hour, service drops since personnel are away at 'lunch.' The far more uniform distribution during the rest of the hours of the day is a result of the fact that service completion is a random event that can happen at any time. The peaks just before 'lunch' and at the end of the working day is a result of the inclination to complete service, if possible, before a break.

SUMMARY

The introduction of diagnostic tools will affect only some of the work orders at each service facility. The relevant work orders that will potentially be affected by the introduction of such diagnostic equipment were identified and stored independently from the TxDOT maintenance data base for the years 1987 to 1990. The work orders were also sorted by district and the ratio of work orders affected by Computerized Diagnostic Analysis Equipment (CDE) to the total number of work orders at each service facility was calculated and tabulated. The year 1989-1990 shows a significant increase in the total number of work orders at the service facility

The timewise work order arrival and service completion pattern is ascertained by plotting the number of work order arrivals and completions against the time of the day for each district. The trend for work order arrivals is to have a peak of highest arrivals in the hour immediately following the opening of the service facility and again a smaller peak in the hour immediately following 'lunch.' In the case of service completions, the largest number of service completions occur towards the closing hour of the facility. Here too a smaller peak occurs at mid-day though now it is the hour just preceding the 'lunch' hour that has the peak of higher service completions. Generally the service completion regime is more uniform than that of work order arrivals.

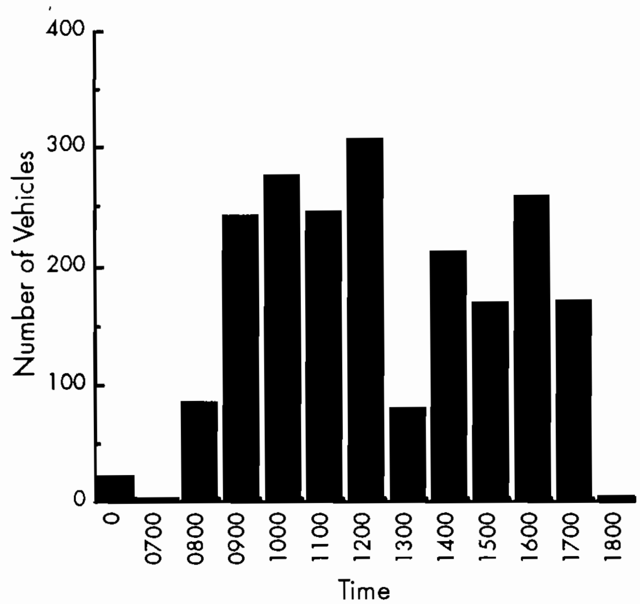

Figure 3.2 Departure distribution 1989-90, Houston district

CHAPTER 4. DEVELOPMENT OF SCENARIOS

Analysis has shown that the benefits that can be expected from the introduction of diagnostic equipment are dependent on a number of factors principal among which is the quantity of service demands, that is, the size of the vehicle fleet served by the facility. Other factors taken into account are the expected efficiency increases due to the introduction of CDE and labour cost that the repair facility incurs.

Benefits to a large repair facility which serves a large vehicle fleet are significantly larger than those to a small repair facility as service demands on the large facility are considerably higher when all other variables are kept constant. This has a direct impact on the diagnostic equipment cost that a small repair facility can amortize in a reasonable length of time or within the expected life of such equipment. In order to characterize the economic relationships for Districts with different service demands and therefore the equipment costs that Districts may be able to amortize, 'most likely' scenarios were developed.

VARIABLES

Districts

Three Districts with very different service demands (different fleet sizes) were chosen to develop a sensitivity study of the effect of service demands on benefits and therefore the diagnostic equipment costs that can be recovered. The point of interest is, specifically, the number of years over which equipment of a given cost can be amortized. A District with a very high demand for service is the Fort Worth District, which is chosen as an example of a large repair facility. Austin is chosen as a District with moderate service demand. One might guess that a small District facility like that in Brownwood might have fewer requirements for CDE and therefore may not be able to justify the purchase of more expensive equipment as would larger district facilities.

The Districts chosen cover the entire range of service demands. The service demands (in vehicles per year) for the latest year for which data are available were used, as these data most likely reflect the service demands that can be expected in the future. In the year 1989-1990, Fort Worth had 3,588 maintenance actions which had repair codes indicating they could be impacted by CDE. Additionally, medium and low demand levels could be represented by Austin, which had a demand of 1,363, and Brownwood, with 679.

Service Completion Rate

Service is provided to a vehicle at the repair facility dependent on the availability of personnel, equipment or facilities, and spare parts. Often considerable time is spent in diagnosis before any repairs can begin. The time taken to service a work order is dependent on the type of repairs required and therefore varies. Vehicles that spend extended time in the repair facility are usually there because of spare parts unavailability or other uncontrollable factors. The productive time a vehicle spends in a service facility is that time during which the vehicle is being diagnosed or physically repaired.

In calculating service completion rates delays due to uncontrollable factors were excluded. This is accomplished by excluding unusually long service times. The average time for service completion, regardless of the specific problem, was used as an estimator of the service completion rate. This can be interpreted as the mean time to complete service for an 'average' problem. From the analysis of data it was found that a reasonable value, one that can be used in developing the most likely scenario, for the rate of service completions is 1 hour per vehicle.

Efficiency Improvement

The use of CDE in repair facilities will have an impact upon total repair time for those work orders needing the type of service which can benefit from speedier, more comprehensive diagnosis. As noted earlier, a small percentage of all work orders (about 5 to 10 percent) based on 1989-1990 data, were coded as problems clearly susceptible to CDE diagnosis. CDE diagnosis of other problems might lead to early recognition and preventive maintenance which could produce significant long term benefits. For purposes of the following analysis, such unplanned benefits are ignored. Rather the analysis is concentrated upon those work orders which could be accelerated through CDE analysis. For these cases, total repair time is considered as the sum of diagnosis, physical repair and other time (including parts waiting time). Diagnostic time typically ranges from almost nil to 80 or 90 percent of total repair time with about 35 percent being typical. CDE will directly impact only diagnostic time, but its effect on the repair system is simulated in the following analysis as a percentage reduction in total repair time. Through the following analysis, total repair time reductions of 5 to 35 percent, with a typical value of 20 percent, are used. These values are termed as efficiency improvements.

Labor Cost

The service facilities employ personnel all of whom either are cross trained and/or perform maintenance work on all types of equipment. Pay scales differ for personnel depending on experience and other factors and are based on their pay grade.

Data on the number of 'Motor Vehicle Mechanics' at each District shop and their pay grade were used in estimating a weighted average labor cost per motor vehicle mechanic to each District facility (see Table 4.1). This calculated labor cost includes benefits and overhead assessed on each mechanic at 58.8% of his basic salary.

For each District the number of motor vehicle mechanics at each pay grades is tabulated with their respective monthly salary. The monthly salary used corresponds to that in column 5 (considered mean salary within each pay grade) of the monthly salary rates of the TxDOT's pay scales effective September 1, 1989. The Department cost is calculated as 1.588 times the monthly salary. The product of the number of mechanics at each District's shop and the Department cost gives the total cost to the Department at each pay grade. The sum of this total cost is divided by the total number of mechanics at each of the District shops to give the weighted average labor cost to each District. This weighted average labor cost is used in the economic analysis of CDE. The tabulation and calculation of this labor cost is shown in Table 4.1.

Internal Rate of Return

Benefits expected in the future have to be discounted to reflect present value before they can be used in any comparative study involving an outflow or inflow of capital. The rate at which expected benefits are discounted within the organization is the internal rate of return. The internal rate of return reflects the current state of the economy and attempts to predict future trends or the future state of the economy. The current state of the economy suggests the adoption of a conservative value and for the development of the most likely scenario an internal rate of return of 8 percent per year has been adopted.

Benefits are calculated as a product of the labour cost, service demands, rate of service completions, and the expected improvement in efficiency by the introduction of CDE.

$$\text{BENEFITS} = (\text{L.C.}) * (\text{S.D.}) * (\text{S.C.}) * (\text{I.E.})$$

where BENEFITS is in dollars per person-month,

L.C. = labor cost in dollars per person-month,
S.D. = service demands on the service facility in vehicles per month,
S.C. = rate of service completions in months per vehicle, and
I.E. = improvement in efficiency of the service facility expected as a result of introduction of diagnostic equipment as a percentage.

Diagnostic Equipment Cost

CDE is available in a wide range of capabilities and technological sophistication. The equipment is therefore available in a wide range of costs. The number of years that the District facility will take to amortize the cost of equipment is obviously directly dependent on the cost of the equipment. A range of costs has therefore been incorporated into this development of most likely cases. Calculation has been done for a sophisticated but expensive piece of equipment costing $50,000, a moderately priced piece of equipment at $25,000 and a comparatively inexpensive but less sophisticated one at $10,000.

Amortization

The number of years to recover the investment made in a piece of CDE can be easily calculated given the benefits expected to accrue from the use of such equipment and the rate of return. This period is calculated based upon the CDE.

$$N = \sum_{i=1}^{n} \left[\frac{\text{Ben}}{(1+i)^n} \right] - \text{C.I.}$$

where N = number of years to amortize cost of equipment,
Ben = benefits in dollars per person-year, and
i = internal rate of return per year,
C.I. = initial cost of diagnostic equipment.

Comments

The cost of annual maintenance on the CDE has been assumed to be zero in the previous section. This assumption will be relaxed later. No maintenance may be justified since computerized diagnostic equipment is relatively maintenance-free and is usually covered by an extensive warranty through most of the expected life of such equipment. On the rare occasion that one does break down outside the coverage provided by the manufacturer it may often be advisable to invest in a new piece of equipment that is more suited to the then prevailing service demands on the service facility. Alternately, repairs on breakdown of such equipment can be done with an upgrading of capabilities if upgrading is possible. CDE is assumed to have a useful life of 15 years for the purposes of this analysis.

The most likely cases for the three Districts considered (Fort Worth, Austin, and Brownwood) are given in Table 4.2.

Table 4.1 Calculation of weighted average labor cost

District	Number of Mechanics at Pay Grade 8 \$1,519 [1] \$2,412 [2]	Number of Mechanics at Pay Grade 10 \$1,731 [1] \$2,749 [2]	Number of Mechanics at Pay Grade 11 \$1,849 [1] \$2,936 [2]	Number of Mechanics at Pay Grade 12 \$1,975 [1] \$3,136 [2]	Number of Mechanics at Pay Grade 13 \$2,108 [1] \$3,348 [2]	Total Number of Mechanics	Weighted Average Cost (\$)
Paris				5		5	3,136
Fort Worth	3	3	1	10	1	18	2,952
Wichita Falls		3		5		8	2,991
Amarillo		3		5		8	2,991
Lubbock				15		15	3,136
Odessa	1			4	1	6	3,051
San Angelo		2		2		4	2,943
Abilene		2		7		9	3,050
Waco	1	2		9		12	3,011
Tyler	2	4		3		9	2,803
Lufkin		3		8	1	12	3,057
Houston	4	3		16		23	2,960
Yoakum				9		9	3,136
Austin		1		8		9	3,093
San Antonio	3	5		4		12	2,794
Corpus Christi		4		4	1	9	2,988
Bryan		3		5		8	2,991
Dallas	1	5		5		11	2,894
Atlanta		2		6		8	3,039
Beaumont		1		10		11	3,101
Pharr		2		2		4	2,943
Brownwood				5		5	3,136
El Paso	5	4				9	2,562
Childress				5		5	3,136
Camp Hubbard				5		5	3,136

[1] Monthly Salary
[2] Department Cost

Table 4.2 CDE cost amortization for most likely conditions

Conditions Considered Most Likely:
Internal Rate of Return = 8%
Rate of Service Completions = 1 Hour per Vehicle
Improvement in Efficiency Due to Use of CDE = 20%

District	Service Demand (Work Orders/Year)	Labor Cost ($/Person-Month)	Benefits ($/Month)	Cost of CDE ($)	Number of Years to Amortize CDE
Large (Fort Worth)	3,588	2,951.65	1,020.28	10,000	0.8
				25,000	2.2
				50,000	5.0
Medium (Austin)	1,363	3,093.25	406.17	10,000	2.2
				25,000	6.6
				50,000	*
Small (Brownwood)	679	3,136.30	205.16	10,000	4.9
				25,000	*
				50,000	*

* Implies that the cost of the diagnostic equipment will not be recovered within its expected life

DISTRICT BY DISTRICT ANALYSIS USING MOST CURRENT DEMAND RATES

Each District is now analyzed to give the number of years in which it could amortize the cost of CDE. The variables used are the same as discussed in the previous section. A spreadsheet is developed which, when appropriate values are given to the variables, will give the number of years over which the cost of a diagnosing tool will be amortized.

The most current demand rates, those for the year 1989-1990, are used to calculate the benefits that will accrue each month when a diagnostic tool is introduced. A service rate of one vehicle per hour is used as representative and constant for all the District service facilities. The labor cost calculated as the average weighted labor cost per person-month is used for each District. An internal rate of return of 8% per year is chosen as an acceptable rate of return given the current state of the economy. An efficiency improvement of 20% is also used for all the Districts. This efficiency improvement is moderate and it is expected that most Districts will be able to achieve it with the introduction of computerized diagnostic equipment.

Benefits that accrue each month are calculated as the product of the service demand, service completion rate, efficiency improvement and the labor cost. This is calculated through a microcomputer based spreadsheet. As noted earlier, diagnostic equipment is available in a wide variety of capabilities and cost. For the purpose of this study CDE costs per unit were $50,000, $25,000, or $10,000 each. The number of years to amortize the equipment cost is calculated given the internal rate of return, the benefits that will accrue, and the CDE cost.

A service life of 15 years is assumed for the diagnostic equipment. If, on calculation of the number of years to amortize equipment, it is found to be greater than 15 years, then a less expensive piece of equipment is assumed to be bought. This lower cost of the equipment is entered in the appropriate column and the number of years to amortize it is calculated.

Given these values, the number of years required for amortization of what appears to be the most appropriate CDE for each District is shown in Table 4.3. The chart is divided into three parts corresponding to the cost of equipment ($50,000, $25,000, and $10,000 each) that each group of Districts can amortize within 15 years. The spreadsheet is designed to be user friendly and on plugging in different values for different variables it will generate the number of years to amortize a given piece of diagnostic equipment.

A second spreadsheet was developed to provide the maximum cost of diagnostic equipment that can be amortized within 15 years under the conditions given. This spreadsheet with values for variables previously described is presented as Table 4.4.

UPGRADING COSTS

In recognition of the fact that CDE may have the capability to be upgraded to diagnose the latest model vehicles or to improve its capabilities, an upgrading cost is introduced. This upgrading cost is assumed to accrue to each CDE in the fifth and tenth year of the equipment life. The cost of such an upgrade is assumed to be 10% of the initial cost of equipment at both the fifth and tenth years of its life. This upgrading cost is discounted to give its present value and added to the initial cost to give a revised total cost. This cost is used in recalculating the number of years to amortize the piece of equipment. A separate spreadsheet does this and for the values used the resulting chart is given in Table 4.5.

All three spreadsheets allow the user to specify values for all variables that the user considers appropriate and will give:

Table 4.3 - the number of years to amortize the cost of the equipment,

Table 4.4 - the maximum cost of diagnostic equipment that each district can purchase if it is to be amortized in exactly 15 years,

Table 4.5 - the number of years to amortize the cost of the equipment as well as upgrading costs, at 10% of initial cost in the fifth and tenth year.

It is significant to note that the Houston District, which is large and therefore expected to be suited to an expensive piece of CDE, appears in the moderately priced equipment group in Tables 4.3 and 4.5. This is a direct result of the service demands made on the Houston District. In the year 1989-1990, the latest year for which data is available, only 1542 CDE related service demands were coded by the Houston service facility. This is significantly lower than the demands reported by Houston in the previous two years. In 1987-1988 the demand for service on Houston was 2,241, while that in the year 1988-1989 was 1,923 (Table 4.6). Thus Houston has seen a decreasing number of CDE impactable service demands on its service facility. This must be compared to the trend of increasing service demands for most other Districts: in fact, the year 1989-1990 saw a cumulative increase, over all Districts, of nearly 50% over the previous year.

Table 4.3 Amortization time for Districts

Service Demand in Hours per Vehicle = 1
Rate of Return as a Percent per Year = 8%
Improvement in Efficiency as a Percent = 20%

District	Service Demand (Work Orders/ Year)	Labor Cost ($/Person-Month)	Benefits ($/Month)	Cost of CDE ($)	Number of Years to Amortize CDE
Fort Worth	3,588	2,951.65	1,020.28	50,000	5.0
Dallas	3,389	2,894.35	944.98	50,000	5.5
San Antonio	2,997	2,793.82	806.66	50,000	6.7
San Angelo	2,646	2,942.56	750.10	50,000	7.4
Abilene	2,399	3,050.20	704.95	50,000	8.0
Amarillo	2,158	2,991.00	621.83	50,000	9.6
Pharr	2,128	2,942.56	603.25	50,000	10.1
Atlanta	2,010	3,039.43	588.56	50,000	10.5
Odessa	1,988	3,050.81	584.30	50,000	10.6
Paris	1,892	3,136.30	571.66	50,000	11.0
Yoakum	1,755	3,136.30	530.27	50,000	12.4
Wichita Falls	1,709	2,991.00	492.45	50,000	14.2
Waco	1,680	3,011.38	487.39	50,000	14.4
Childress	1,670	3,136.30	504.59	50,000	13.6
Houston	1,542	2,959.82	439.70	25,000	6.0
Beaumont	1,412	3,101.08	421.84	25,000	6.3
Austin	1,363	3,093.25	406.17	25,000	6.6
Bryan	1,331	2,991.00	383.53	25,000	7.2
Lubbock	1,156	3,136.30	349.28	25,000	8.1
Corpus Christi	1,067	2,987.56	307.10	25,000	9.8
El Paso	916	2,561.80	226.07	10,000	4.4
Tyler	784	2,803.17	211.72	10,000	4.7
Lufkin	732	3,057.03	215.58	10,000	4.6
Brownwood	679	3,136.30	205.16	10,000	4.9
Camp Hubbard	150	3,136.30	45.32	3,000	7.3

Table 4.4 Maximum CDE cost amortized within 15 years

Service Rate in hous per vehicle = 1
Rate of Return as a percent per year = 8%
Improvement in Efficiency as a percent = 20%
Number of Years to Amortize CDE = 15

District	Service Demand (Work Orders/ Year)	Labor Cost ($/Person-Month)	Benefits ($/Month)	Maximum CDE Cost Amortized ($)
Fort Worth	3,588	2,951.65	1,020.28	106,762.87
Dallas	3,389	2,894.35	944.98	98,883.75
San Antonio	2,997	2,793.82	806.66	84,408.89
San Angelo	2,646	2,942.56	750.10	78,490.77
Abilene	2,399	3,050.20	704.95	73,766.76
Amarillo	2,158	2,991.00	621.83	65,068.44
Pharr	2,128	2,942.56	603.25	63,124.85
Atlanta	2,010	3,039.43	588.56	61,587.32
Odessa	1,988	3,050.81	584.30	61,141.31
Paris	1,892	3,136.30	571.66	59,819.33
Yoakum	1,755	3,136.30	530.27	55,487.81
Wichita Falls	1,709	2,991.00	492.45	51,530.10
Waco	1,680	3,011.38	487.39	51,000.84
Childress	1,670	3,136.30	504.59	52,800.36
Houston	1,542	2,959.82	439.70	46,010.10
Beaumont	1,412	3,101.08	421.84	44,141.78
Austin	1,363	3,093.25	406.17	42,502.39
Bryan	1,331	2,991.00	383.53	40,132.57
Lubbock	1,156	3,136.30	349.28	36,549.23
Corpus Christi	1,067	2,987.56	307.10	32,135.38
El Paso	916	2,561.80	226.07	23,656.09
Tyler	784	2,803.17	211.72	22,154.85
Lufkin	732	3,057.03	215.58	22,558.69
Brownwood	679	3,136.30	205.16	21,467.93
Camp Hubbard	150	3,136.30	45.32	4,742.55

Table 4.5 Amortization time where cost includes upgrading

Service Rate in Hours per Vehicle =	1
Labor Cost in Dollars per Person Month =	$2,000
Rate of Return as a Percent per Year =	8%
Improvement in Efficiency as a Percent =	20%

District	Service Demand (Work Orders/ Year)	Labor Cost ($/Person-Month)	Benefits ($/Month)	Cost of CDE ($)	Upgrading Cost at 5 & 10 Years (10% Initial Cost)	Present Value of Upgrading (Initial Year $)	Number of Years to Amortize CDE
Fort Worth	3,588	2,951.65	1,020.28	50,000	5,000	6,122.45	5.7
Dallas	3,389	2,894.35	944.99	50,000	5,000	6,122.45	6.3
San Antonio	2,997	2,793.82	806.65	50,000	5,000	6,122.45	7.8
San Angelo	2,646	2,942.56	750.10	50,000	5,000	6,122.45	8.7
Abilene	2,399	3,050.20	704.95	50,000	5,000	6,122.45	9.5
Amarillo	2,158	2,991.00	621.83	50,000	5,000	6,122.45	11.5
Pharr	2,128	2,942.56	603.25	50,000	5,000	6,122.45	12.1
Atlanta	2,010	3,039.43	588.56	50,000	5,000	6,122.45	12.7
Odessa	1,988	3,050.81	584.30	50,000	5,000	6,122.45	12.8
Paris	1,892	3,136.30	571.66	50,000	5,000	6,122.45	13.3
Yoakum	1,755	3,136.30	530.27	25,000	2,500	3,061.22	5.5
Wichita Falls	1,709	2,991.00	492.45	25,000	2,500	3,061.22	6.0
Waco	1,680	3,011.38	487.39	25,000	2,500	3,061.22	6.1
Childress	1,670	3,136.30	504.59	25,000	2,500	3,061.22	5.8
Houston	1,542	2,959.82	439.70	25,000	2,500	3,061.22	7.0
Beaumont	1,412	3,101.08	421.84	25,000	2,500	3,061.22	7.3
Austin	1,363	3,093.25	406.18	25,000	2,500	3,061.22	7.7
Bryan	1,331	2,991.00	383.53	25,000	2,500	3,061.22	8.4
Lubbock	1,156	3,136.30	349.28	25,000	2,500	3,061.22	9.6
Corpus Christi	1,067	2,987.56	307.10	25,000	2,500	3,061.22	11.8
El Paso	916	2,561.80	226.07	10,000	1,000	1,224.49	5.0
Tyler	784	2,803.17	211.72	10,000	1,000	1,224.49	5.5
Lufkin	732	3,057.03	215.58	10,000	1,000	1,224.49	5.3
Brownwood	679	3,136.30	205.16	10,000	1,000	1,224.49	5.7
Camp Hubbard	150	3,136.30	45.32	2,500	250	306.12	6.7

Table 4.6 Service demands impacted by CDE for 1987-1990

	Service Demands Impacted by CDE in Vehicles per Year		
District	**1987-1988**	**1988-1989**	**1989-1990**
Fort Worth	1,634	1,591	*3,588*
Dallas	1,078	1,054	*3,389*
San Antonio	2,598	2,652	*2,997*
San Angelo	1,316	1,202	*2,646*
Abilene	774	890	*2,399*
Amarillo	1,014	1,169	*2,158*
Pharr	1,687	1,555	*2,128*
Atlanta	589	986	*2,010*
Odessa	1,170	1,310	*1,988*
Paris	553	641	*1,892*
Yoakum	1,626	1,378	*1,755*
Wichita Falls	979	1,148	*1,709*
Waco	1,356	995	*1,680*
Childress	711	559	*1,670*
Houston	**2,241**	**1,923**	*1,542*
Beaumont	1,233	1,297	*1,412*
Austin	1,250	1,190	*1,363*
Bryan	1,136	1,101	*1,331*
Lubbock	**1,330**	1,051	*1,156*
Corpus Christi	**1,664**	**1,509**	*1,067*
El Paso	629	642	*916*
Tyler	**1,151**	**1,093**	*784*
Lufkin	**1,112**	**1,025**	*732*
Brownwood	**975**	**896**	*679*
Camp Hubbard	139	134	*150*

Notes: The Service Demands in italics are those for the year 1989-1990, the latest year for which data were available. These Service Demand rates were used in the analysis of most likely cases.

All Service Demand rates that were greater than that in the year 1989-1990 are shown in bold numerals.

SUMMARY

The economic analysis attempts to quantify benefits and costs of the introduction of CDE to a District service facility. Costs are the capital costs of the CDE purchased. The variables used to define the possible benefits to a service facility are:

1. The volume of service demands.
2. Rate of service completions.
3. Expected efficiency gains as a percentage of overall service time.
4. Labor cost.

Three scenarios are developed for three classes of Districts where the volume of work orders (service demands)—high, moderate and small—defines each one. The number of work orders at three Districts representing these three classes were used in quantifying possible benefits. A rate of service completions of 1 every hour and a moderate efficiency improvement of 20% were used. The weighted average labor cost was calculated from TxDOT's data on motor vehicle mechanics. The present value of benefits (at 8% internal rate of return) to each class of Districts is taken and the number of years to amortize CDE of different capital costs is calculated. CDE is assumed to have a useful service life of 15 years.

The Districts with larger volumes of work orders reap greater benefits from the introduction of CDE and are therefore capable of amortizing higher CDE cost or alternately can amortize CDE in much shorter time. The Districts with small service demands have small benefits making it difficult to justify high CDE capital cost.

Three microcomputer based spreadsheets were developed to calculate the number of years in which CDE capital cost can be amortized at each District service facility. The first considers a one time initial capital cost. The second spreadsheet calculates the maximum cost of CDE that each District can amortize in 15 years (the expected useful life of such equipment). The possibility of upgrading the CDE in the fifth and tenth year of its use is incorporated into the third spreadsheet which calculates the number of years to amortize both capital as well as upgrading costs.

CHAPTER 5. BEFORE-AFTER ANALYSIS OF CDE OPERATIONAL EFFECTS

The TxDOT equipped a few Districts with CDE of varying capabilities beginning in 1988 and in this section an analysis of these Districts is performed with the intention of identifying the effects CDE has had, if any, on these shops. The District shops with CDE and the year they introduced CDE are listed below.

Fort Worth	District 2	1988
San Angelo	District 7	1988
Waco	District 9	1988
Tyler	District 10	1988
Lufkin	District 11	1988
Houston	District 12	1988
Austin	District 14	1990
San Antonio	District 15	1988
Dallas	District 18	1988
Beaumont	District 20	1990
El Paso	District 24	1988
Childress	District 25	1988

Districts 14 and 20 (Austin and Beaumont) are not used in the following analysis as data of shop performance after the introduction of CDE are not as yet available. The other 10 Districts where CDE was introduced in 1988 were studied with respect to the year 1987-1988 when they did not use CDE against the year 1989-1990 when CDE was used.

These Districts are first analyzed together for trends with respect to total vehicles serviced. This part looks into volumes of work orders that the District shops have serviced and particularly into those serviced by the 10 District shops that introduced CDE in 1988. The second part involves analyzing each District individually for statistically significant changes, after CDE was introduced, from the point of view of the service time. The data for this analysis are from the 'Down Time' record in TxDOT's EOS Repair-Order-Parts-Issue tapes for the years 1987-1988 and 1989-1990.

WORK ORDER VOLUMES ANALYSIS

The total number of work orders that could have been affected by CDE in the year 1987-1988 was 29,946 of a sum total of 859,658 (work orders of all types) serviced at the shops, which is 3.48%. In the year 1989-1990 the figure was 43,141 of a total of 739,701, which is 5.83%. This represents a significant increase in work orders that could have used CDE equipment.

The 10 Districts which introduced CDE in 1988 had a total of 353,922 work orders of all types in 1987-1988 and 338,640 in 1989-1990. This total number of work orders in these 10 Districts represents 41.17% of all the work orders in all the 25 Districts in the year 1987-1988 and 45.78% of all work orders at the 25 Districts in the year 1989-1990.

In the year 1987-1988 the 10 Districts which received CDE in 1988 had work orders potentially affected by CDE of 13,826 of a total of 353,922 work orders—3.91%. The figure for the year 1989-1990 is 19,944 of a total of 338,640 work orders—5.89%. This is again a significant increase in the number of work orders that could have used CDE.

The work orders that are potentially affected by CDE in the 10 Districts under study against that for all the 25 Districts in the year 1987-1988 is 13,826 of 29,946 which is 46.17%. The corresponding figures for the year 1989-1990 are 19,944 of a total for 25 Districts of 43141 which is 46.23%. The proportion of service demands on CDE at the 10 Districts taken together has remained practically the same before and after the introduction of CDE.

The service histories at the 10 Districts are studied individually to try and identify any anomalies. The service demands that could be affected by CDE are normalized to total service demands of 35,000 at each shop to study them comparatively. Normalization to the same total service demand at the 10 District shops removes differences that arise due to different total service demands and gives a scaled basis at which to compare the performance of each District. The normalized CDE impacted work orders in this analysis are the service demands made on CDE if 35,000 work orders were made on each District and the proportion of potential CDE impacted work orders was the same as before.

$$\text{Normalized CDE Demands} = \frac{\text{CDE work orders District 'i'}}{\text{Total work orders District 'i'}} * 35,000$$

The summary of this individualized District-by-District study is tabulated in Table 5.1. It also summarizes all calculation done in this section.

Figure 5.1a plots the total service demands or work orders, Figure 5.1b plots those that could benefit from the use of CDE and Figure 5.1c plots normalized service demands at each of the 10 Districts through the three years 1987 to 1990.

Table 5.1 Comparative study of Districts with CDE against Districts without it

Year: 1987-1988
Work Orders Received at all 25 Districts = 859,658
Total Work Orders at 10 Districts with CDE = 353,922 41.17% of Orders at all 25 Districts.
Total Potential CDE Impacted Work Orders = 29,946 3.48% of Orders at all 25 Districts.
Potential CDE Work Orders at 10 Districts = 13,826 3.91% of Orders at 10 CDE Districts.
Work Orders at 10 Districts as a % of Total at all Districts (Potential CDE Impacted) = 46.17%

Year: 1989-1990
Work Orders Received at all 25 Districts = 739,701
Total Work Orders at 10 Districts With CDE = 338,640 45.78% of Orders at all 25 Districts.
Total Potential CDE Impacted Work Orders = 43,141 5.83% of Orders at all 25 Districts.
Potential CDE Work Orders at 10 Districts = 19,944 5.89% of Orders at 10 CDE Districts.
Work Orders at 10 Districts as a % of Total at all Districts (Potential CDE Impacted) = 46.23%

	Year: 1987-1988			Year: 1989-1990		
District	Total Work Orders	CDE Impacted	As a %	Total Work Orders	CDE Impacted	As a %
Fort Worth	48,737	1,634	3.35	47,277	3,588	7.59
Dallas	40,887	1,078	2.64	44,468	3,389	7.62
San Angelo	48,475	2,598	5.36	48,836	2,997	6.14
San Antonio	34,713	1,316	3.79	33,652	2,646	7.86
Waco	29,020	1,356	4.67	24,831	1,680	6.77
Childress	22,532	711	3.16	23,490	1,670	7.11
Houston	61,000	2,241	3.67	53,174	1,542	2.90
El Paso	22,452	629	2.80	22,386	916	4.09
Tyler	25,844	1,151	4.45	23,006	784	3.41
Lufkin	20,262	1,112	5.49	17,520	732	4.18
Mean	35,392.2	1,382.6		33,864	1,994.4	
Std Dev	13,861.16	625.47		13,314.22	1,082.41	

CDE Impacted Work Orders Normalized to 35,000 Total Work Orders

District	1987-1988	1989-1990	Change	Change as %
Fort Worth	1,173	2,656	1,483	4.24
Dallas	923	2,667	1,744	4.98
San Angelo	1,876	2,148	272	0.78
San Antonio	1,327	2,752	1,425	4.07
Waco	1,635	2,368	733	2.09
Childress	1,104	2,488	1,384	3.95
Houston	1,286	1,015	-271	-0.77
El Paso	981	1,432	451	1.29
Tyler	1,559	1,193	-366	-1.05
Lufkin	1,921	1,462	-459	-1.31
Mean	1,378.5	2,018.1		
Std Dev	355.04	672.18		

HYPOTHESIS TEST

It is desirable to know if the difference in the CDE demands in these 10 Districts before and after the introduction of CDE are larger than could be attributed to chance alone. This is done by conducting a 'Hypothesis Test' on the work order data. The work orders in the year 1987-1988 is compared against those for the year 1989-1990 for the 10 Districts under consideration. Since the same 10 Districts are involved, a preliminary assumption is made that the samples are from the same population and therefore there is no statistically significant difference in the service demands (work orders) between the years 1987-1988 and 1989-1990. This assumption is the basic 'Null' hypothesis for the test. Since we know that CDE was introduced in 1988 we suspect that this introduction may have had some effect on service demands in these Districts in the year 1989-1990. This implies that the number of work orders received in 1987-1988 is significantly different from that in 1989-1990 (that the samples are from different populations). This assumption that the service demands are from different populations is the 'Alternate' hypothesis.

The specific Hypothesis test used is the two tailed 't' test as the data fit the assumptions under which this test can be applied. A confidence level of 95% is chosen and this means that the probability of rejecting the 'Null' hypothesis when it is actually true will be 0.05 or 5%.

H_o = Null Hypothesis
= Samples are from the same population.

H_a = Alternate Hypothesis
= Samples represent different populations.

U_1 = True Mean of population in 1987-1988

U_2 = True Mean of population in 1989-1990

Test Statistic = two tailed 't' test

Confidence level of 95% or α = 0.05

Mean Normalized CDE service demand 1987-1988 = 1378.5

Mean Normalized CDE service demand 1989-1990 = 2,018.1

Difference between sample means = y = 639.6

Standard Deviation Normalized CDE demand 1987-1988 = 355.0

Standard Deviation Normalized CDE demand 1989-1990 = 672.3

Pooled estimate of variance = s^2 = 288,999.082

Decision criteria = Reject H_o of $y < -C$ or $y > +C$
$= \pm C = \pm t_{(\alpha/2, n_1+n_2-2)} * s_y$

where $t_{(\alpha/2, n_1+n_2-2)}$ = 't' statistic value at $\alpha/2$ and n_1+n_2-2 degrees of freedom.

$n_1 = n_2$ = sample sizes for both years = 10

$$s_y = \text{Pooled standard deviation} = \sqrt{s^2} * \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

On calculation 'C' = 505.1

Since 'y' = 639.6 which is greater than 505.1, the 'Null' hypothesis can be rejected with a confidence level of 95%. This implies acceptance of the 'Alternate' hypothesis that the samples are from two different populations. This conclusion implies that the number of work orders received by the 10 Districts in the years 1987-1988 and 1989-1990 are significantly different. However, the test does not say if the introduction of CDE equipment is responsible for this difference.

DOWN TIME ANALYSIS

The 'Down Time' records pertaining to the 10 Districts under consideration were read from the TxDOT EOS Repair-Order-Parts-Issue tapes for the years 1987-1988 and 1989-1990. These 'Down Time' records are the time durations of the work orders. These records were converted to frequencies.

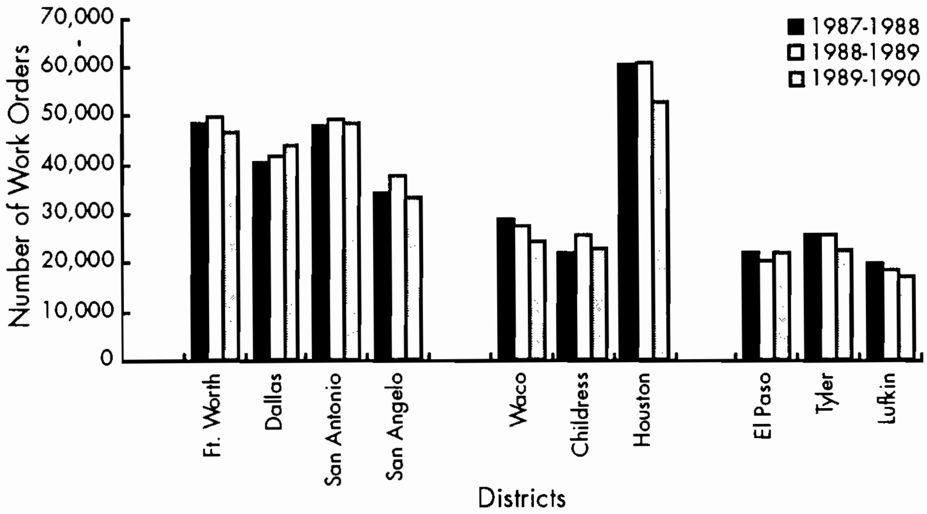

Figure 5.1a **Total work orders 1987 through 1990**

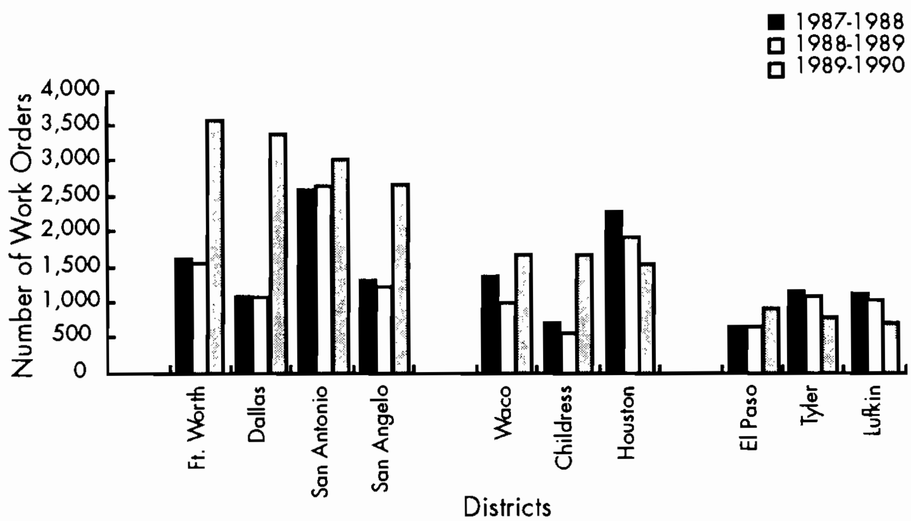

Figure 5.1b **Work orders impacted by CDE 1987 through 1990**

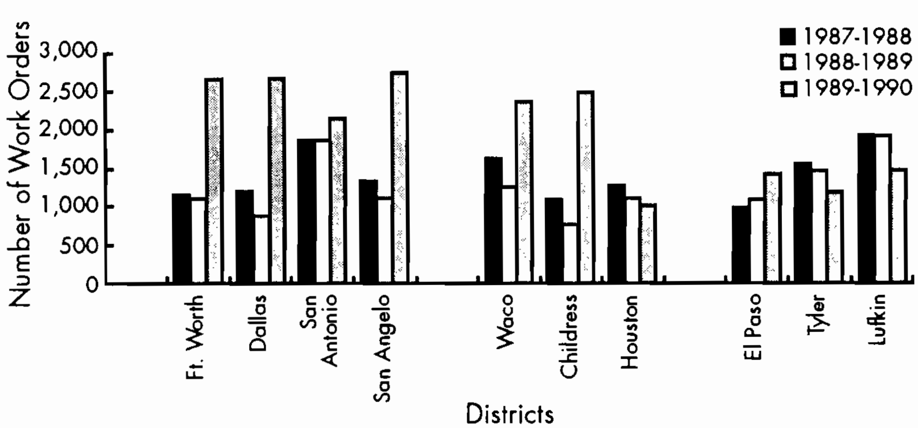

Figure 5.1c **Work orders impacted by CDE normalized to 35,000 1987 through 1990**

It was assumed that work orders that have spent more than 60 hours in the service facility did so because of delays in procuring spare parts or other reasons not under the direct control of the service facilities themselves. Therefore these records were not used in the analysis as they will exert excessive influence on the distributions, shifting the mean to a higher value.

The weighted mean and standard deviation of the down time in each shop for the years 1987-1988 and 1989-1990 were calculated. Hypothesis tests were performed for each District to test if the difference in down time between years was statistically significant.

HYPOTHESIS TESTING

The purpose of this hypothesis testing is to ascertain if there is a significant difference in the down times at the District service facilities after CDE equipment was introduced. The down times in the year 1987-1988 (before CDE was introduced) were compared with those in 1989-1990 (after the introduction of CDE) for each District independently. Since the same District's data for two different years were compared, an assumption can be made that the samples were from the same population. This represents the 'Null' hypothesis for the test. If the samples are from the same population it implies that the CDE has not had a significant effect on the down time at the service facility. The 'Alternate' hypothesis is that the CDE has had a significant effect on the down time at the service facility as the samples are not from the same population.

The selected hypothesis test uses a 'z' statistic and a 95% confidence level.

H_o = Null Hypothesis
= Samples are from the same population. CDE has not had a statistically significant effect

H_a = Alternate Hypothesis
= Samples represent different populations. CDE has had a significant effect on service facility

U_1 = True Mean of population in 1987-1988

U_2 = True Mean of population in 1989-1990

Test Statistic = two tailed 'z' test
Confidence level or 95% or a = 0.05
Decision criteria: Reject H_o if $|Z| > z_{\alpha/2}$

$$\text{Test value} = Z = \frac{(U_1 - U_2) - D_0}{\sqrt{\dfrac{s_1^2}{n_1} + \dfrac{s_2^2}{n_2}}}$$

where s_1^2 = Variance of population in 1987-1988

s_2^2 = Variance of population in 1989-1990

and $z_{\alpha/2}$ = 1.96

The results of the hypothesis tests for each of the 10 Districts that introduced CDE in the year 1988 are summarized in Table 5.2. The effect of CDE on each District is briefly described below.

COMMENTS

The hypothesis test suggests that the introduction of CDE at the larger shops (in terms of service demands) has resulted in a significant reduction in the down time of work orders at these facilities. The only exception to this is District 15 (San Antonio) where no significant difference in down time after the introduction of CDE was perceived. Districts 2, 7, and 18 (Ft. Worth, San Angelo, and Dallas), the largest Districts that have introduced CDE, have had the greatest benefits in terms of reduction in down time. The Districts with moderate service demands show more moderate down time reductions. These are Districts 9, 12, and 25 (Waco, Houston, and Childress).

As indicated by the analysis in the previous section, the introduction of CDE in the smaller Districts (again in terms of volume of service demands) has had very little effect on the down time of work orders at these service facilities. Districts 10, 11, and 24 (Tyler, Lufkin, and El Paso) representing Districts with comparatively small service demands do not show a significant reduction in work order down time. This is again in agreement with the results of the analysis in the previous section.

Table 5.2 Hypothesis testing for District shops using CDE

Ho (Null Hypothesis) : The samples are from the same population. This implies that the CDE may not have had a statistically significant effect.

Alternate Hypothesis: The samples are from different population sets. This implies that the introduction of CDE has had a significant effect on the service facility.

Test Statistic: Z = ((Y1-Y2) - Do)/(((S1^2)/n1)+((S2^2)/n2))^0.5

Alpha of 0.05 implies an acceptable level of confidence of 95%: Z = 1.96

District	Year	Mean Time in Shop (hours)	Standard Deviation	Sample Size	Test Value	Result of Test
Fort Worth	1987-1988	7.72610169	10.9944276	1,475	8.935593911	REJECT Ho
	1989-1990	4.9303207	7.39511766	3,430		
Dallas	1987-1988	10.7254464	14.7086589	896	14.20195198	REJECT Ho
	1989-1990	3.48827759	7.63568755	3,199		
San Antonio	1987-1988	6.58470825	9.60779631	2,485	0.641580134	CANNOT REJECT Ho
	1989-1990	6.41932133	9.19946388	2,888		
San Angelo	1987-1988	7.71932773	10.4249594	1,190	8.273784419	REJECT Ho
	1989-1990	4.84655449	8.54154601	2,496		
Waco	1987-1988	7.33092949	10.6110172	1,248	4.794076028	REJECT Ho
	1989-1990	5.52283951	9.18030746	1,620		
Childress	1987-1988	5.29864253	8.63080172	663	3.164453269	REJECT Ho
	1989-1990	4.14198286	5.89233157	1,634		
Houston	1987-1988	10.7510163	14.3435939	1,968	2.018909453	REJECT Ho
	1989-1990	9.78108712	13.0219819	1,343		
El Paso	1987-1988	8.8267148	11.7993598	554	1.459509843	CANNOT REJECT Ho
	1989-1990	7.84409257	12.8768105	821		
Tyler	1987-1988	6.54751131	9.39972612	1,105	1.309535731	CANNOT REJECT Ho
	1989-1990	5.97889182	9.0722669	758		
Lufkin	1987-1988	5.78009479	9.75696034	1,055	0.710495641	CANNOT REJECT Ho
	1989-1990	5.45285714	9.23725153	700		
Austin	1987-1988	8.02668891	10.3942784	1,199	6.186452628	REJECT Ho
	1989-1990	5.65011287	8.7392918	1,329		

PLOTS OF DOWN TIME

The introduction of CDE in District service facilities is expected to significantly affect comparatively shorter work order down times as the savings in time will be a proportionally large part of the total down time. Reduction in down time due to CDE analysis is not expected to be significant for work orders with long down time as the savings will be a small fraction of total down time. Long down time is often the result of uncontrollable factors (for example, spare part non-availability) causing repair time to become long and not necessarily the result of long diagnostic time. To observe the effect that the introduction of CDE has had on down time at District service facilities, the volume of work orders as a percentage is plotted against the down time at each service facility for the two years 1987-1988 (corresponding to the year before CDE was introduced) and 1989-1990 (a year after CDE introduction). Down time longer than 18 hours are not plotted as the effects of CDE are not significant enough to be observed on a plot. The plots for the 10 Districts which introduced CDE in 1988 are in Figures 5.2a through 5.2j.

The plots are to be interpreted in terms of the distribution being shifted to the left where a larger proportion of work orders are diagnosed in shorter time, reducing the down time for a significant proportion of work orders. All the plots show a larger proportion of work orders being serviced in shorter intervals of time, the larger volume Districts showing a greater shift (San Antonio being the exception) and the smaller volume Districts a more modest one.

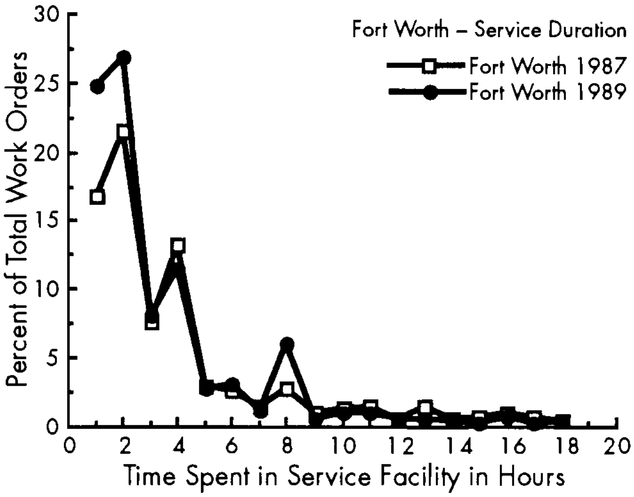

Figure 5.2a

SUMMARY

Ten Districts of the TxDOT were equipped with CDE in the year 1988. This section analyzes the performance of these Districts in the year 1987-1988 when they did not have CDE against the year 1989-1990 when they used CDE. The study focuses on the volume of work orders serviced through these shops before and after CDE introduction and secondly on the effect CDE has had on the down time of work orders.

The work order volume analysis shows significantly larger volumes of CDE oriented work orders, processed through most of the District service facilities using CDE. A hypothesis test of service demands shows that the service demand in the year 1987-1988 is from a different population than that of the year 1989-1990. This implies a significant change in work order volume between the years 1987-1988 and 1989-1990. However, this change may not necessarily be due to the introduction of CDE only. The higher volume of work orders is consistent with the hypothesis that CDE use will detect abnormalities in systems that may not be ordinarily apparent before these defects cause a major breakdown. The introduction of CDE may therefore increase the number of work orders that can be serviced in a small time and decrease the number of major breakdown repairs.

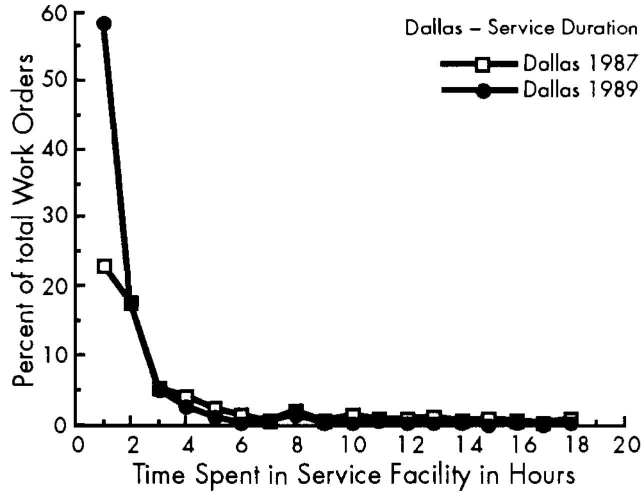

Figure 5.2b

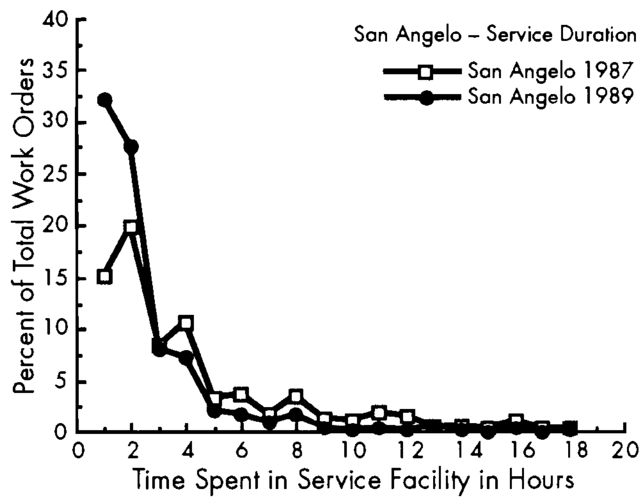

Figure 5.2c

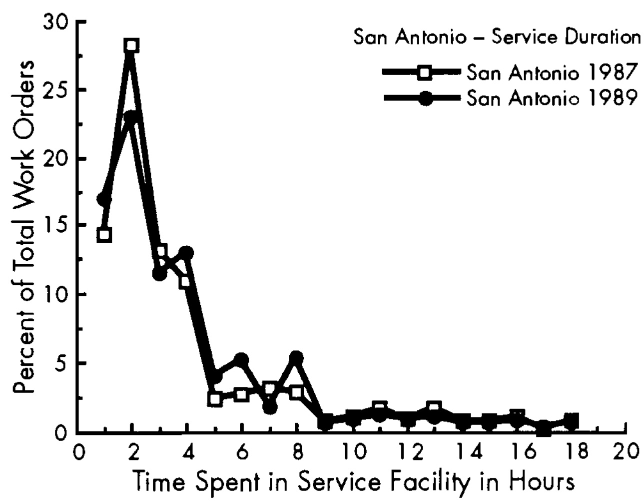

Figure 5.2d

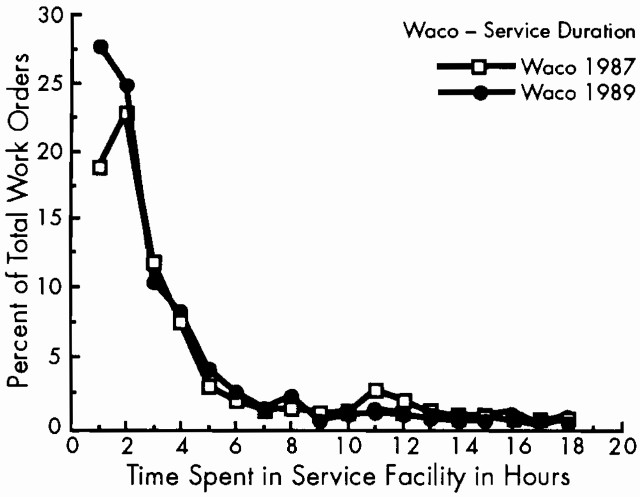

Figure 5.2e

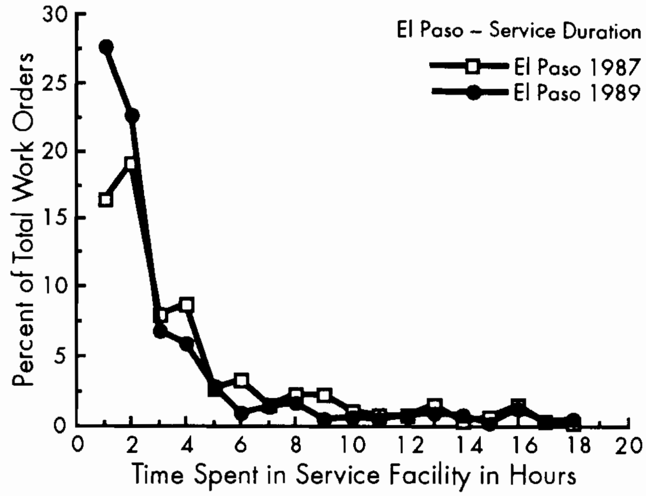

Figure 5.2h

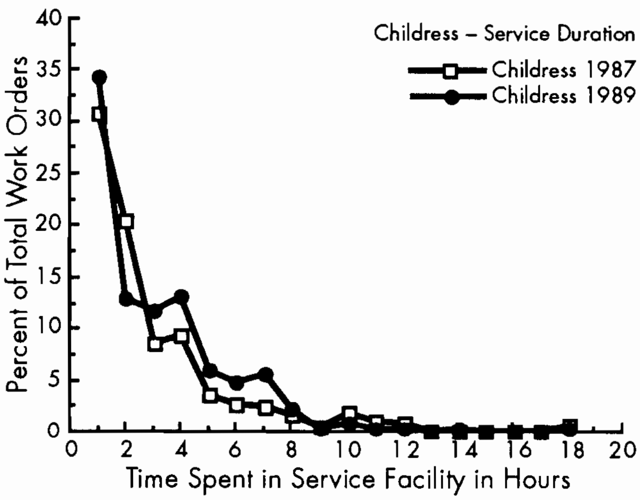

Figure 5.2f

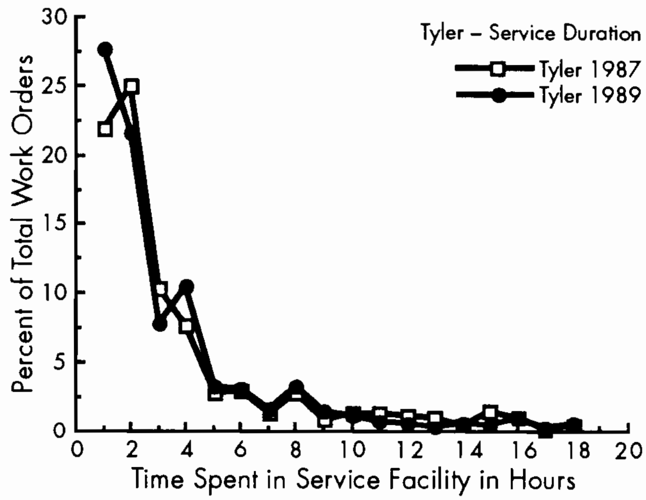

Figure 5.2i

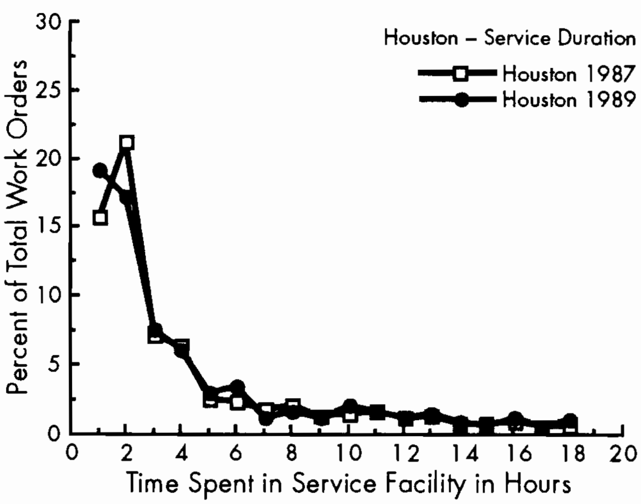

Figure 5.2g

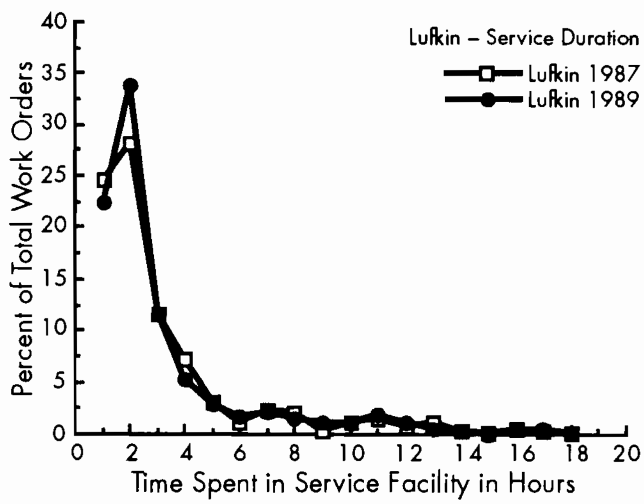

Figure 5.2j

The down time analysis is done for each of the 10 Districts that introduced CDE. Reduction in the average down time of work orders is found in all District service facilities. Hypothesis tests indicate that, except in Districts 15, 10, 11, and 24 (San Antonio, Tyler, Lufkin, and El Paso), the introduction of CDE has significantly reduced down time. It is important to note that except for District 15 (San Antonio) the other Districts that did not show a significant savings in down time had comparatively small service demands. Earlier analysis had predicted just such a scenario where Districts with high service demands could reap significant rewards from the introduction of CDE whereas Districts with more modest service demands would be much less affected.

The percentage of CDE oriented work orders for 1987-1988 and 1989-1990 are plotted to observe the effect that the introduction of CDE has had on down time. The plots show a larger proportion of work orders being serviced in shorter intervals of time with larger volume Districts generally showing significant gains in efficiency indicating that CDE has affected service facility operations positively. The smaller volume Districts have not been significantly affected.

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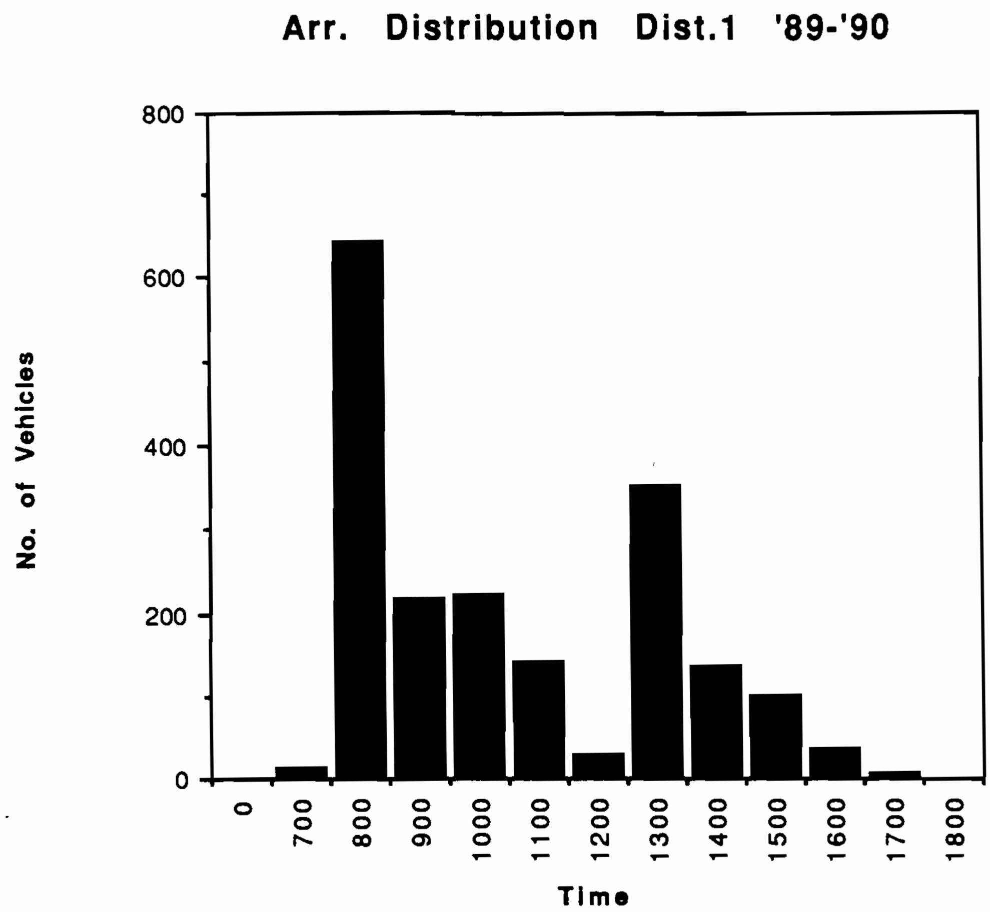
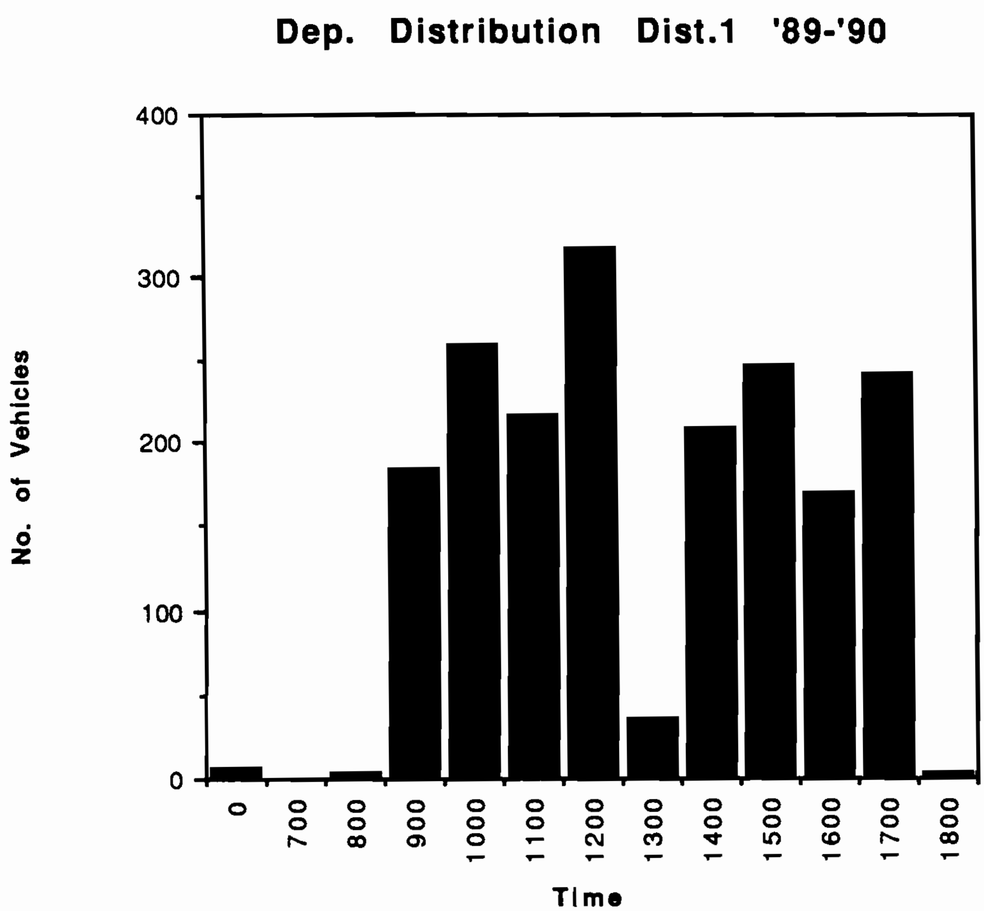
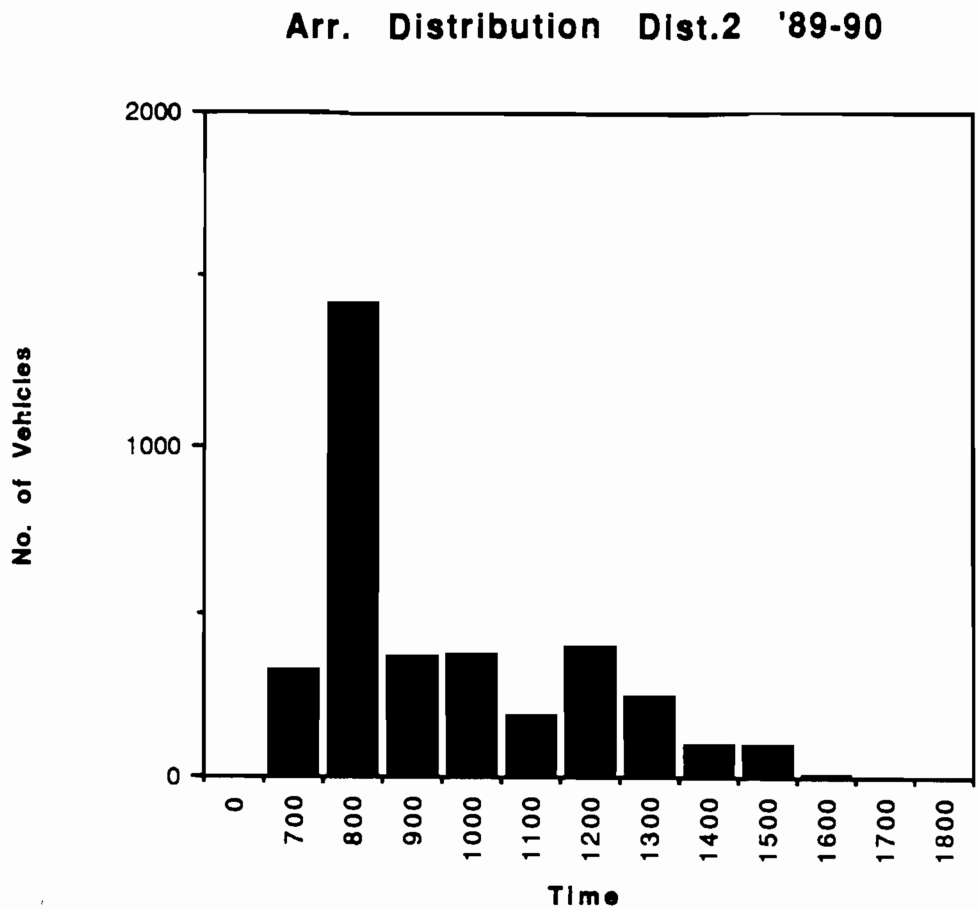
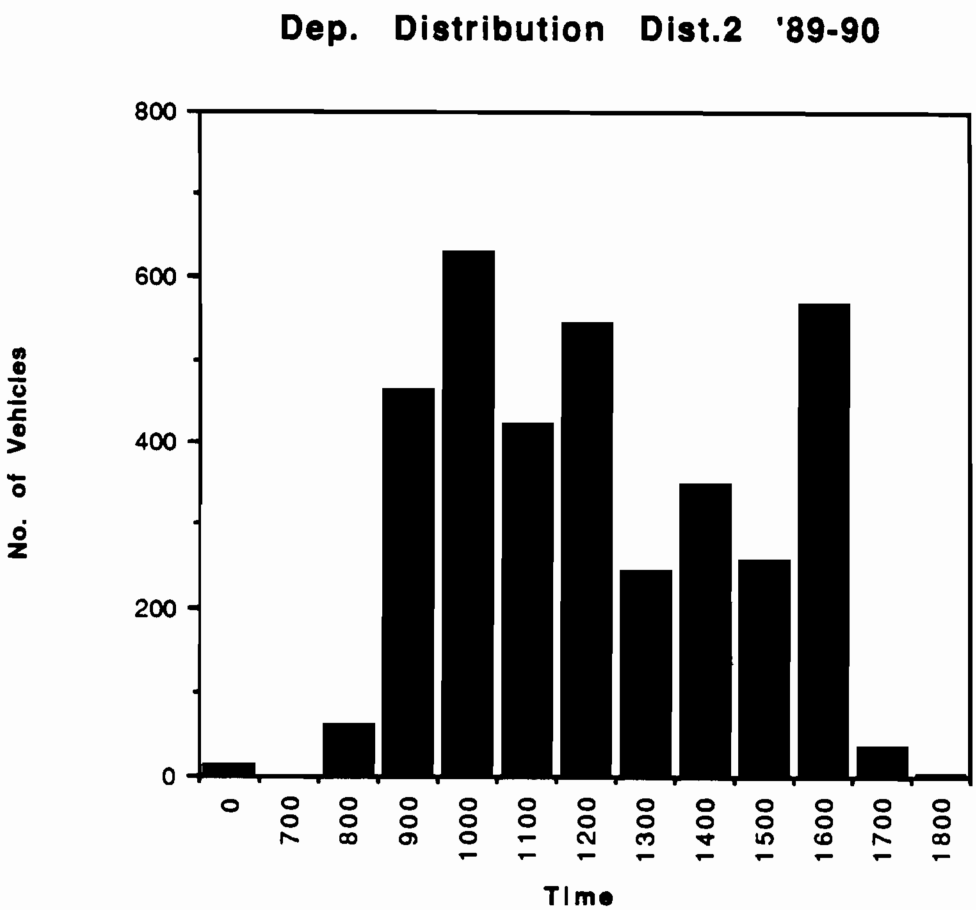
APPENDIX A. WORK ORDER ARRIVAL AND DEPARTURE FREQUENCY DISTRIBUTION FOR FY 1989-90

Note: Work orders with times from 1800 - 0600 appear as Time 0

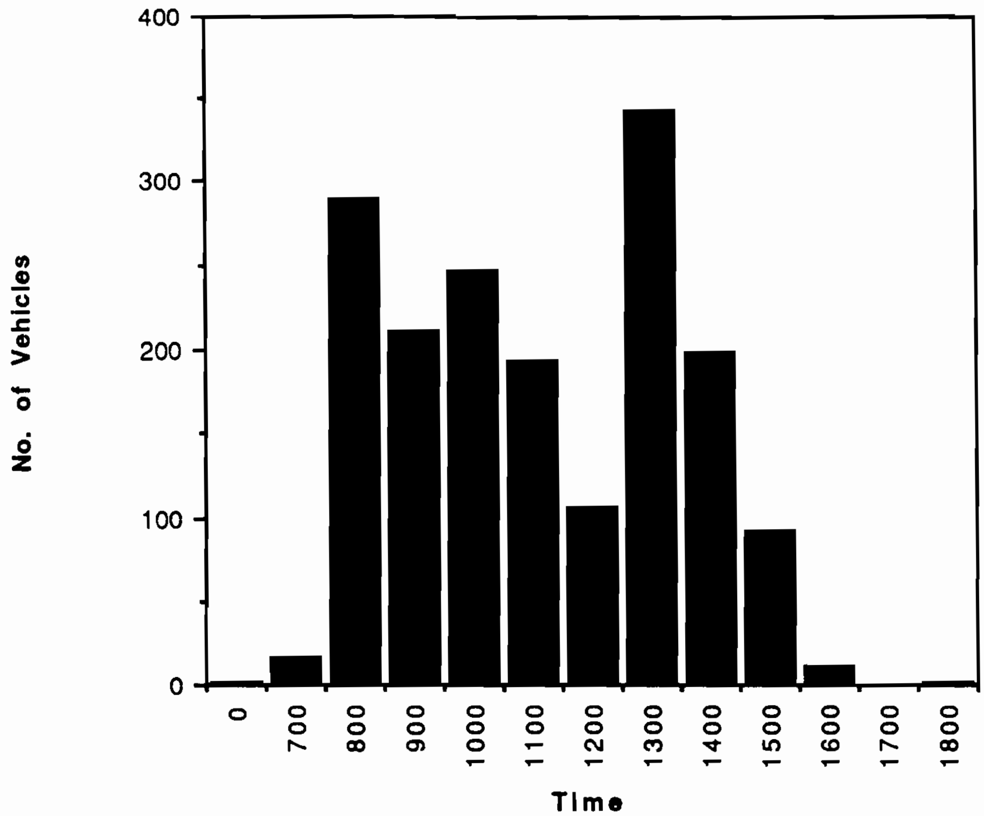

Arr. Distribution Dist.1 '89-'90
800
600
400
200
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.1 '89-'90
400
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

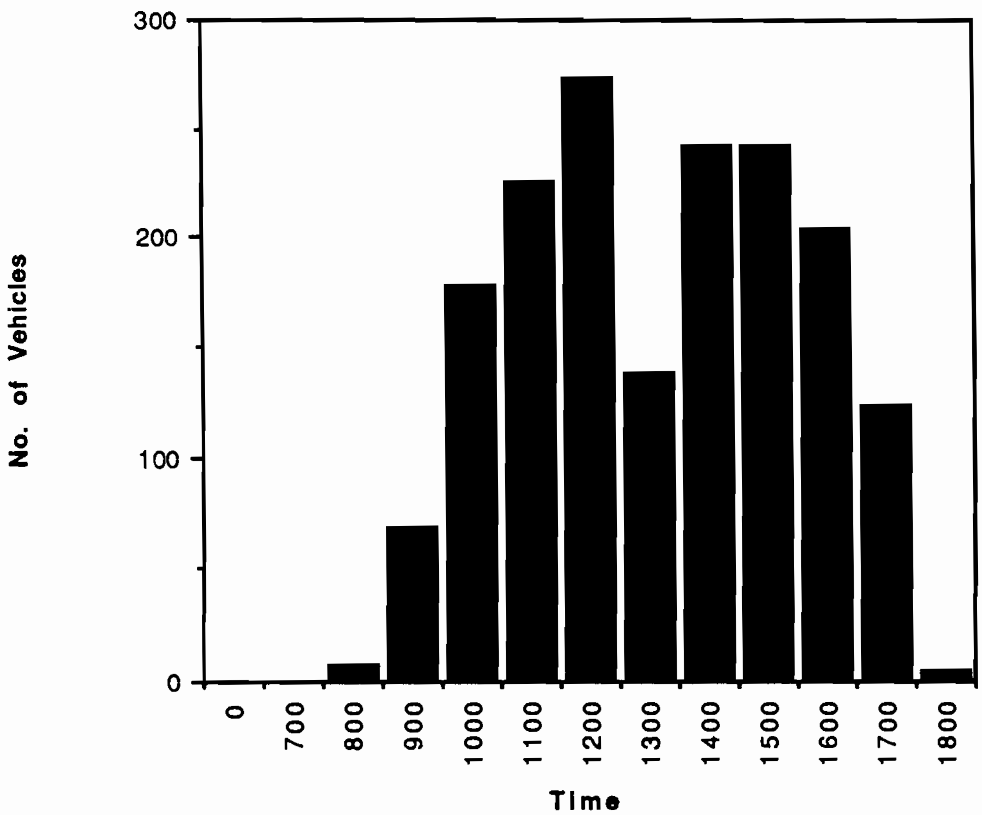

Arr. Distribution Dist.2 '89-90
2000
1000
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

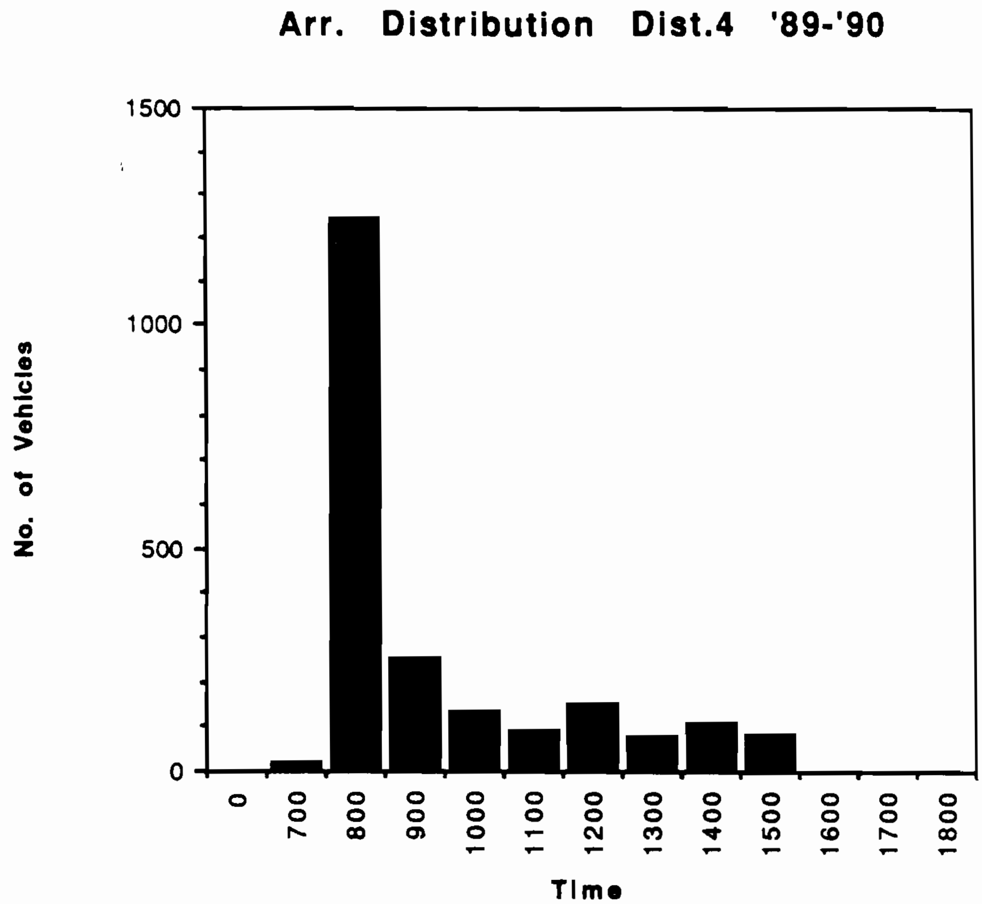

Dep. Distribution Dist.2 '89-90
800
600
400
200
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

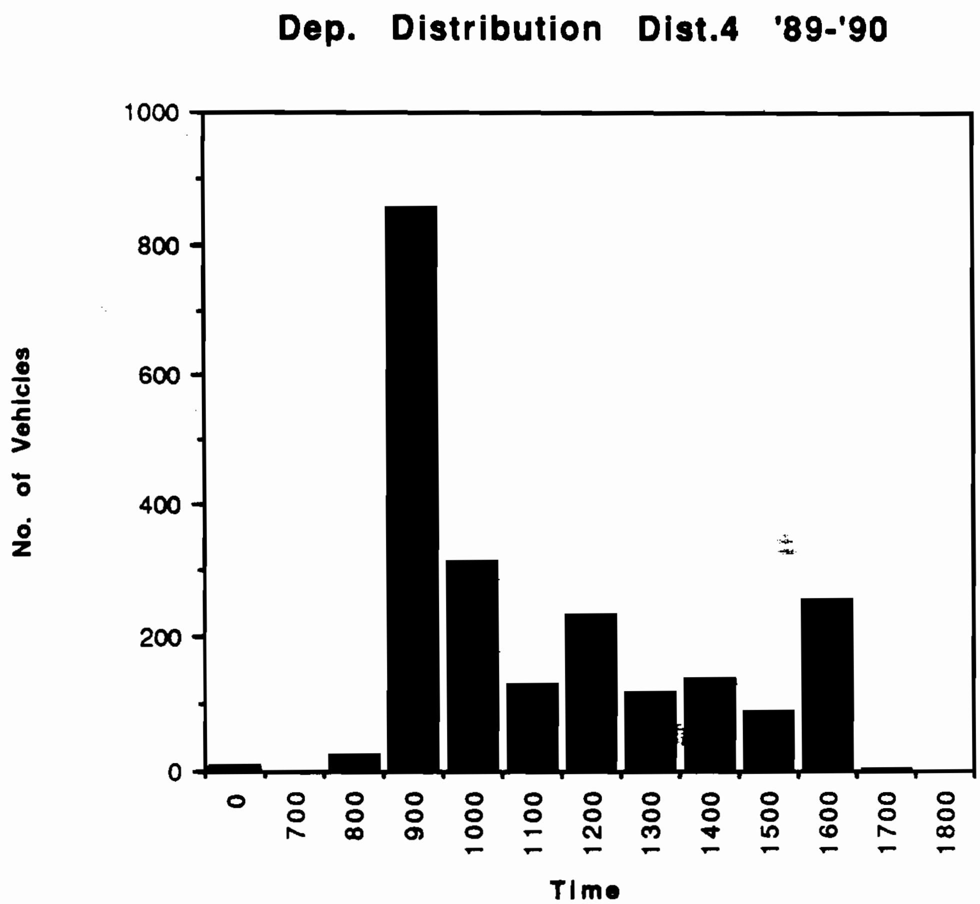
Arr. Distribution Dist.3 '89-'90

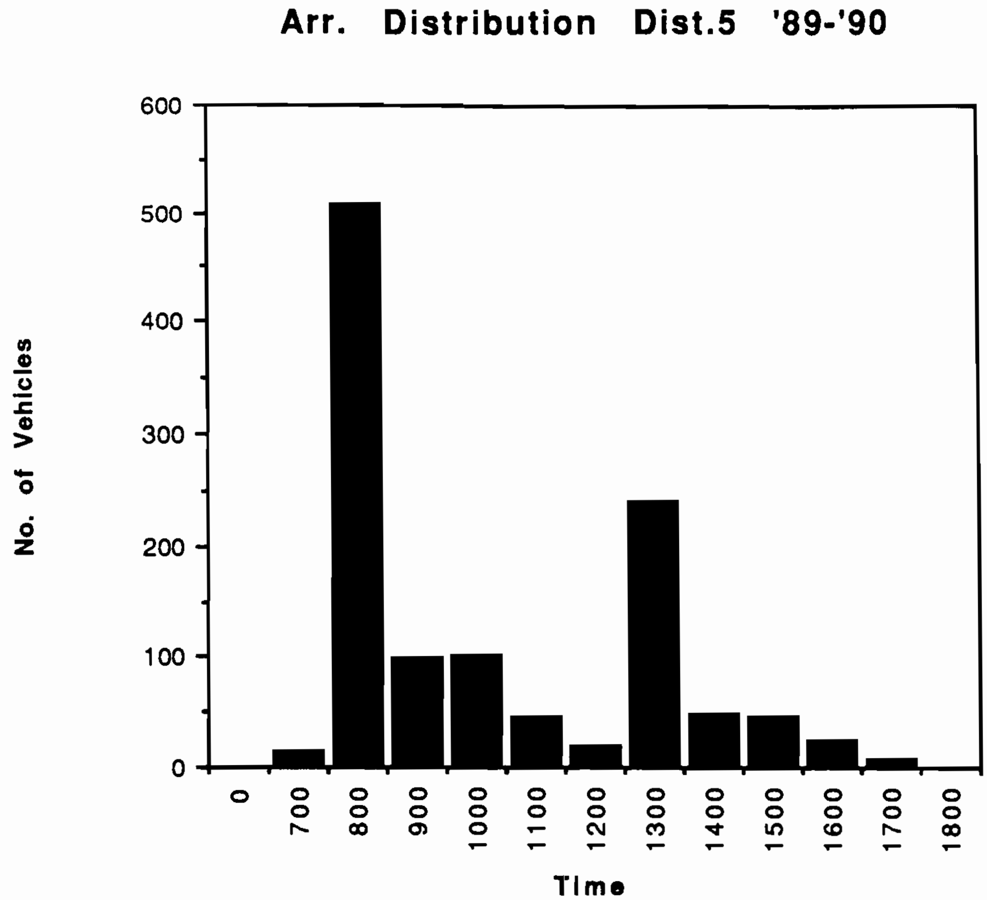


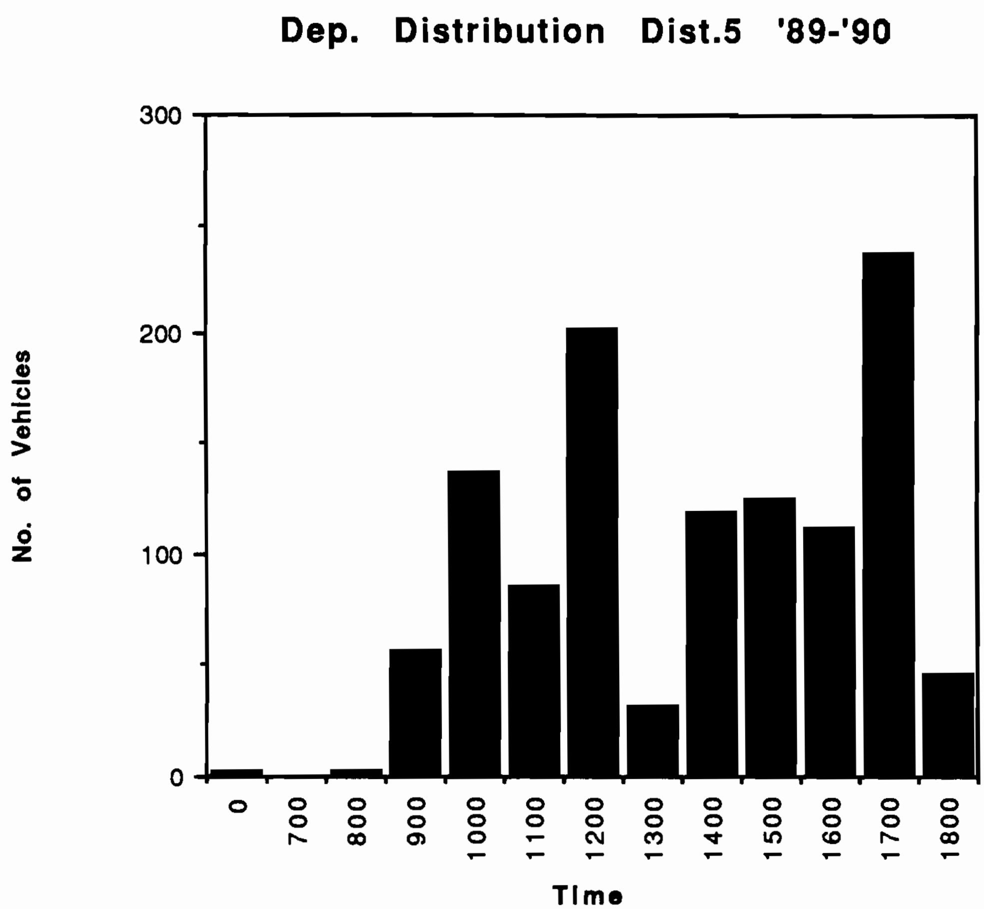
Dep. Distribution Dist.3 '89-'90



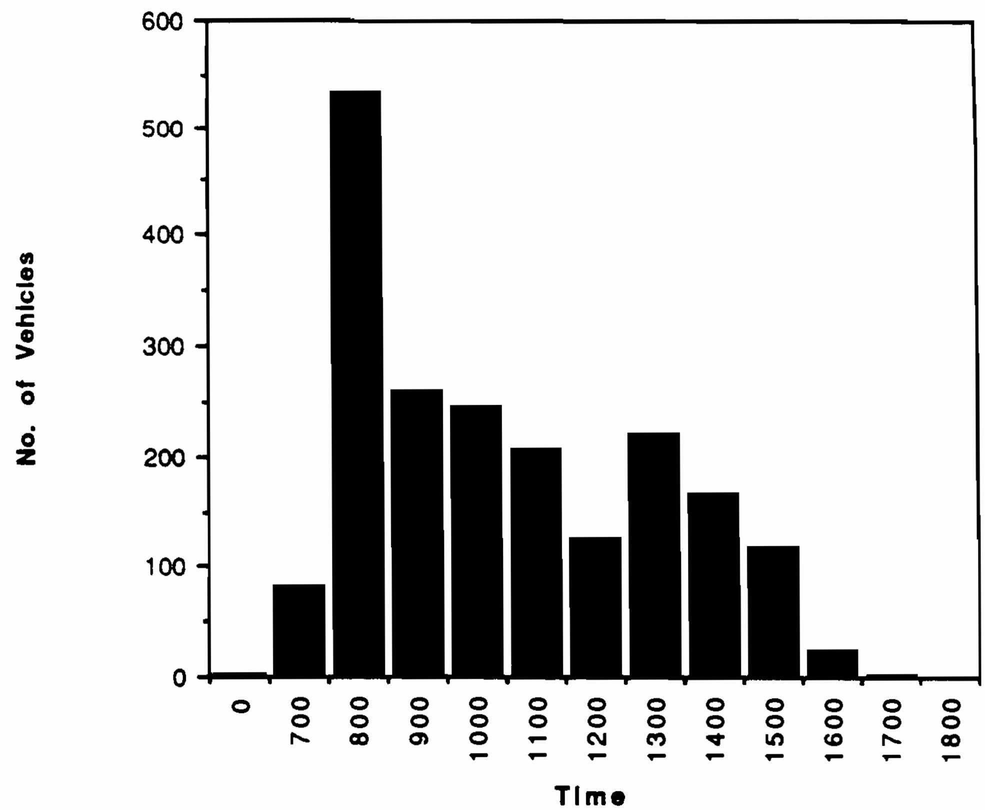

Arr. Distribution Dist.4 '89-'90
1500
1000
500
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.4 '89-'90
1000
800
600
400
200
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

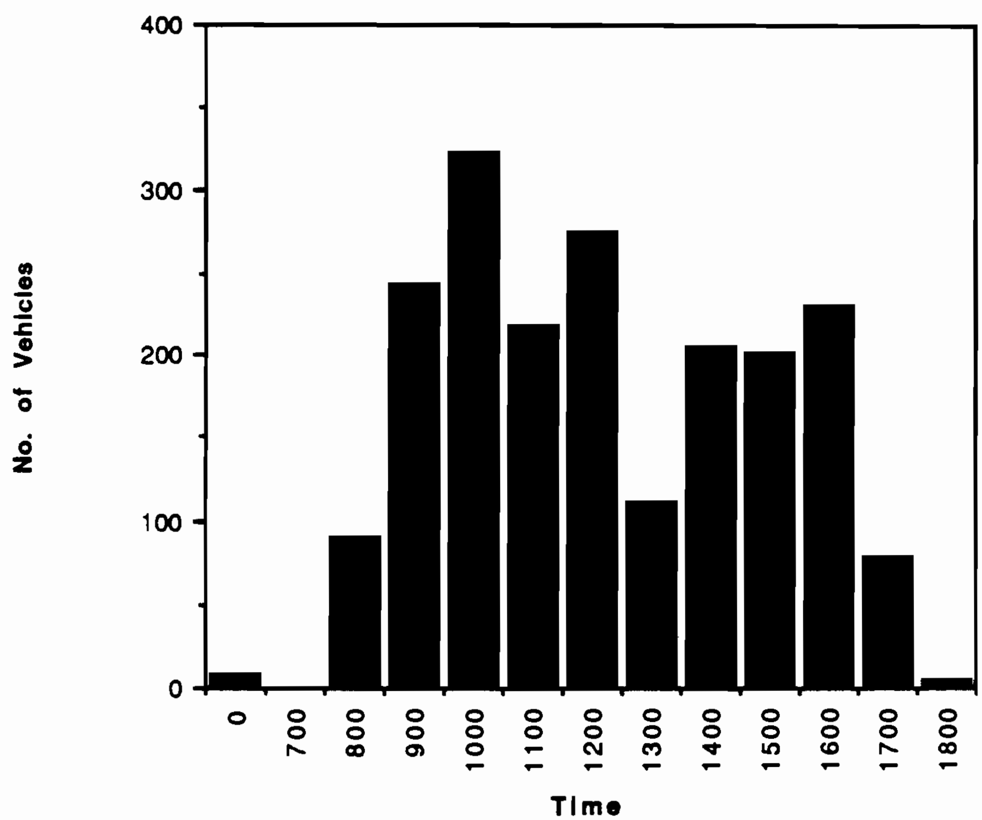

Arr. Distribution Dist.5 '89-'90
No. of Vehicles
600
500
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

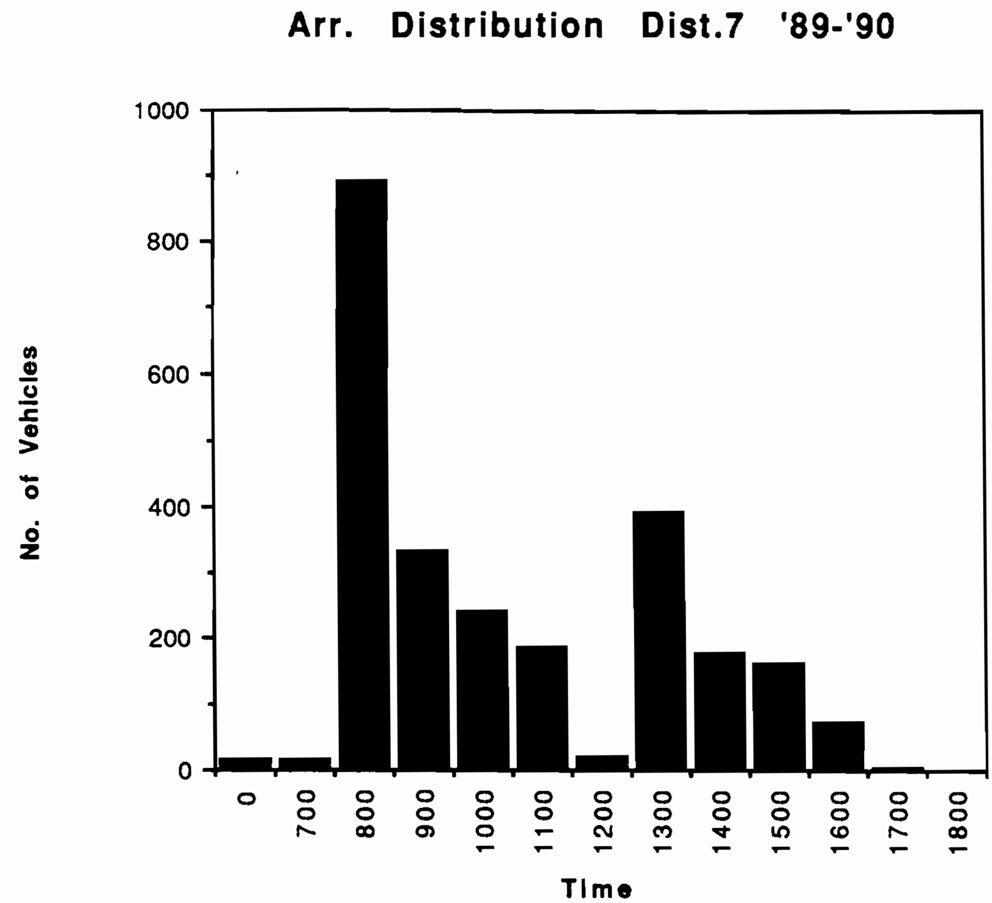

Dep. Distribution Dist.5 '89-'90
No. of Vehicles
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

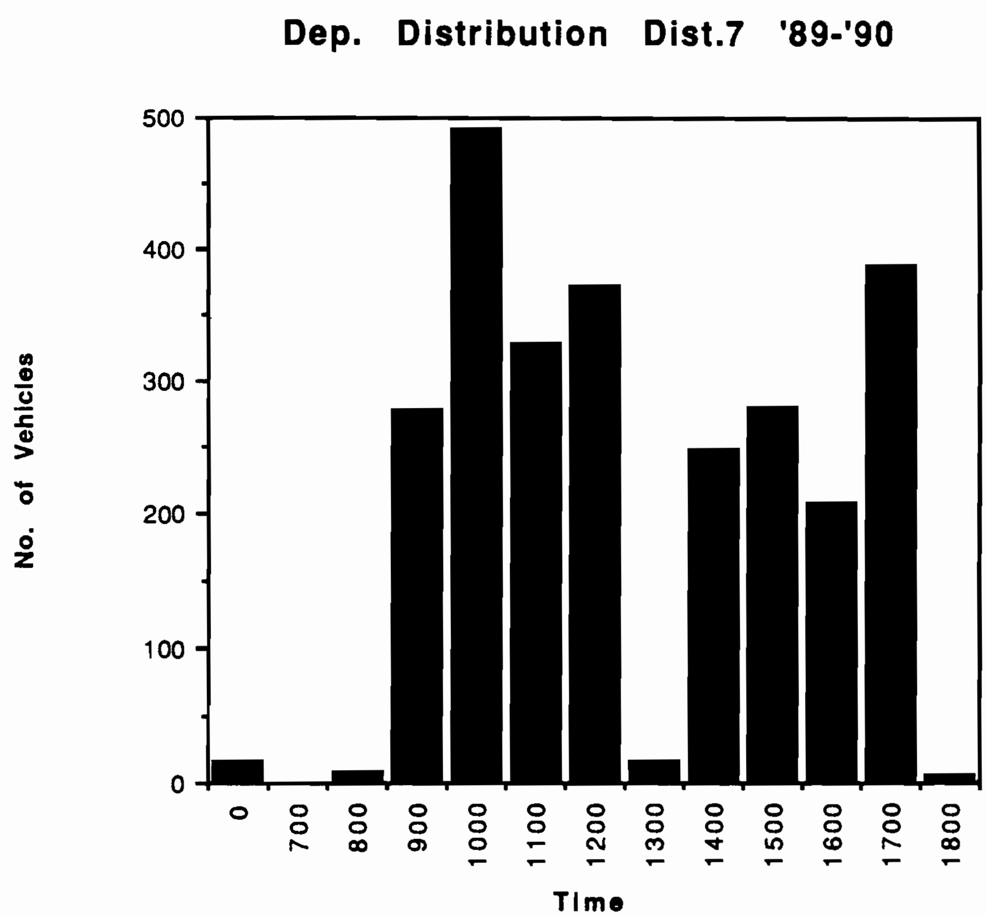
Arr. Distribution Dist.6 '89-'90



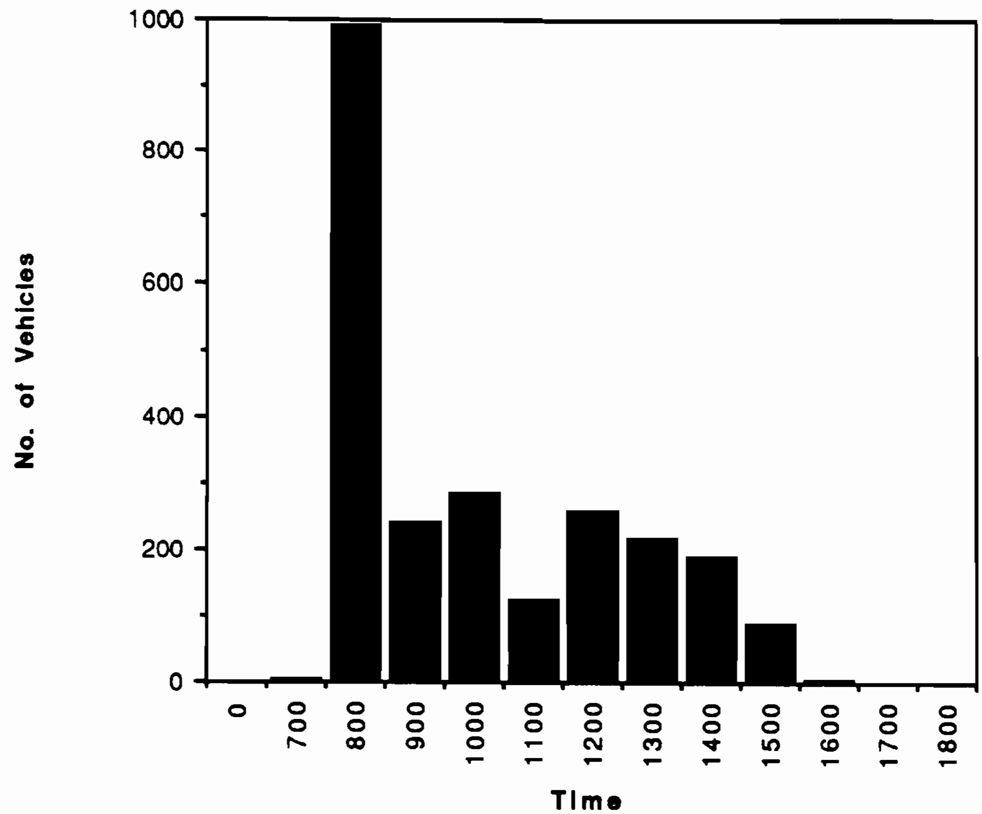
Dep. Distribution Dist.6 '89-'90



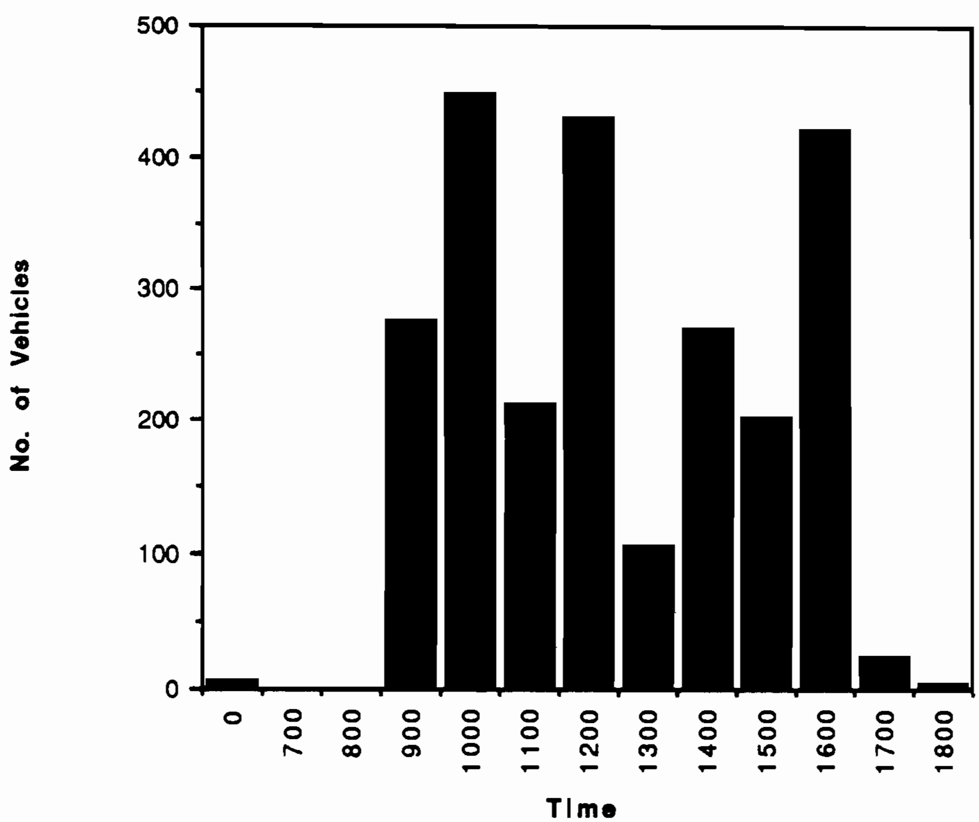

Arr. Distribution Dist.7 '89-'90
No. of Vehicles
0
200
400
600
800
1000
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

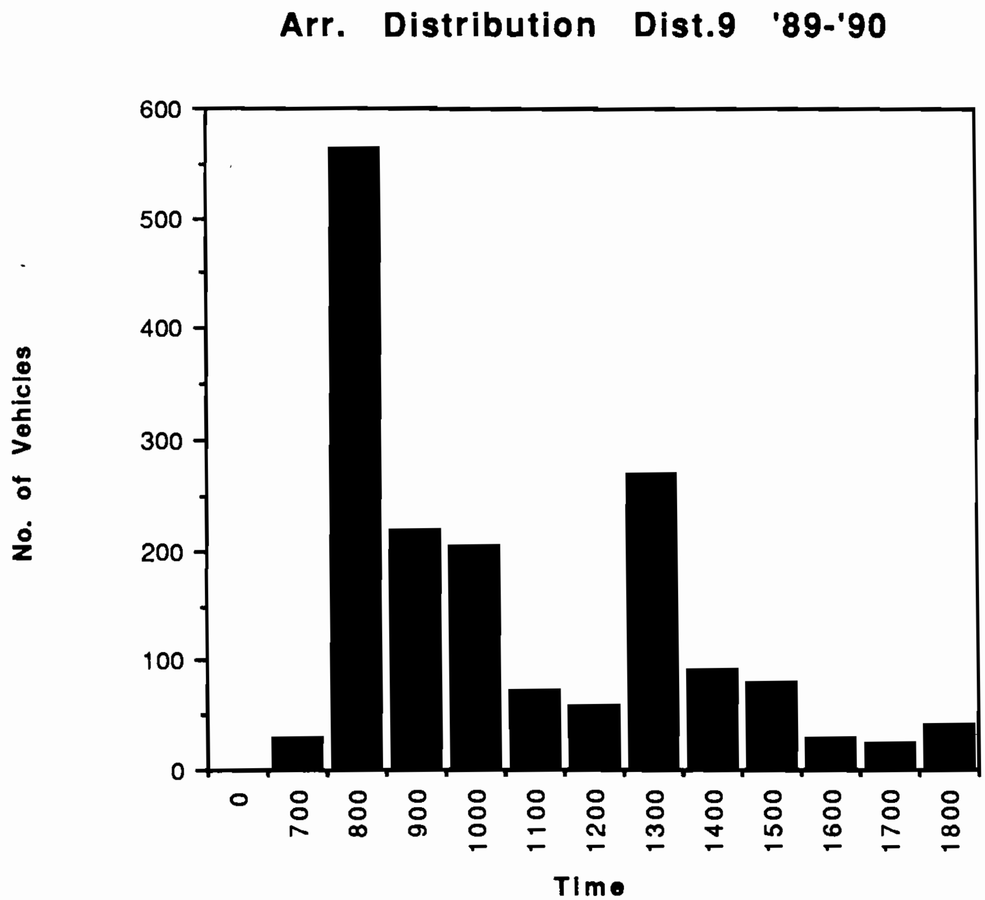

Dep. Distribution Dist.7 '89-'90
No. of Vehicles
0
100
200
300
400
500
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

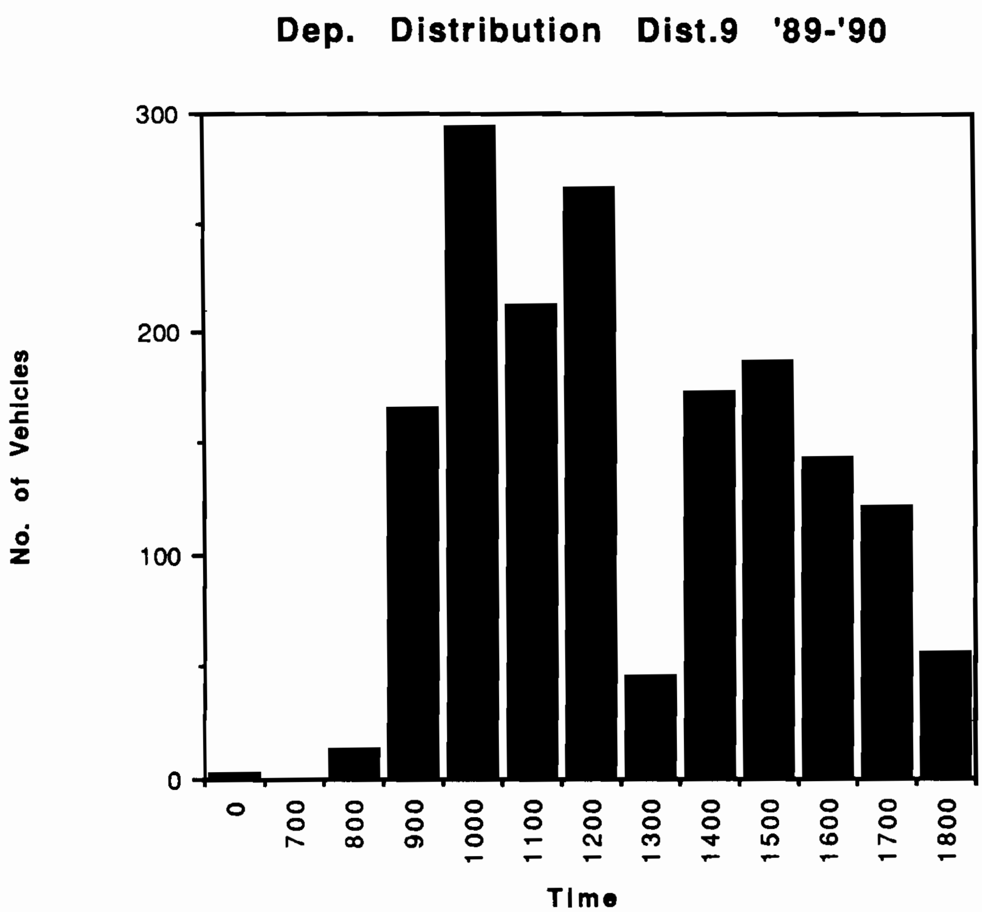
Arr. Distribution Dist.8 '89-'90



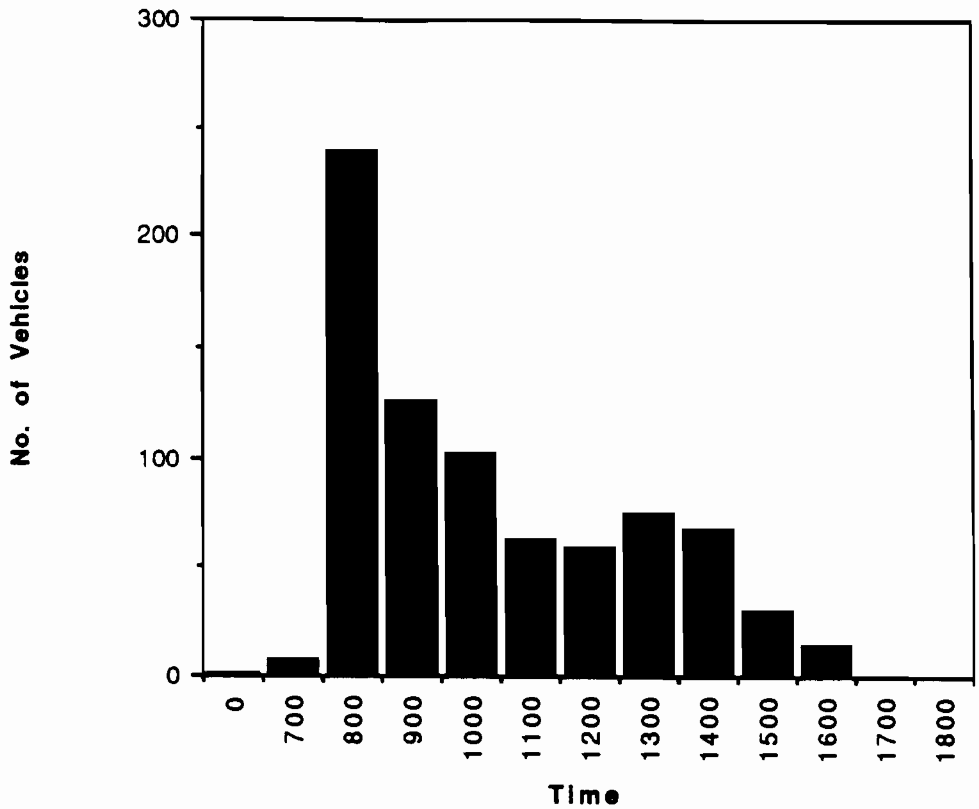
Dep. Distribution Dist.8 '89-'90



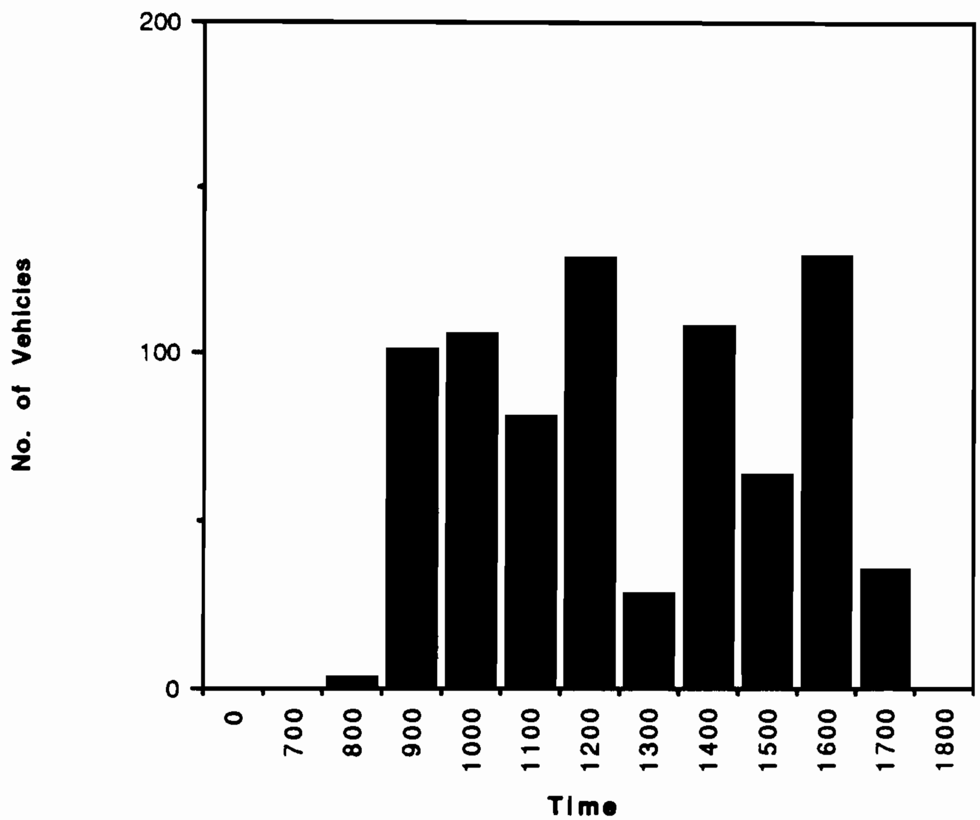

Arr. Distribution Dist.9 '89-'90
No. of Vehicles
600
500
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

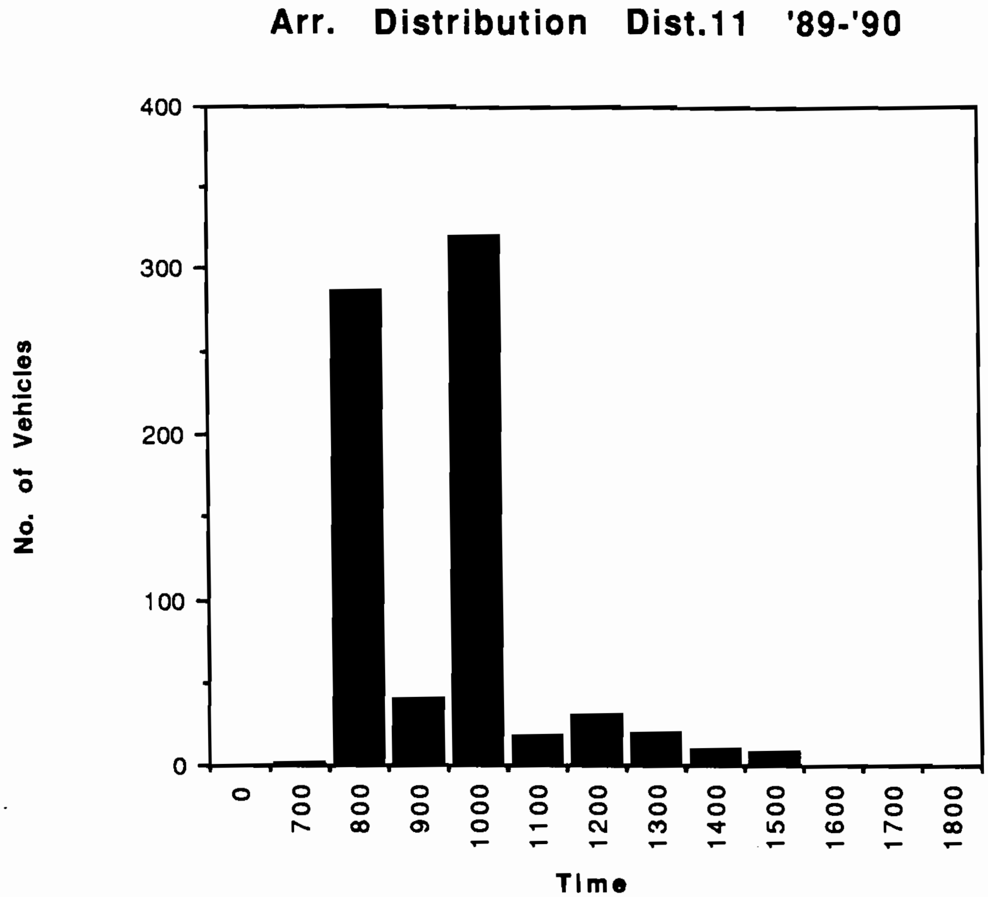

Dep. Distribution Dist.9 '89-'90
No. of Vehicles
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

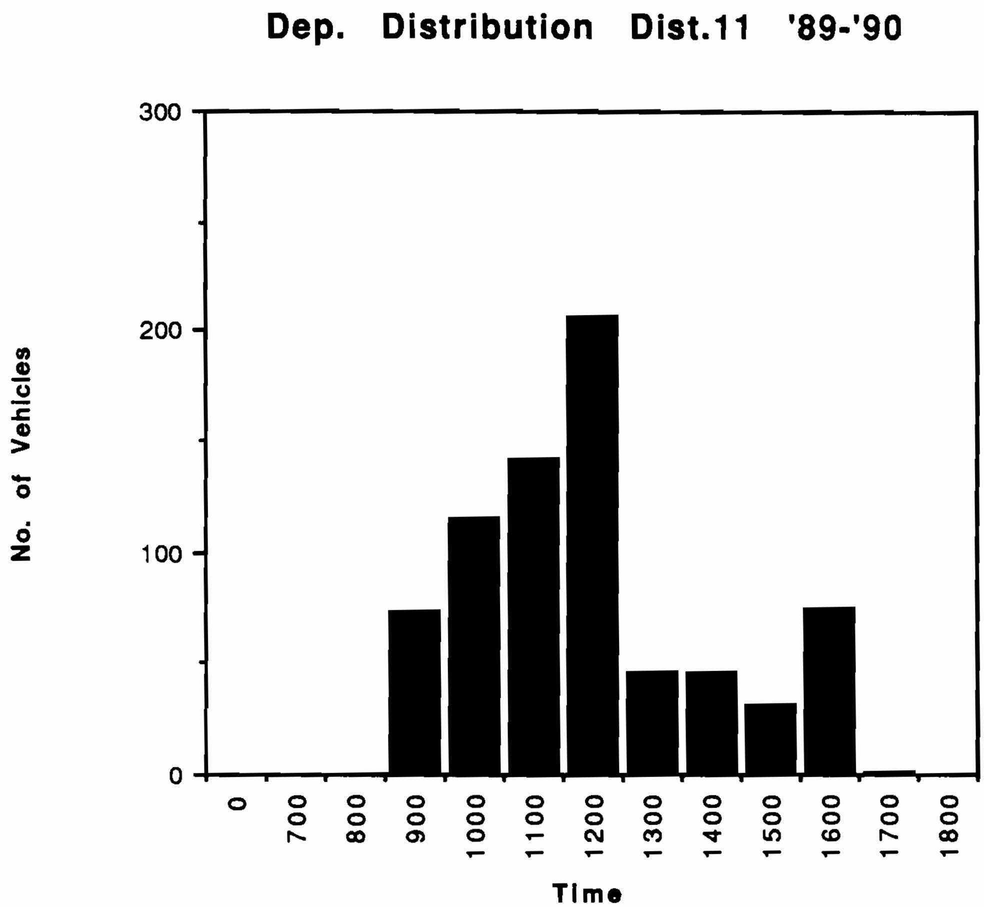
Arr. Distribution Dist.10 '89-'90

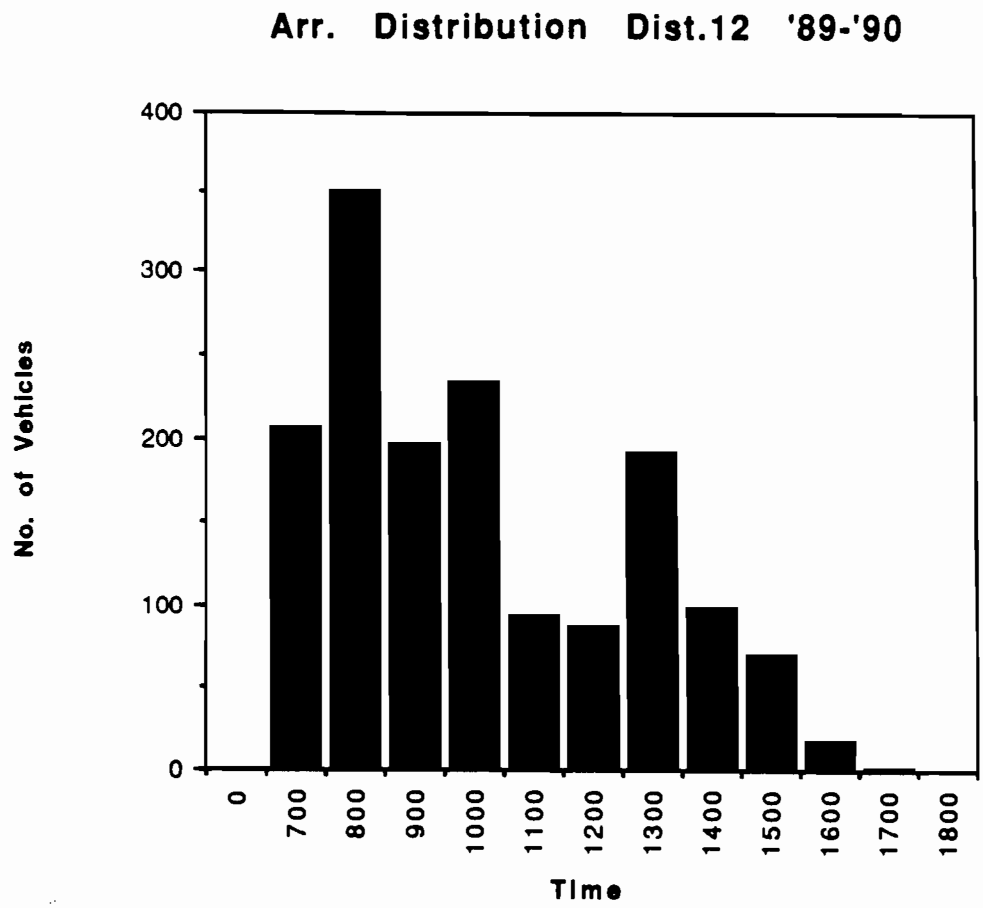


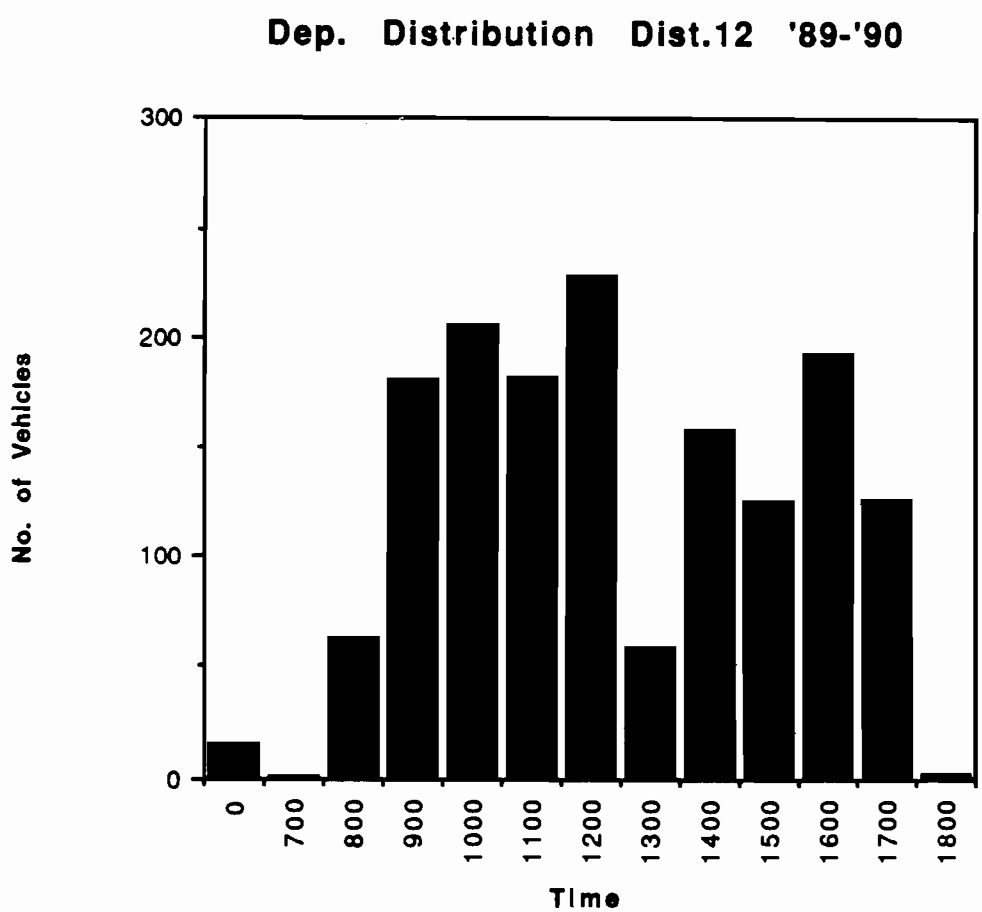
Dep. Distribution Dist.10 '89-'90



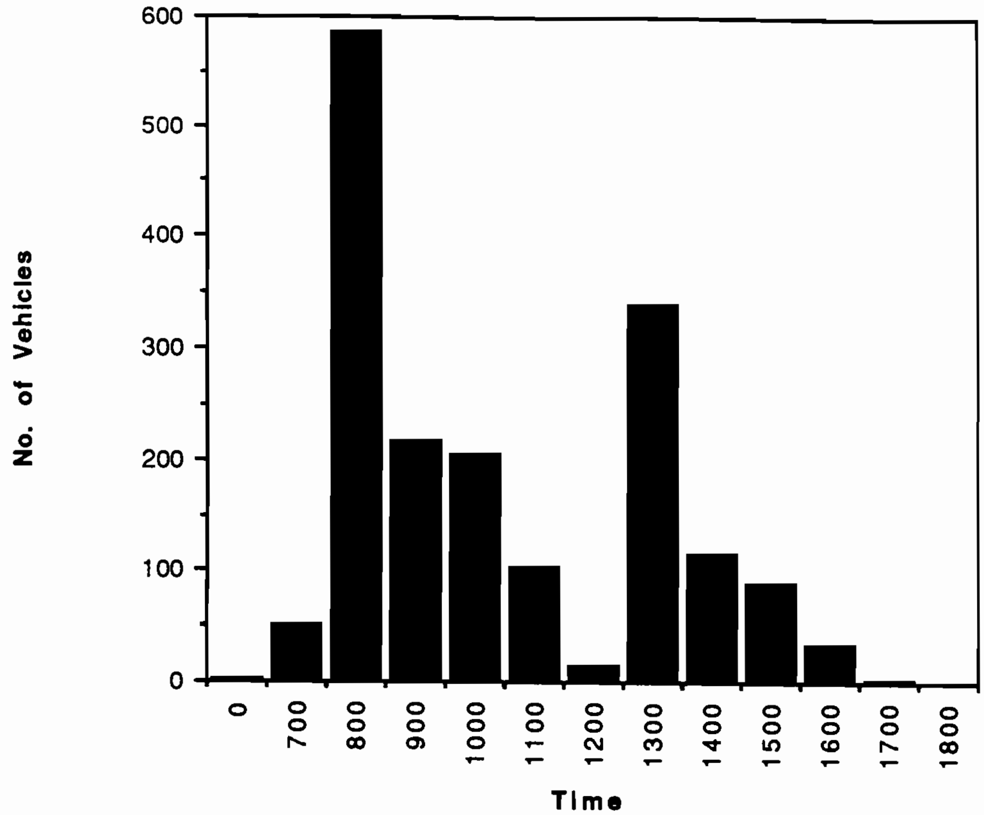

Arr. Distribution Dist.11 '89-'90
No. of Vehicles
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.11 '89-'90
No. of Vehicles
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

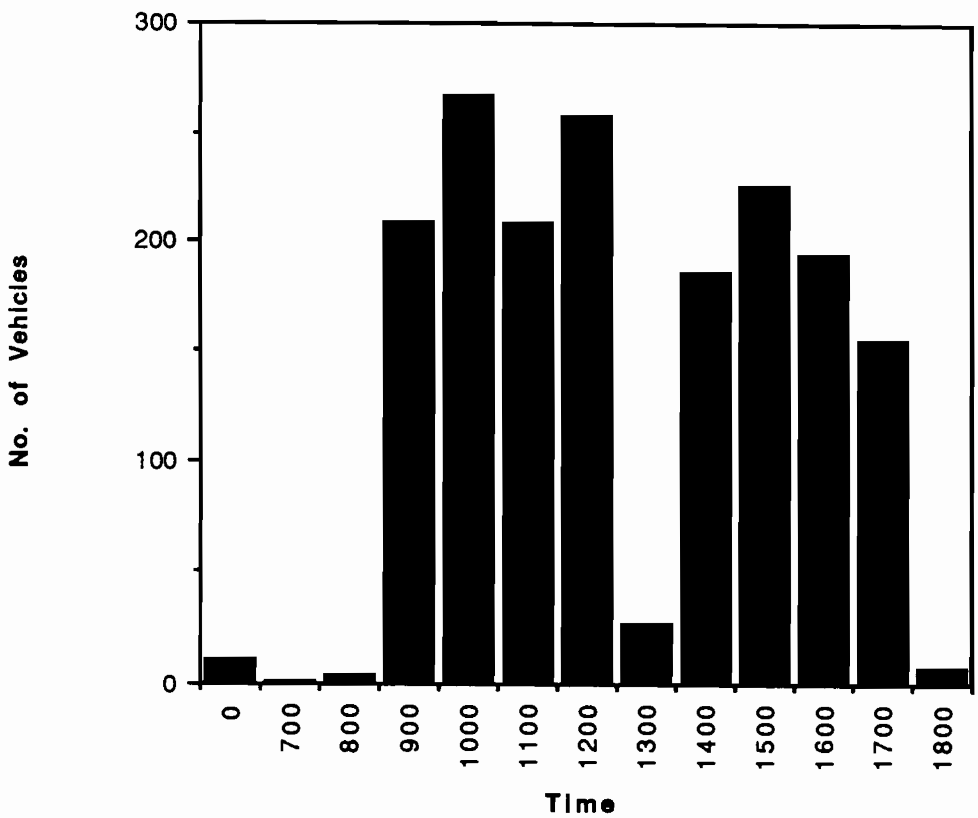

Arr. Distribution Dist.12 '89-'90
400
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.12 '89-'90
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

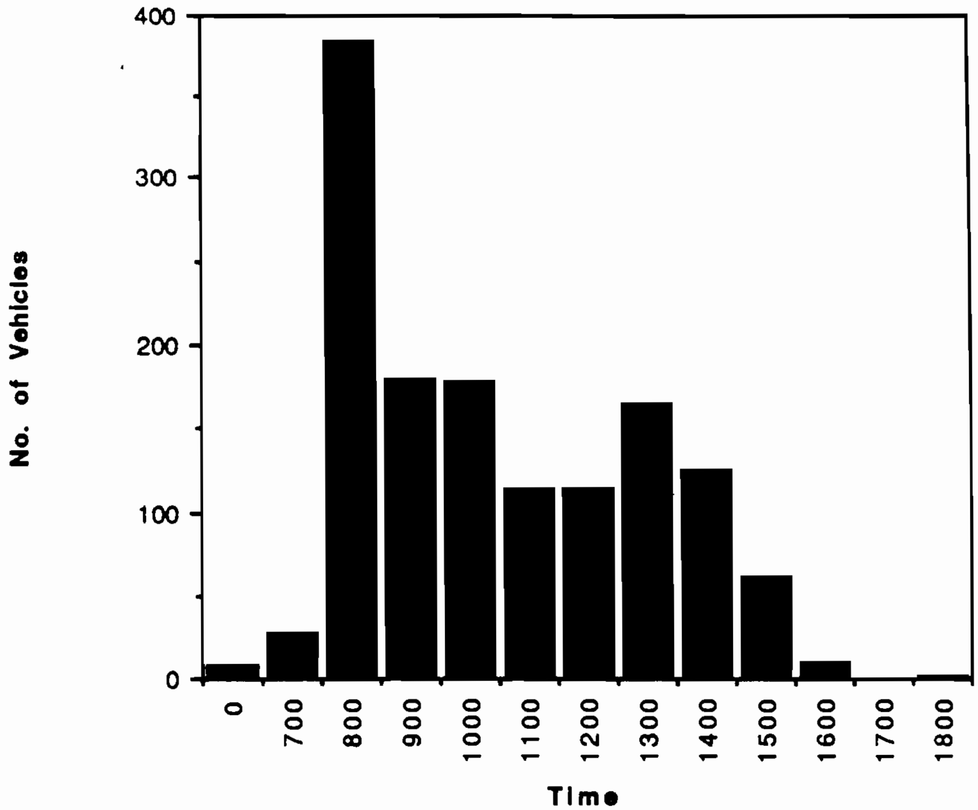
Arr. Distribution Dist.13 '89-'90



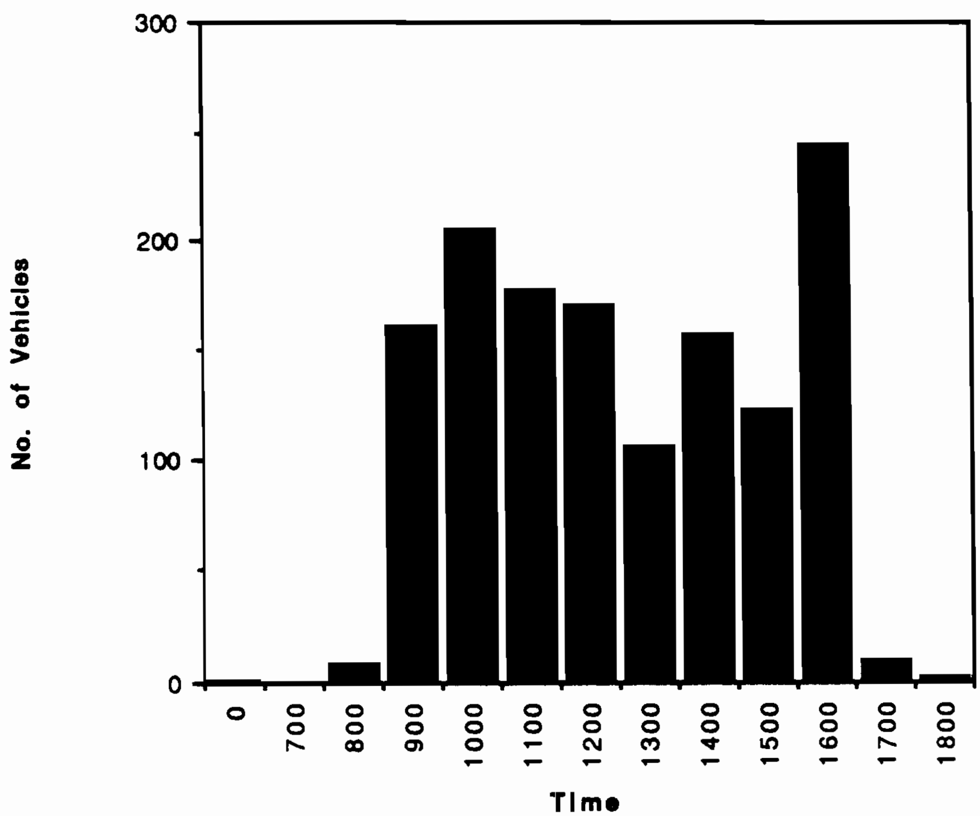
Dep. Distribution Dist.13 '89-'90



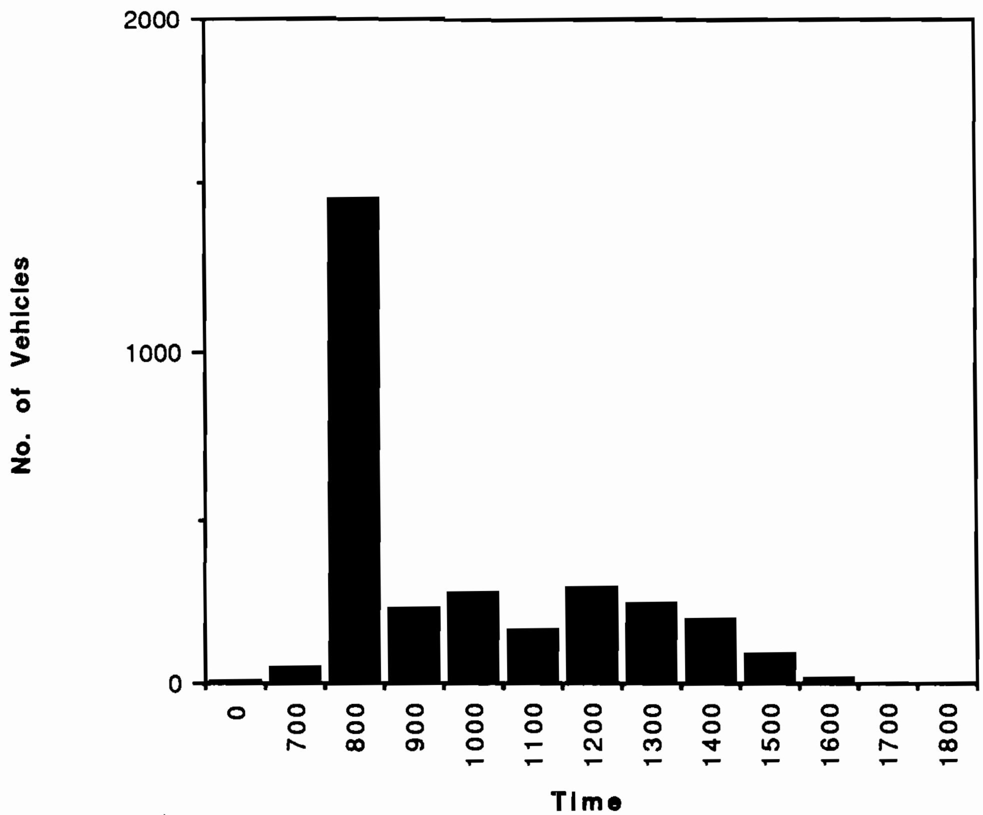
Arr. Distribution Dist.14 '89-'90



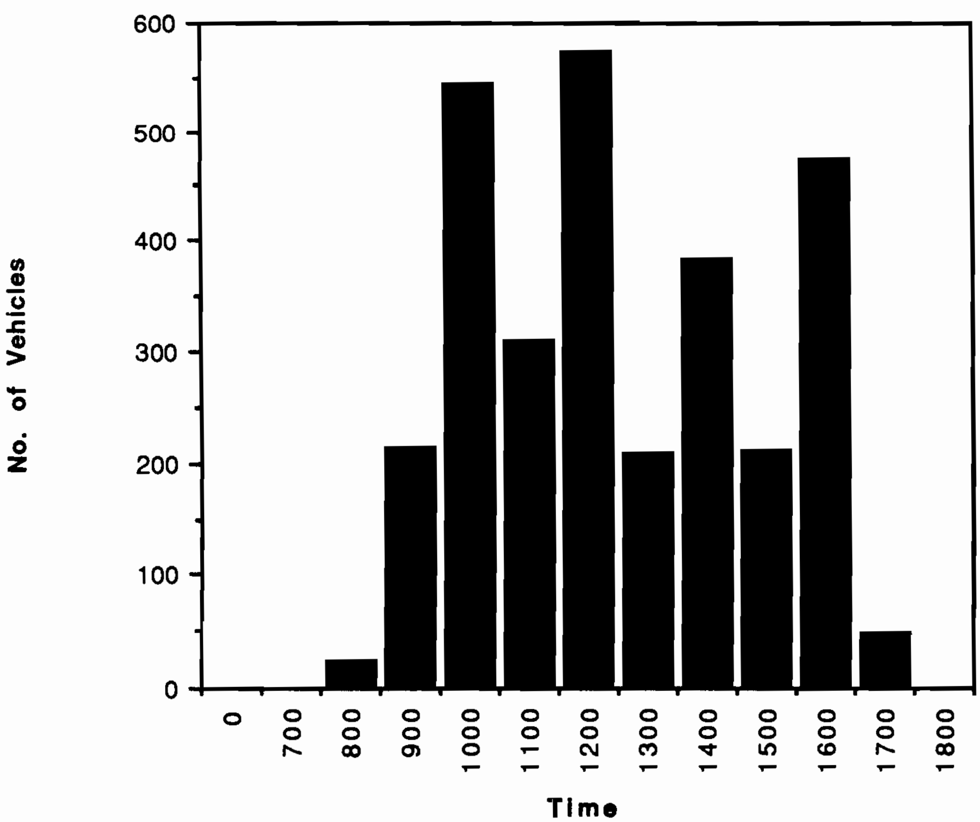
Dep. Distribution Dist.14 '89-'90

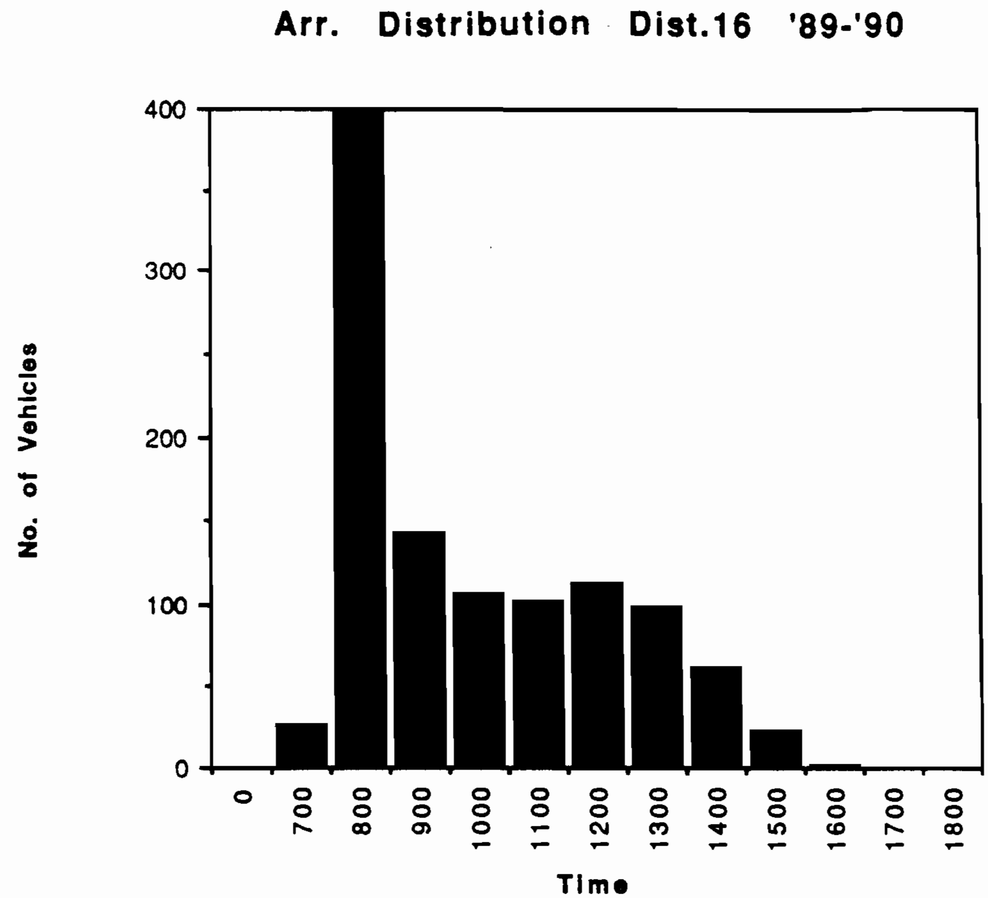


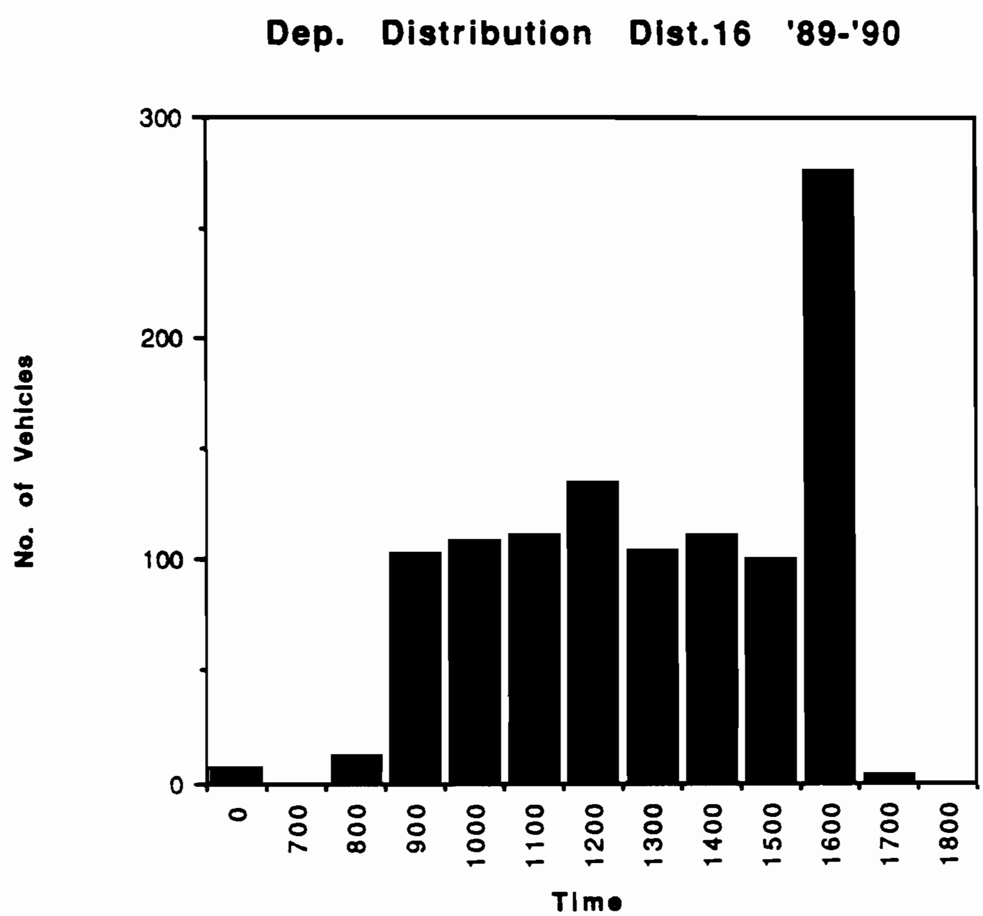
Arr. Distribution Dist.15 '89-'90



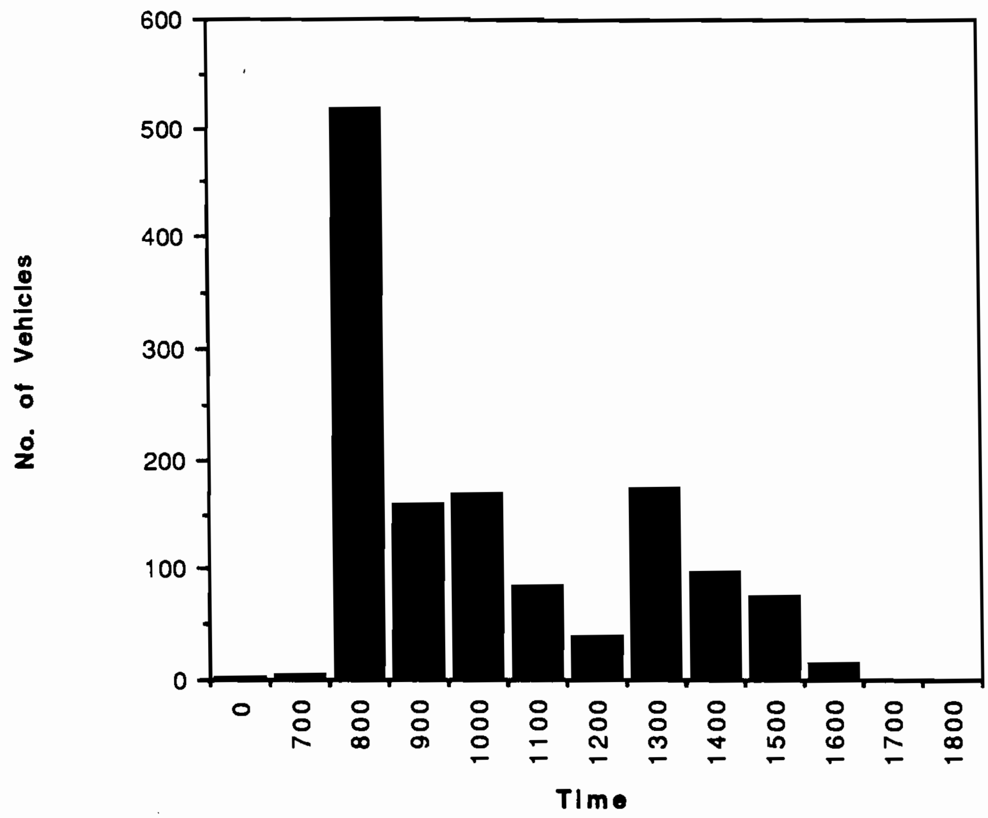
Dep. Distribution Dist.15 '89-'90



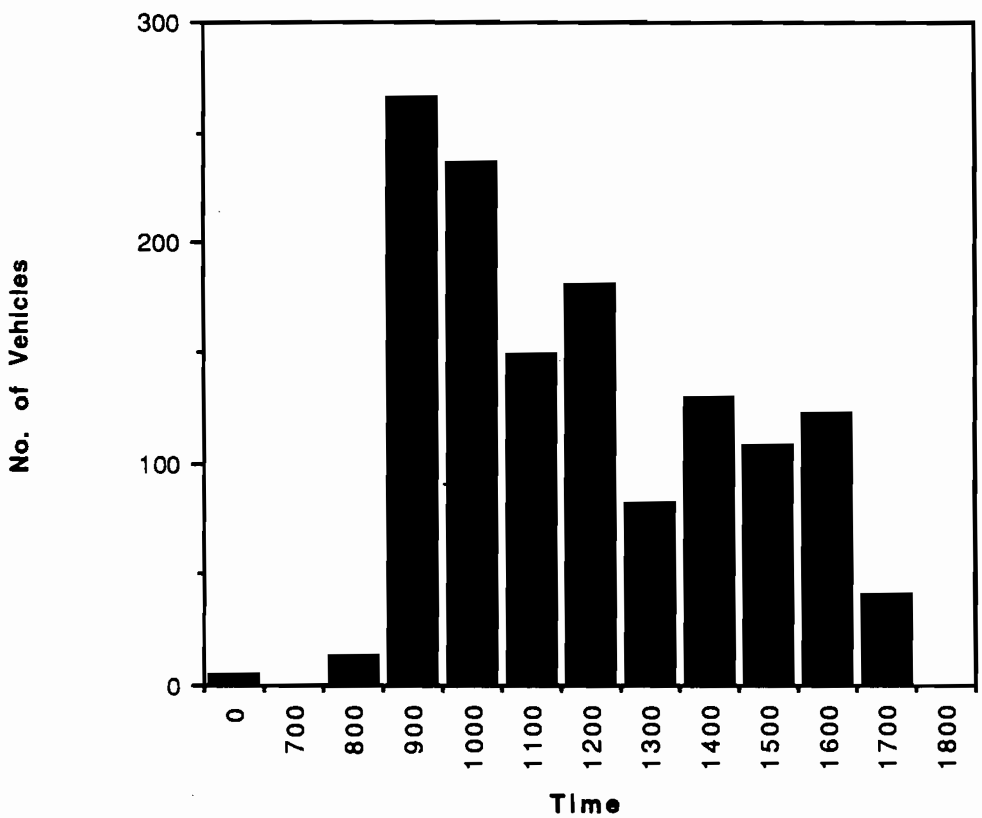

Arr. Distribution Dist.16 '89-'90
No. of Vehicles
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

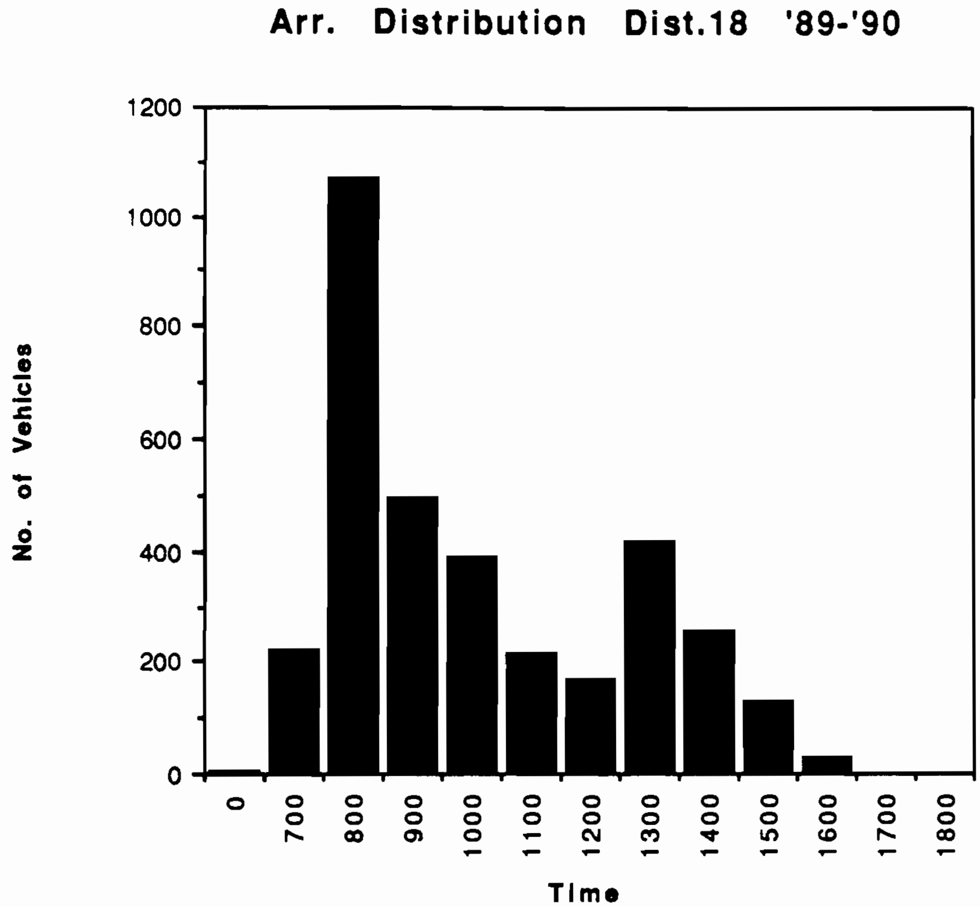

Dep. Distribution Dist.16 '89-'90
No. of Vehicles
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

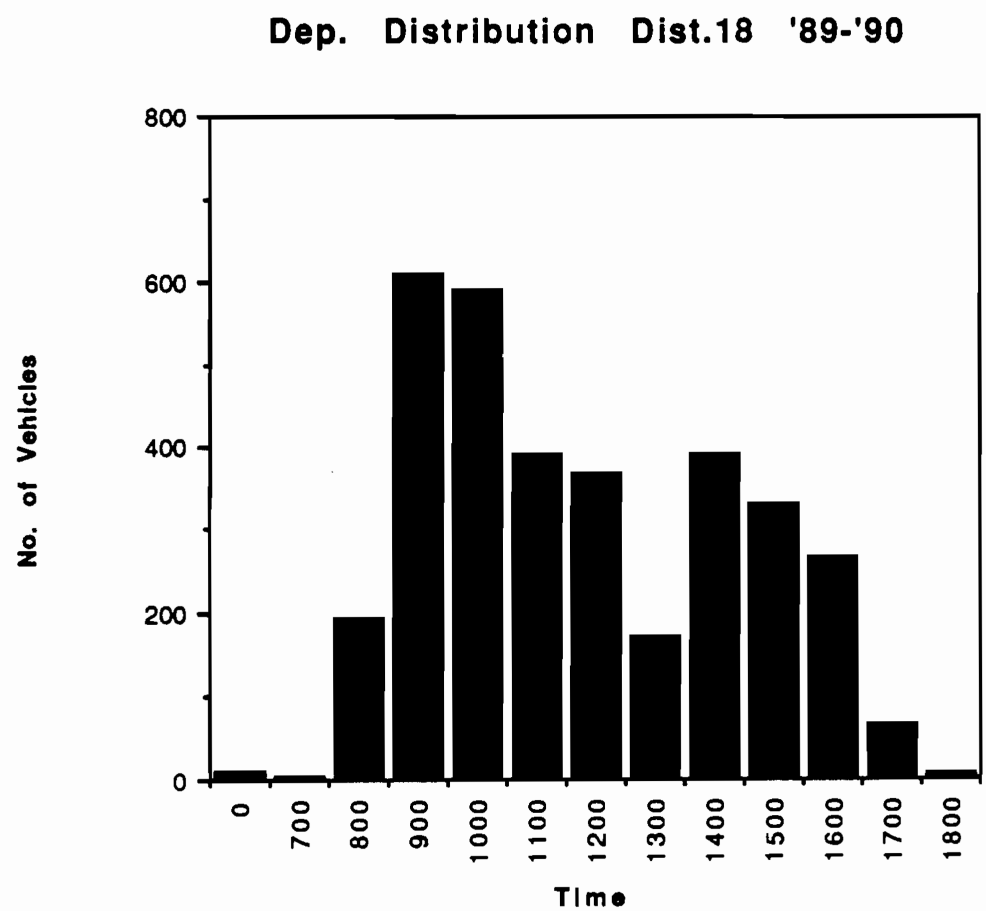
Arr. Distribution Dist.17 '89-'90

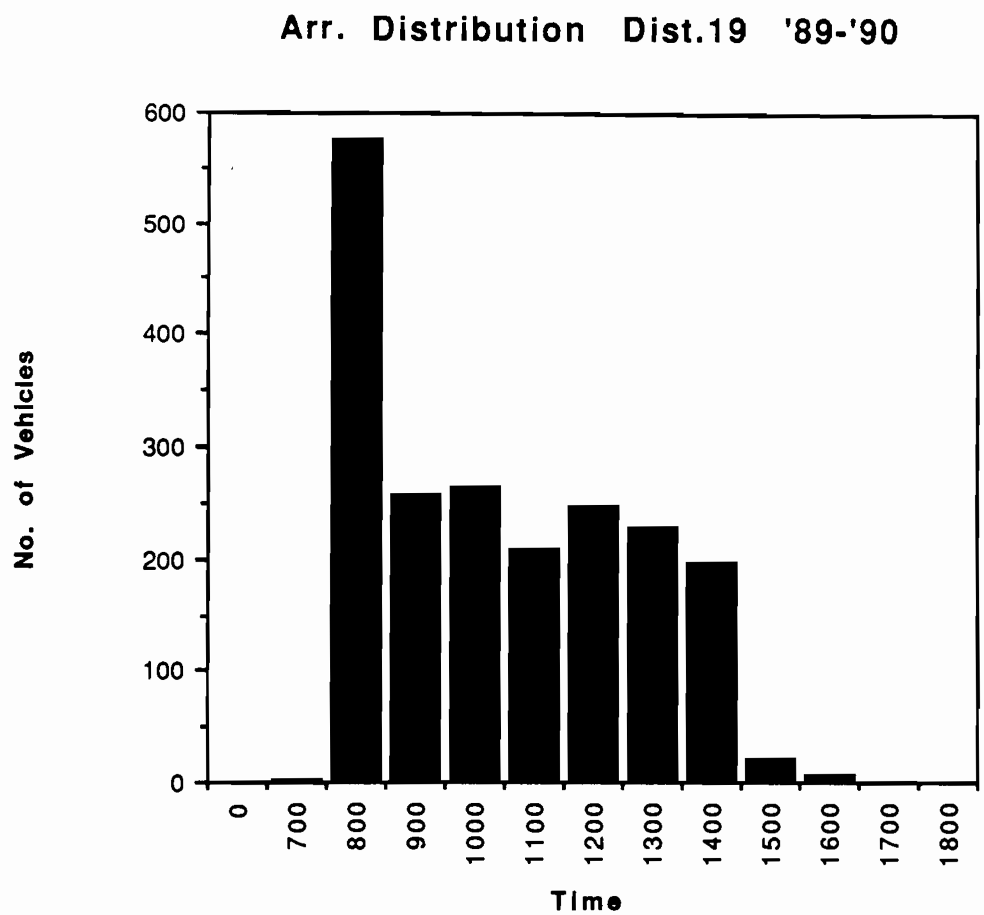


Dep. Distribution Dist.17 '89-'90

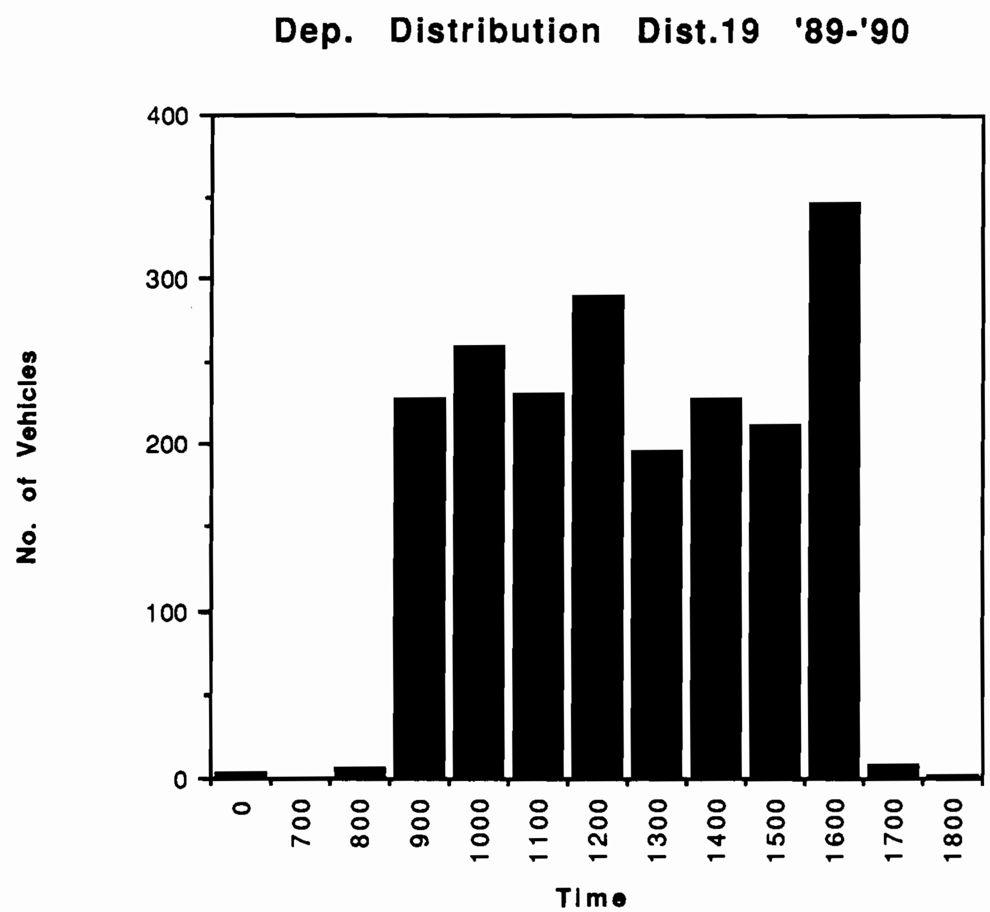



Arr. Distribution Dist.18 '89-'90
1200
1000
800
600
400
200
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

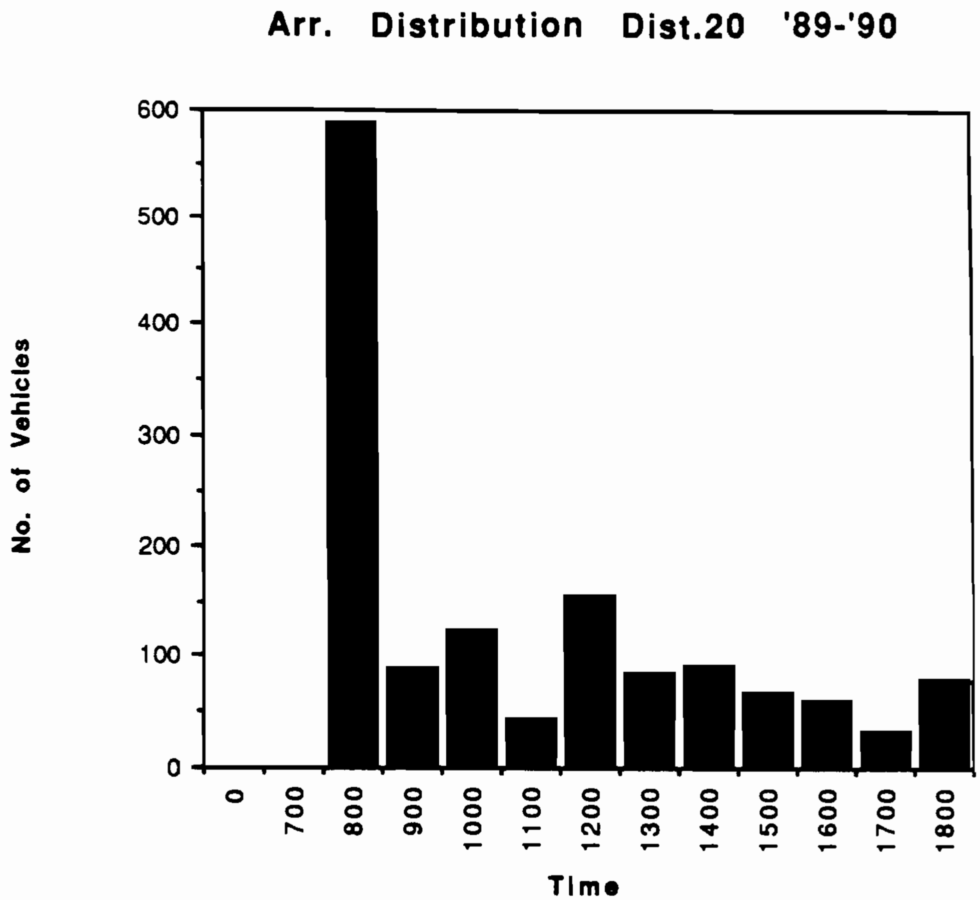

Dep. Distribution Dist.18 '89-'90
800
600
400
200
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

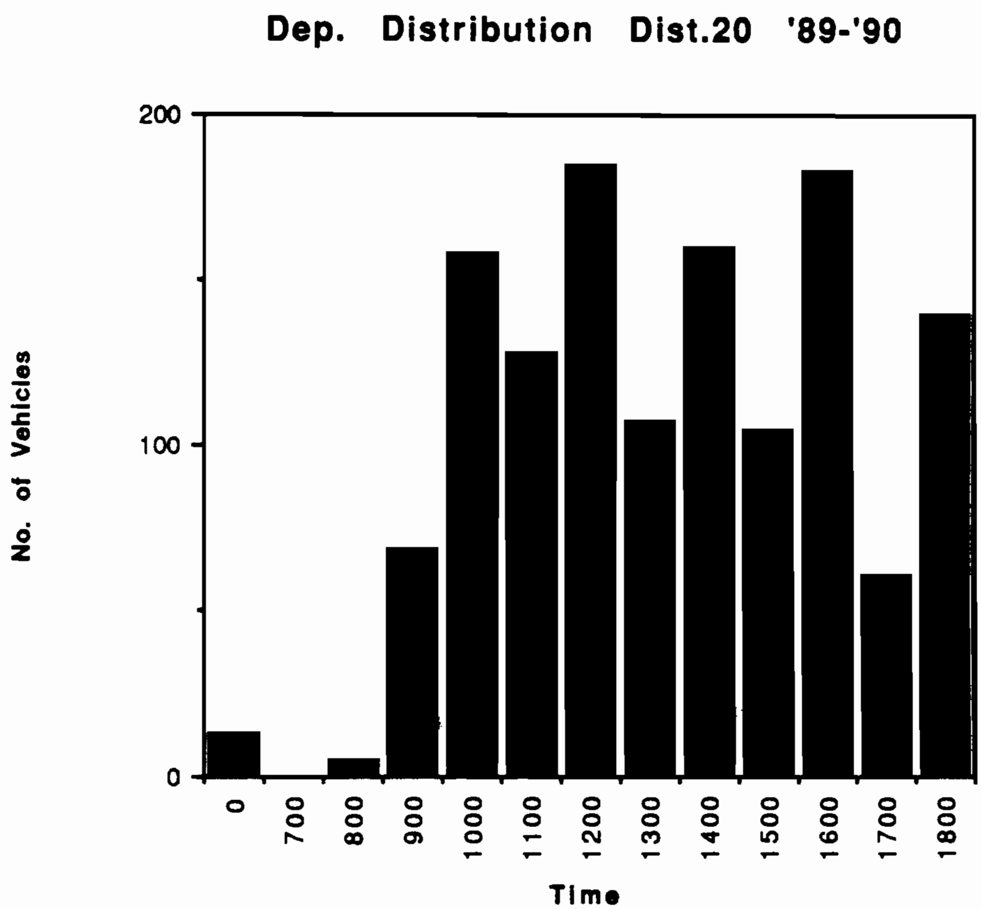


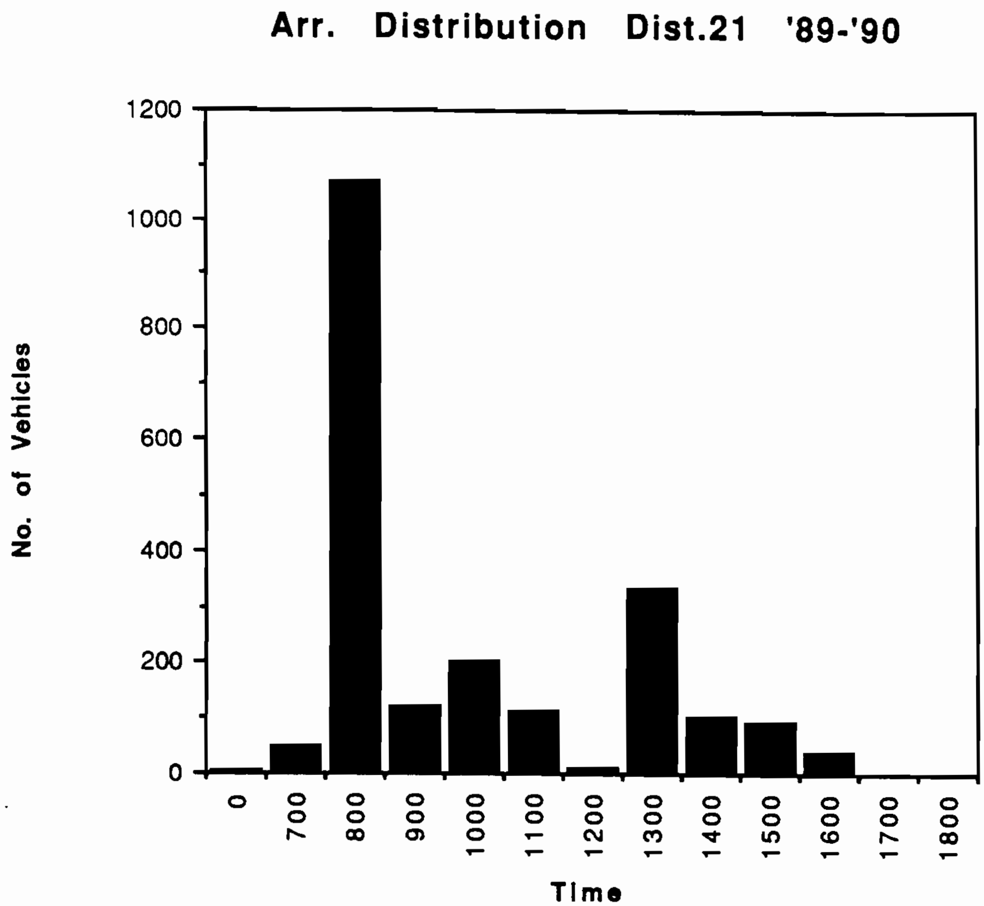
Arr. Distribution Dist.19 '89-'90
No. of Vehicles
600
500
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

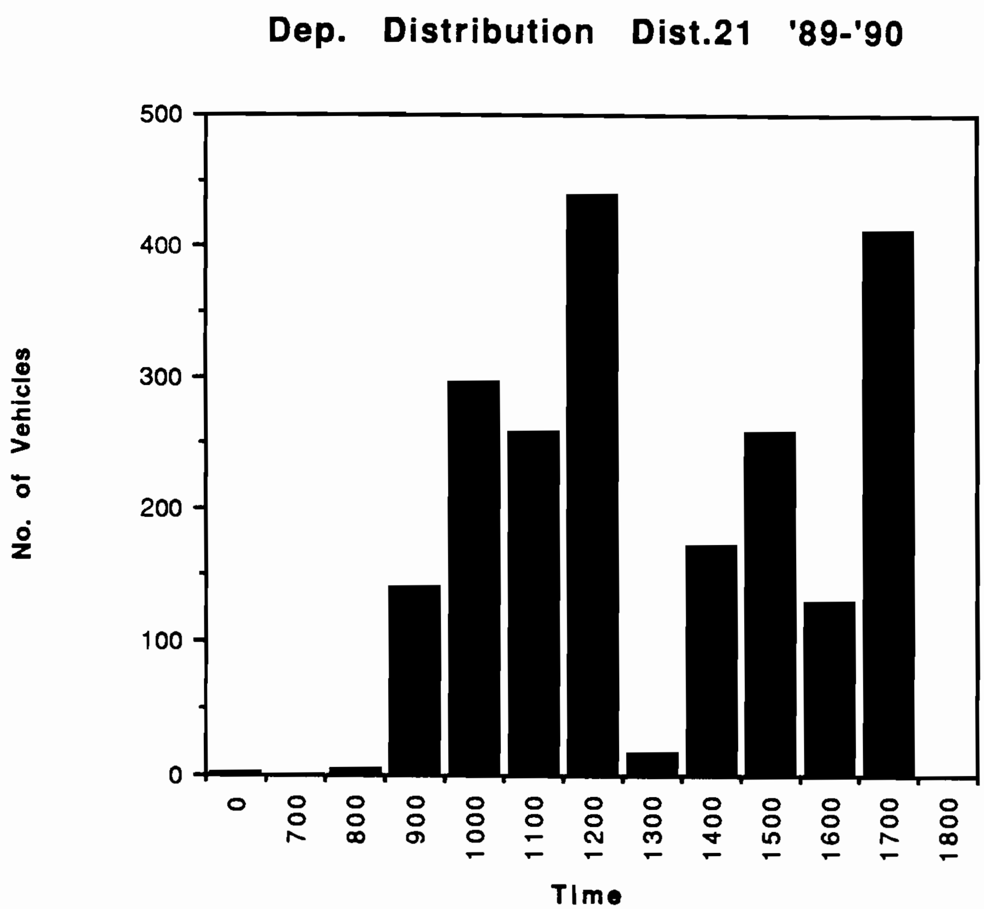


Dep. Distribution Dist.19 '89-'90
No. of Vehicles
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

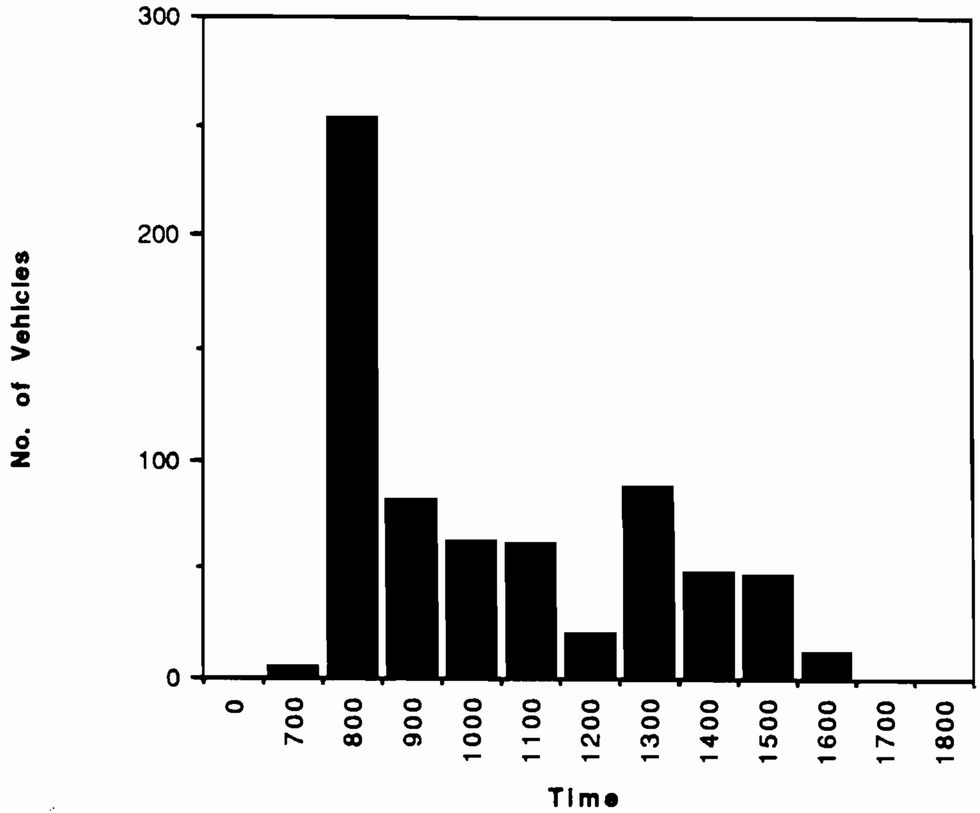

Arr. Distribution Dist.20 '89-'90
No. of Vehicles
600
500
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.20 '89-'90
No. of Vehicles
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

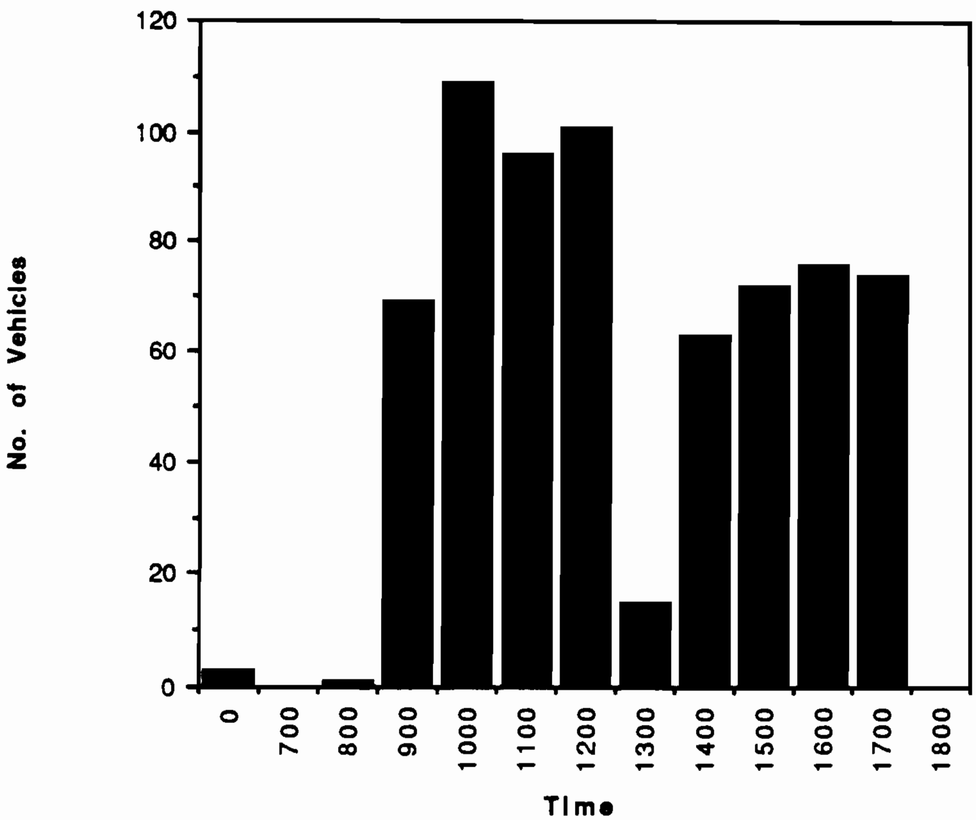

Arr. Distribution Dist.21 '89-'90
1200
1000
800
600
400
200
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

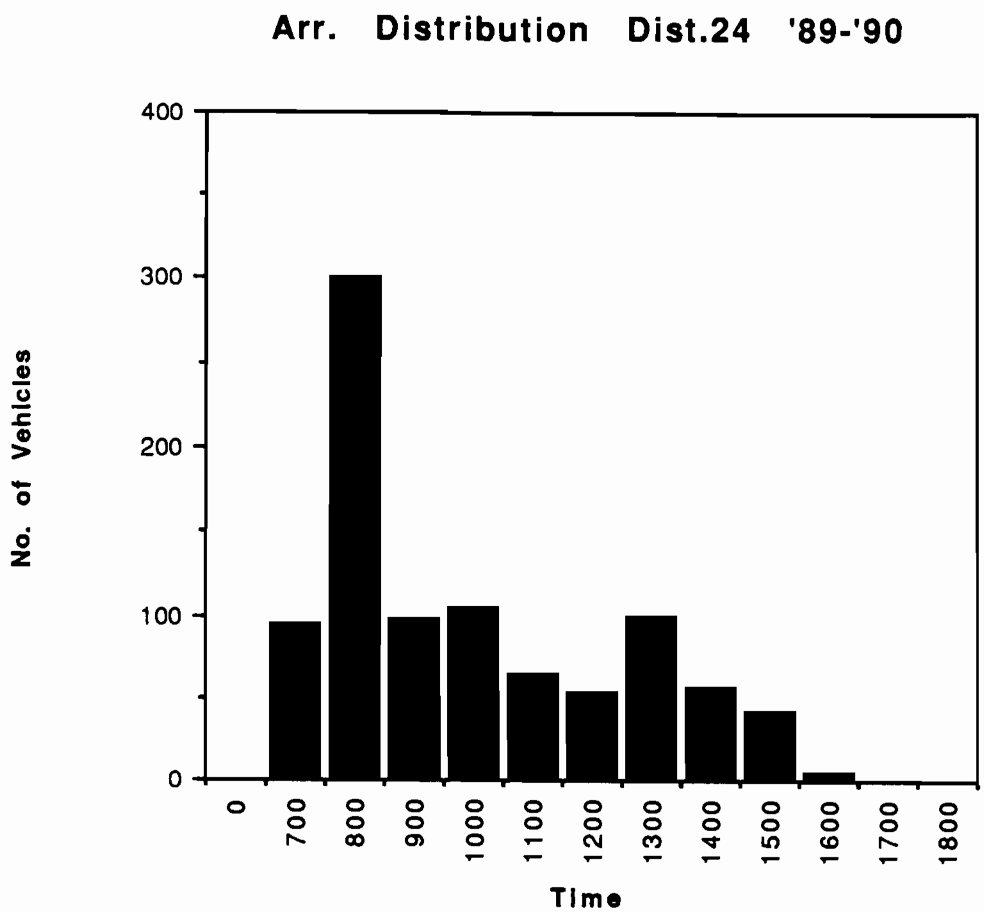

Dep. Distribution Dist.21 '89-'90
500
400
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

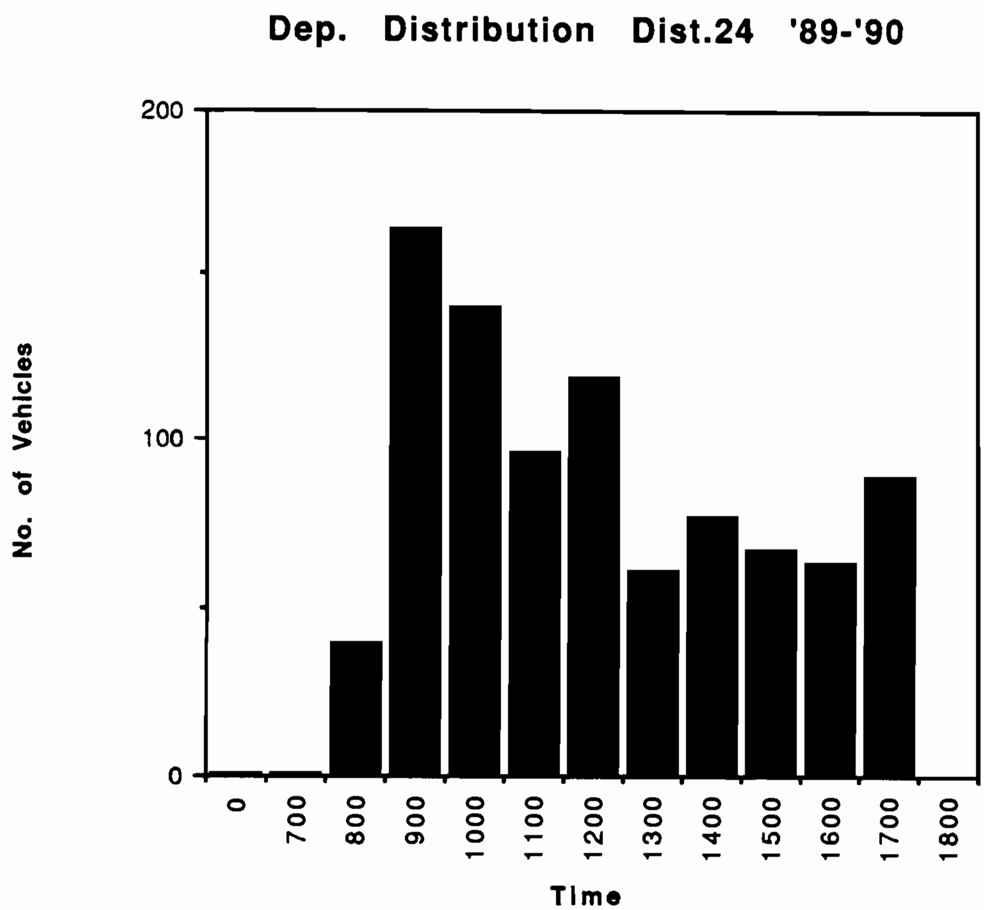
Arr. Distribution Dist.23 '89-'90



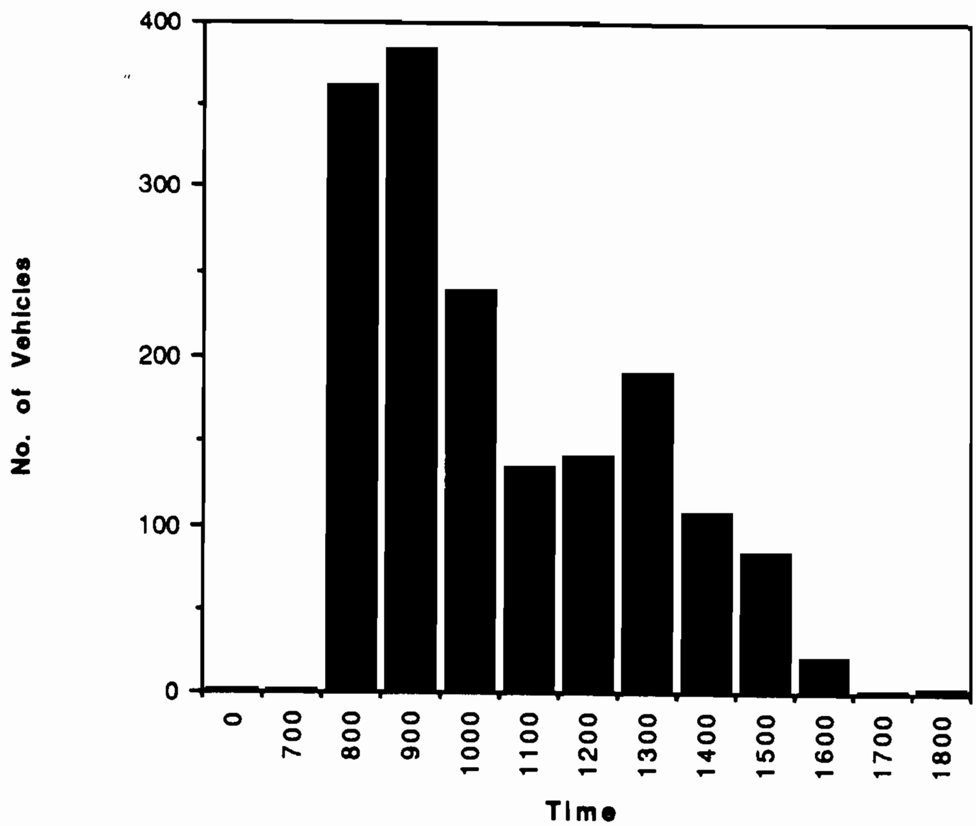
Dep. Distribution Dist.23 '89-'90



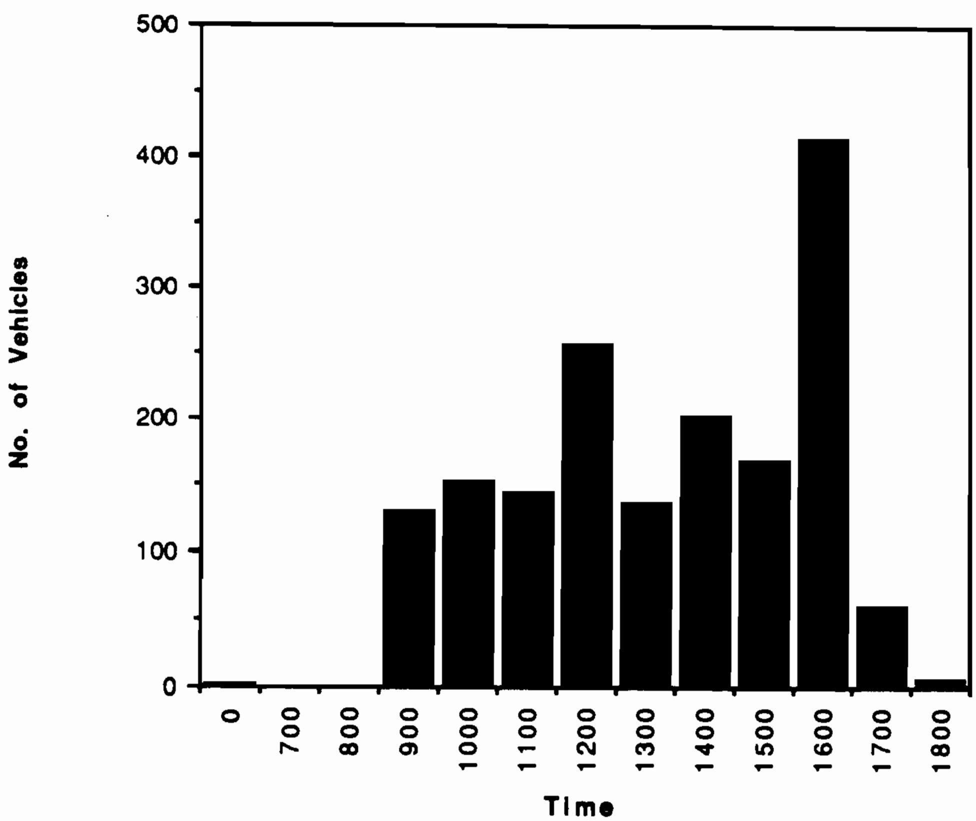

Arr. Distribution Dist.24 '89-'90
400
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.24 '89-'90
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

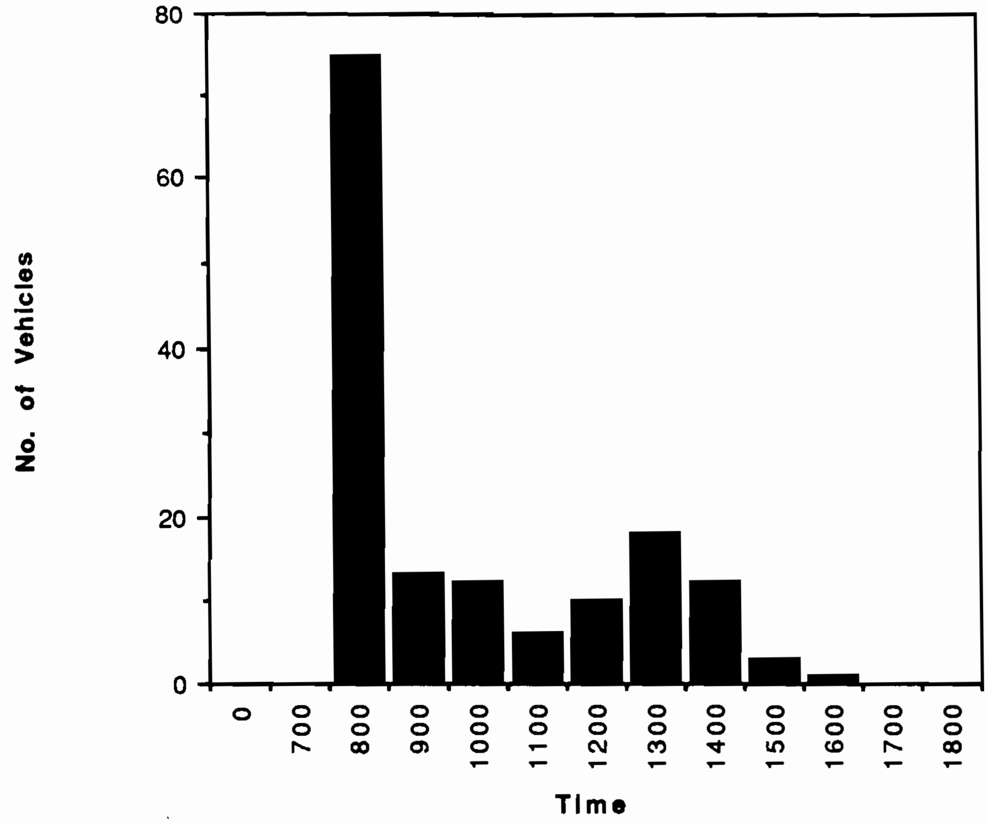
Arr. Distribution Dist.25 '89-'90



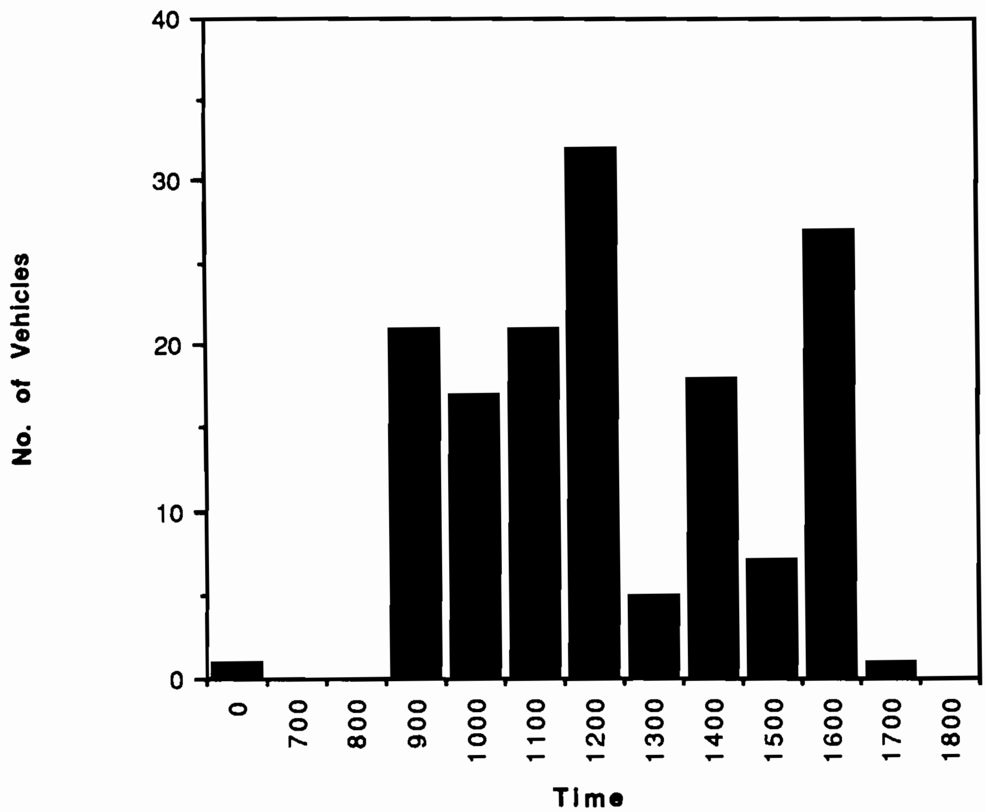
Dep. Distribution Dist.25 '89-'90



Arr. Distribution Dist.29(22?) '89-'90

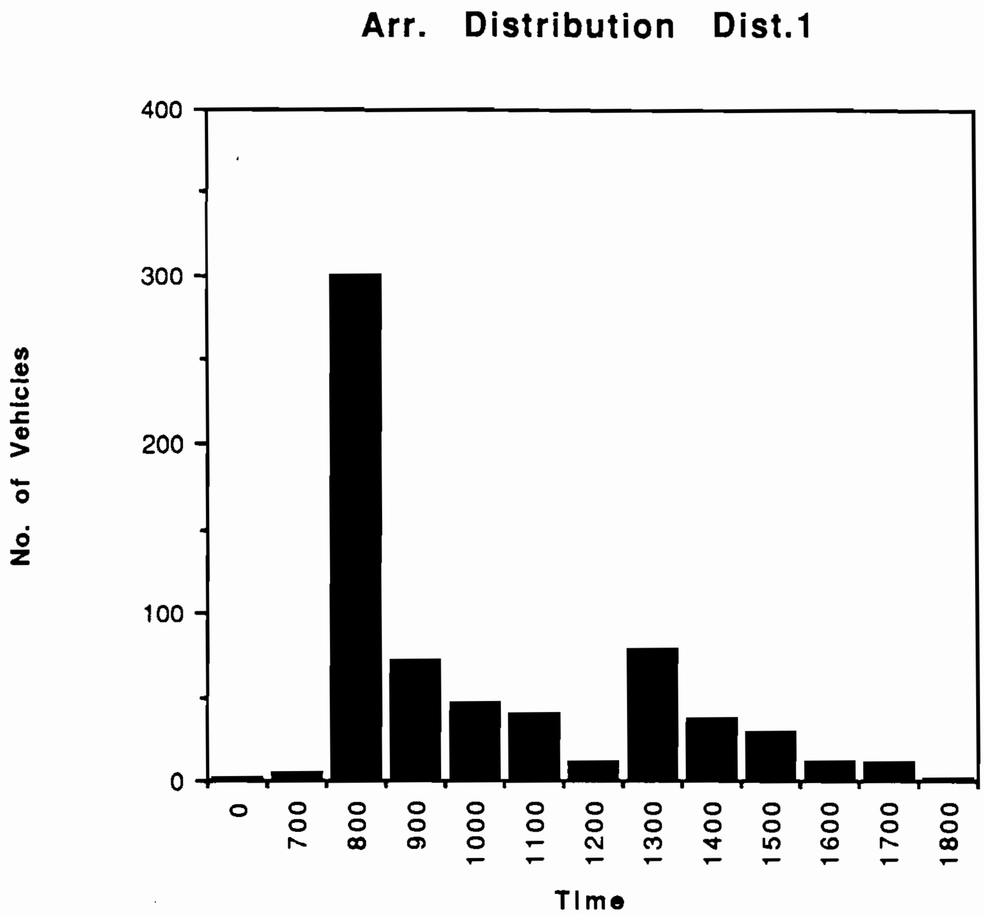


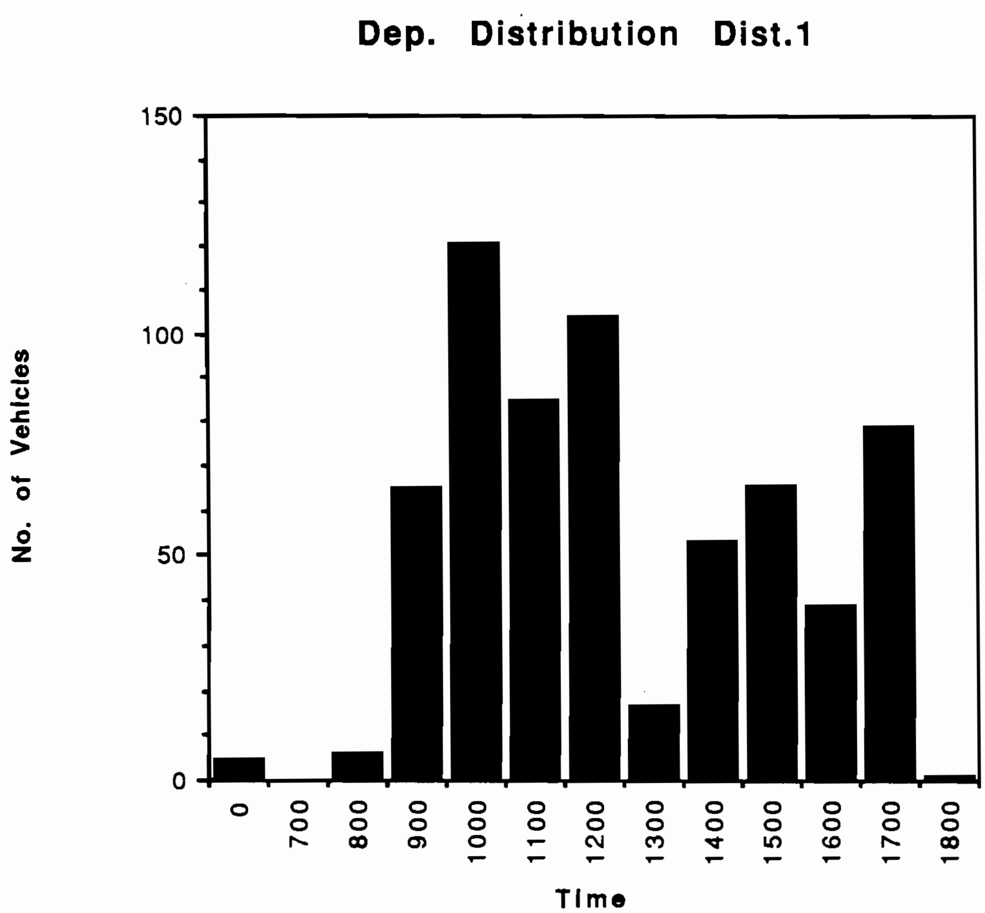
Dep. Distribution Dist.29(22?) '89-'90

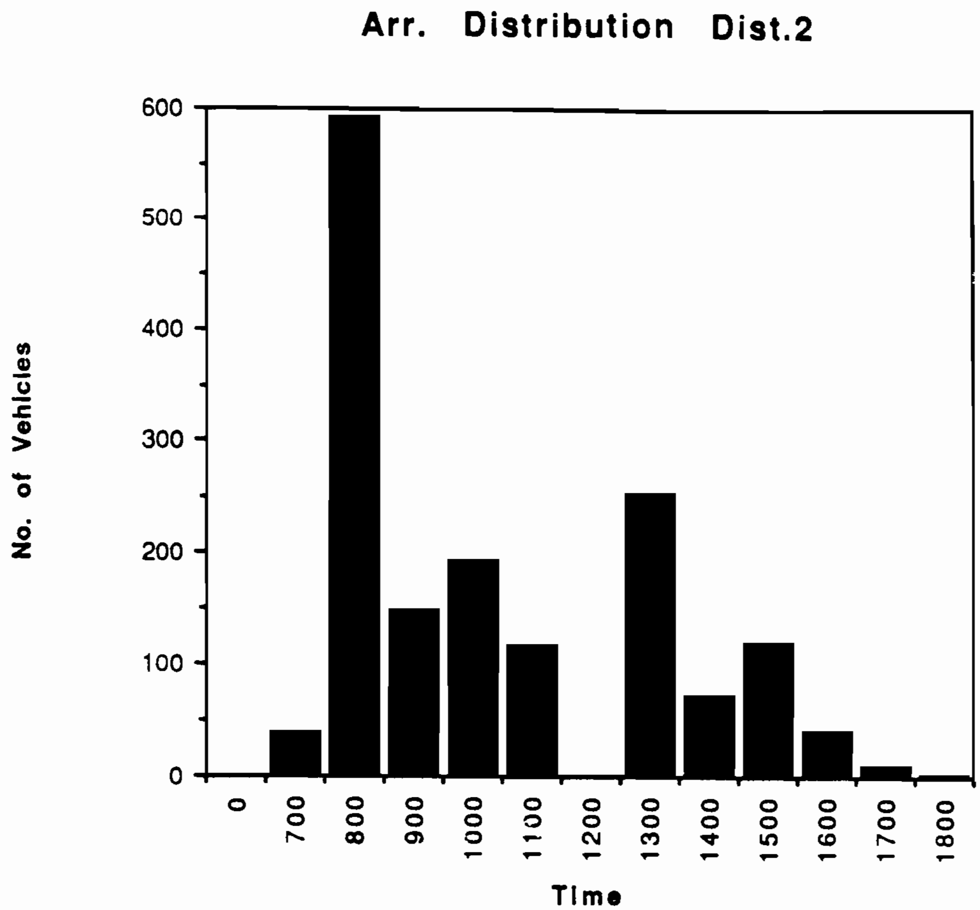


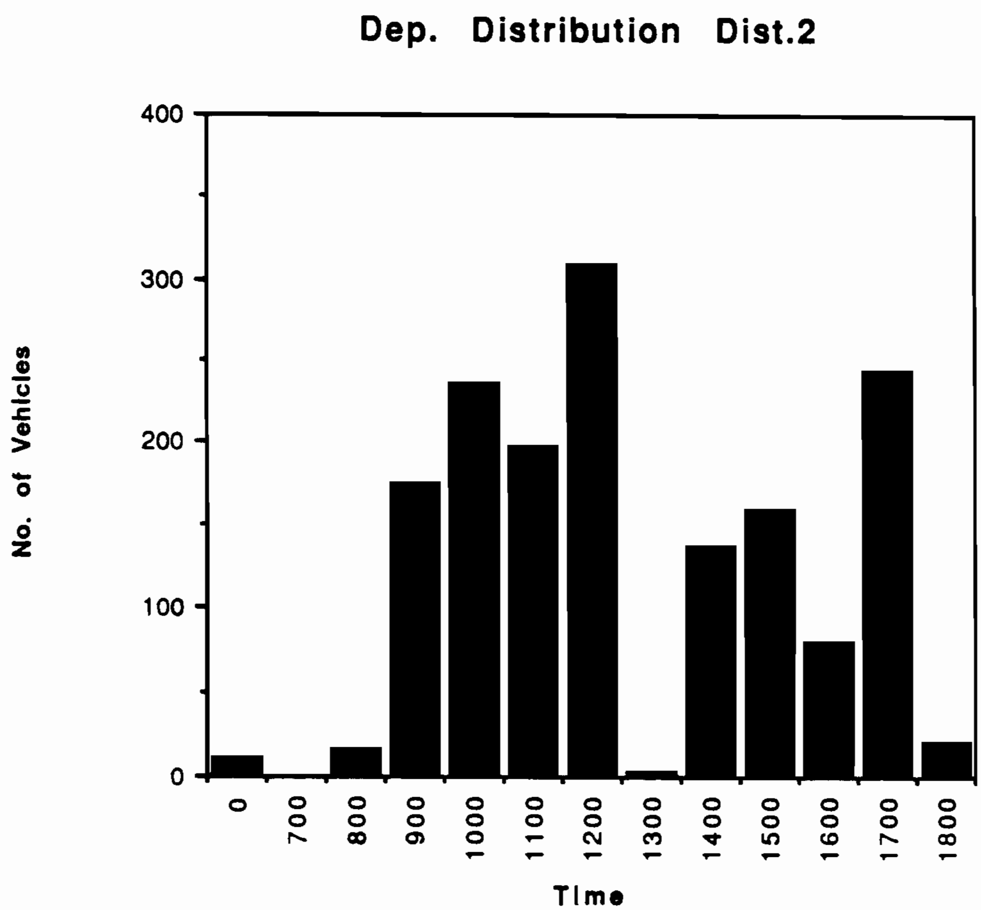
APPENDIX B. WORK ORDER ARRIVAL AND DEPARTURE FREQUENCY DISTRIBUTION FOR FY 1988-89

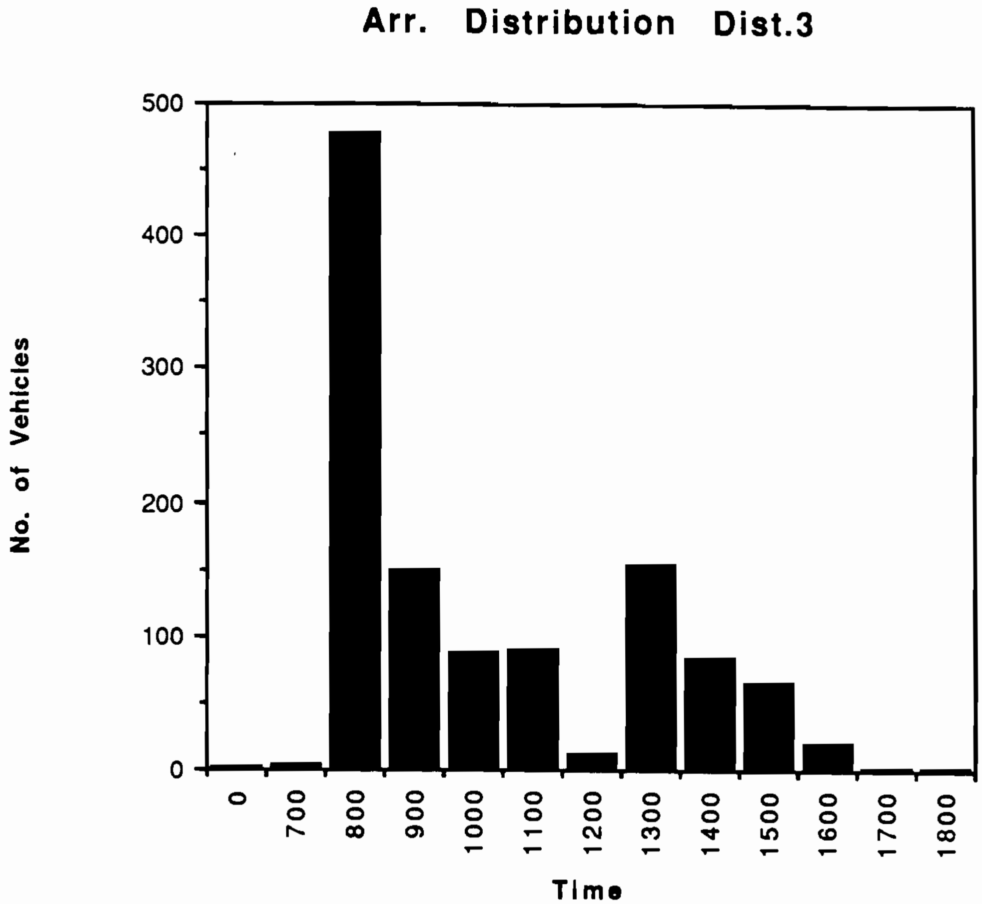
Note: Work orders with times from 1800 - 0600 appear as Time 0

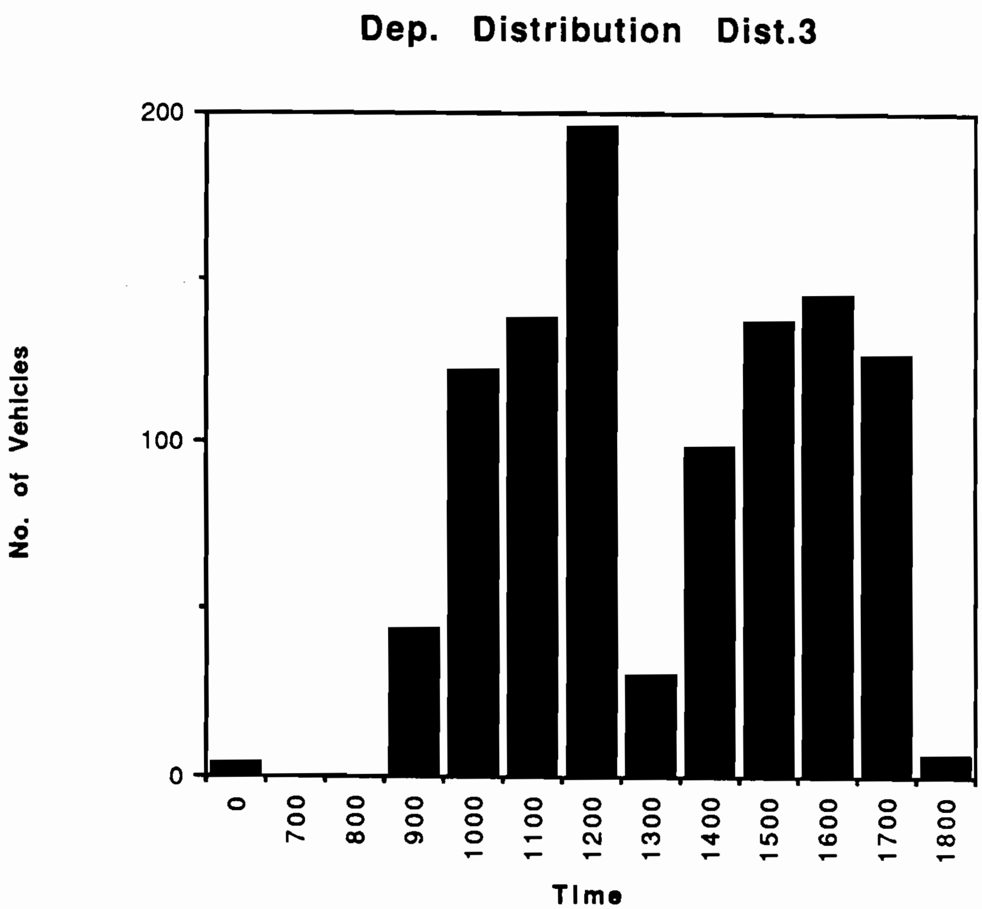

Arr. Distribution Dist.1
No. of Vehicles
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

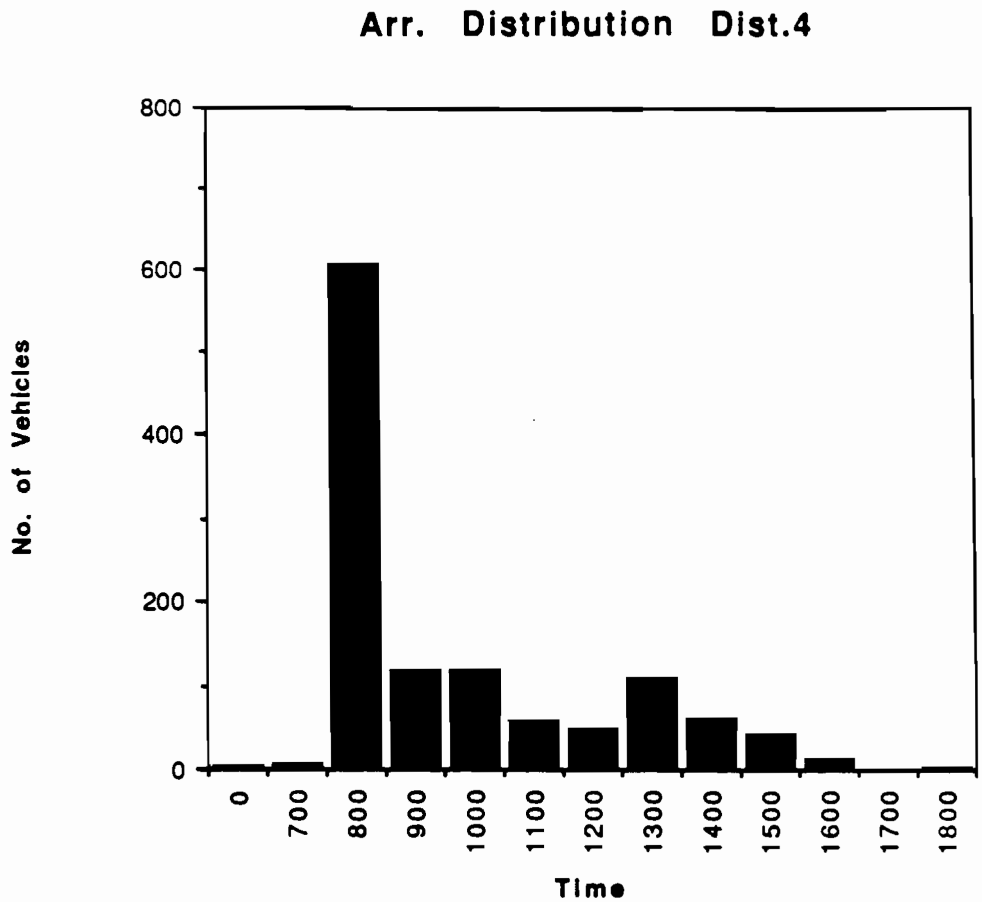

Dep. Distribution Dist.1
No. of Vehicles
150
100
50
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

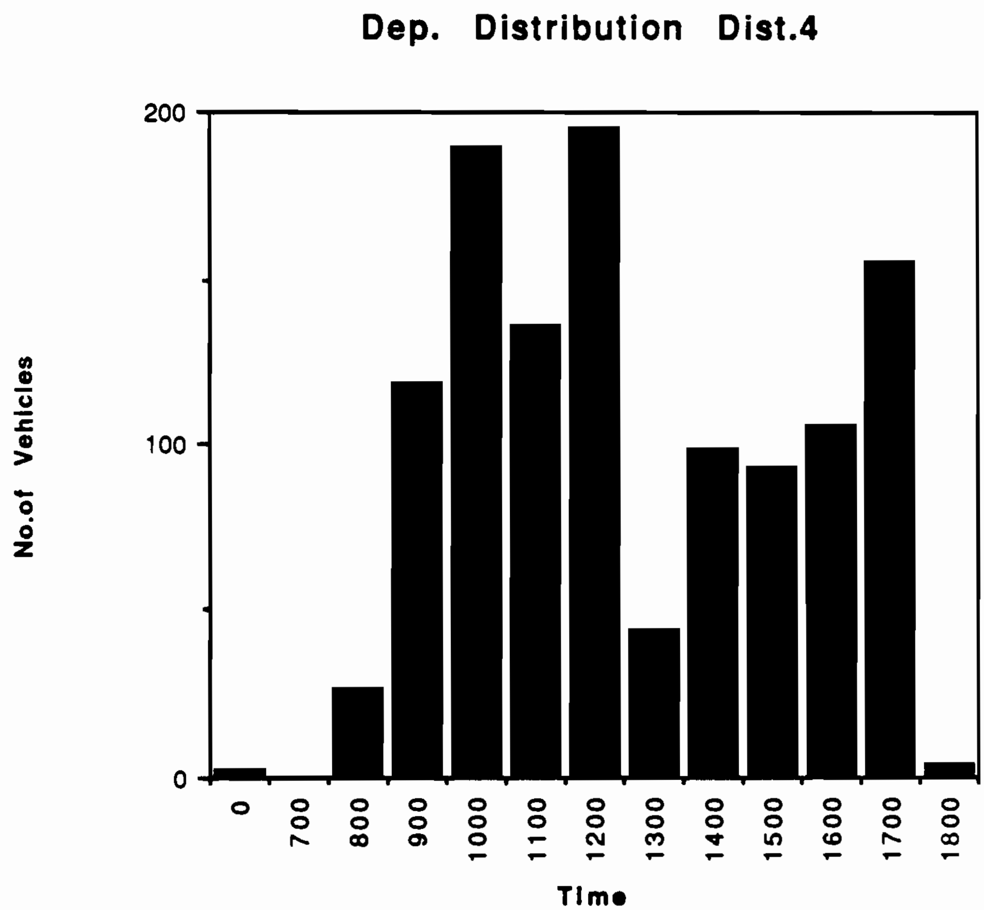

Arr. Distribution Dist.2
600
500
400
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.2
400
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

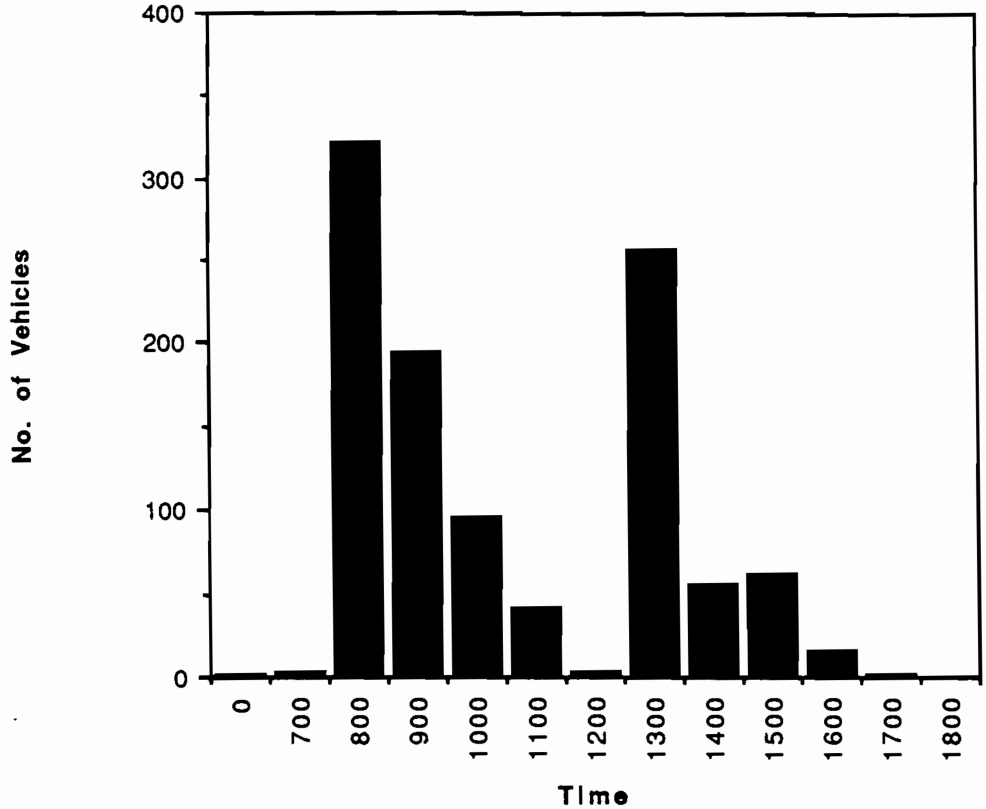

Arr. Distribution Dist.3
No. of Vehicles
500
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.3
No. of Vehicles
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

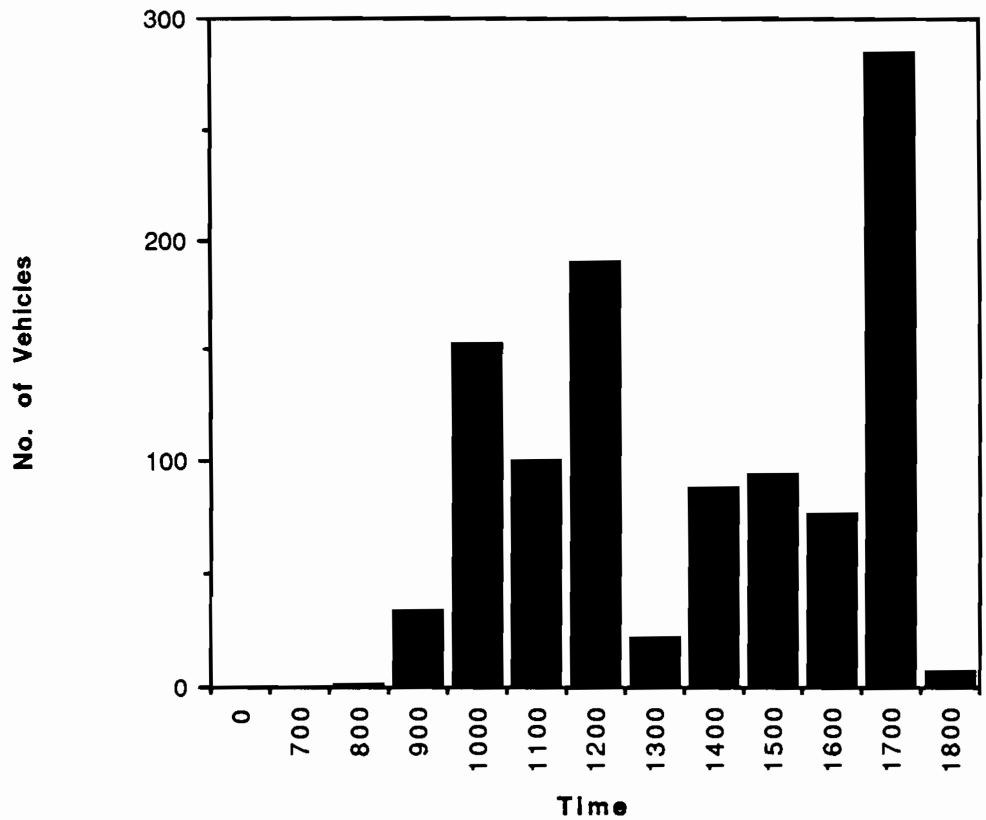

Arr. Distribution Dist.4
800
600
400
200
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.4
200
100
0
No.of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

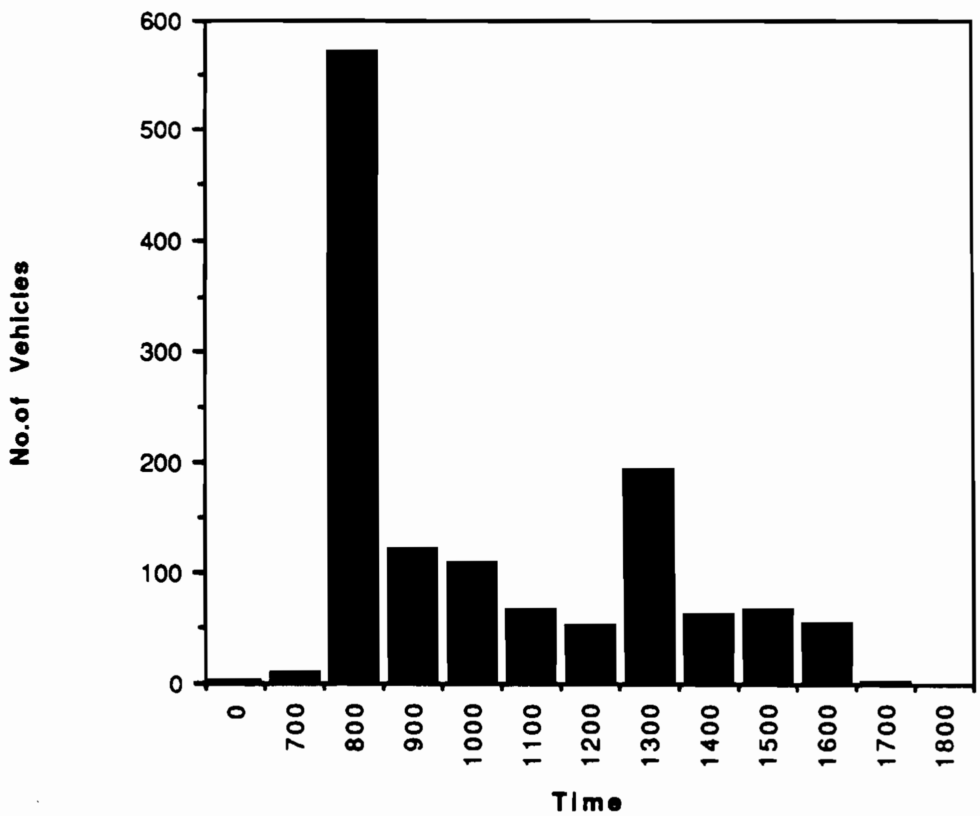
Arr. Distribution Dist.5



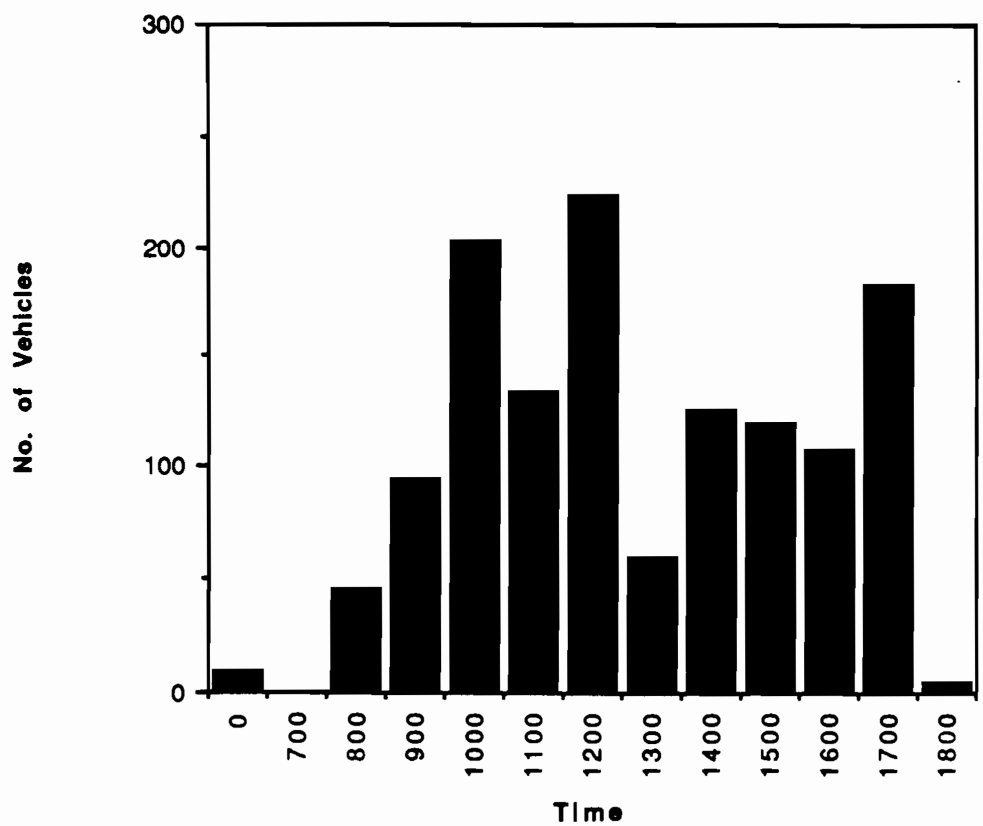
Dep. Distribution Dist.5

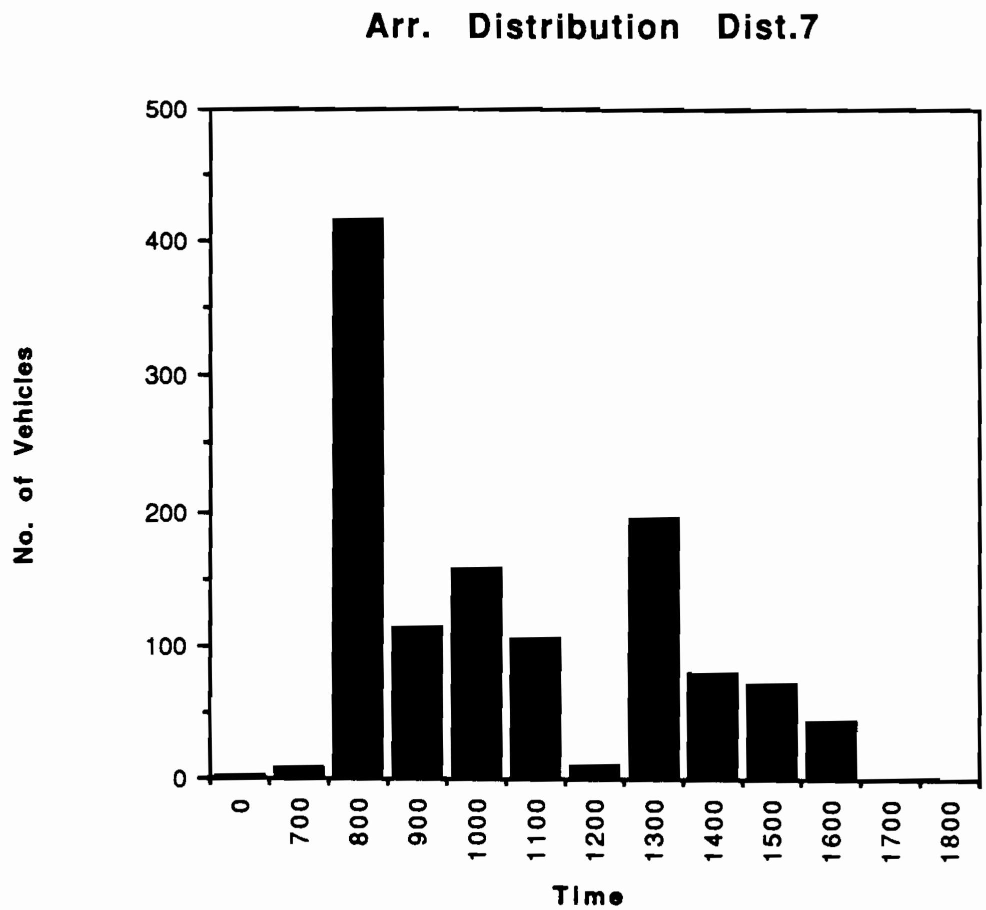


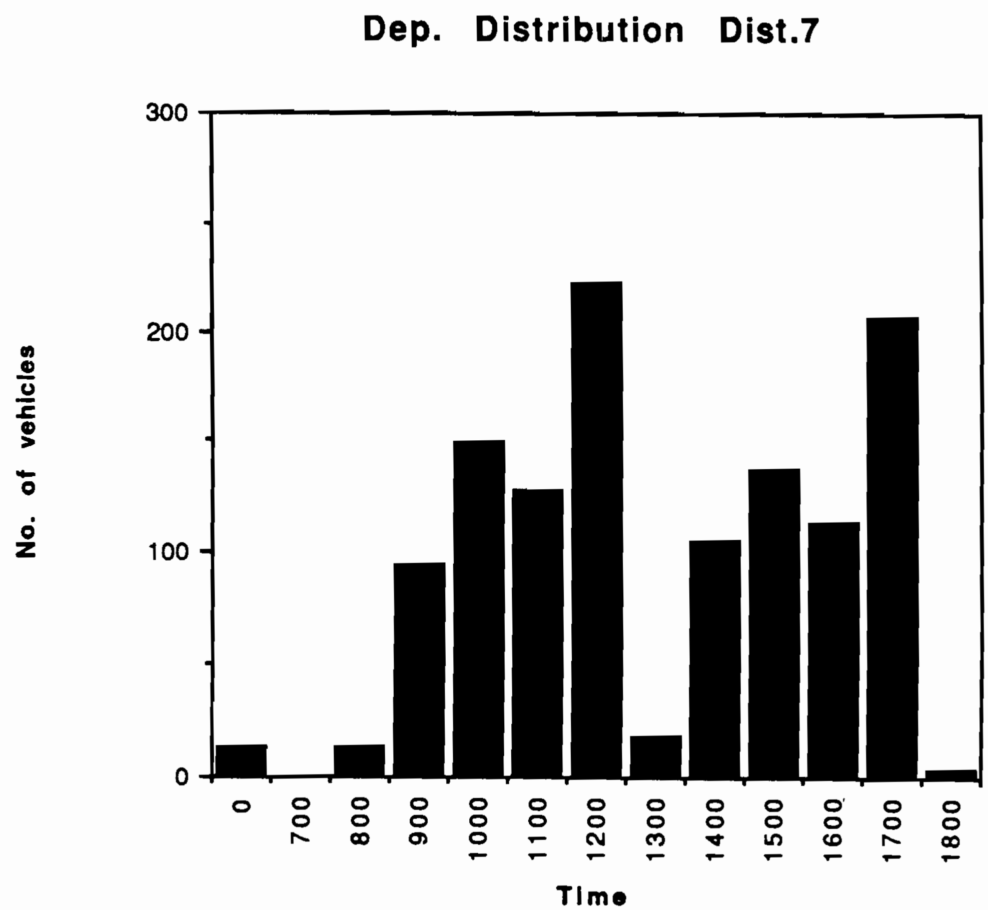
Arr. Distribution Dist.6



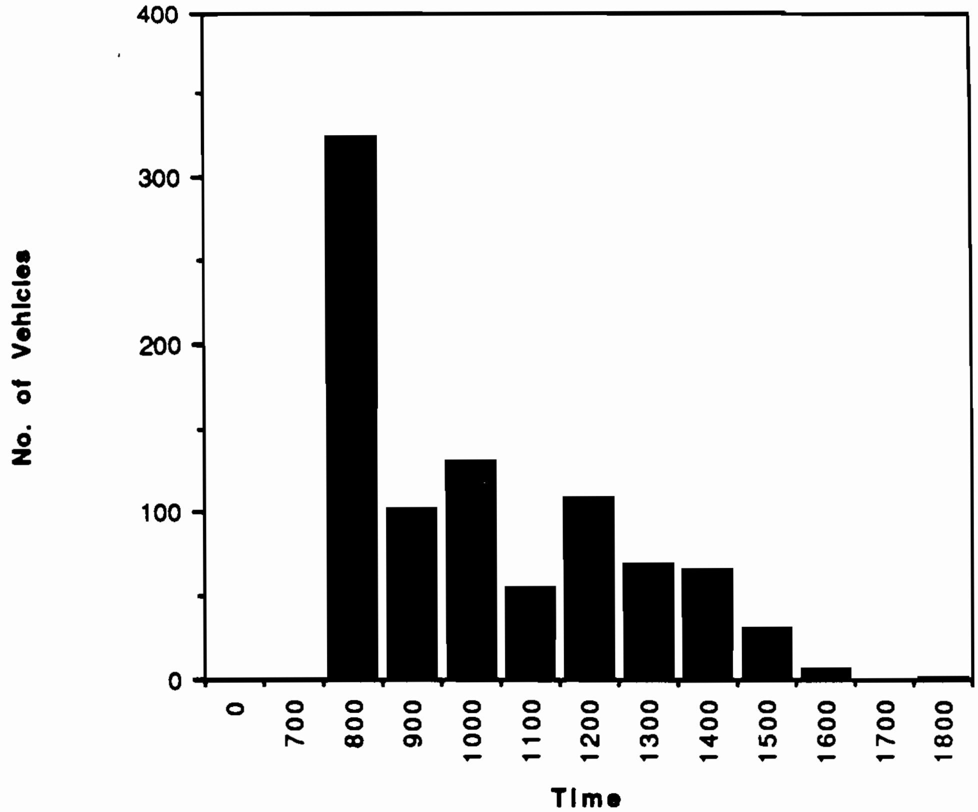
Dep. Distribution Dist.6



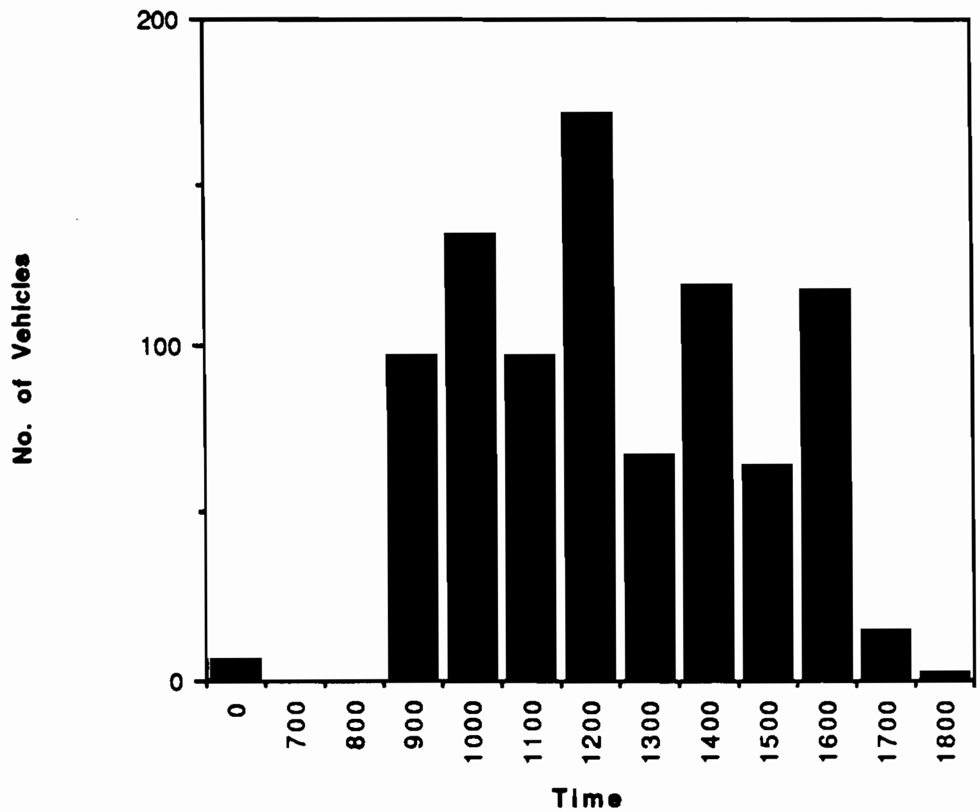

Arr. Distribution Dist.7
No. of Vehicles
500
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

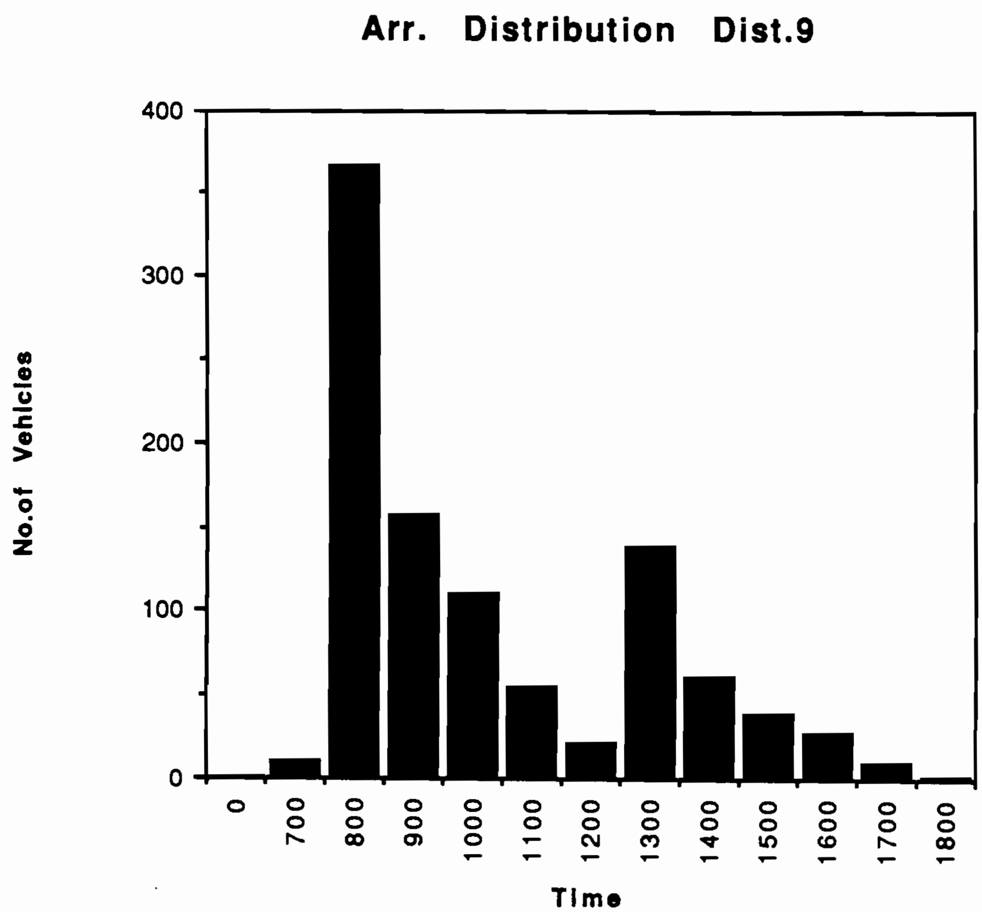

Dep. Distribution Dist.7
No. of vehicles
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

Arr. Distribution Dist.8

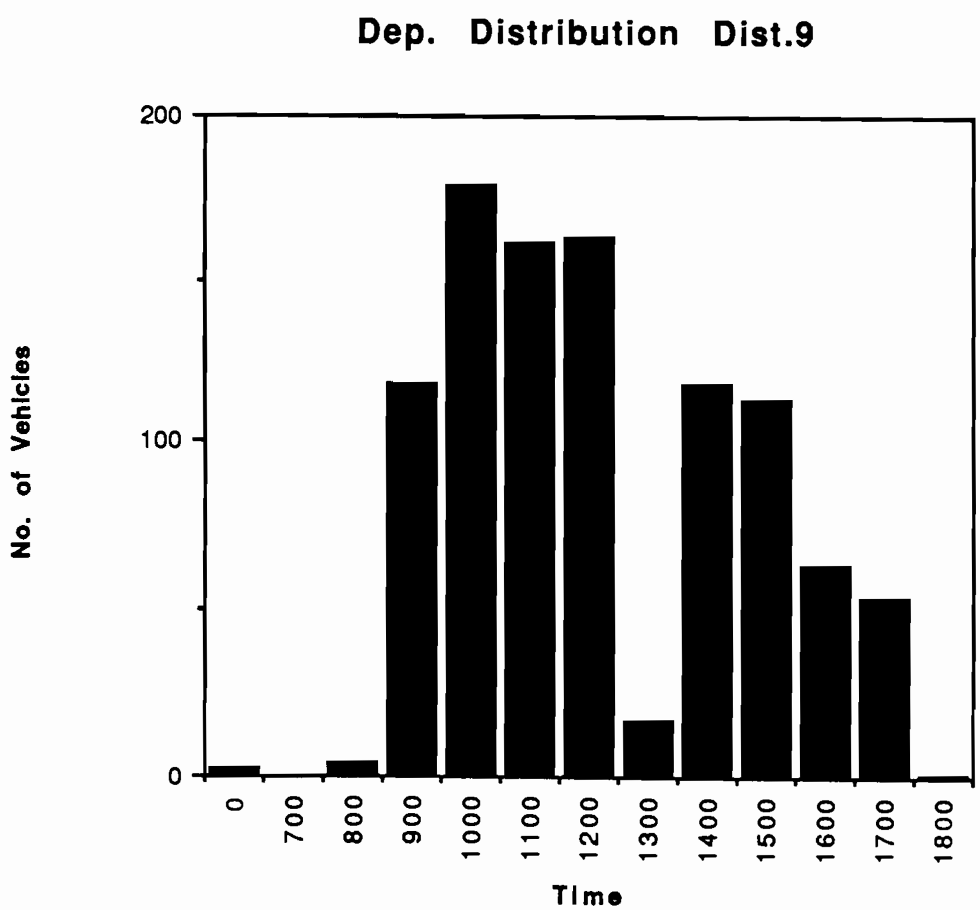


Dep. Distribution Dist.8

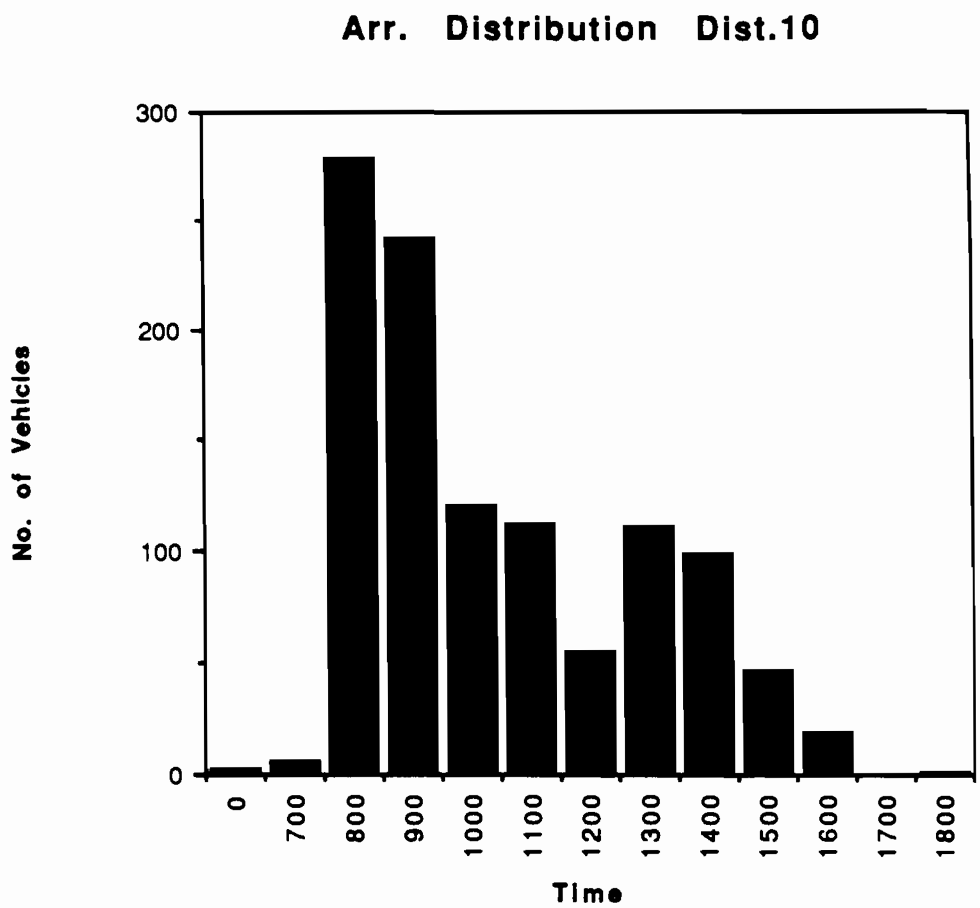


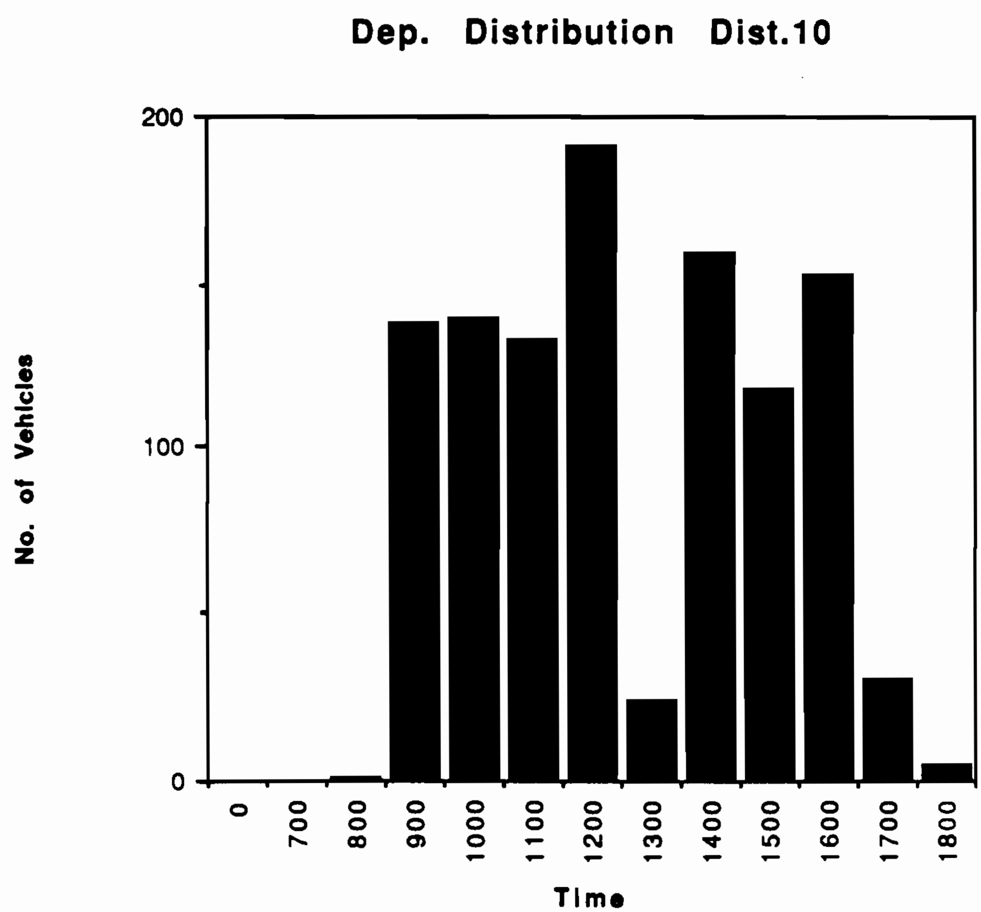


Arr. Distribution Dist.9
No.of Vehicles
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

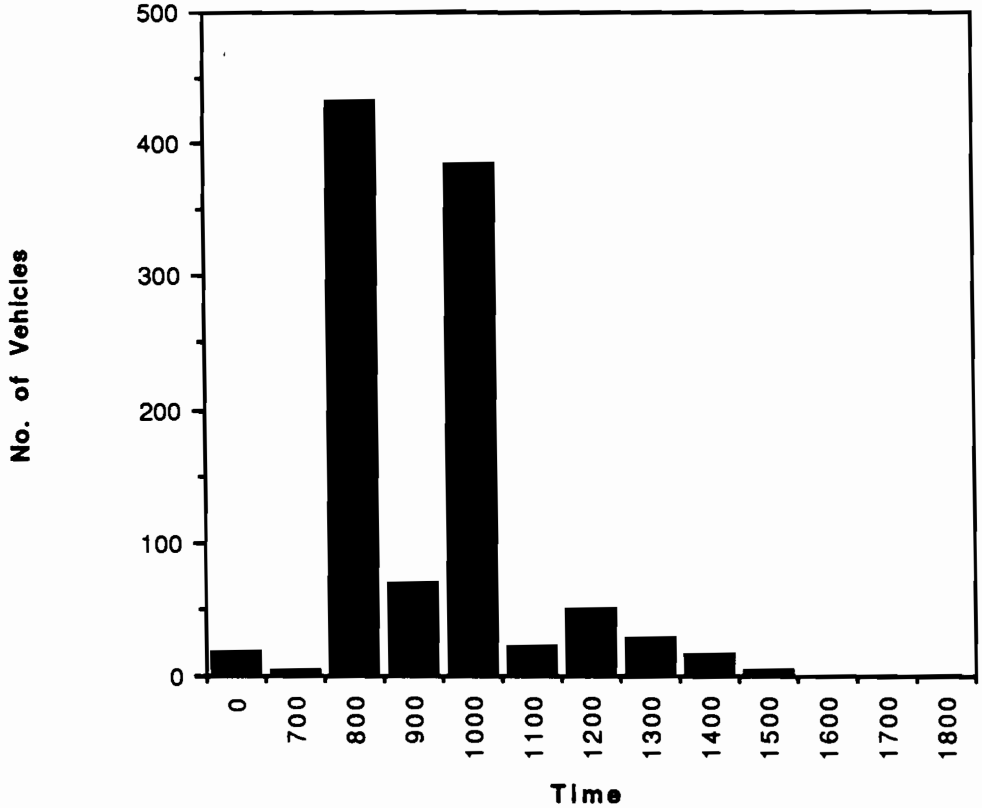


Dep. Distribution Dist.9
No. of Vehicles
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

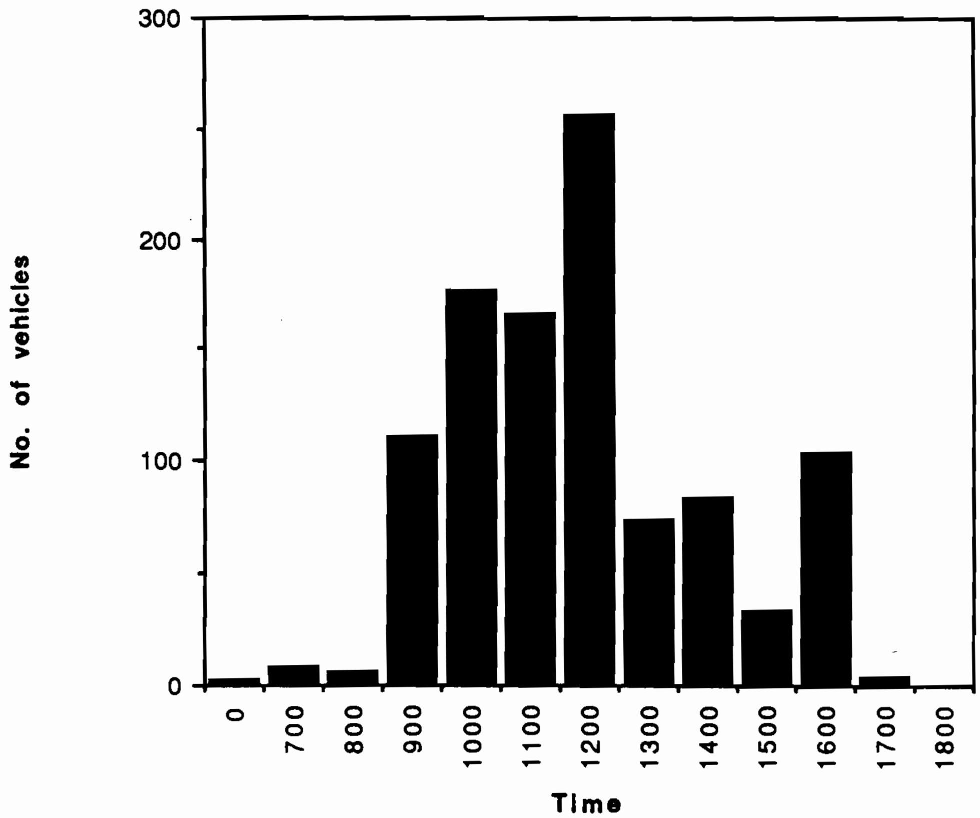

Arr. Distribution Dist.10
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.10
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

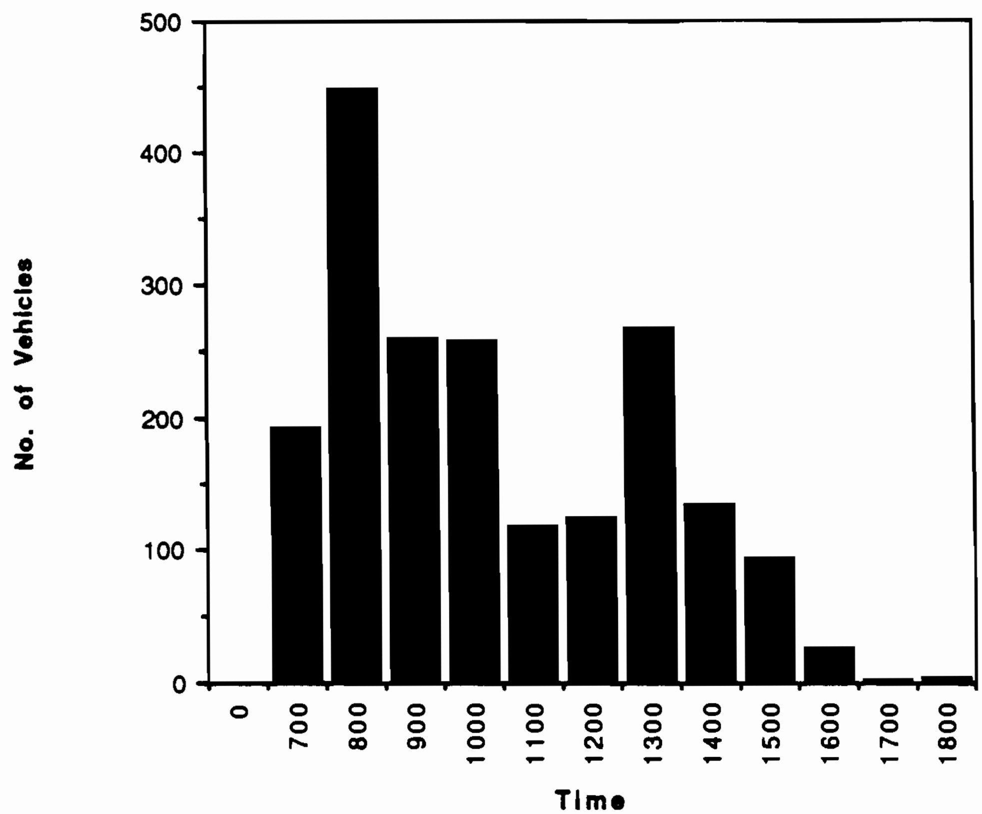
Arr. Distribution Dist.11



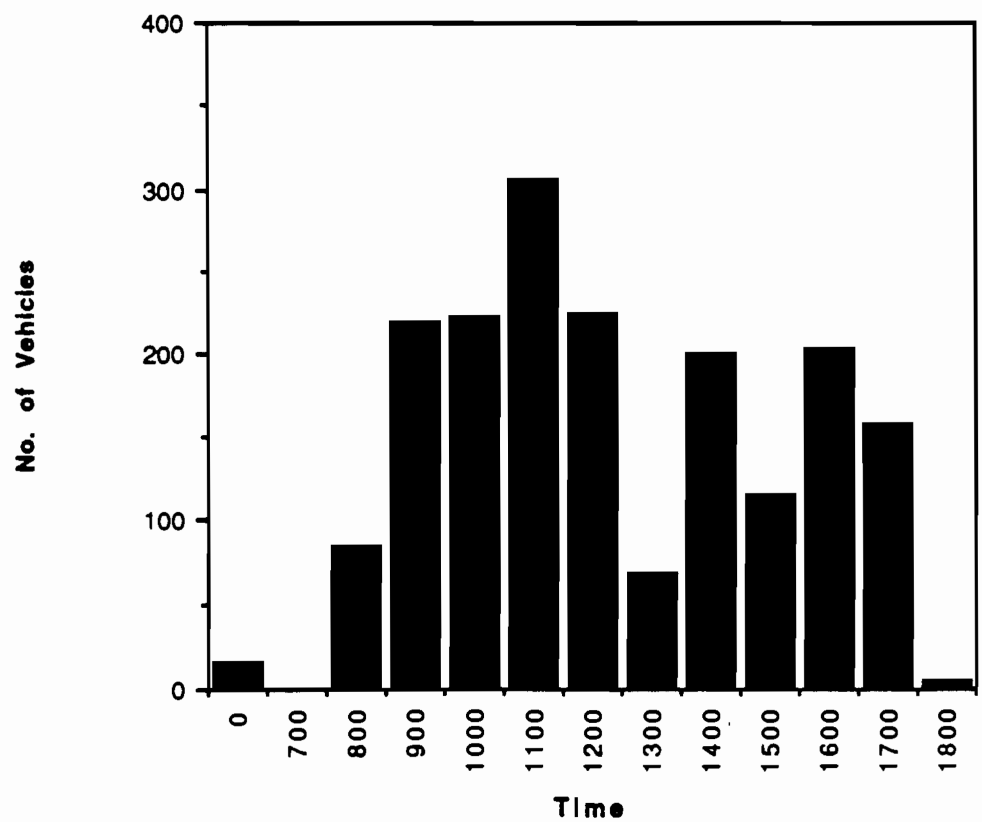
Dep. Distribution Dist.11

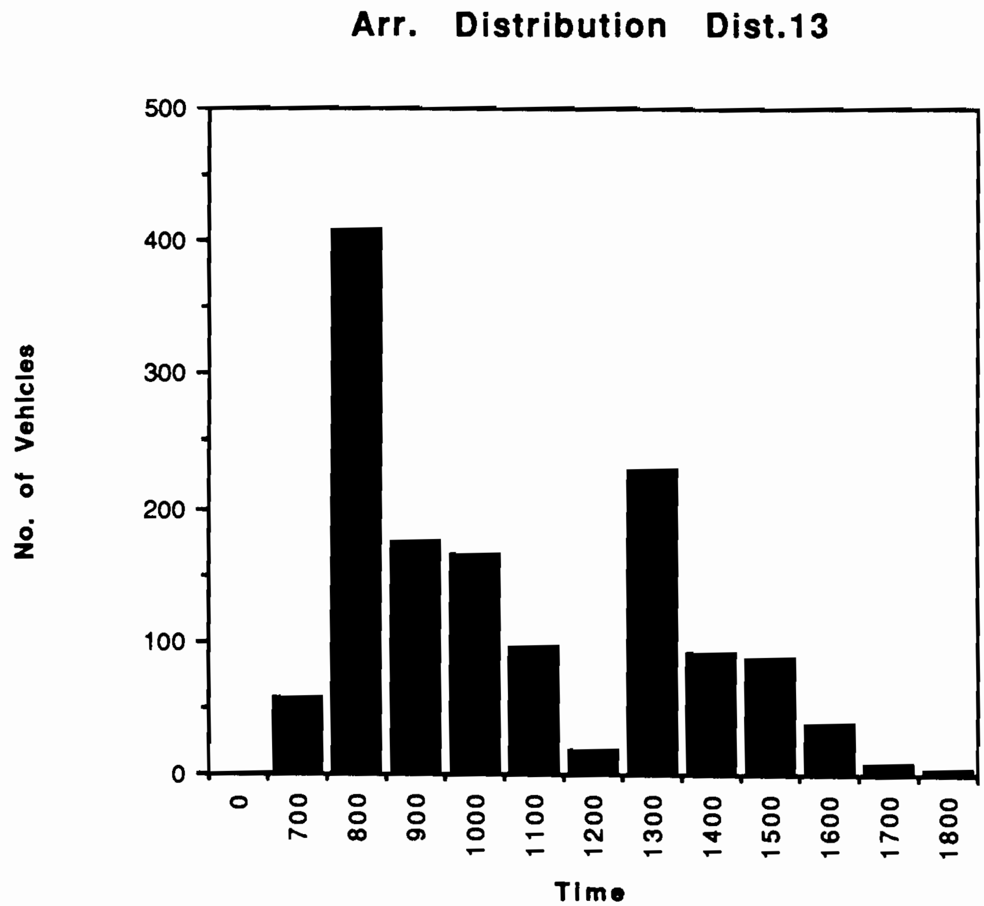


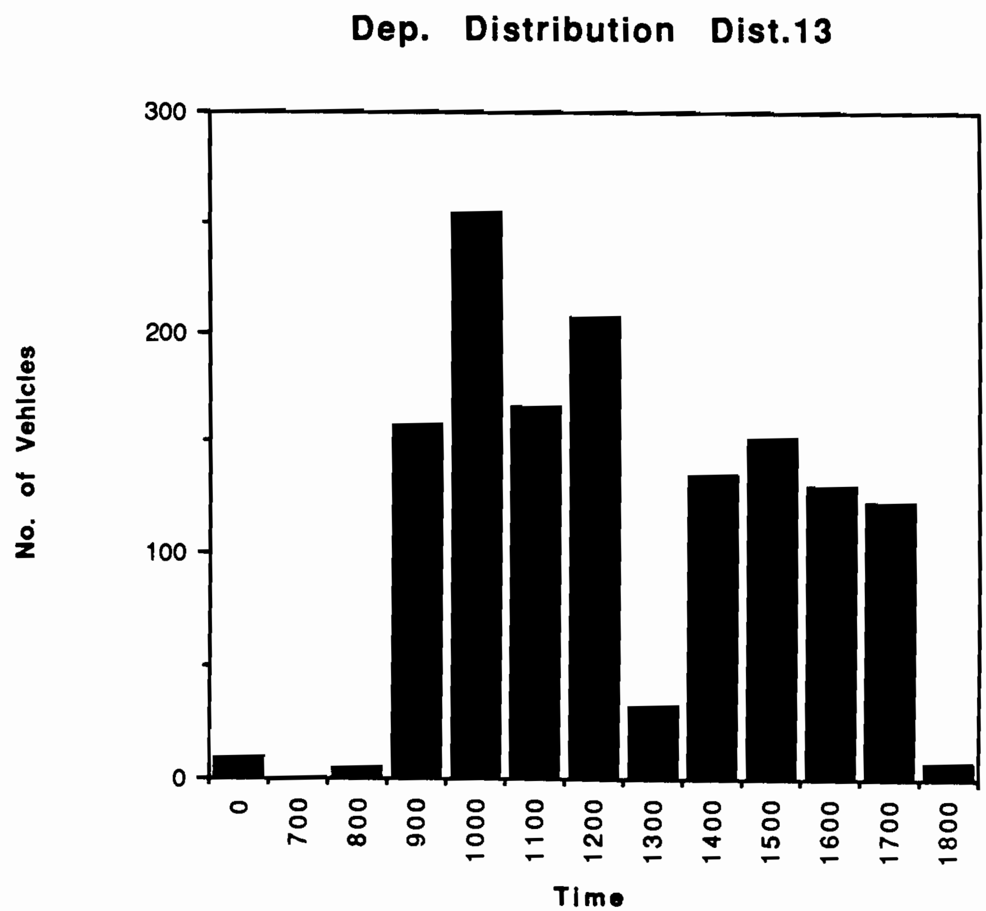
Arr. Distribution Dist.12

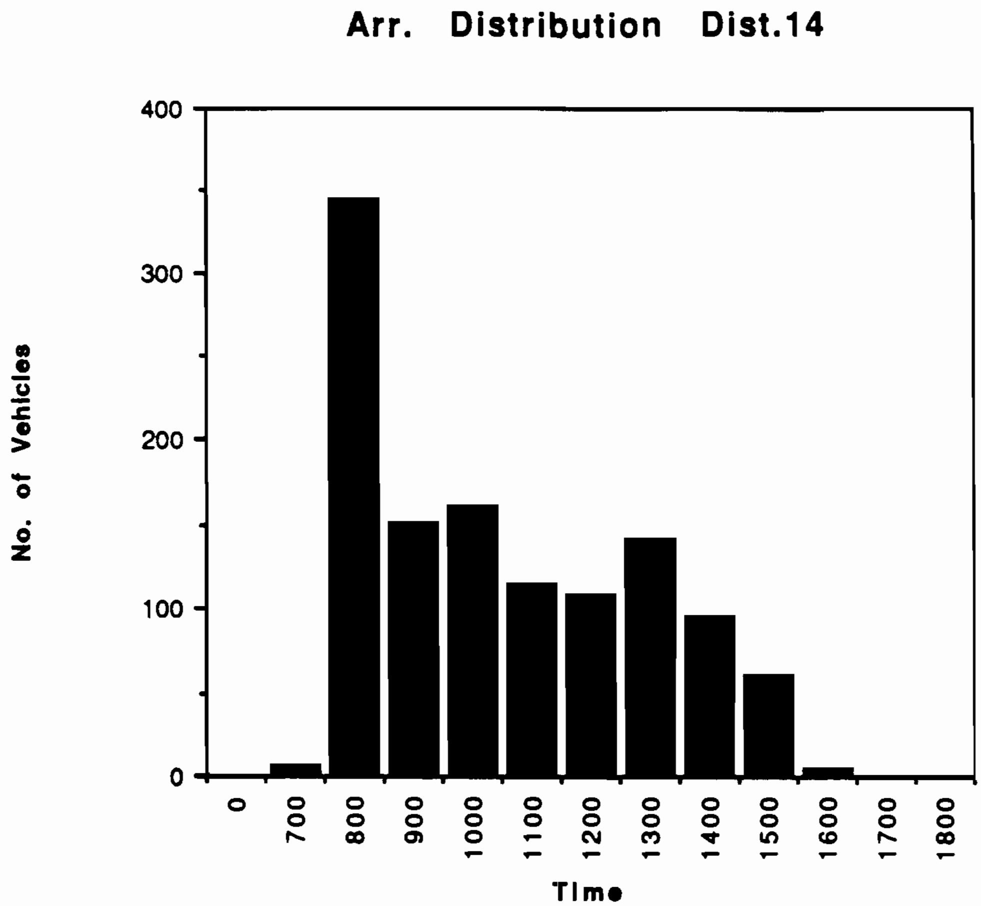


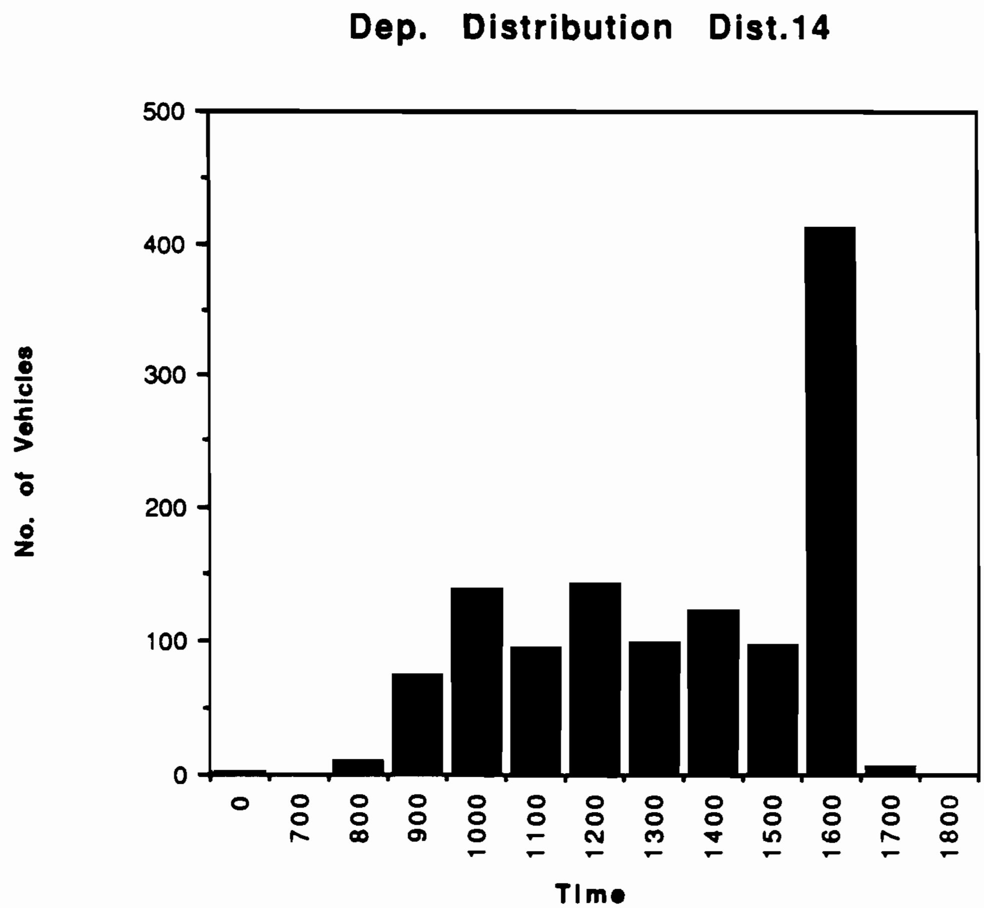
Dep. Distribution Dist.12



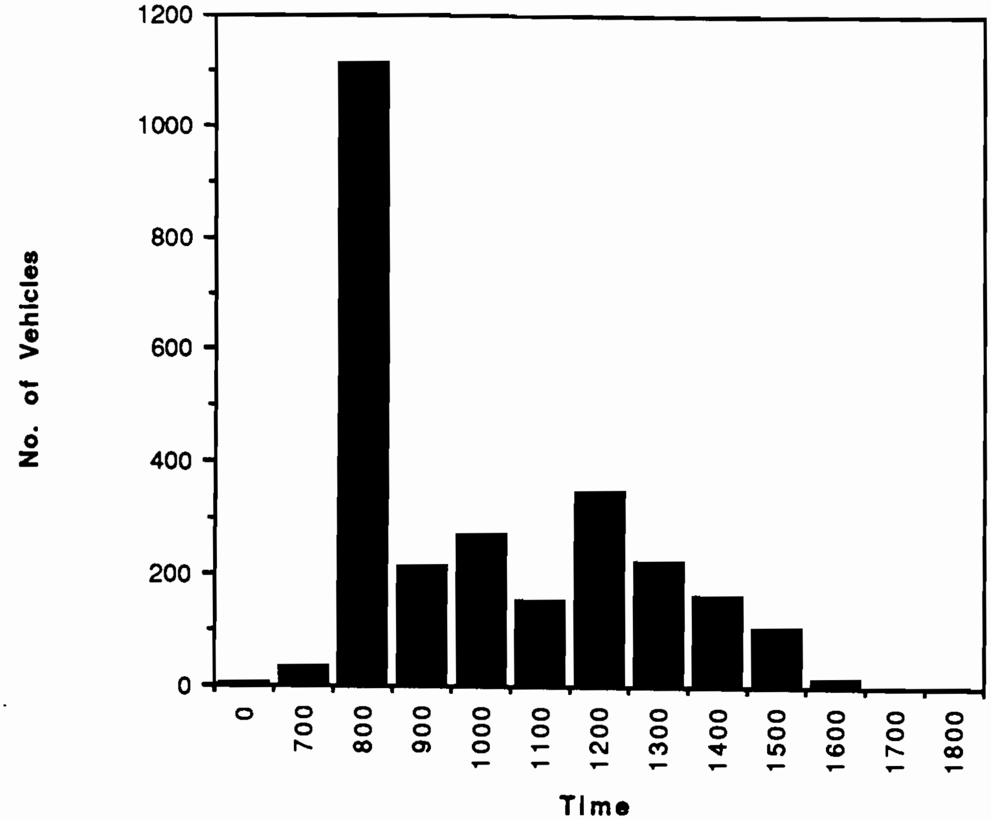

Arr. Distribution Dist.13
No. of Vehicles
500
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.13
No. of Vehicles
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

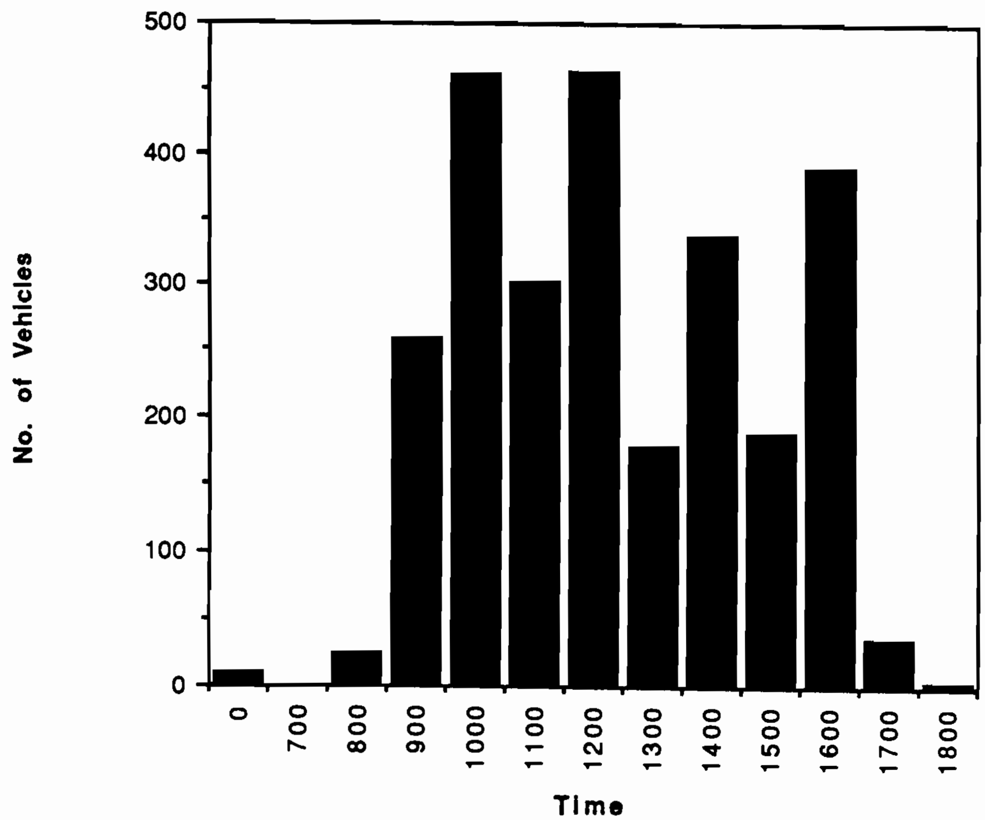

Arr. Distribution Dist.14
No. of Vehicles
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.14
No. of Vehicles
500
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

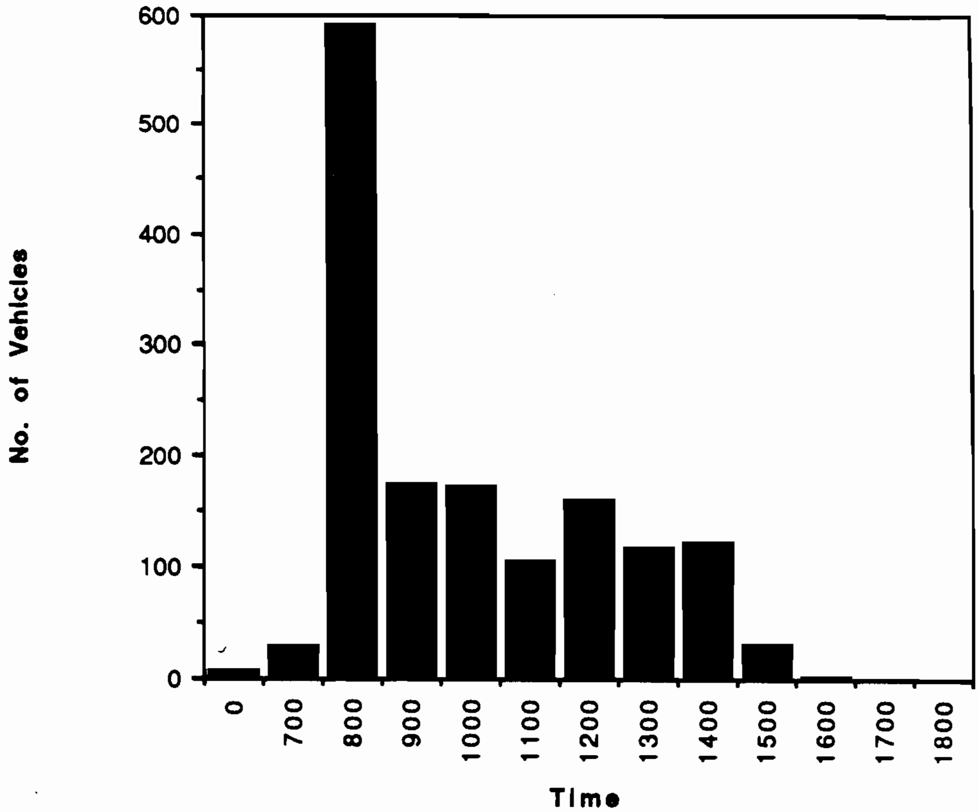
Arr. Distribution Dist.15



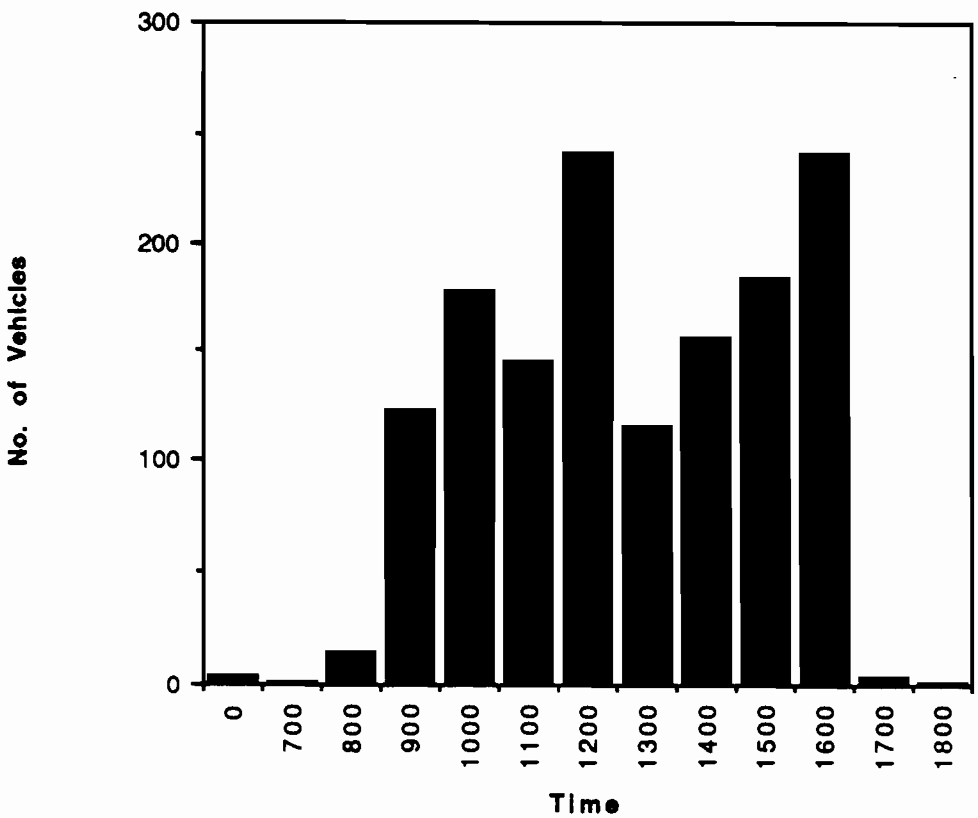
Dep. Distribution Dist.15



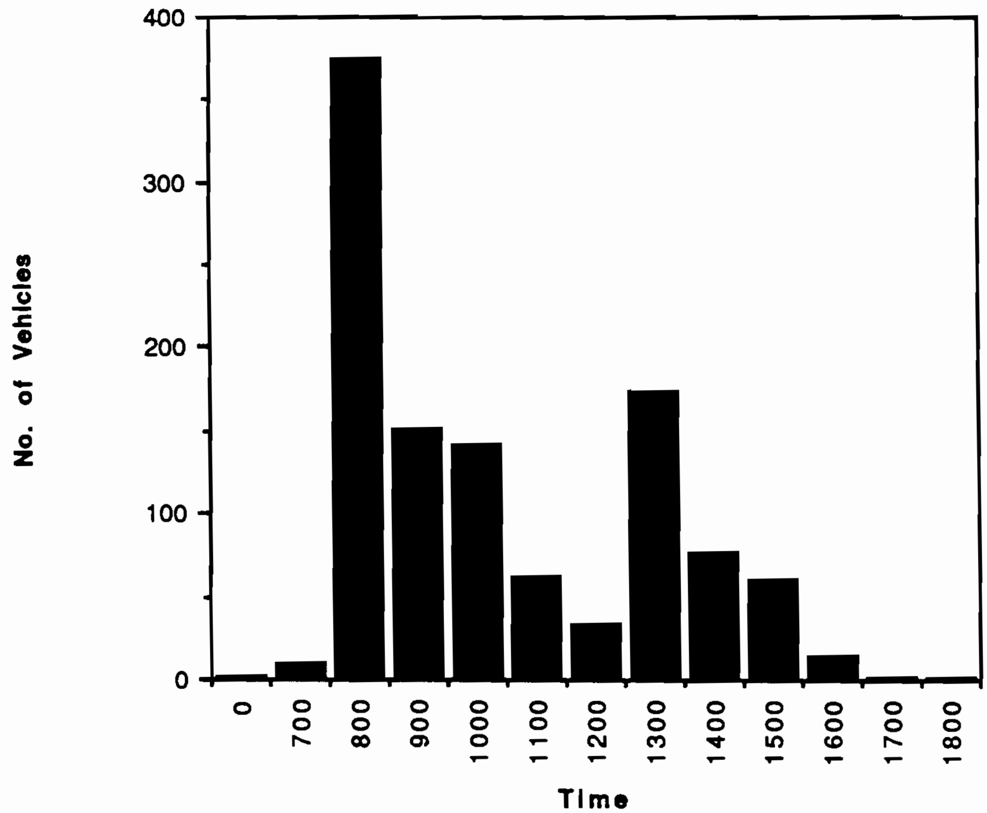
Arr. Distribution Dist.16



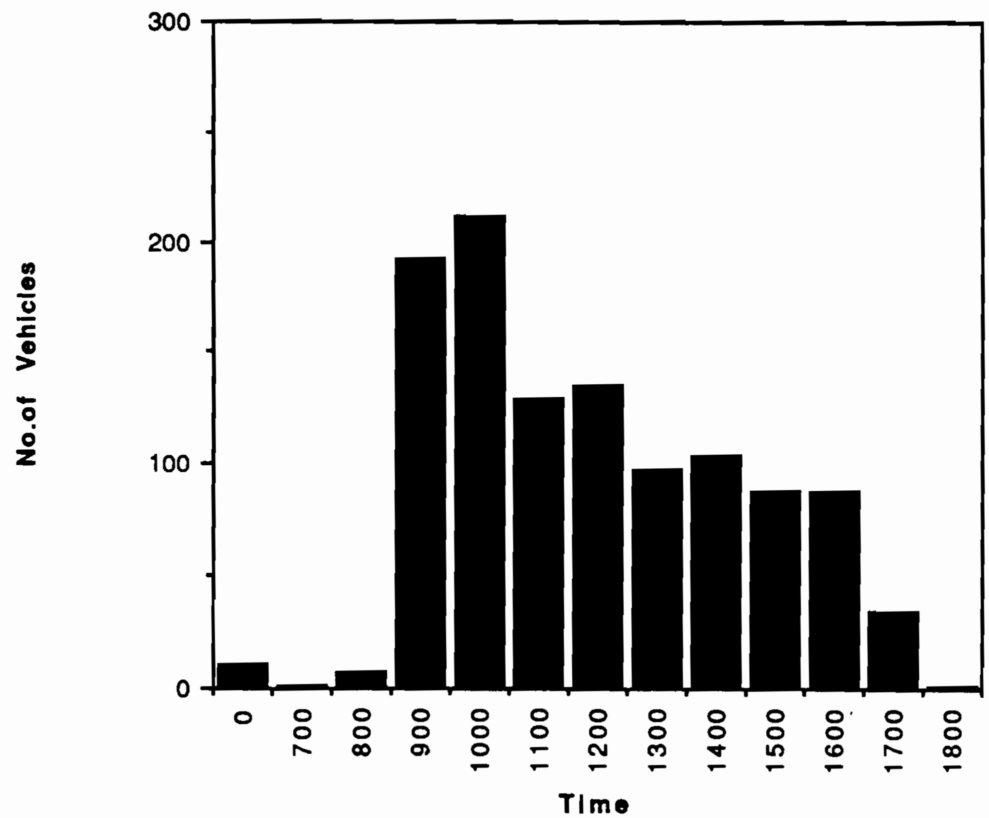
Dep. Distribution Dist.16



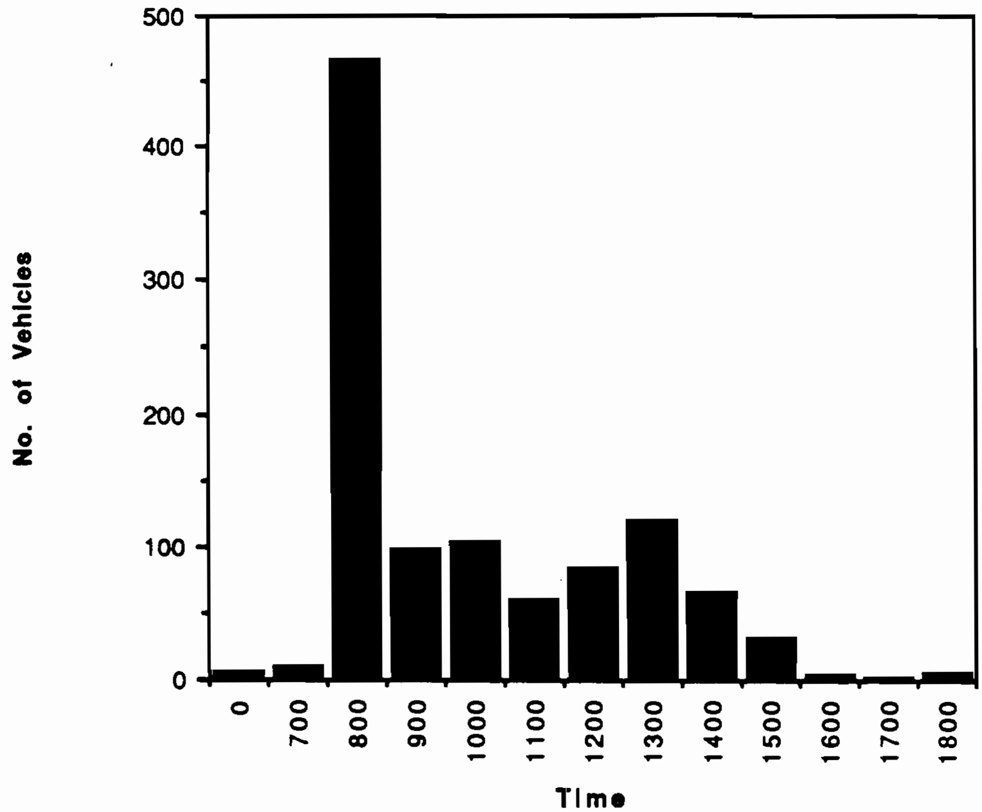
Arr. Distribution Dist.17



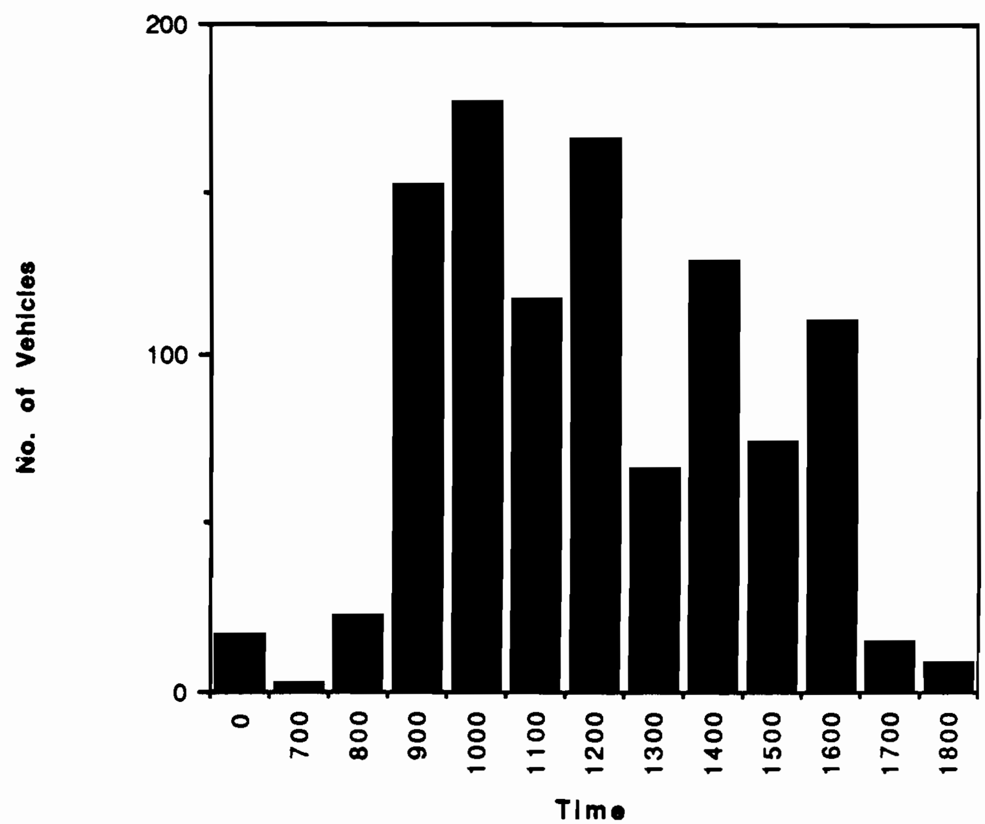
Dep. Distribution Dist.17



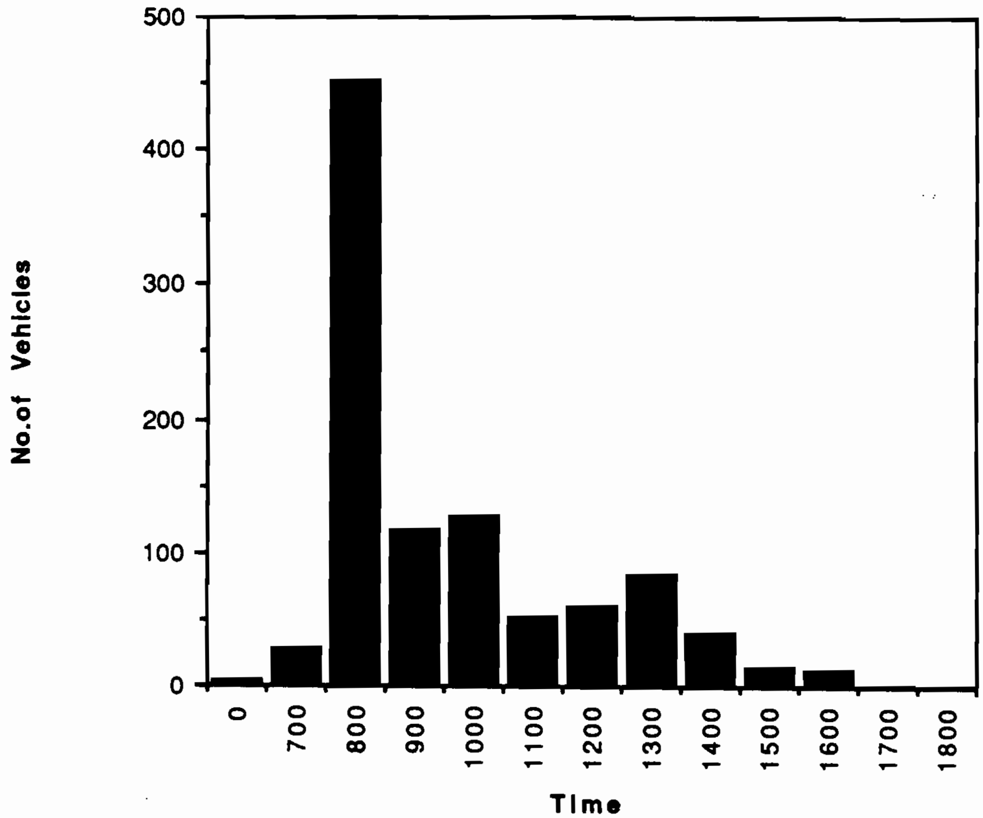
Arr. Distribution Dist.18



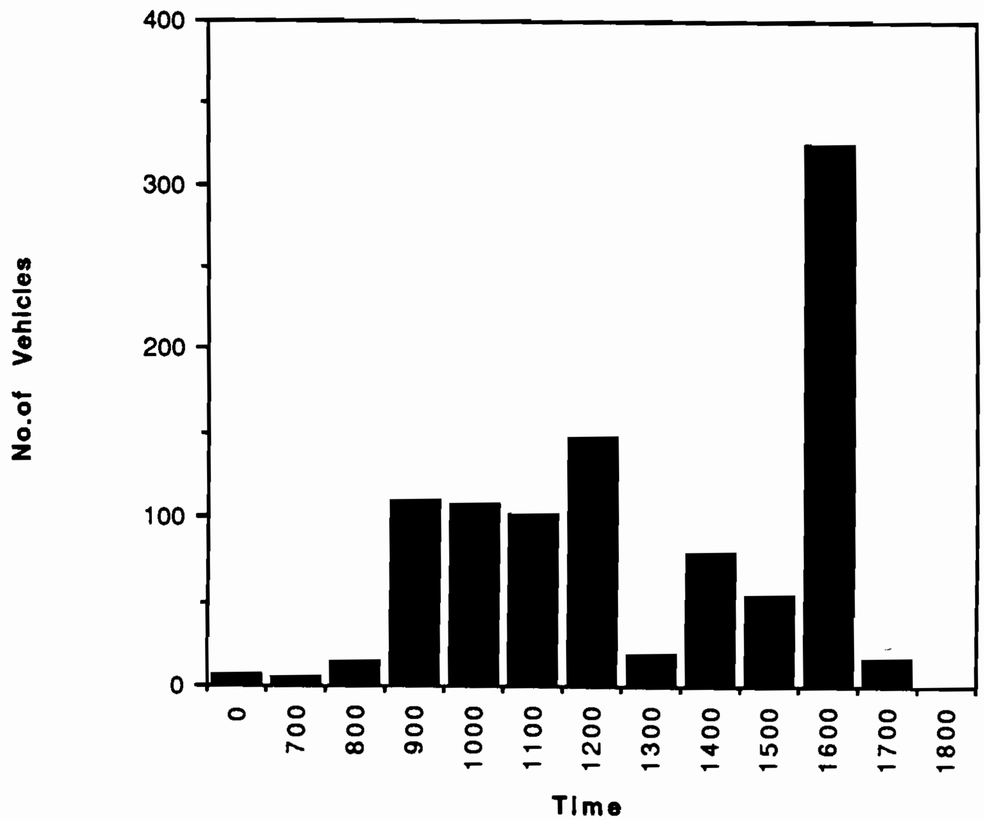
Dep. Distribution Dist.18

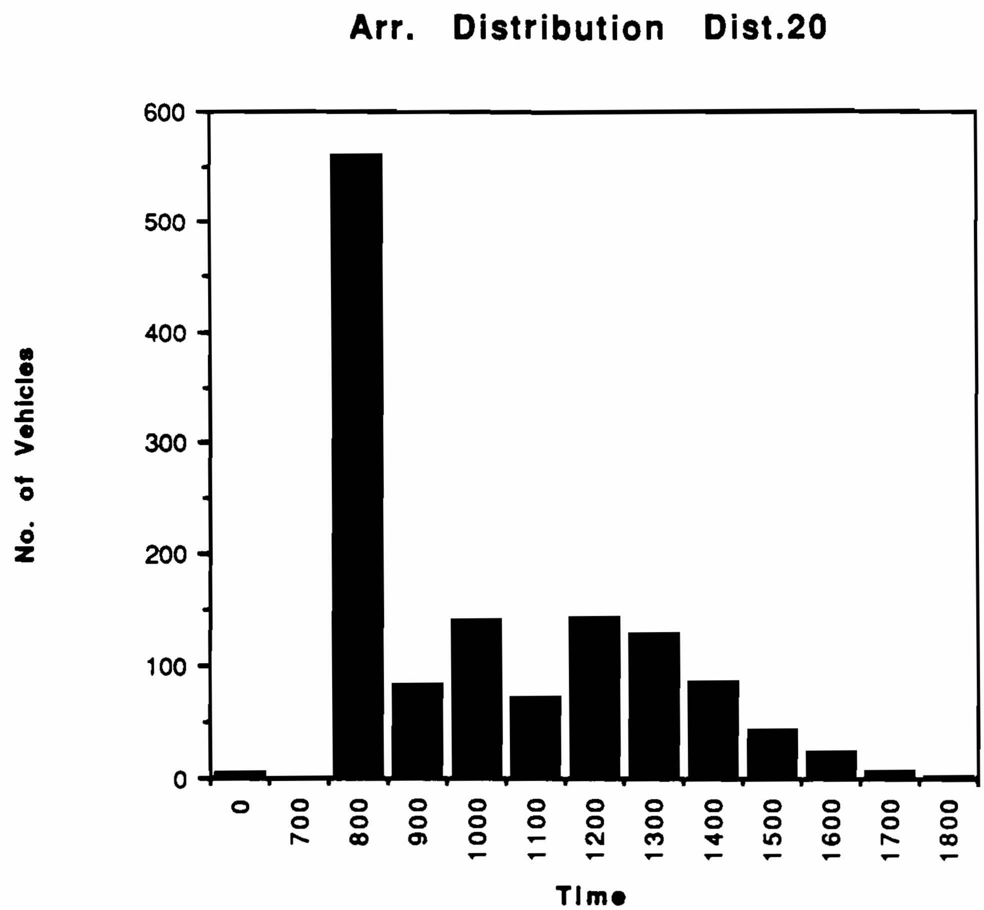


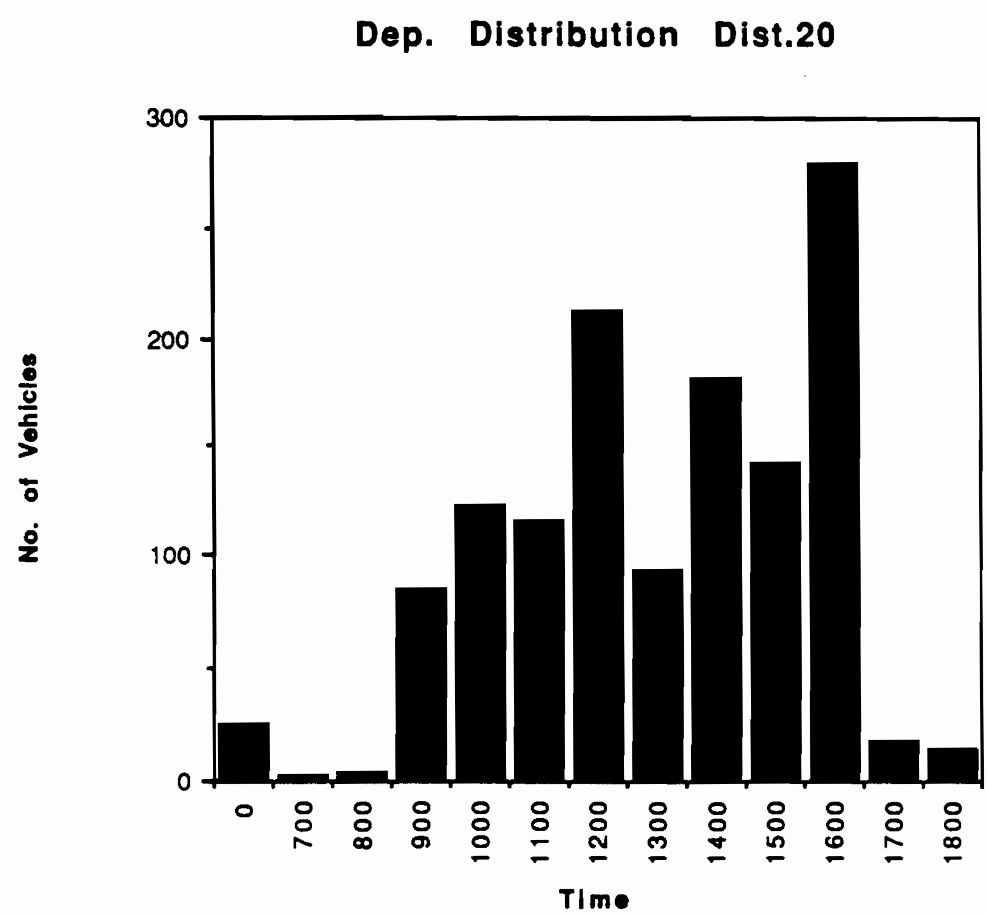
Arr. Distribution Dist.19

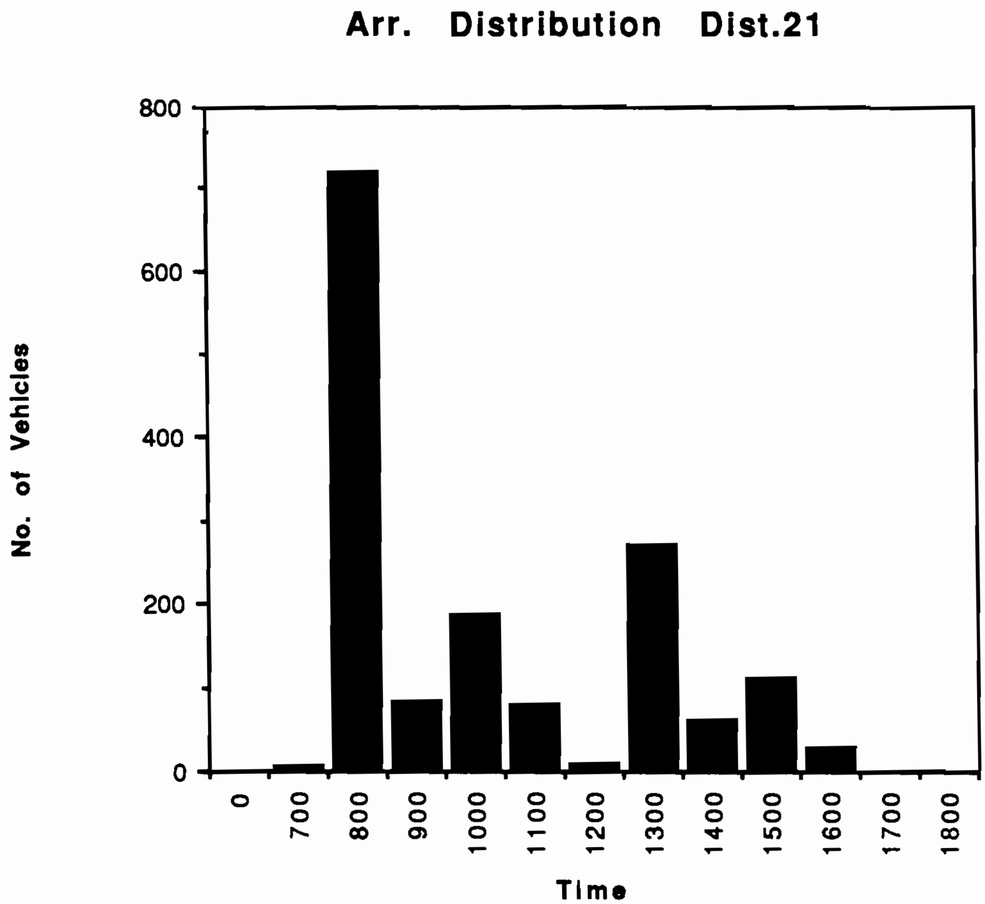


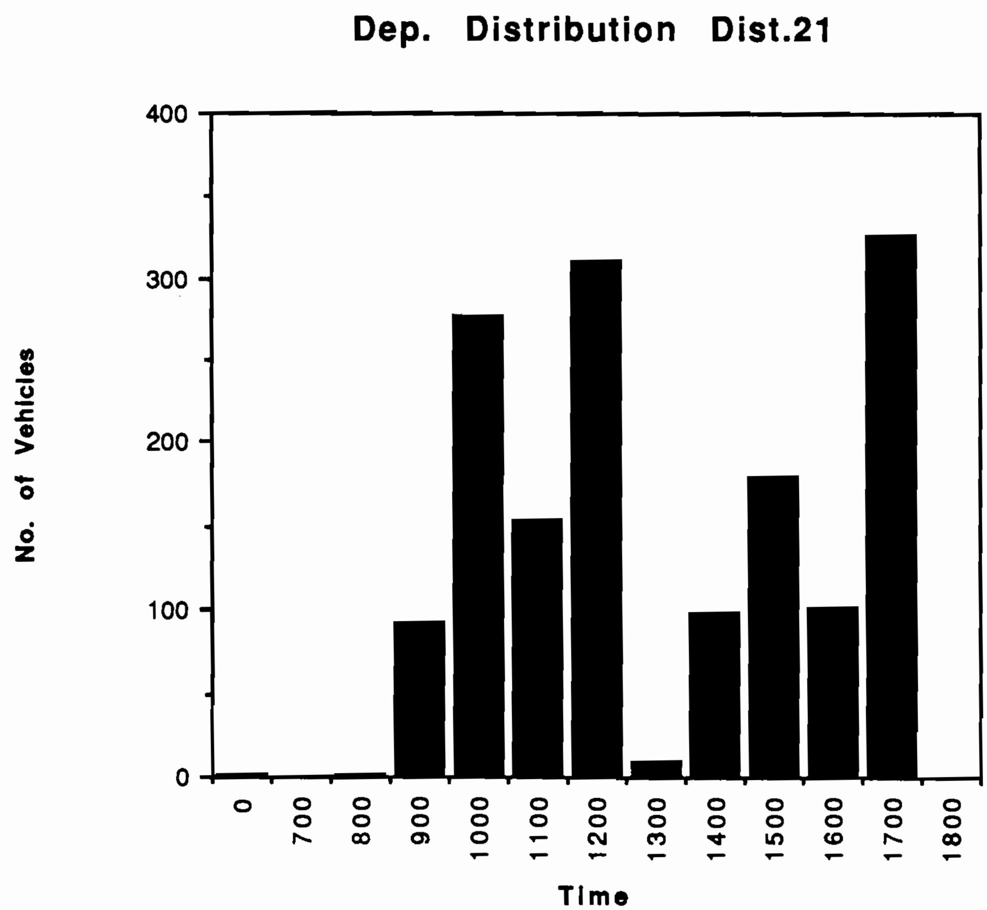
Dep. Distribution Dist.19

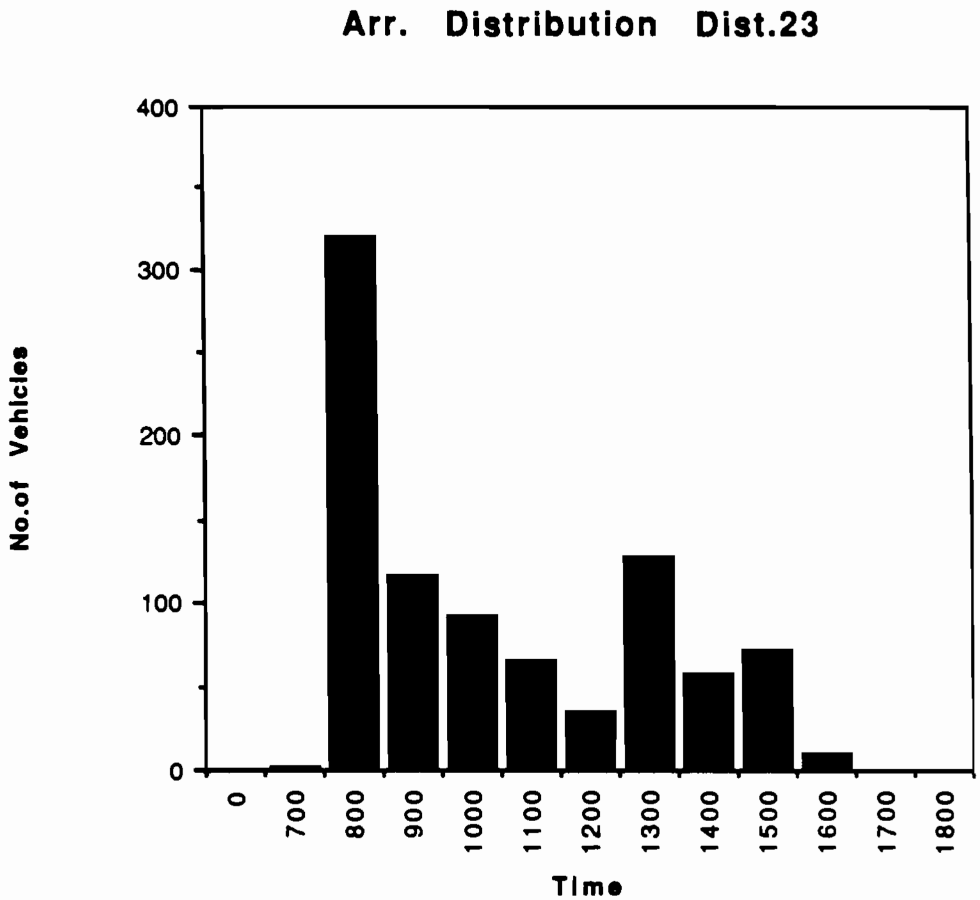


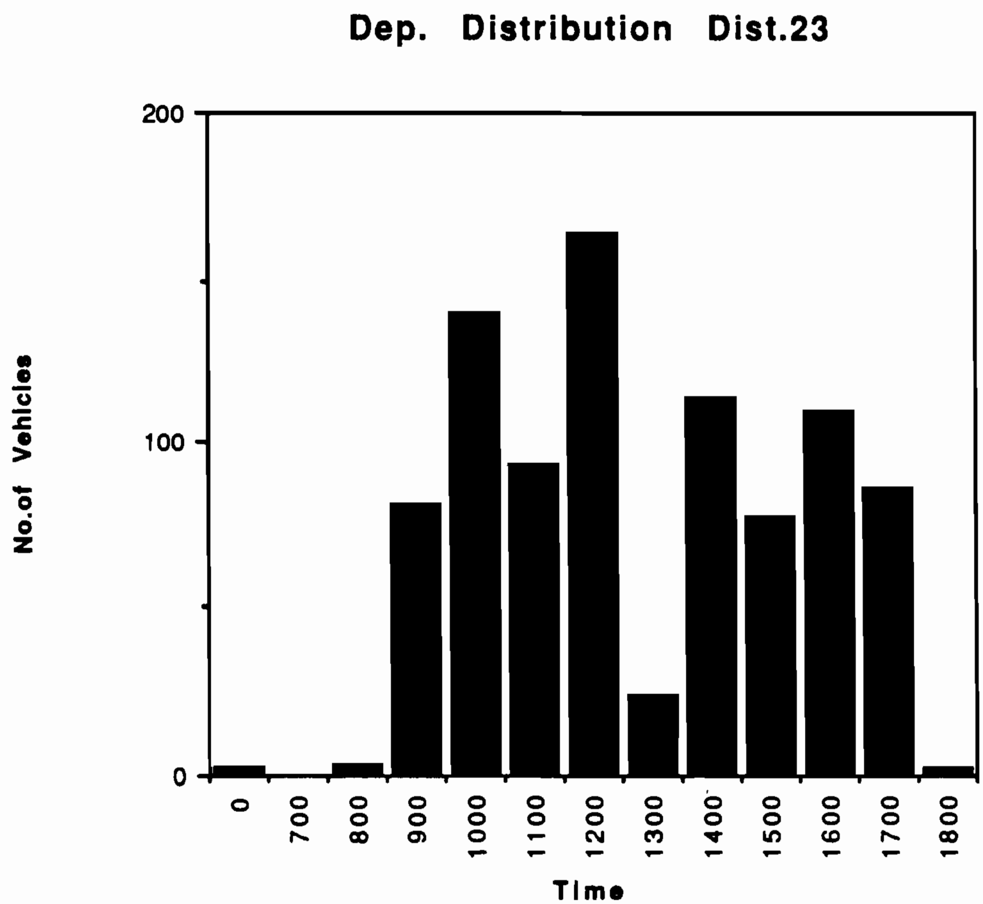

Arr. Distribution Dist.20
600
500
400
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

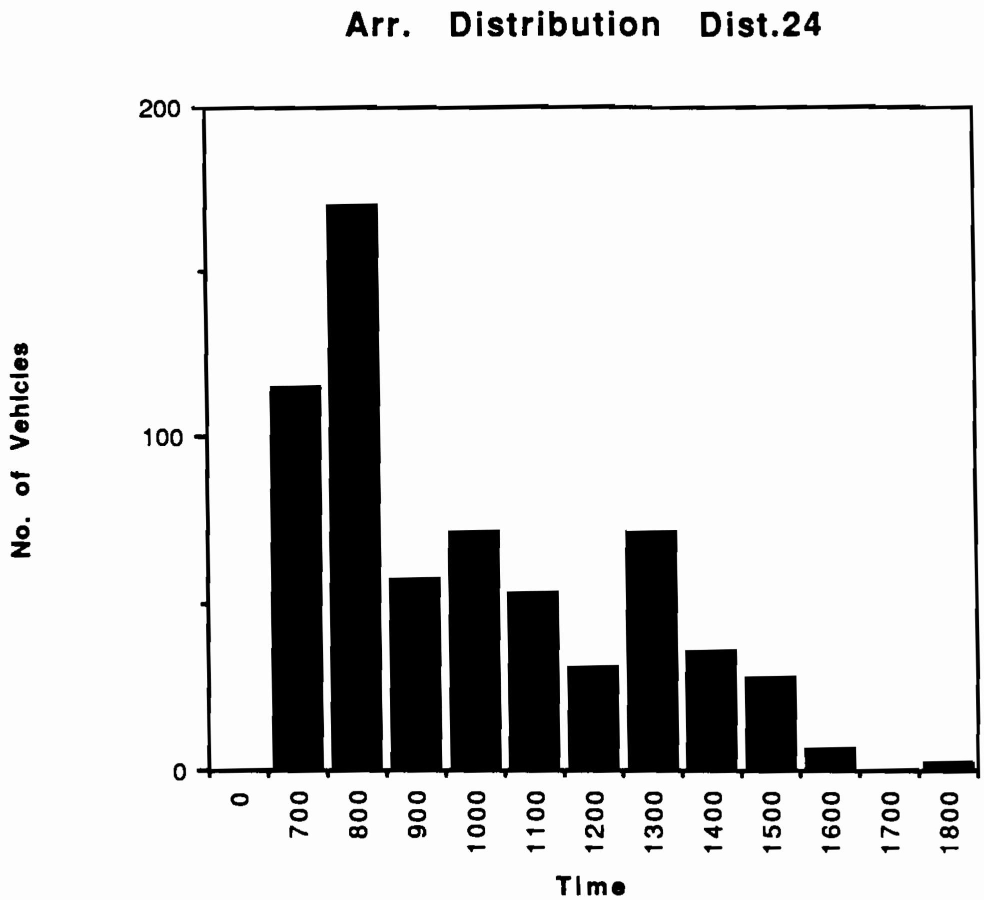

Dep. Distribution Dist.20
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

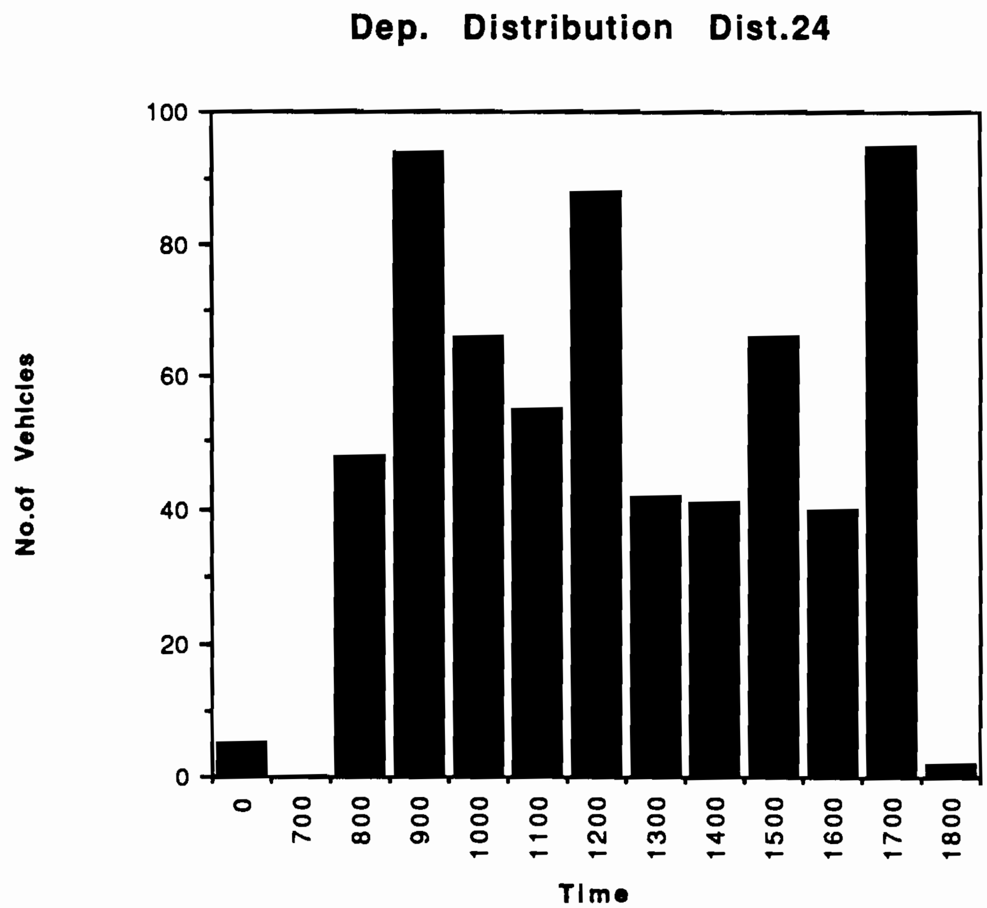

Arr. Distribution Dist.21
800
600
400
200
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

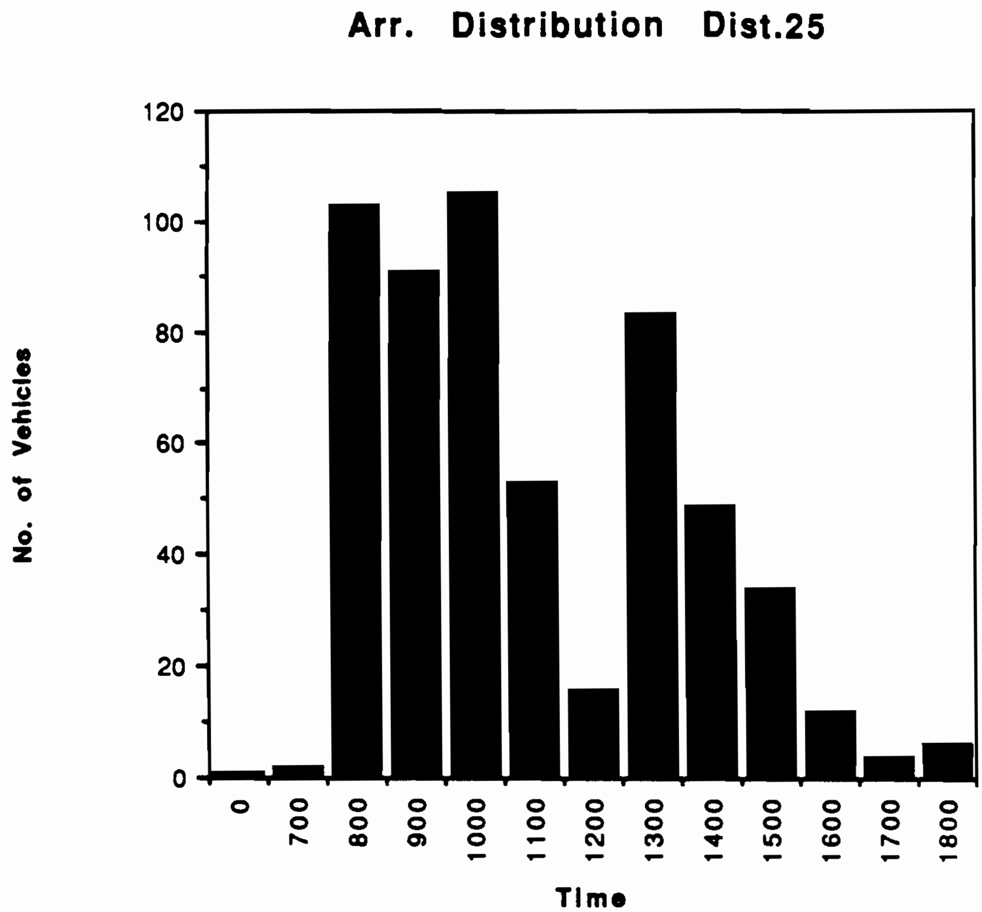

Dep. Distribution Dist.21
400
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

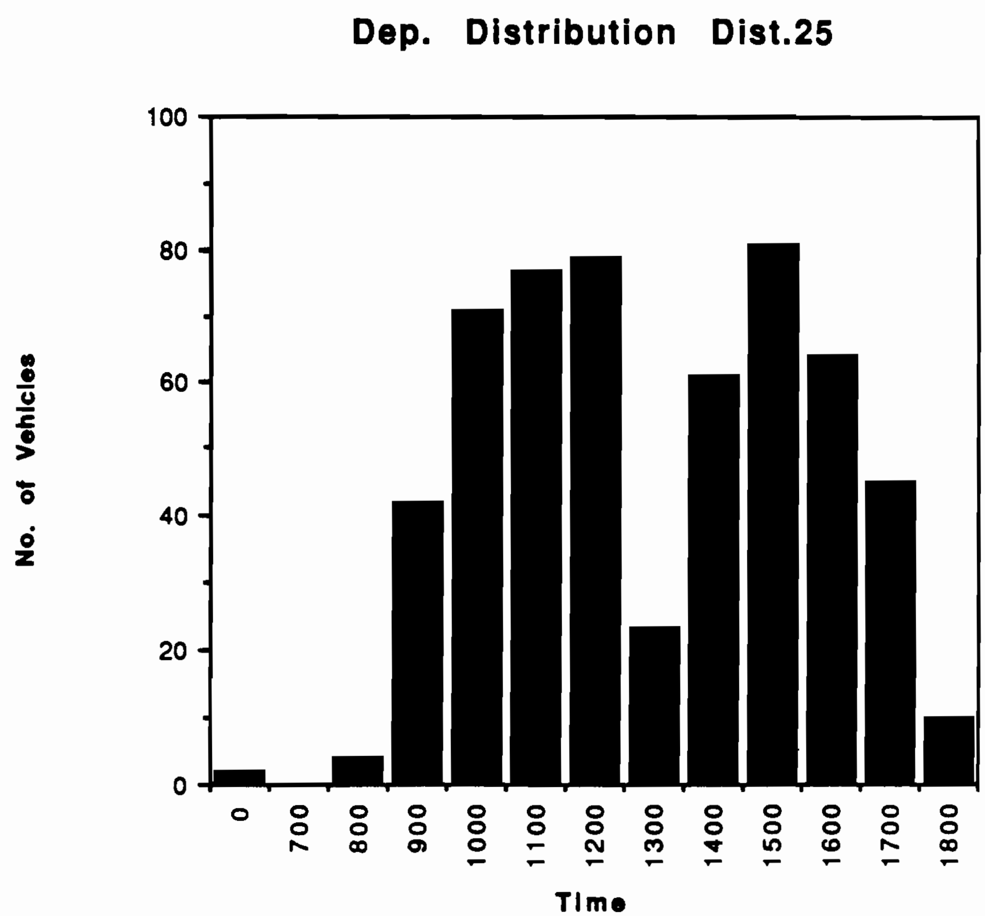

Arr. Distribution Dist.23
No.of Vehicles
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.23
No.of Vehicles
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

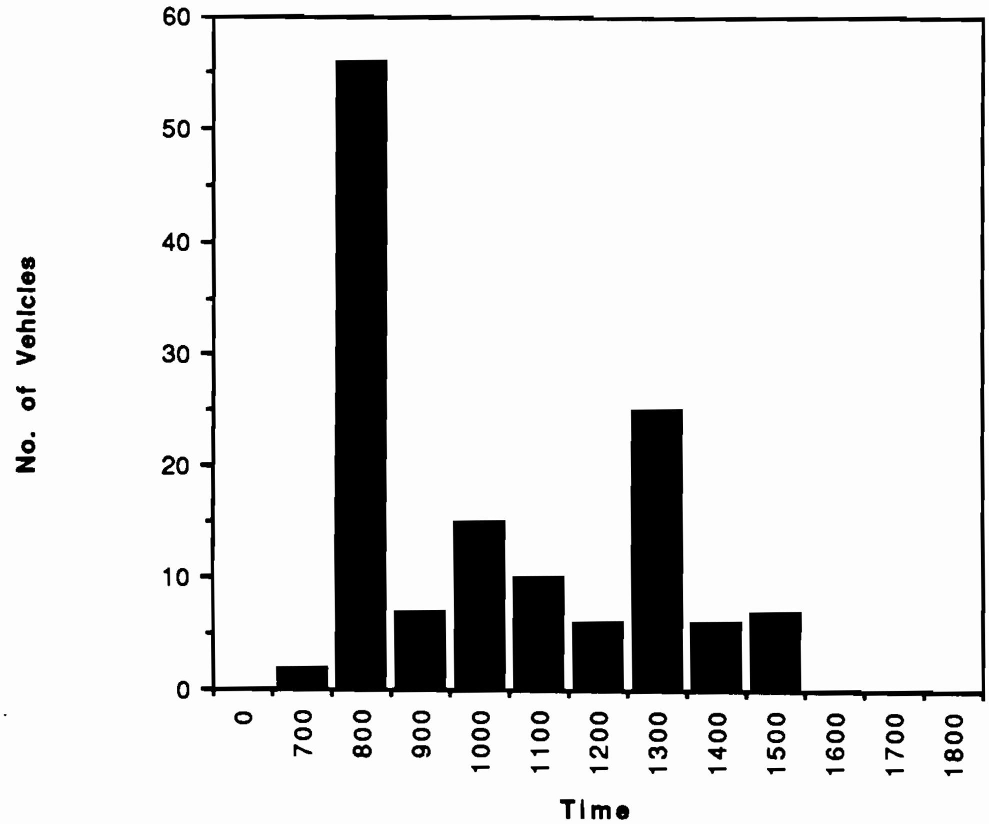

Arr. Distribution Dist.24
No. of Vehicles
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.24
No.of Vehicles
100
80
60
40
20
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

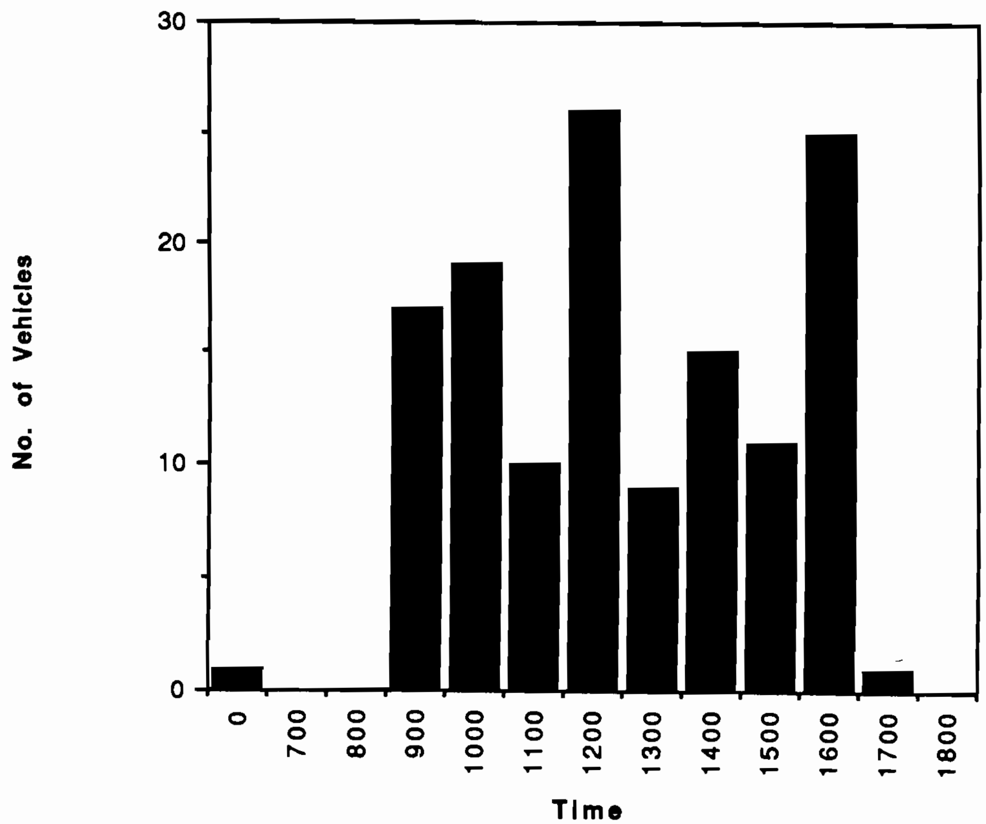

Arr. Distribution Dist.25
No. of Vehicles
120
100
80
60
40
20
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.25
No. of Vehicles
100
80
60
40
20
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

Arr. Distribution Dist.29(22?)



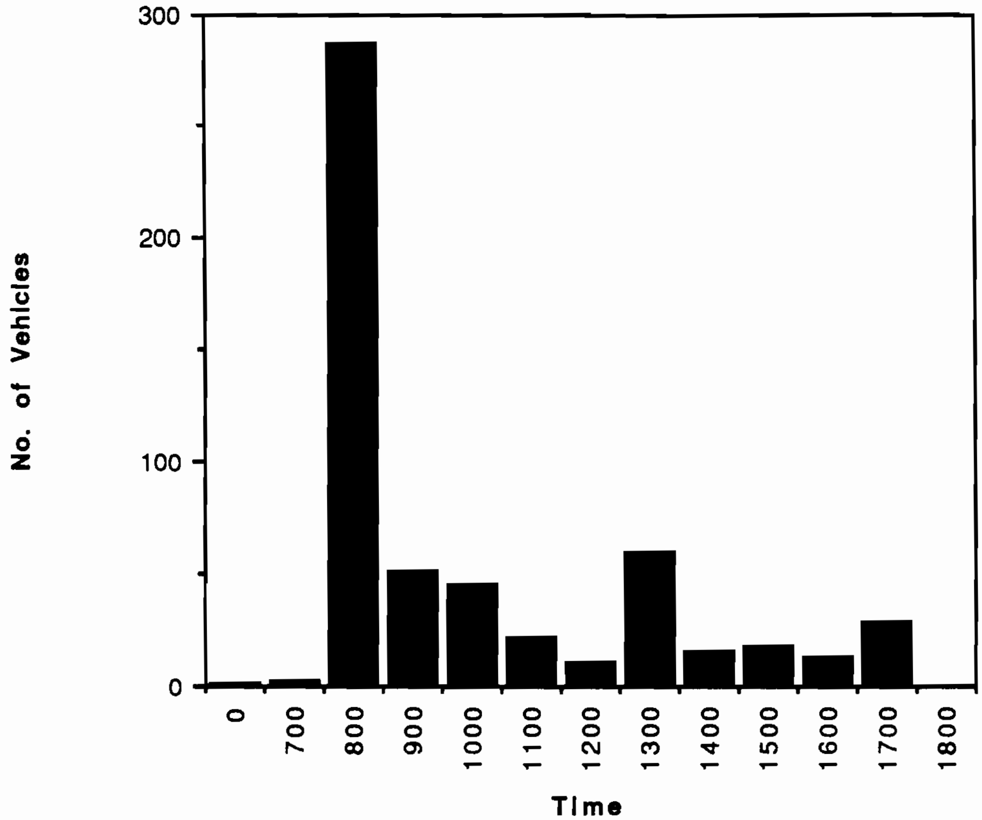
Dep. Distribution Dist.29(22?)



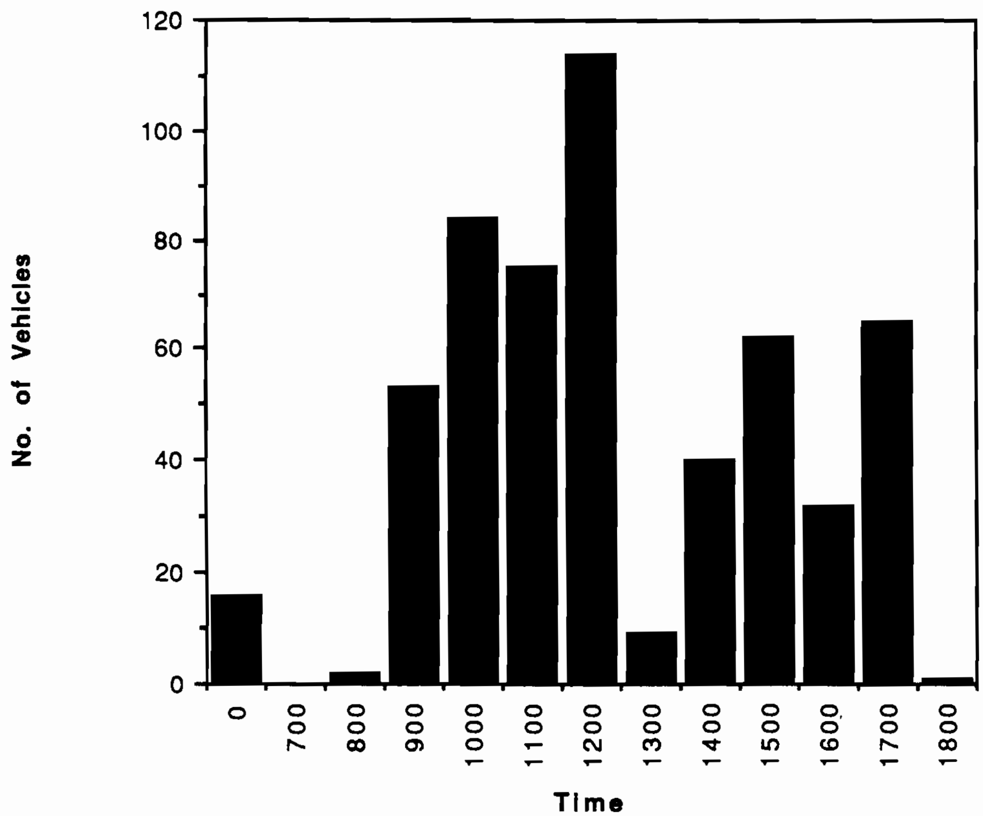
APPENDIX C. WORK ORDER ARRIVAL AND DEPARTURE FREQUENCY DISTRIBUTION FOR FY 1987-88

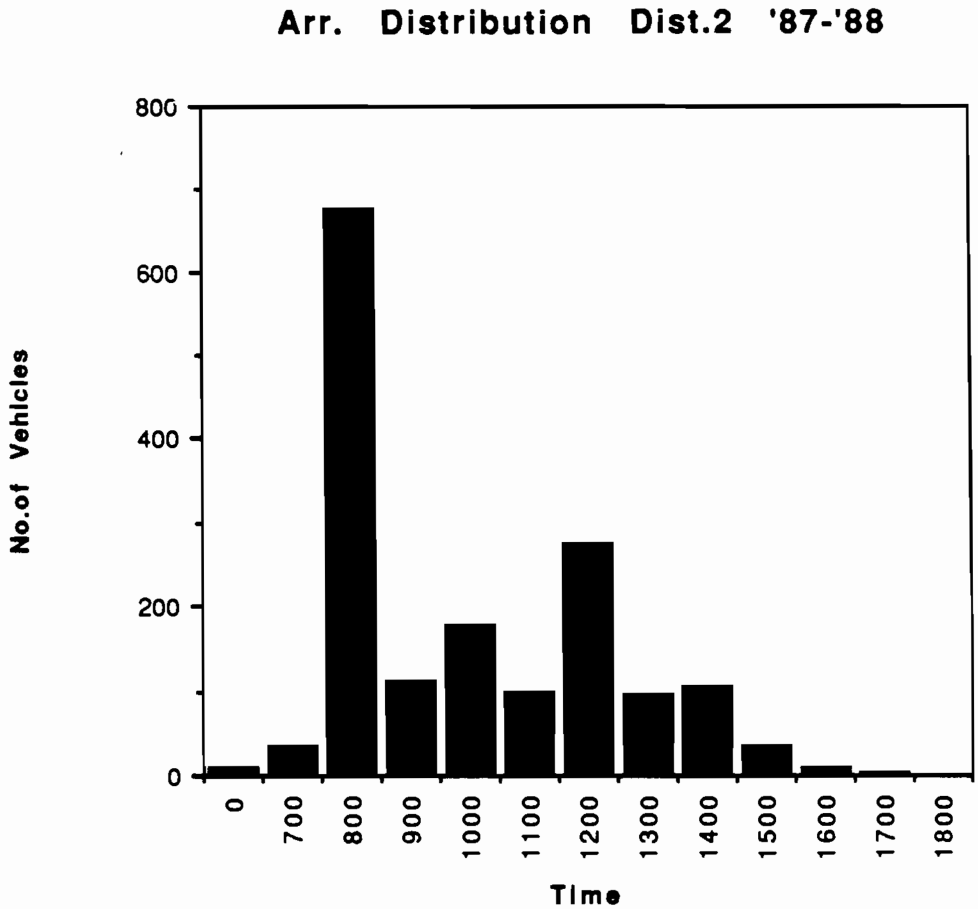
Note: Work orders with times from 1800 - 0600 appear as Time 0

Arr. Distribution Dist.1 '87-'88

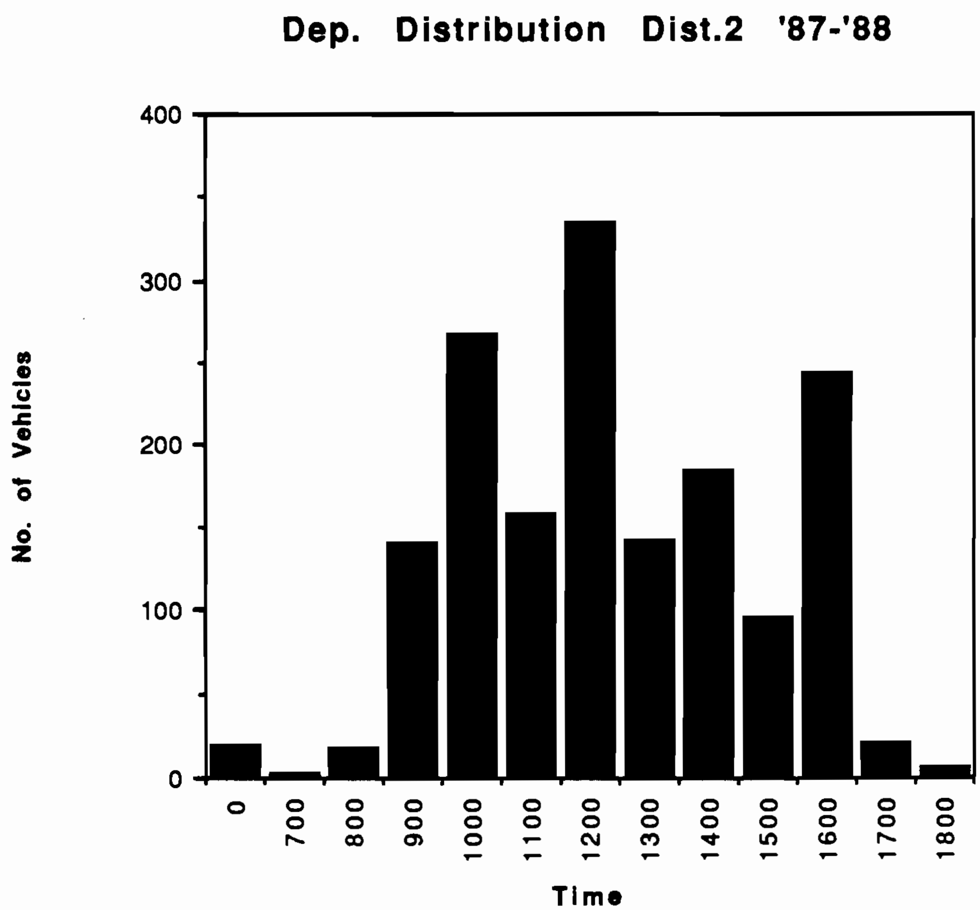


Dep. Distribution Dist.1 '87-'88

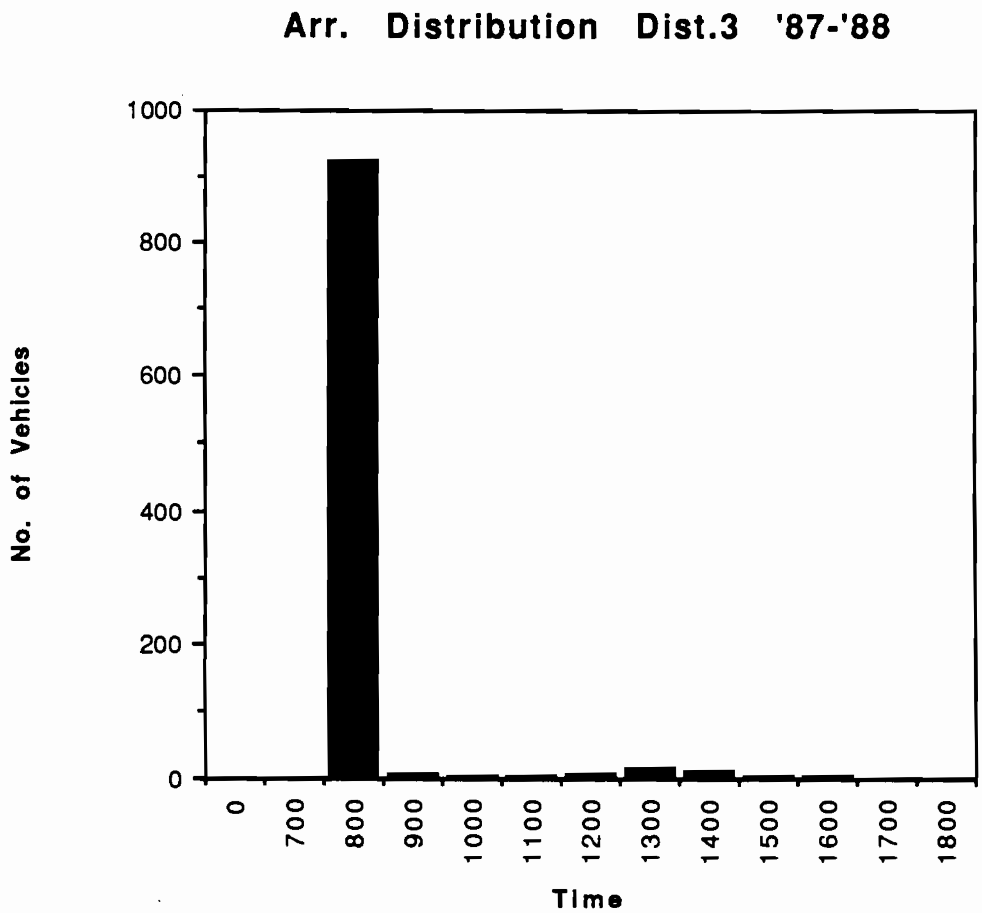


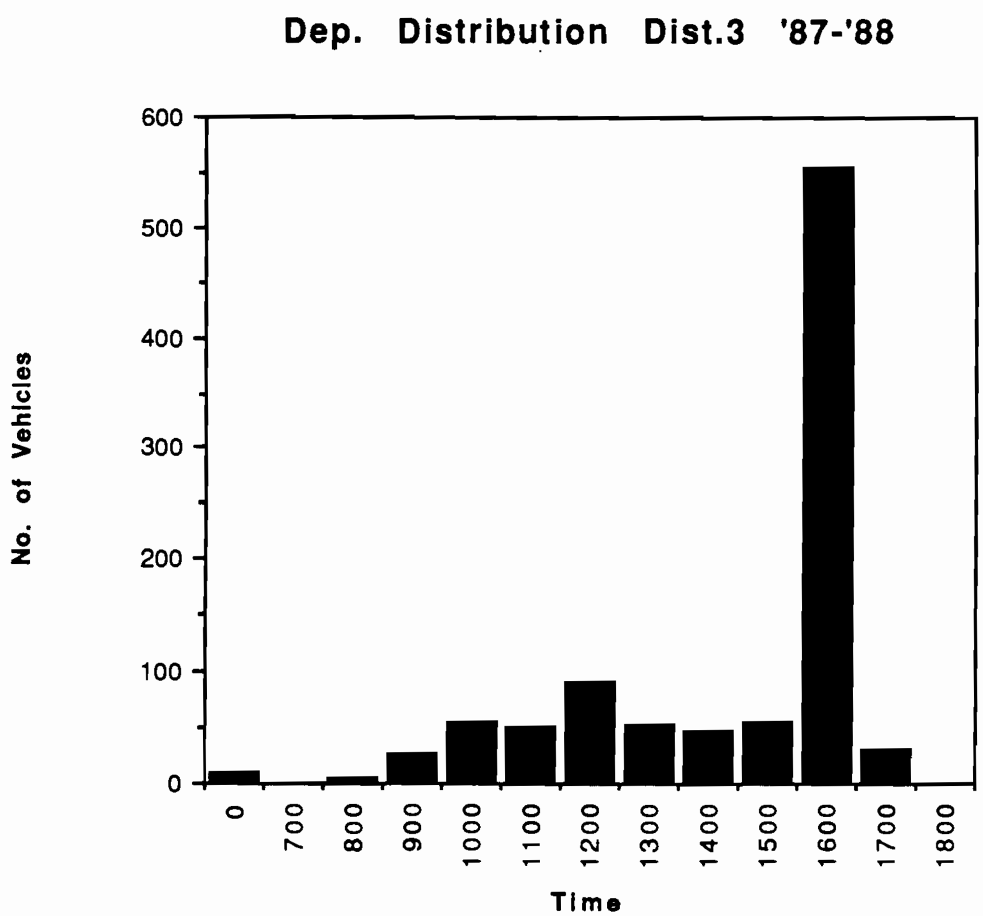


Arr. Distribution Dist.2 '87-'88
800
600
400
200
0
No.of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

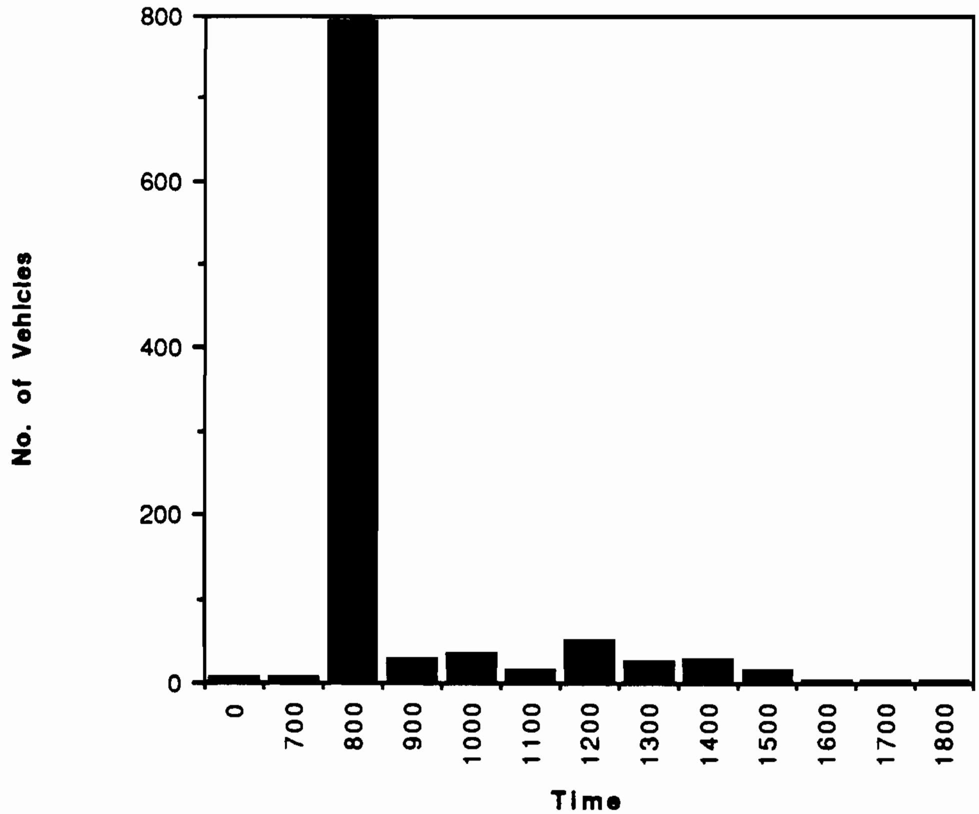


Dep. Distribution Dist.2 '87-'88
400
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

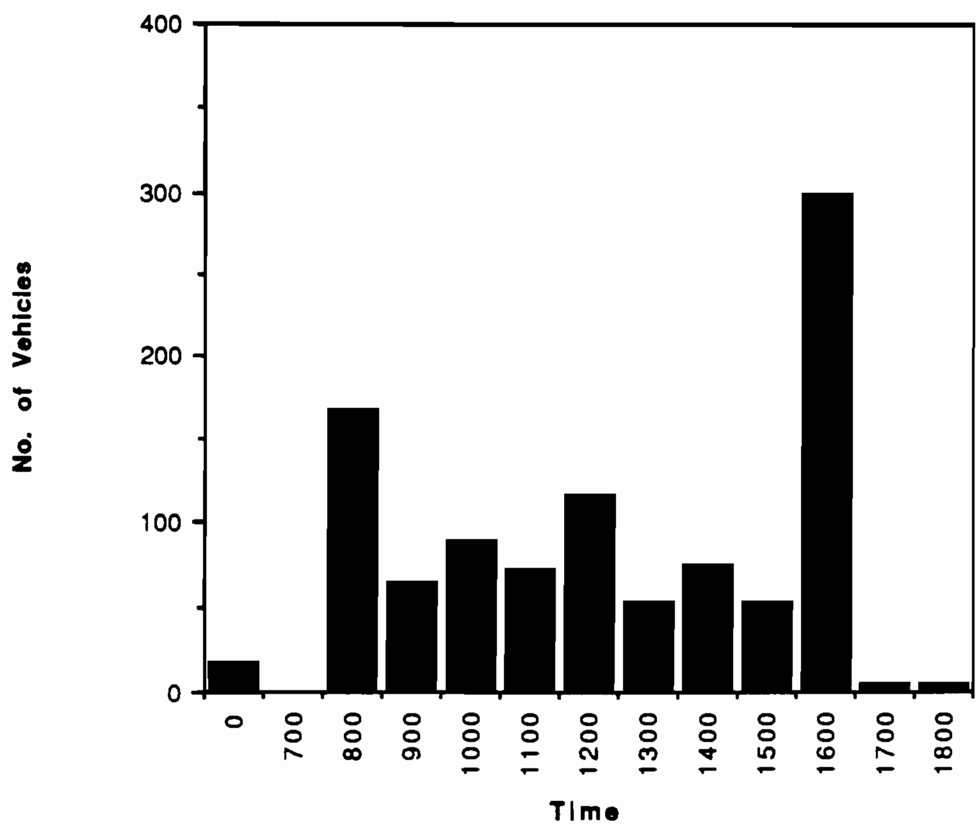

Arr. Distribution Dist.3 '87-'88
No. of Vehicles
1000
800
600
400
200
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.3 '87-'88
No. of Vehicles
600
500
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

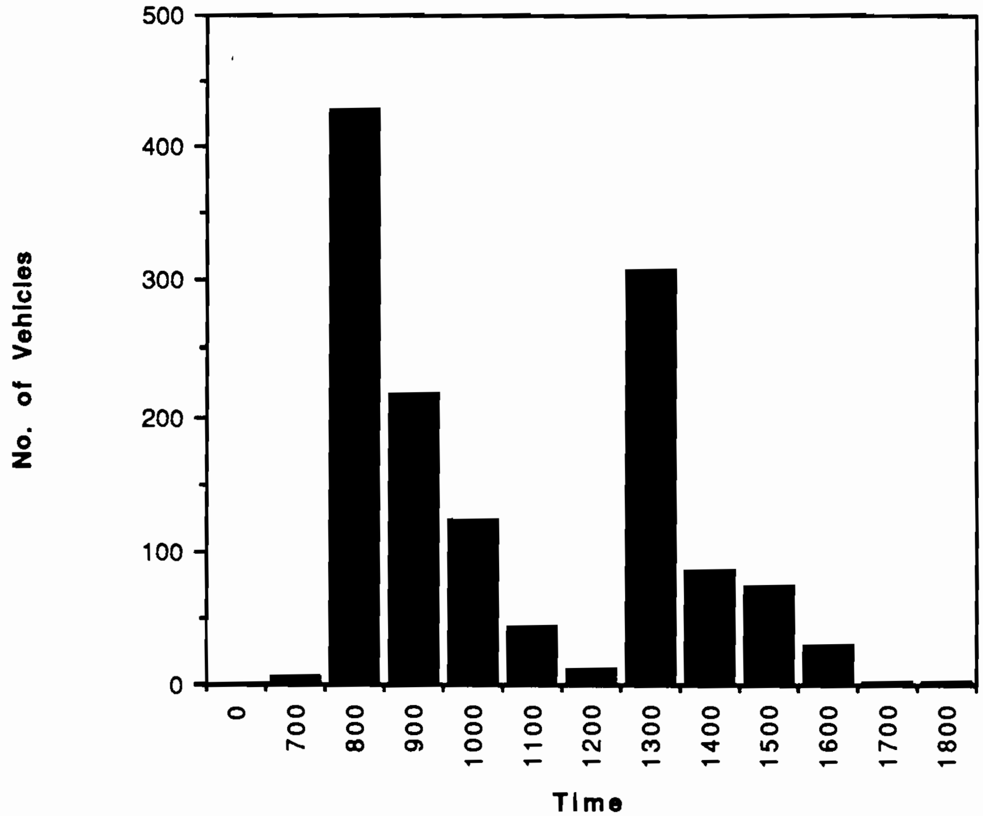
Arr. Distribution Dist.4 '87-'88



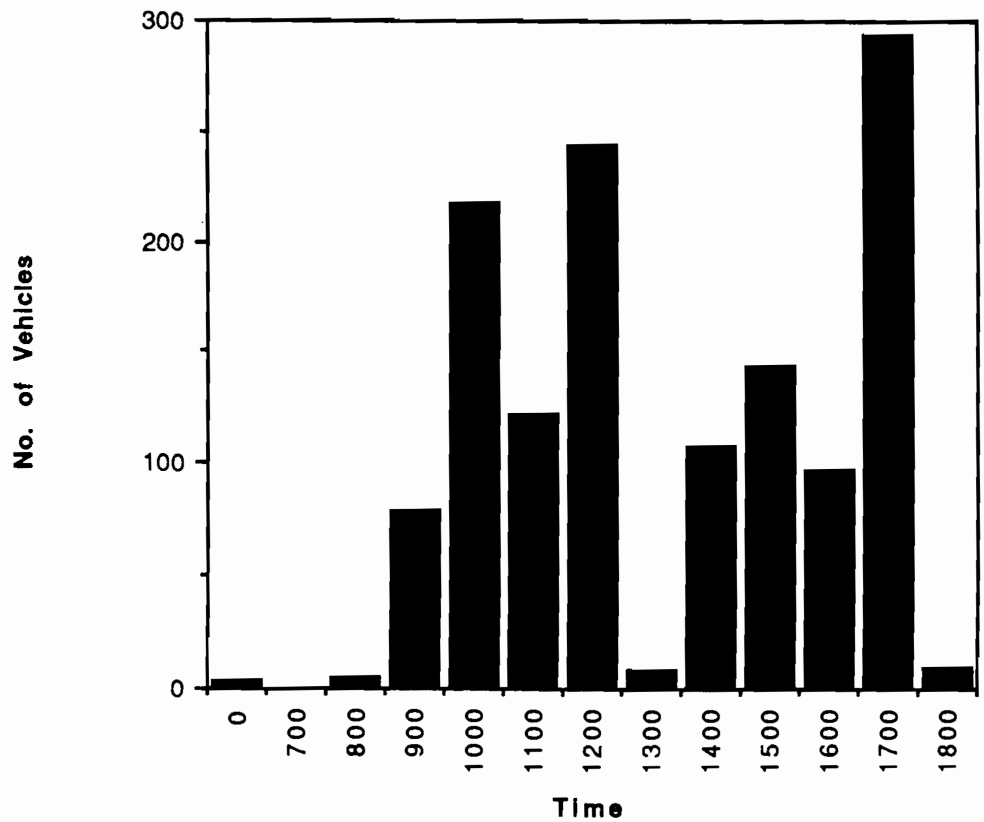
Dep. Distribution Dist.4 '87-'88



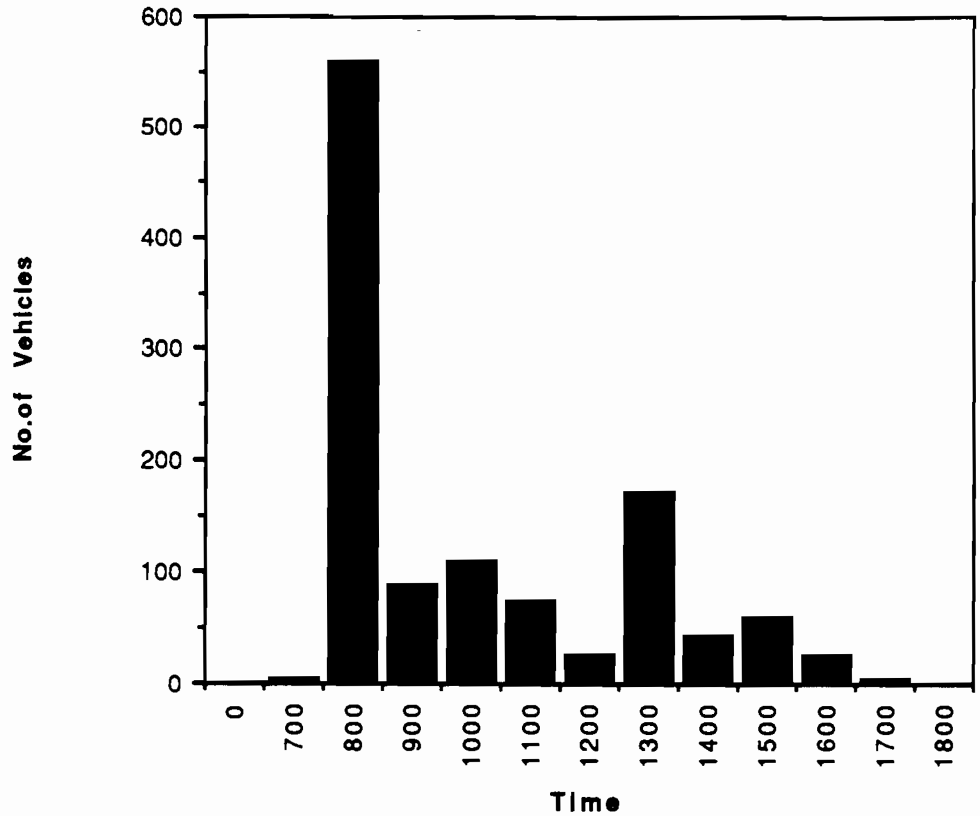
Arr. Distribution Dist.5 '87-'88



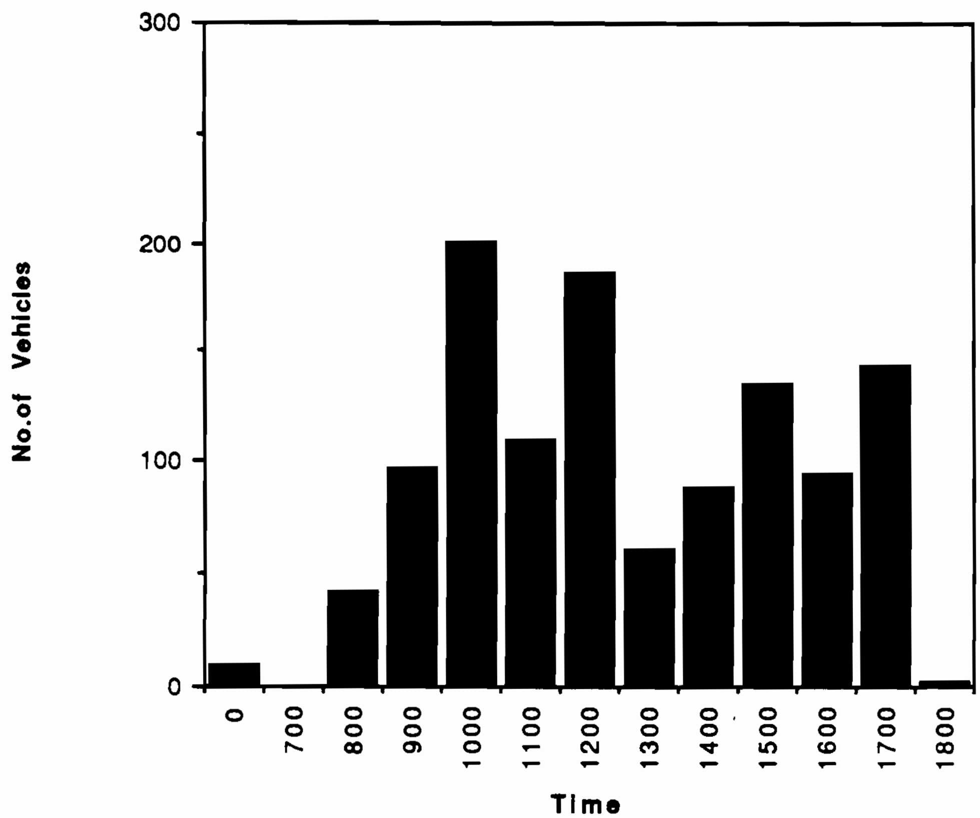
Dep. Distribution Dist.5 '87-'88

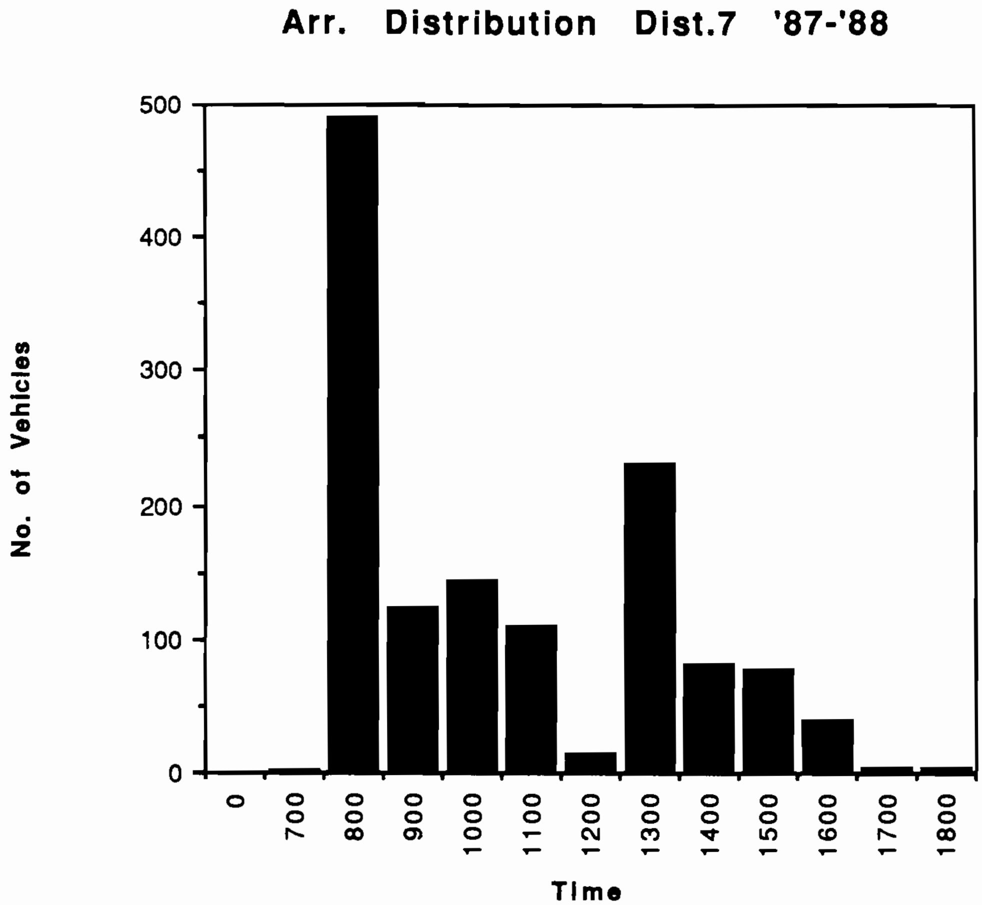


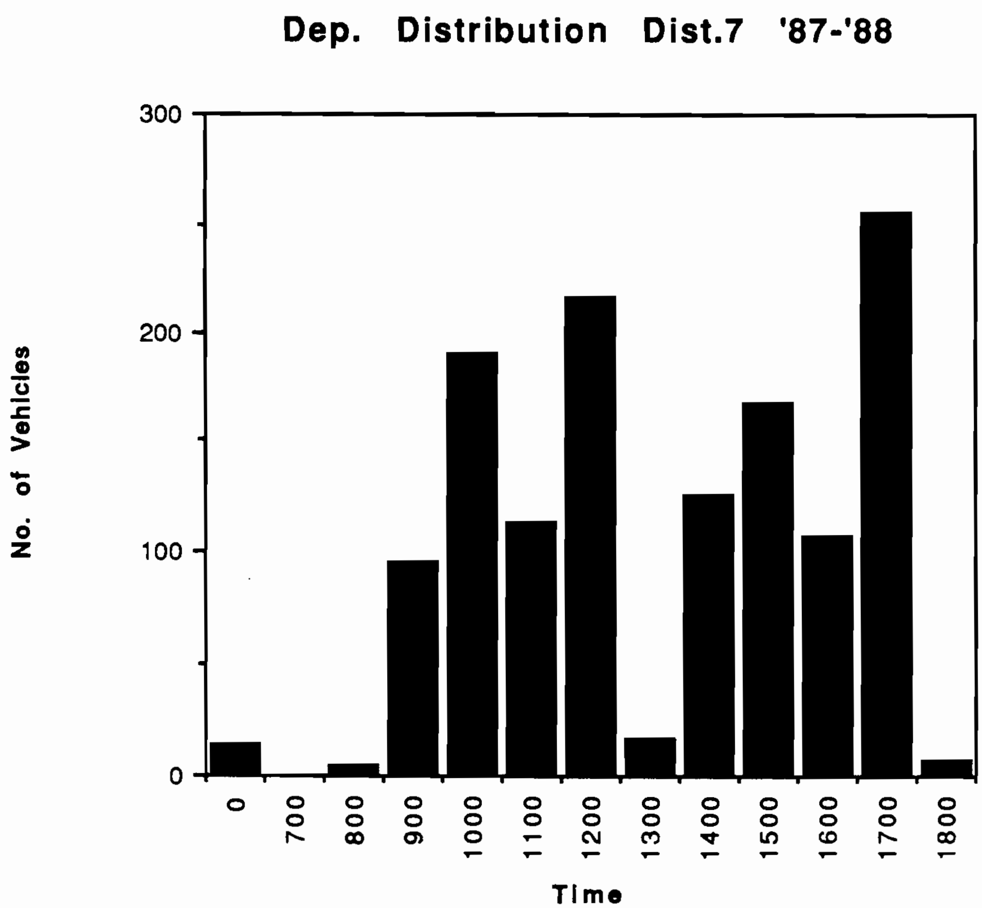
Arr. Distribution Dist.6 '87-'88



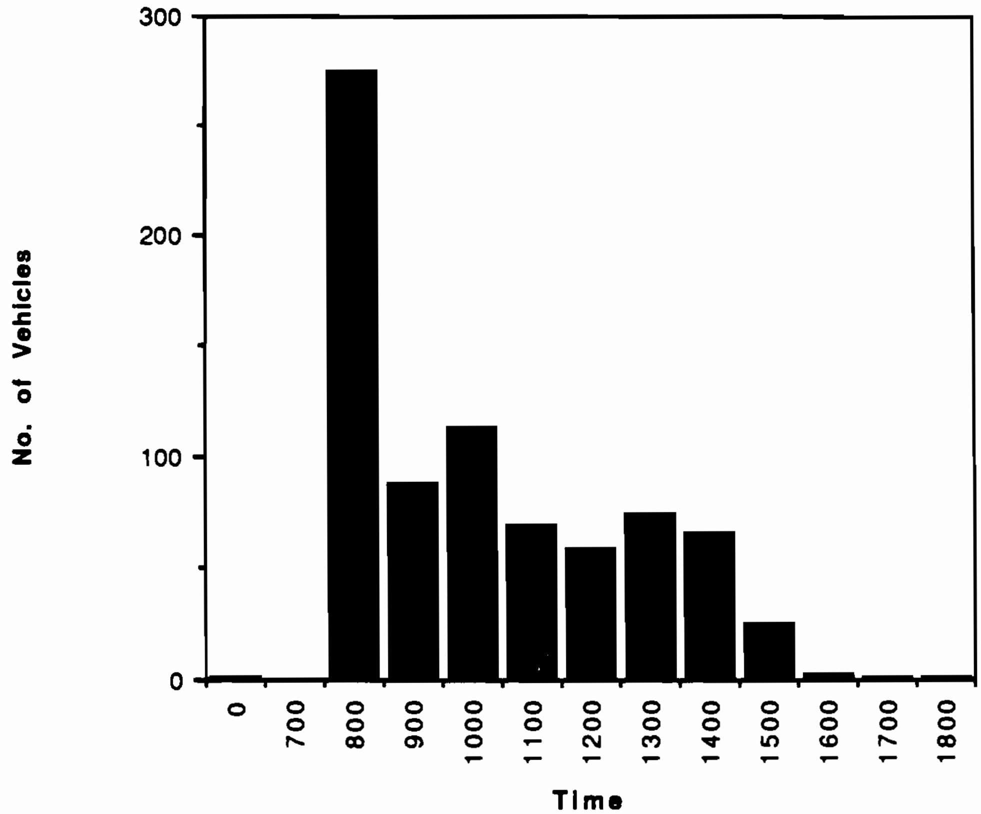
Dep. Distribution Dist.6 '87-'88



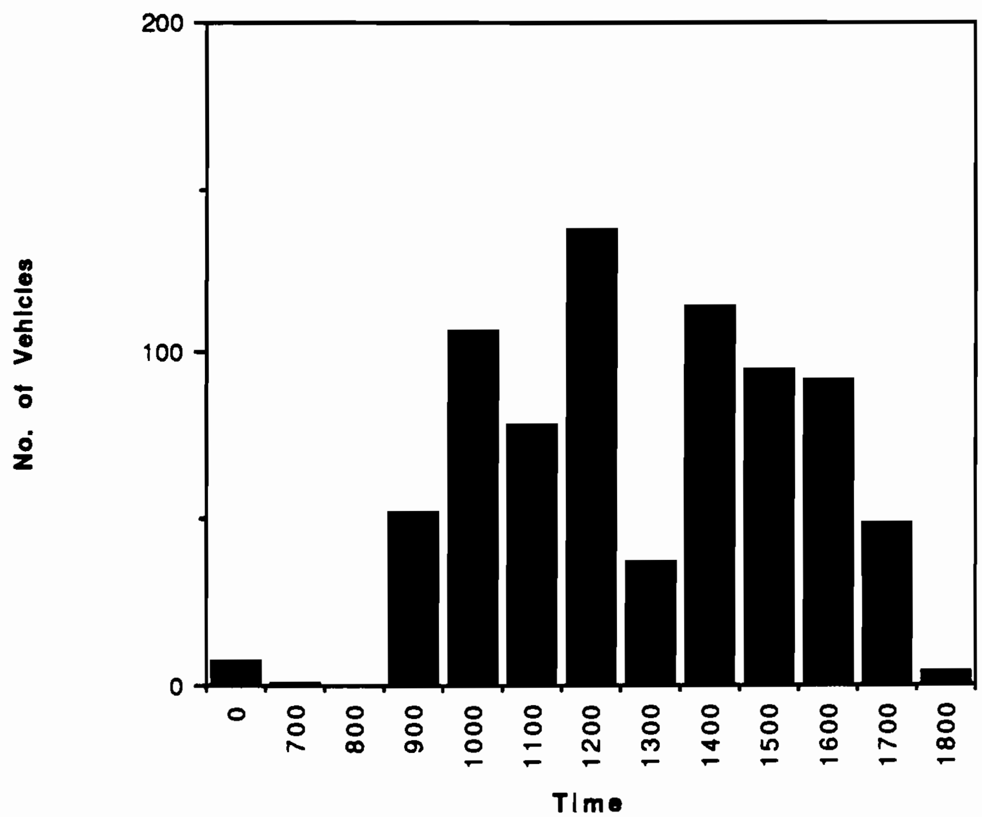

Arr. Distribution Dist.7 '87-'88
No. of Vehicles
500
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

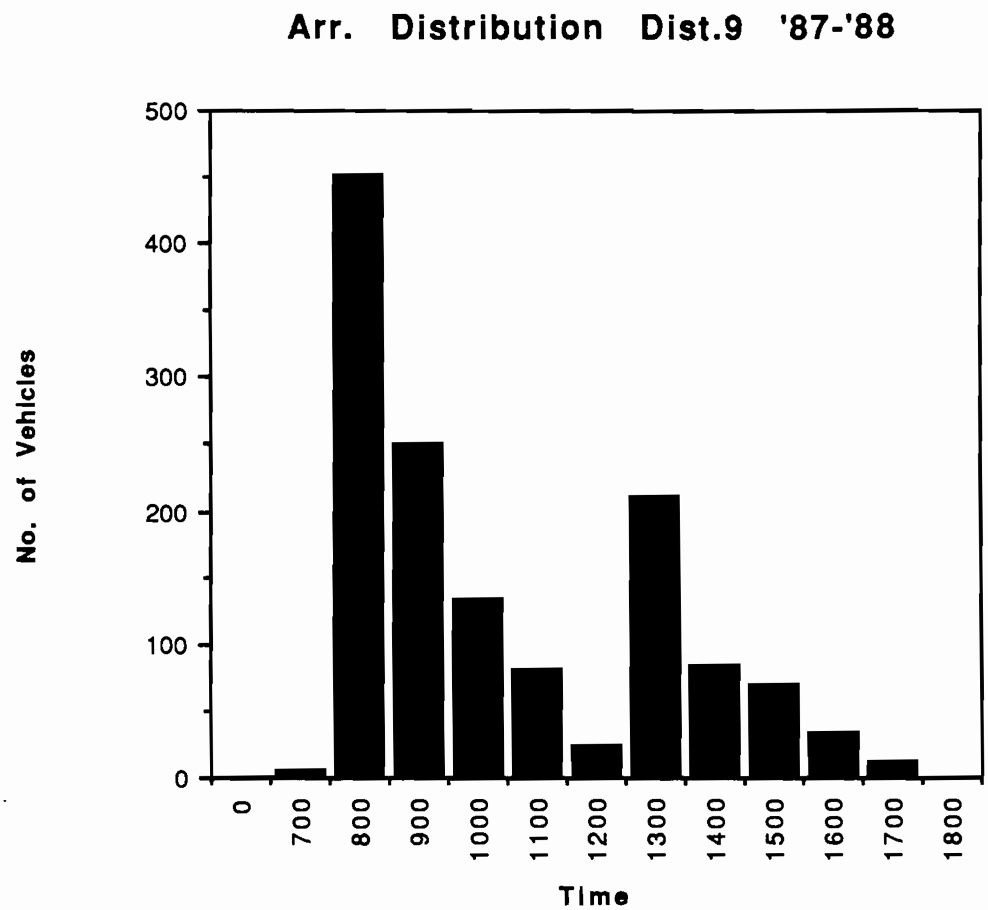

Dep. Distribution Dist.7 '87-'88
No. of Vehicles
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

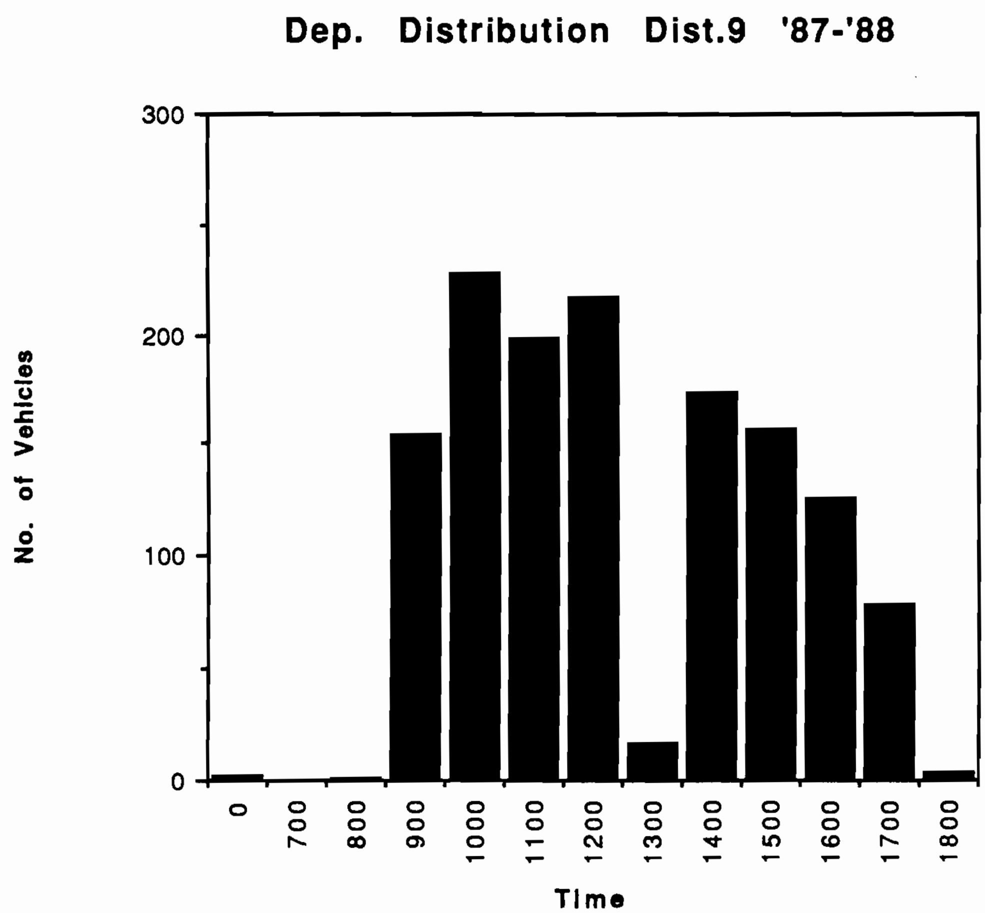
Arr. Distribution Dist.8 '87-'88



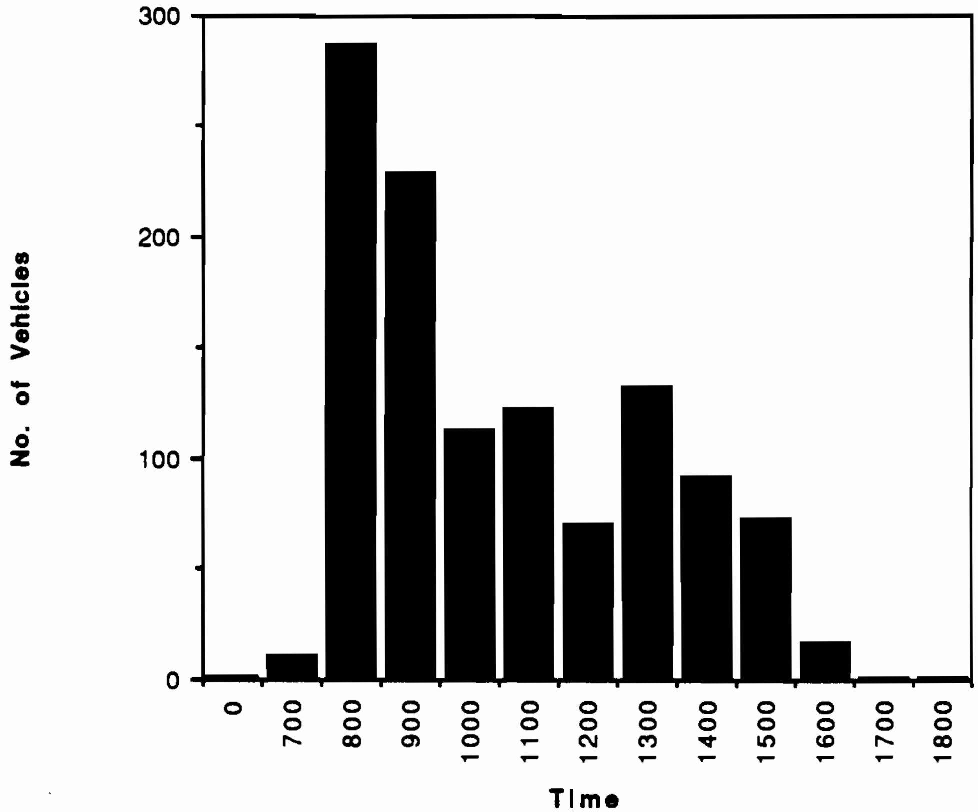
Dep. Distribution Dist.8 '87-'88



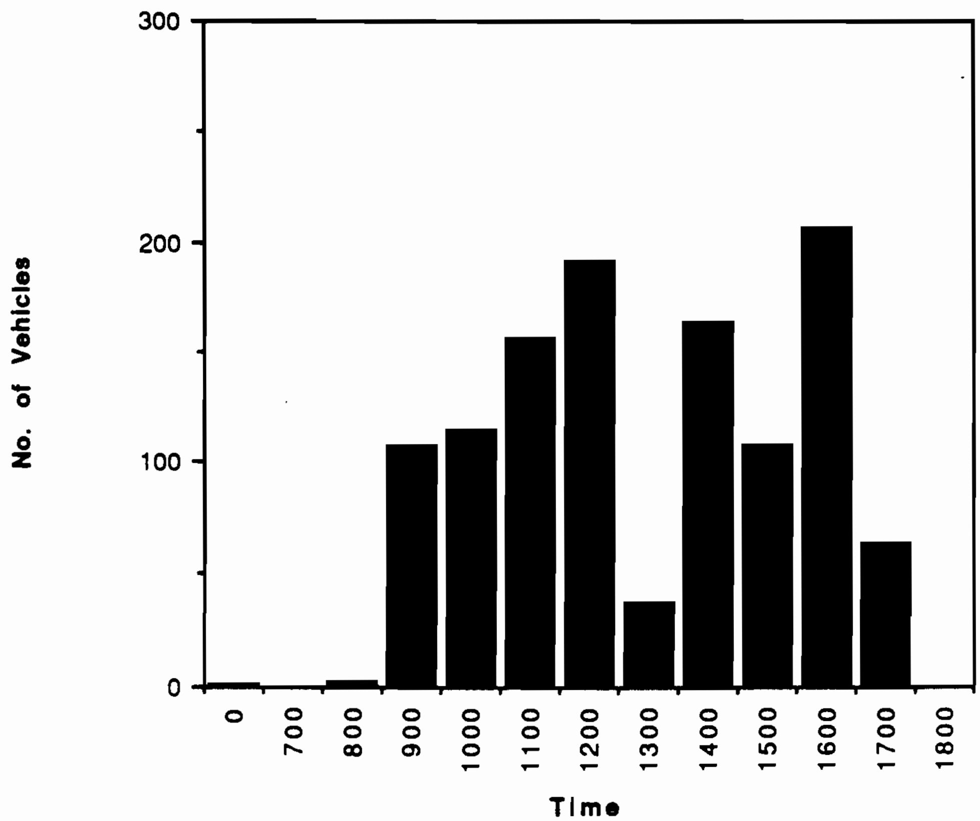

Arr. Distribution Dist.9 '87-'88
500
400
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.9 '87-'88
300
200
100
0
No. of Vehicles
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

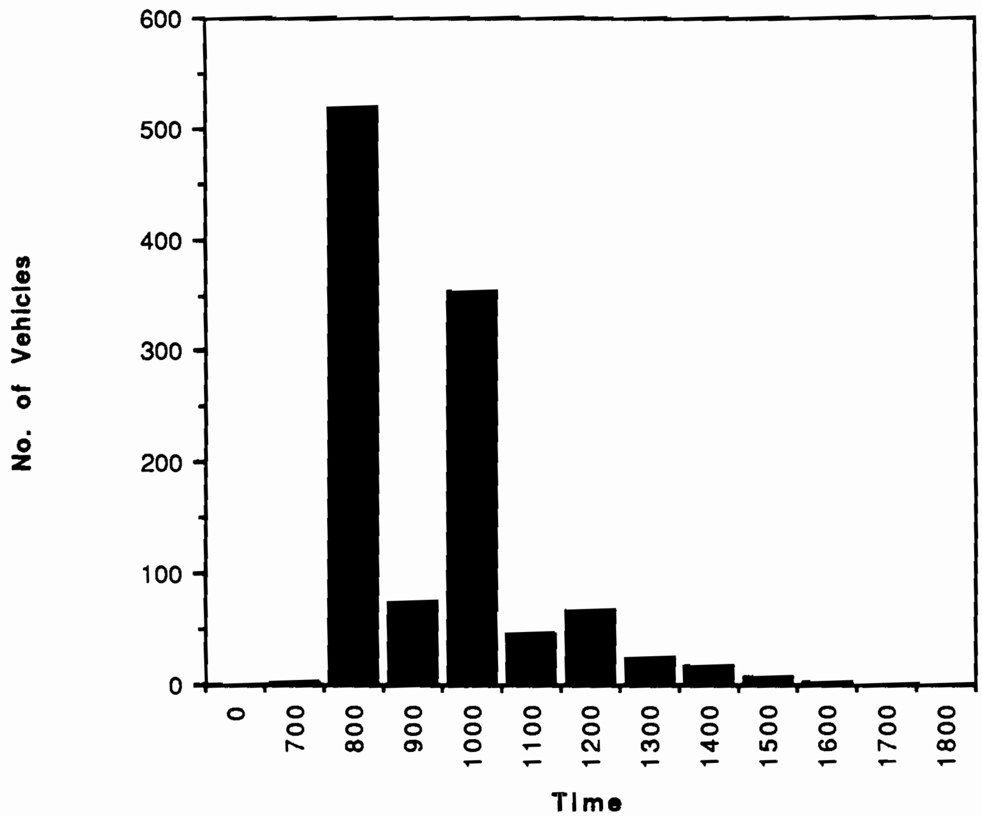
Arr. Distribution Dist.10 '87-'88



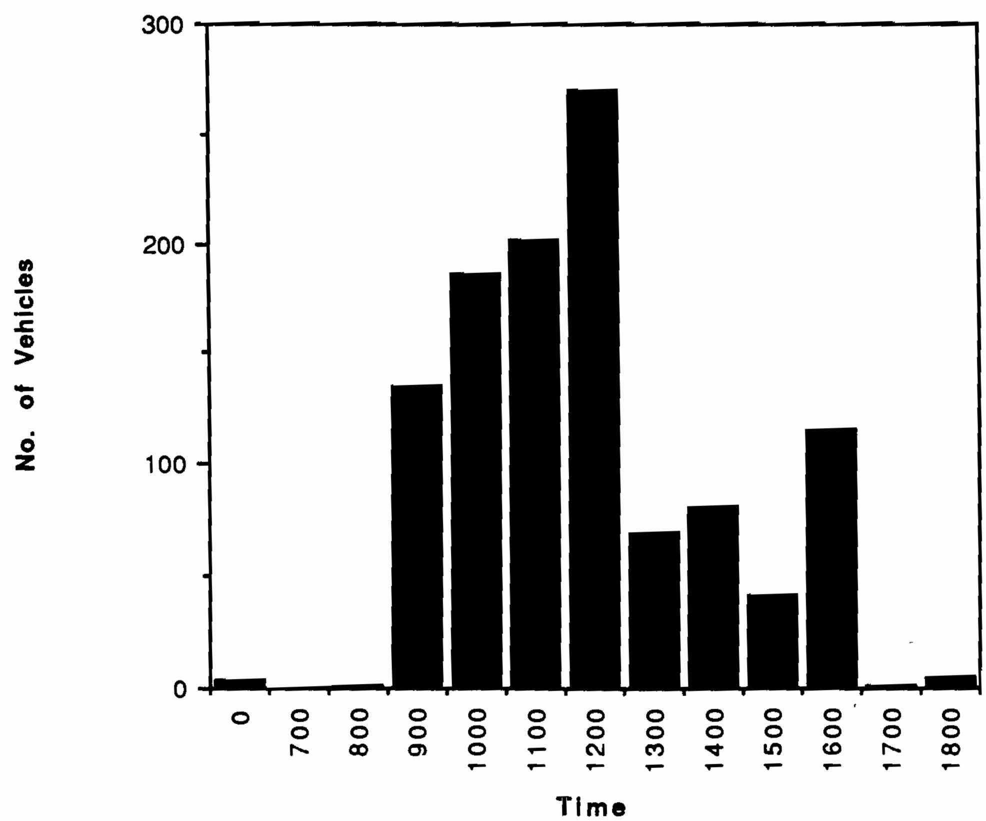
Dep. Distribution Dist.10 '87-'88



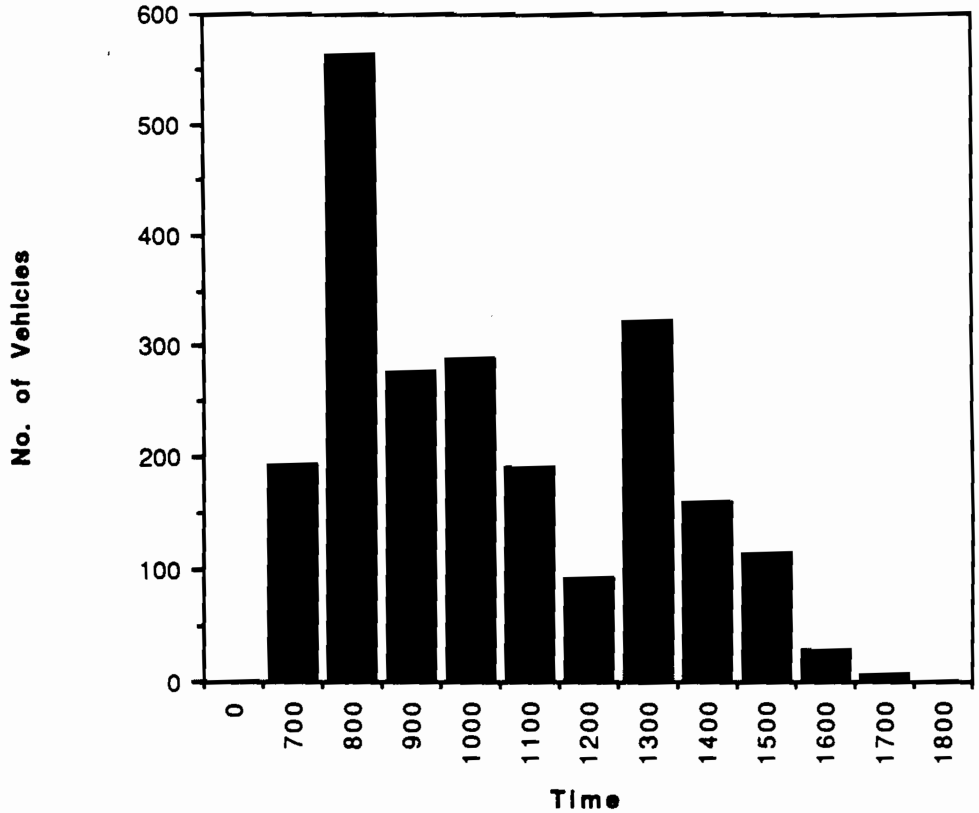
Arr. Distribution Dist.11 '87-'88



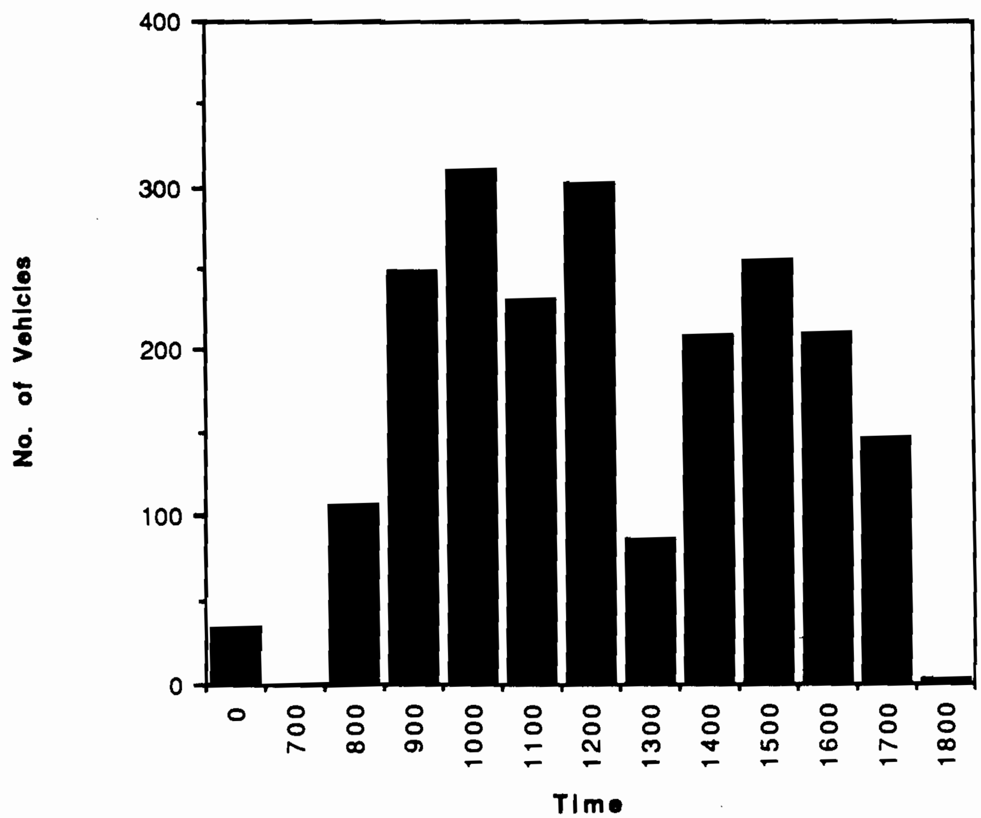
Dep. Distribution Dist.11 '87-'88



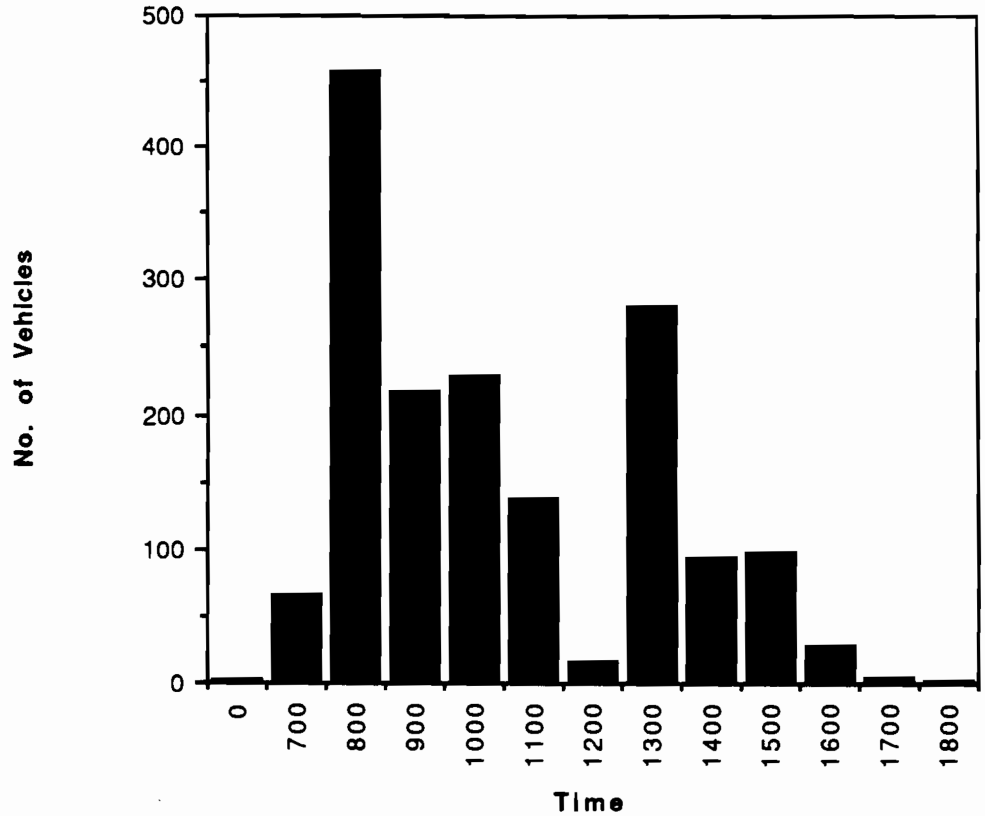
Arr. Distribution Dist.12 '87-'88



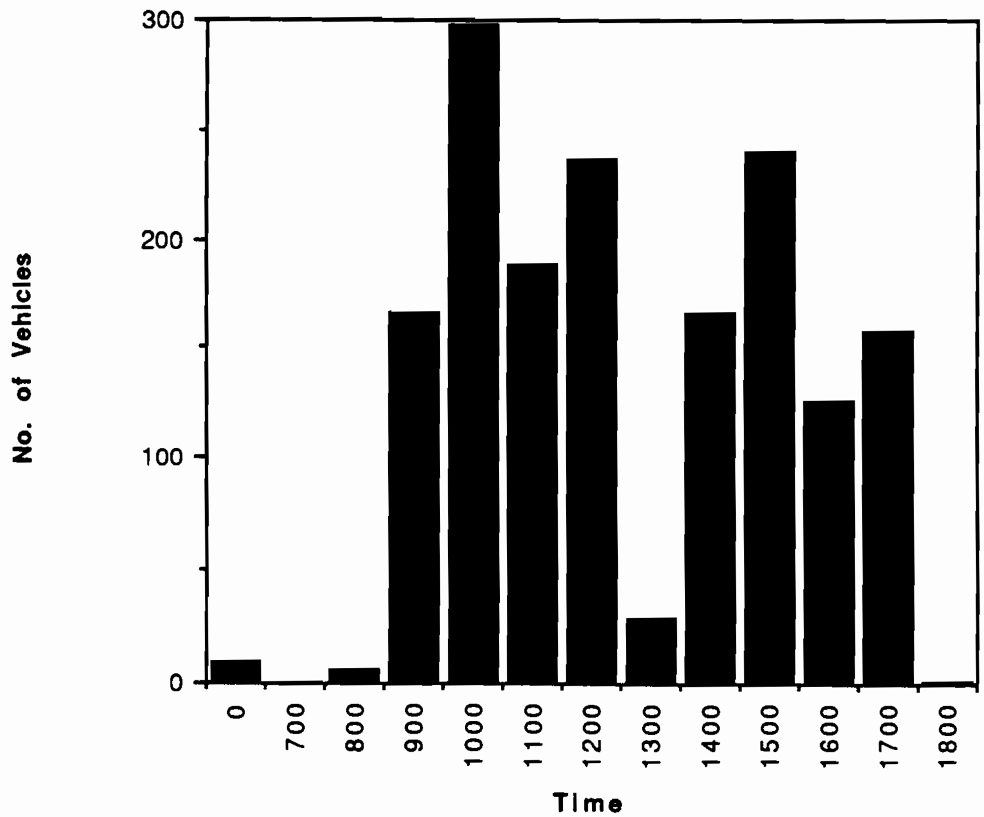
Dep. Distribution Dist.12 '87-'88



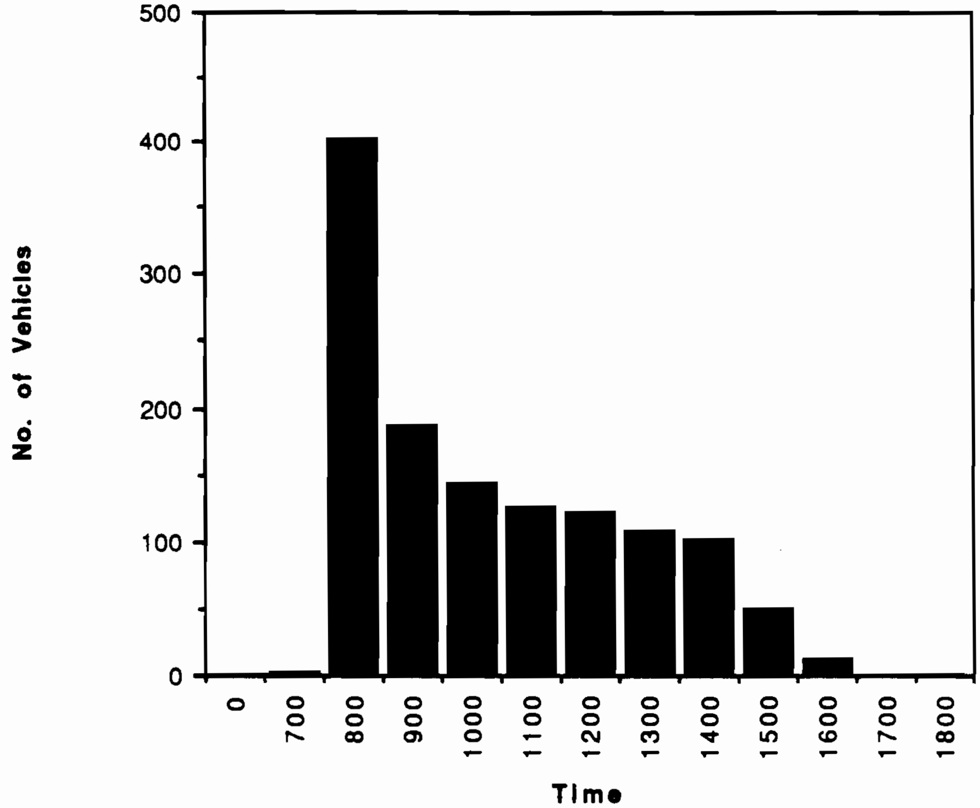
Arr. Distribution Dist.13 '87-'88



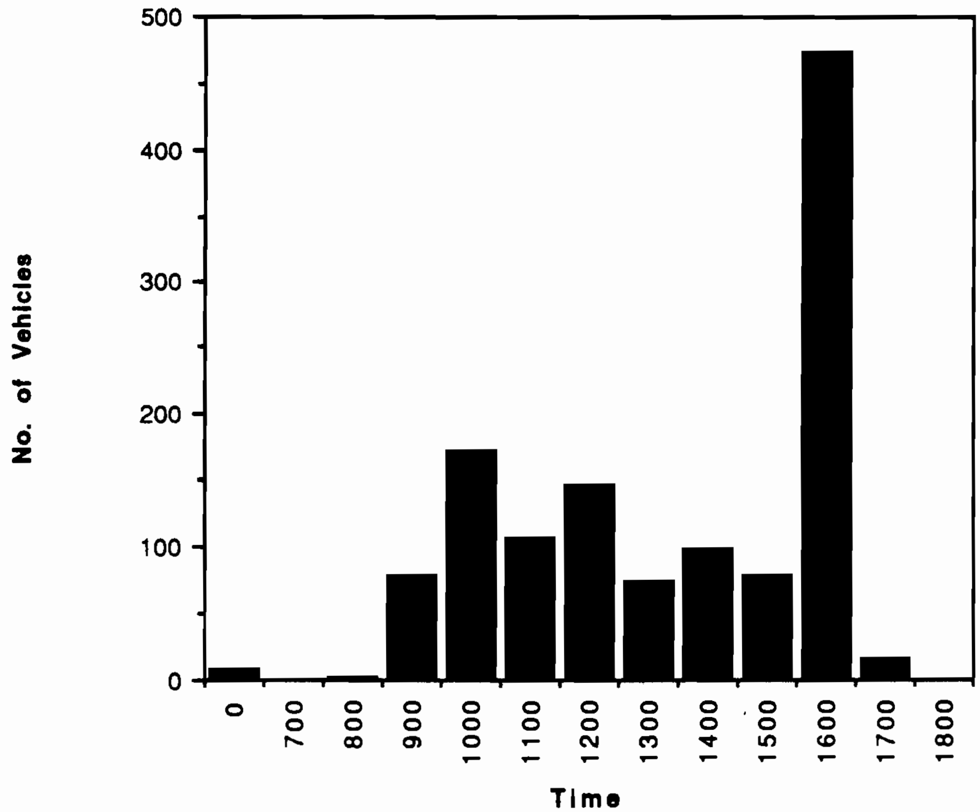
Dep. Distribution Dist.13 '87-'88

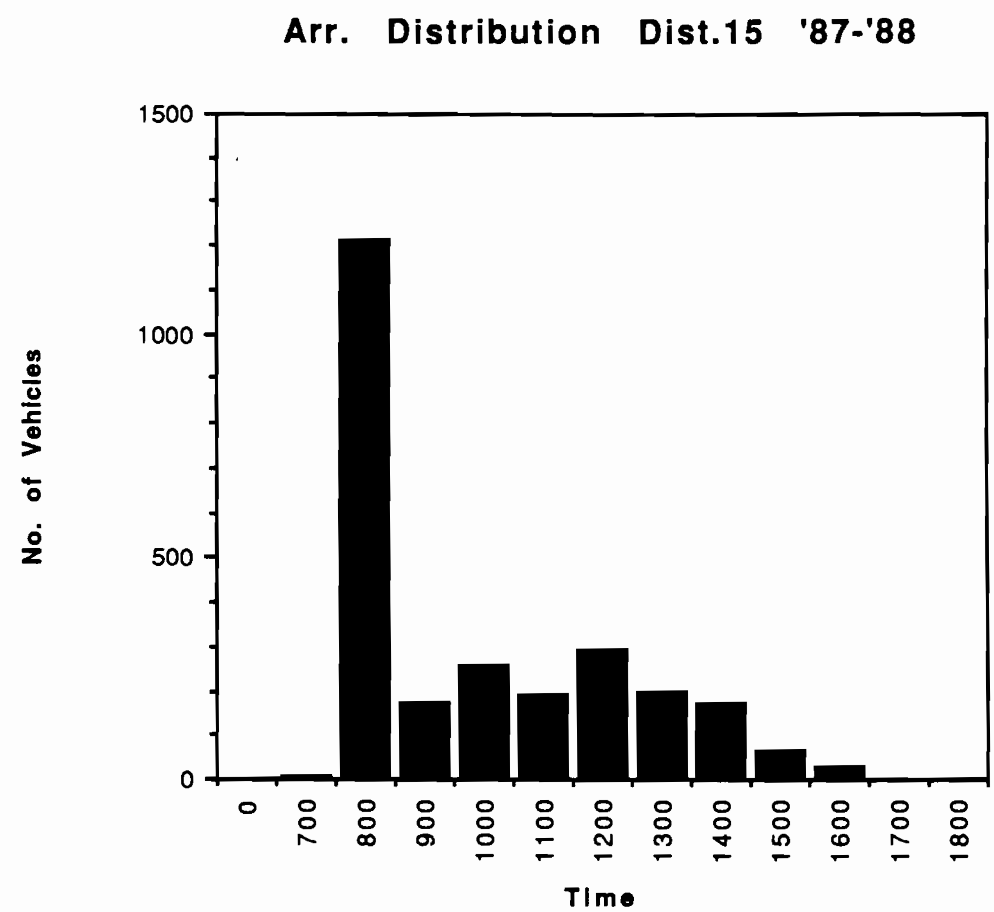


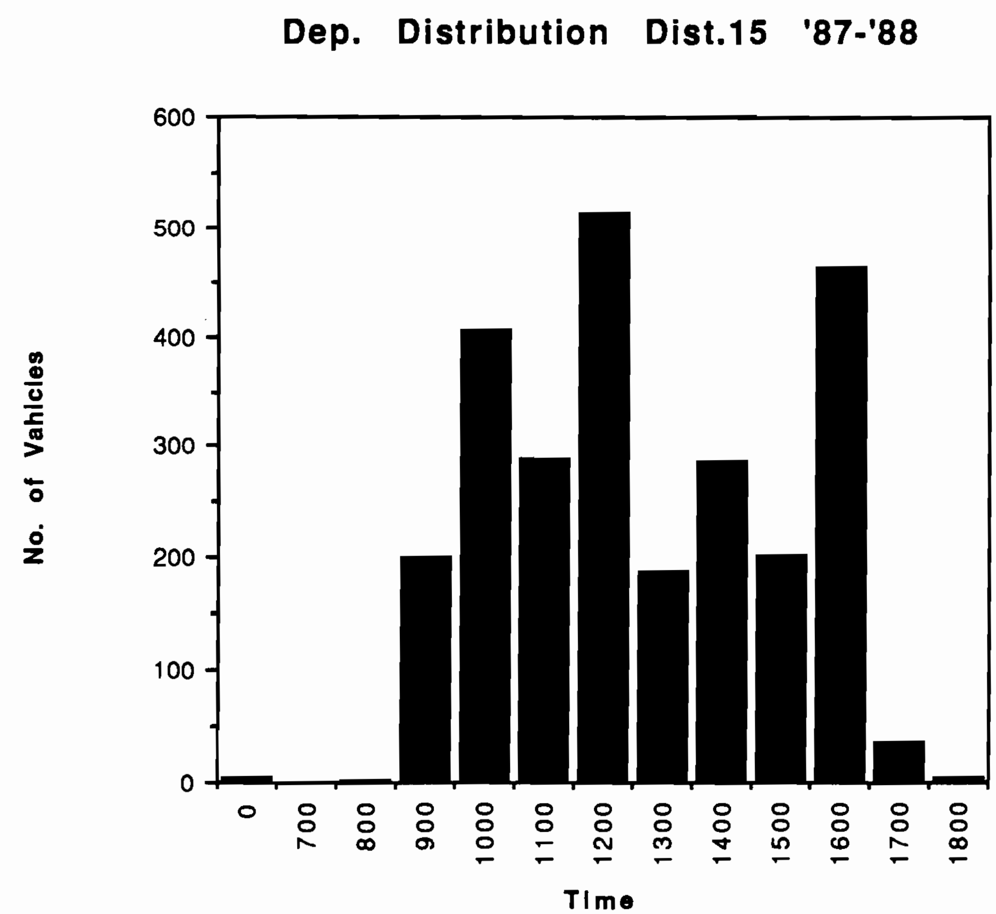
Arr. Distribution Dist.14 '87-'88



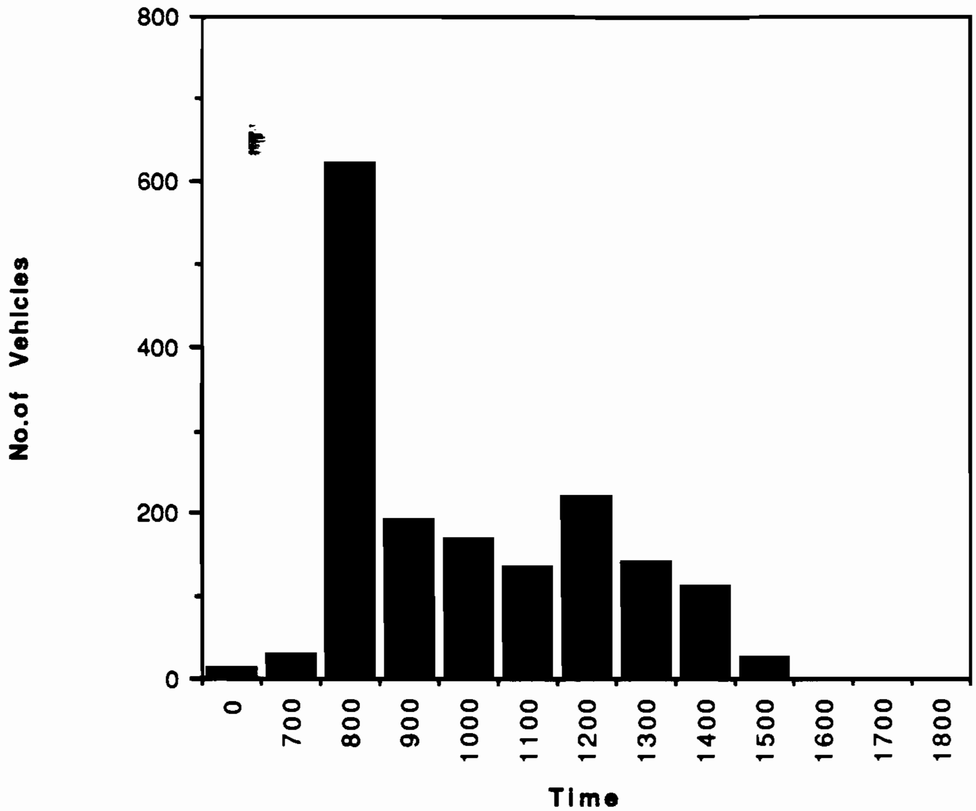
Dep. Distribution Dist.14 '87-'88



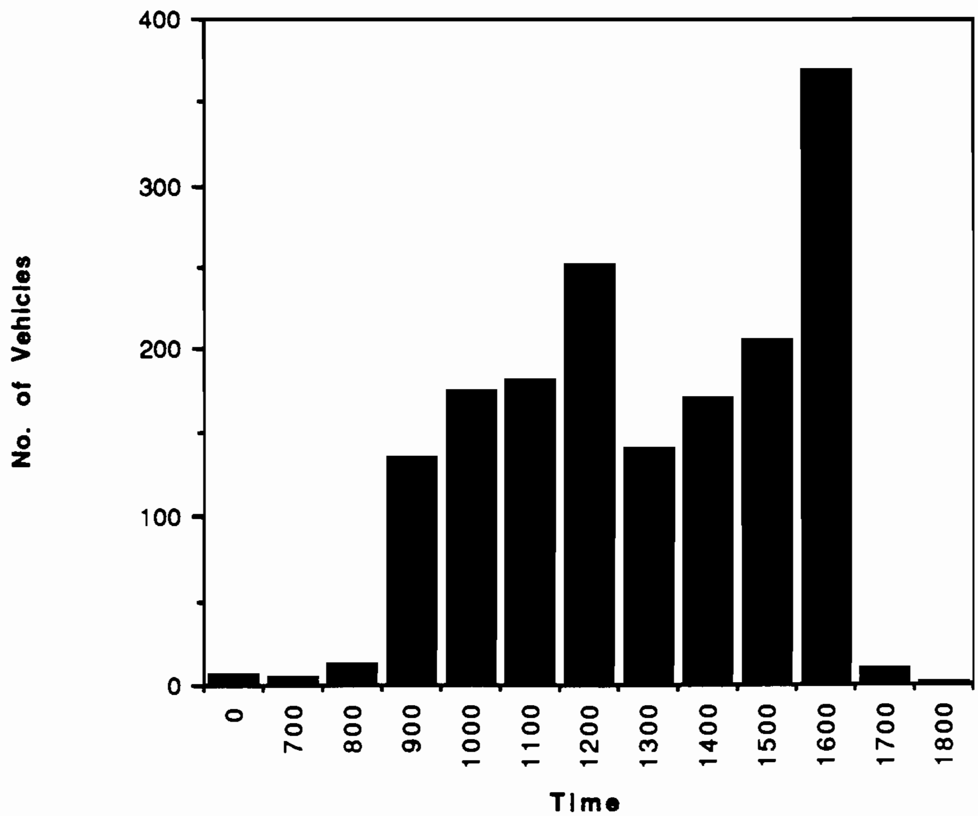

Arr. Distribution Dist.15 '87-'88
No. of Vehicles
1500
1000
500
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

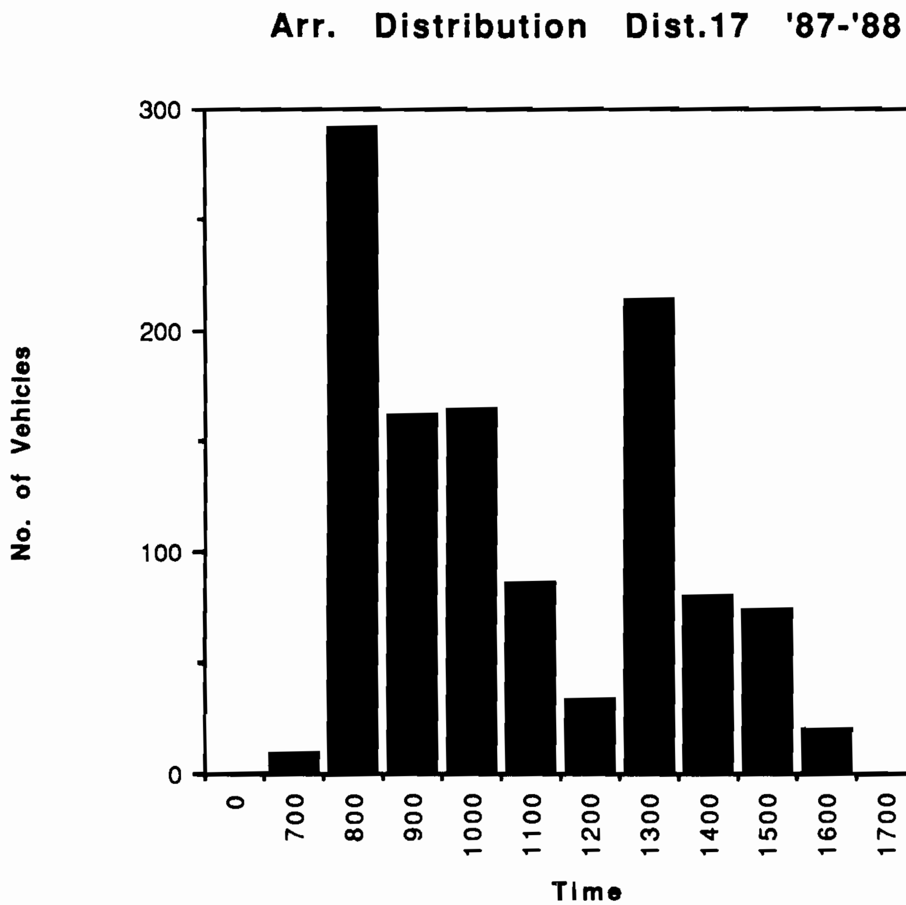

Dep. Distribution Dist.15 '87-'88
No. of Vahicles
600
500
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

Arr. Distribution Dist.16 '87-'88

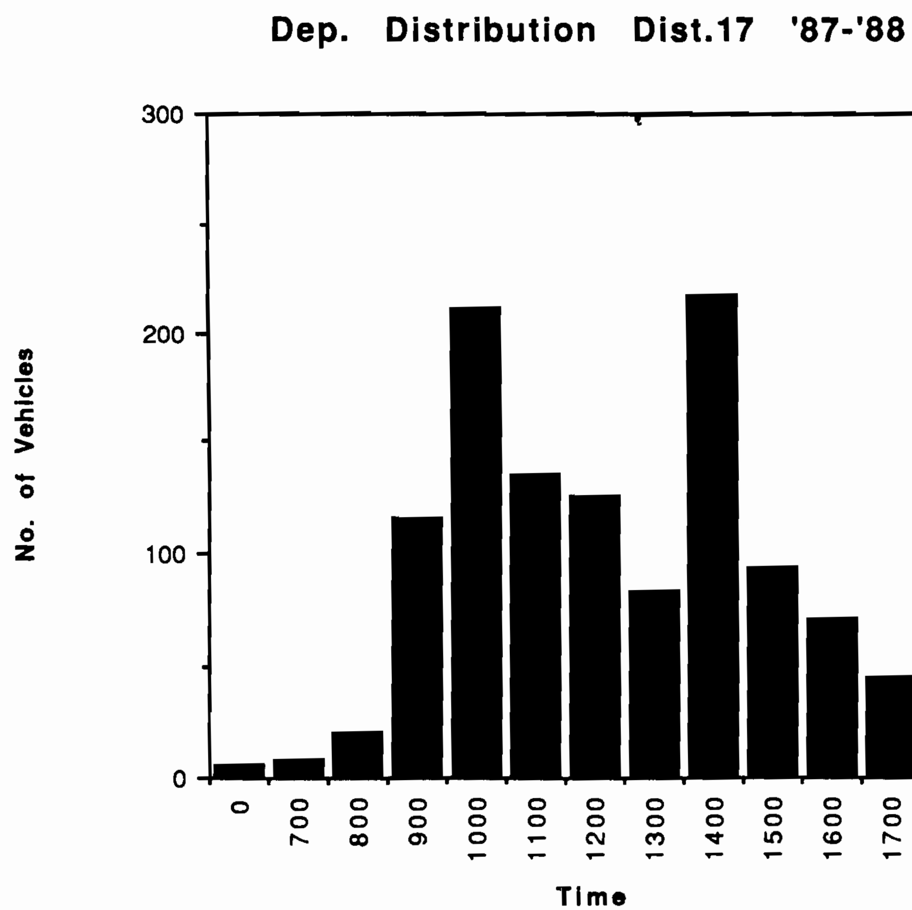


Dep. Distribution Dist.16 '87-'88

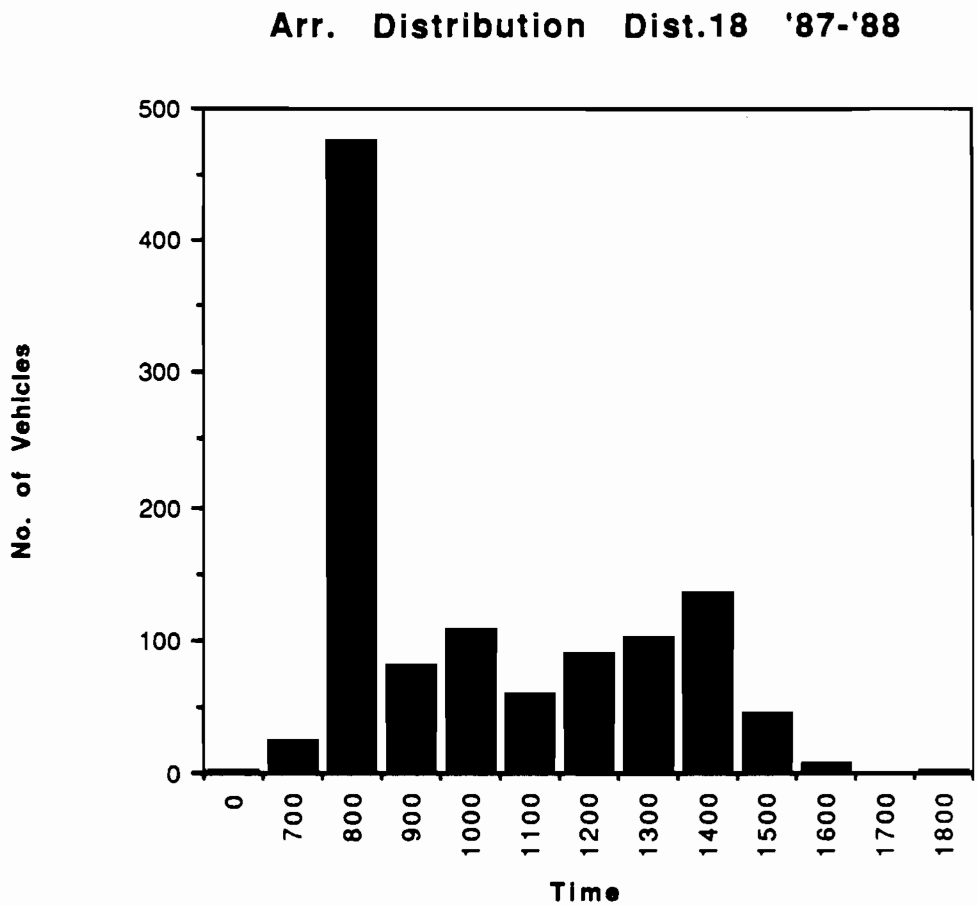


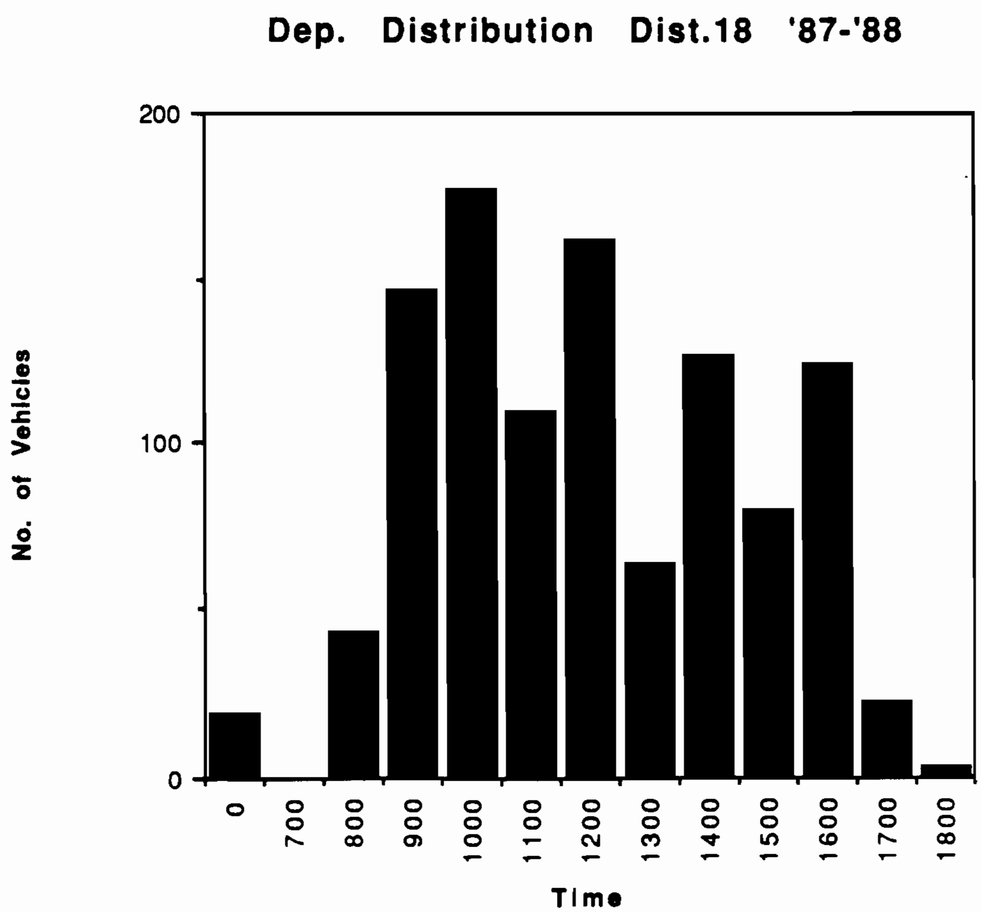


Arr. Distribution Dist.17 '87-'88
No. of Vehicles
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

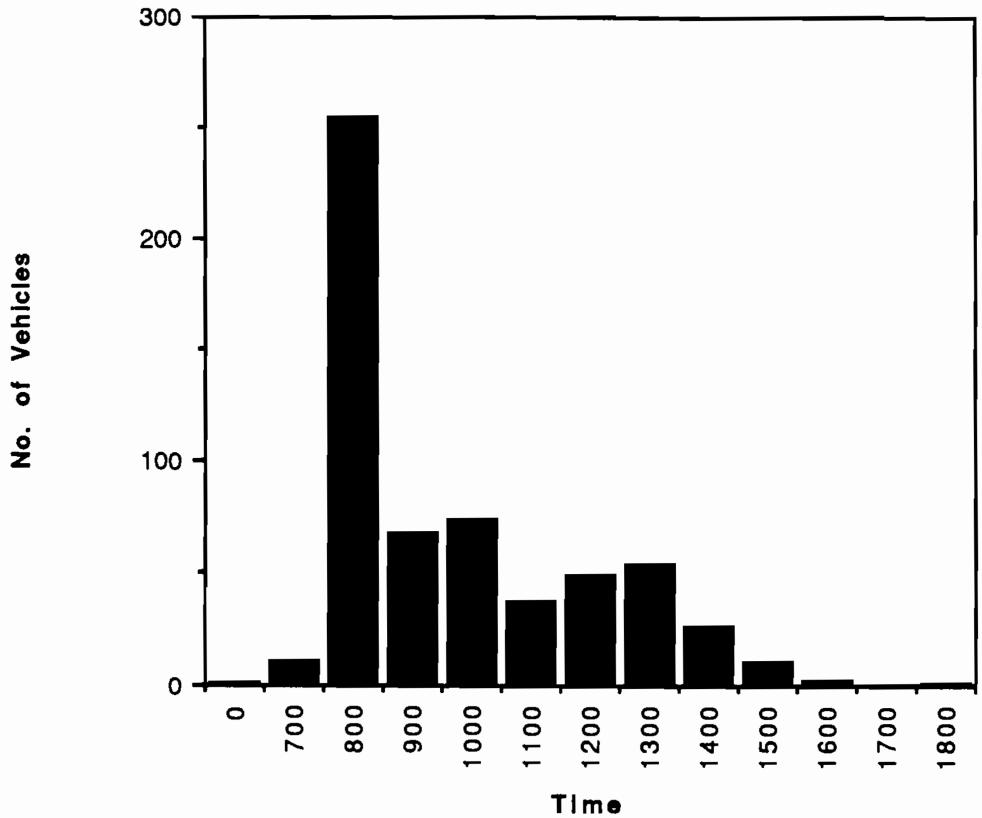


Dep. Distribution Dist.17 '87-'88
No. of Vehicles
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

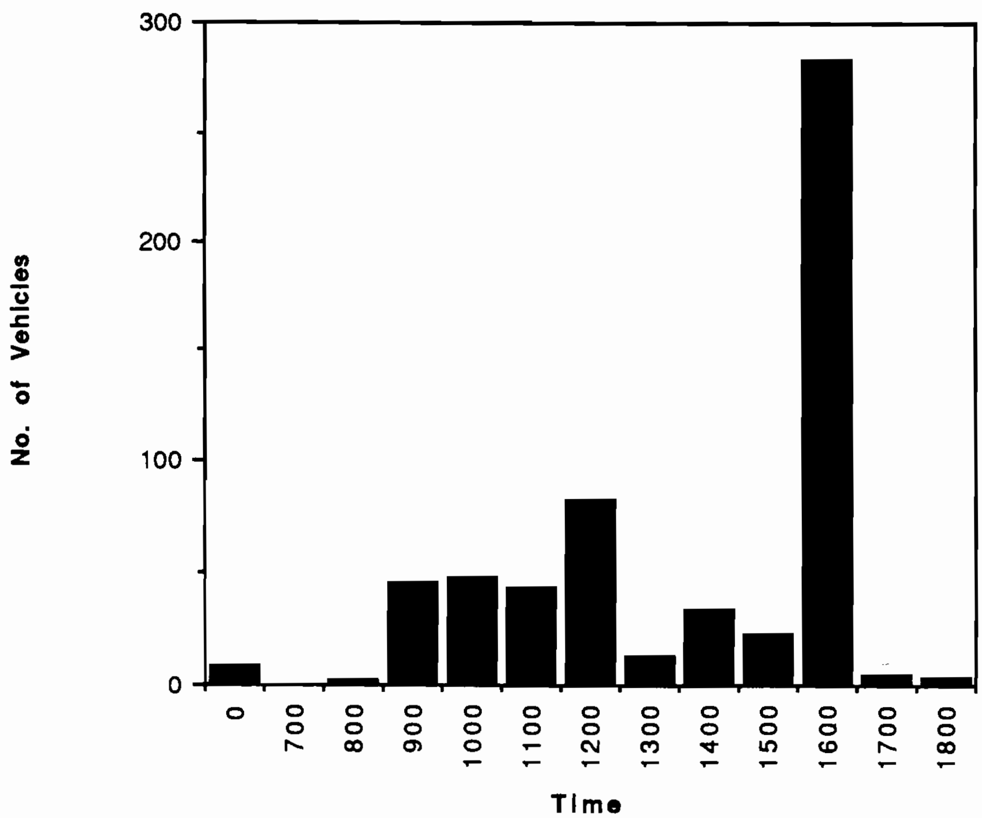

Arr. Distribution Dist.18 '87-'88
No. of Vehicles
500
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

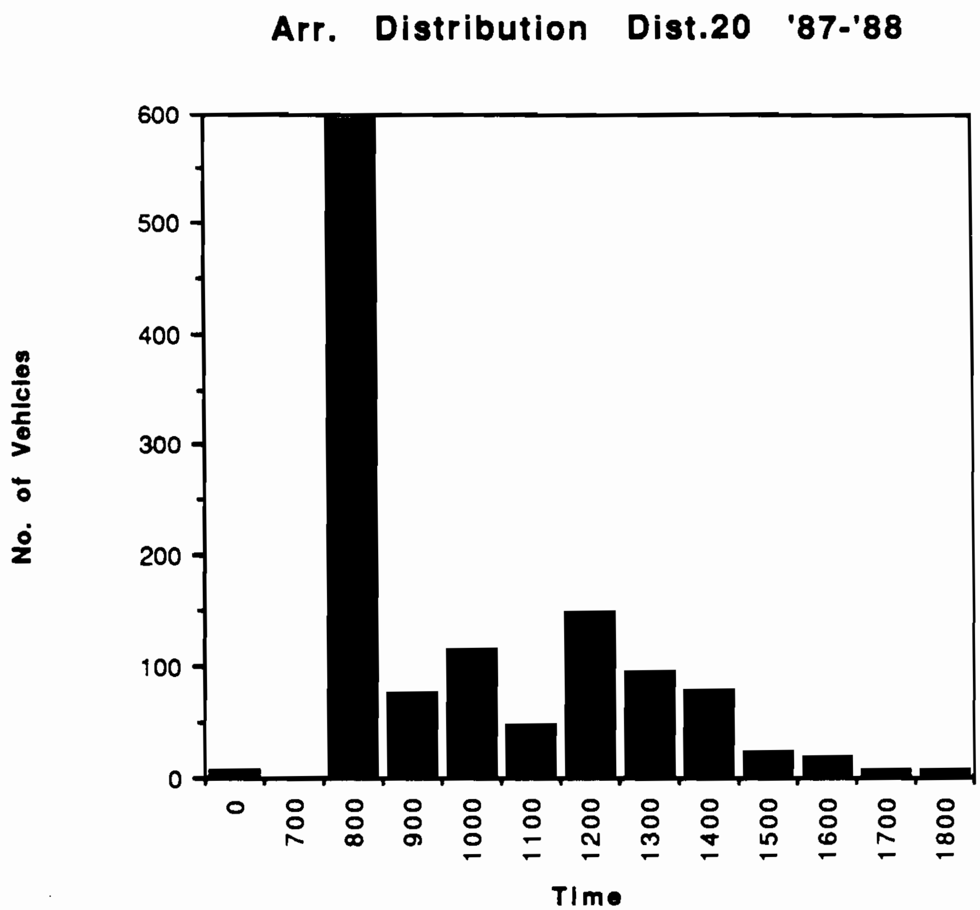

Dep. Distribution Dist.18 '87-'88
No. of Vehicles
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

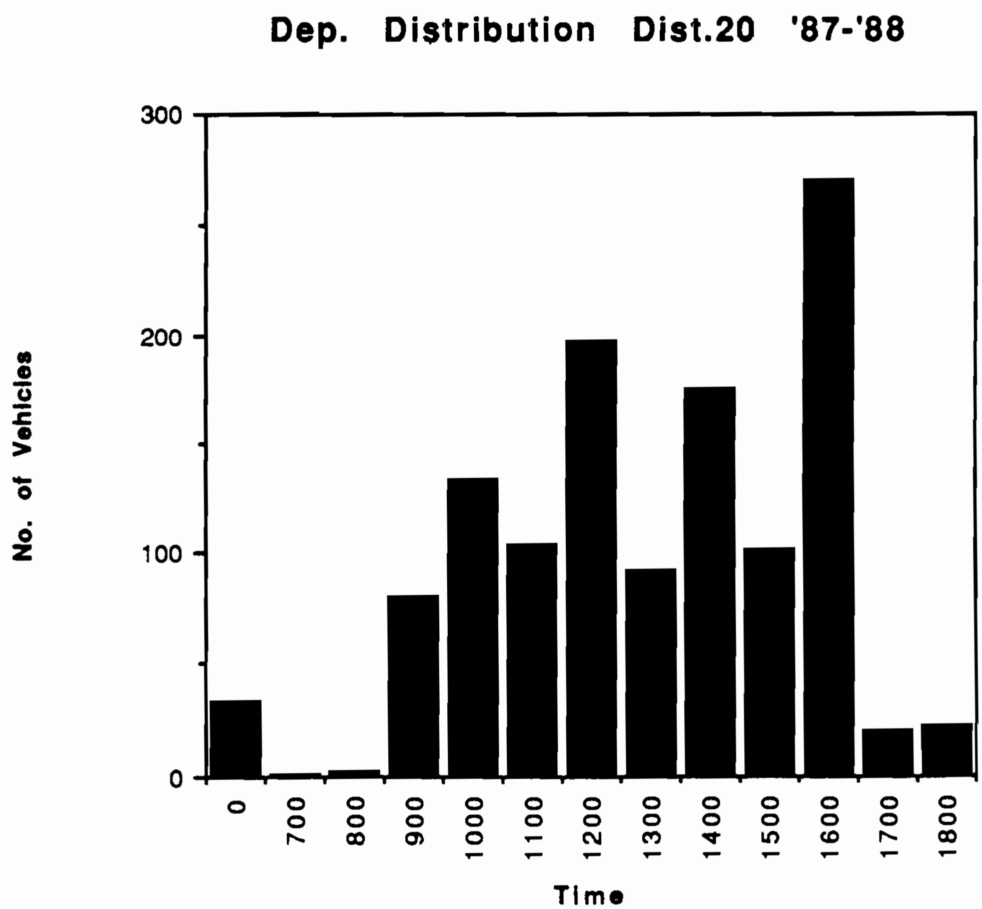
Arr. Distribution Dist.19 '87-'88



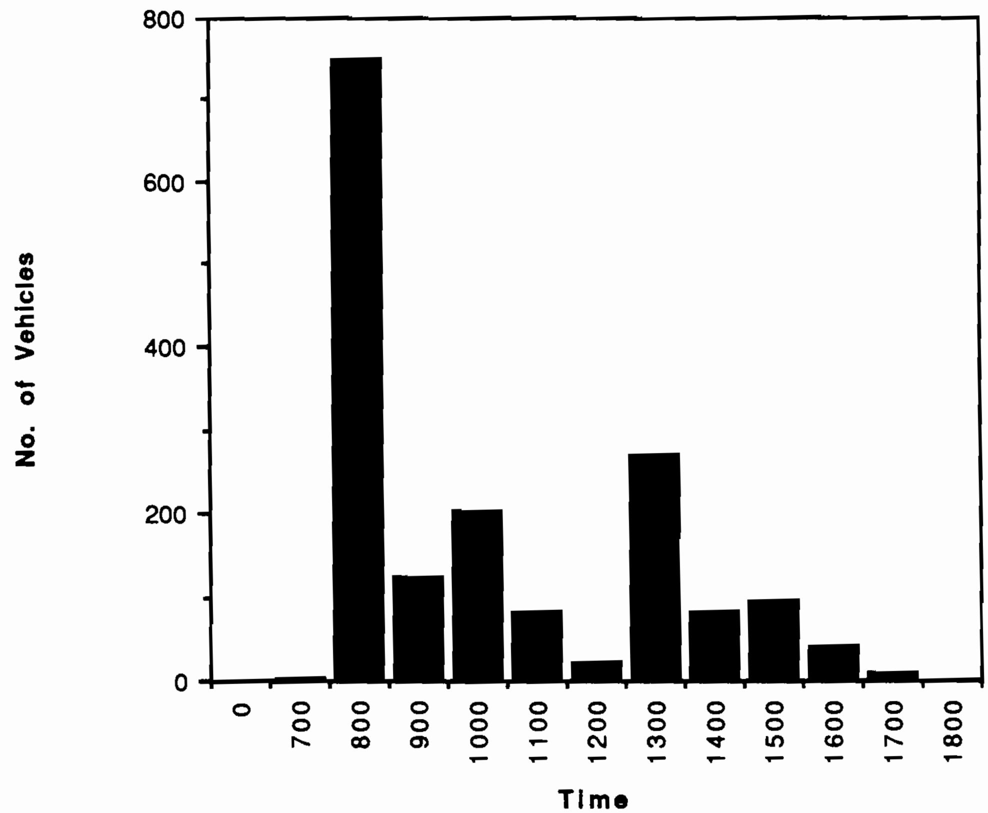
Dep. Distribution Dist.19 '87-'88



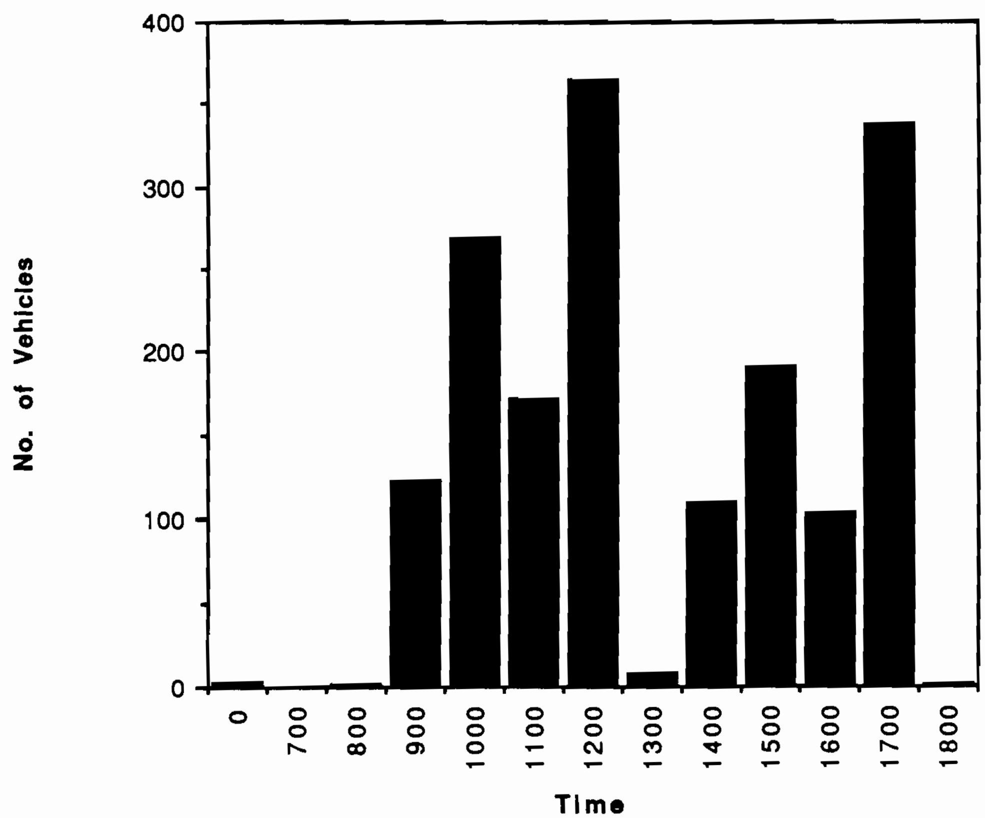

Arr. Distribution Dist.20 '87-'88
No. of Vehicles
600
500
400
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time


Dep. Distribution Dist.20 '87-'88
No. of Vehicles
300
200
100
0
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time

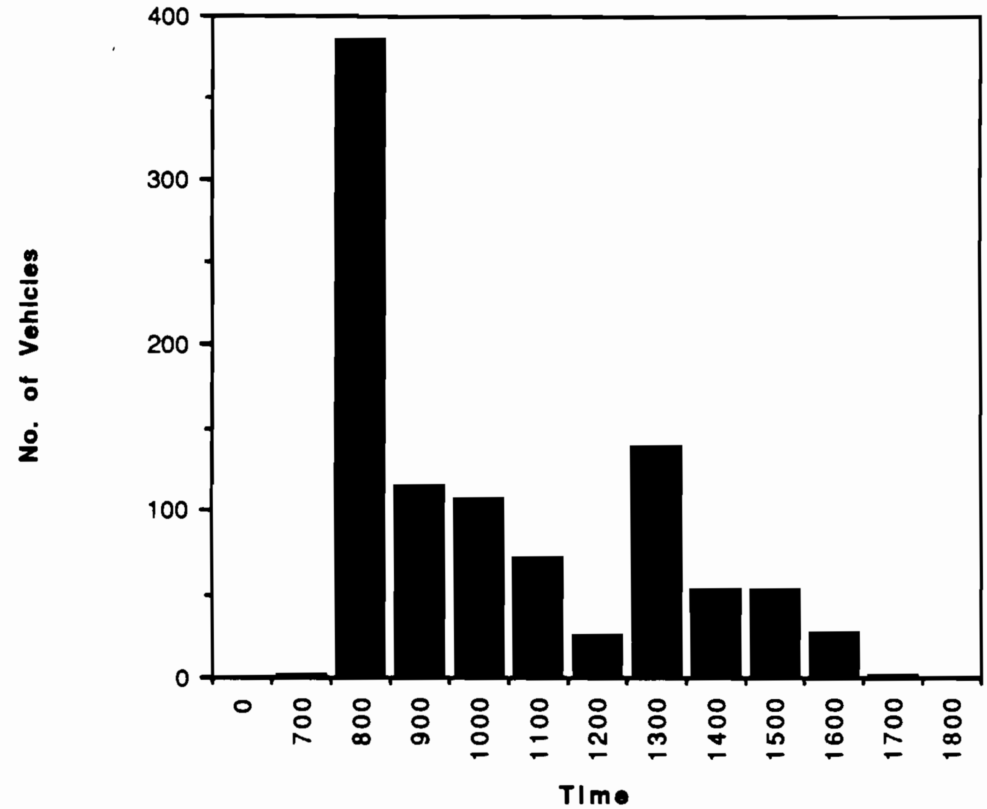
Arr. Distribution Dist.21 '87-'88



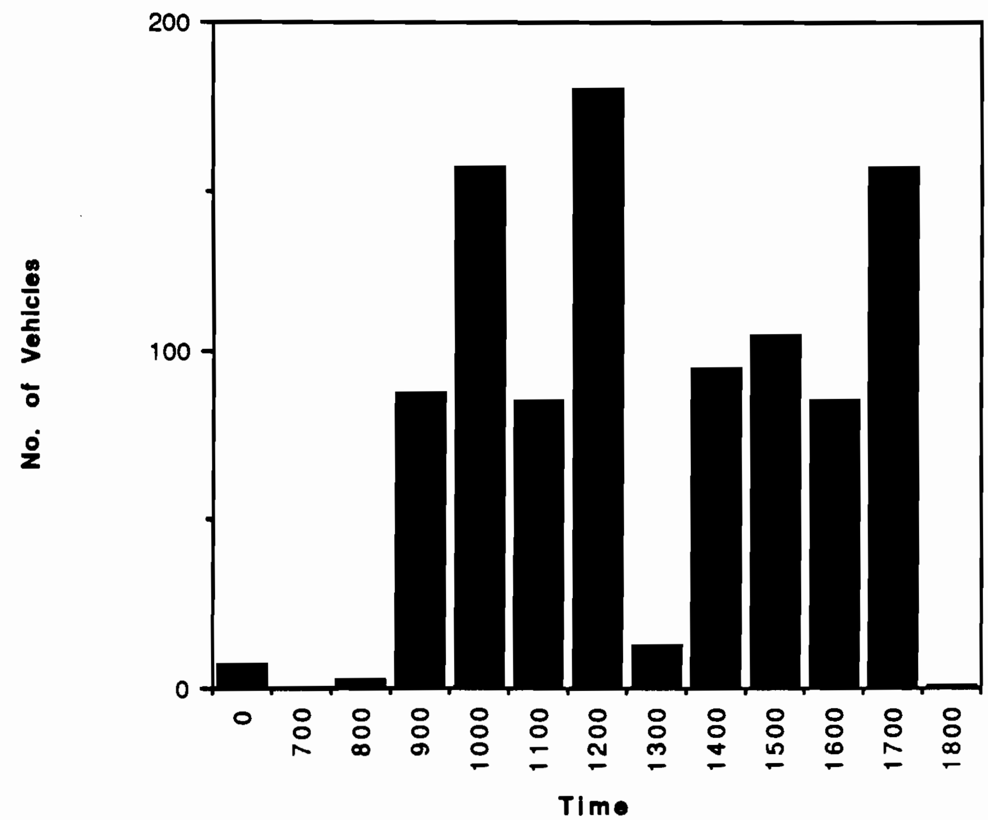
Dep. Distribution Dist.21 '87-'88



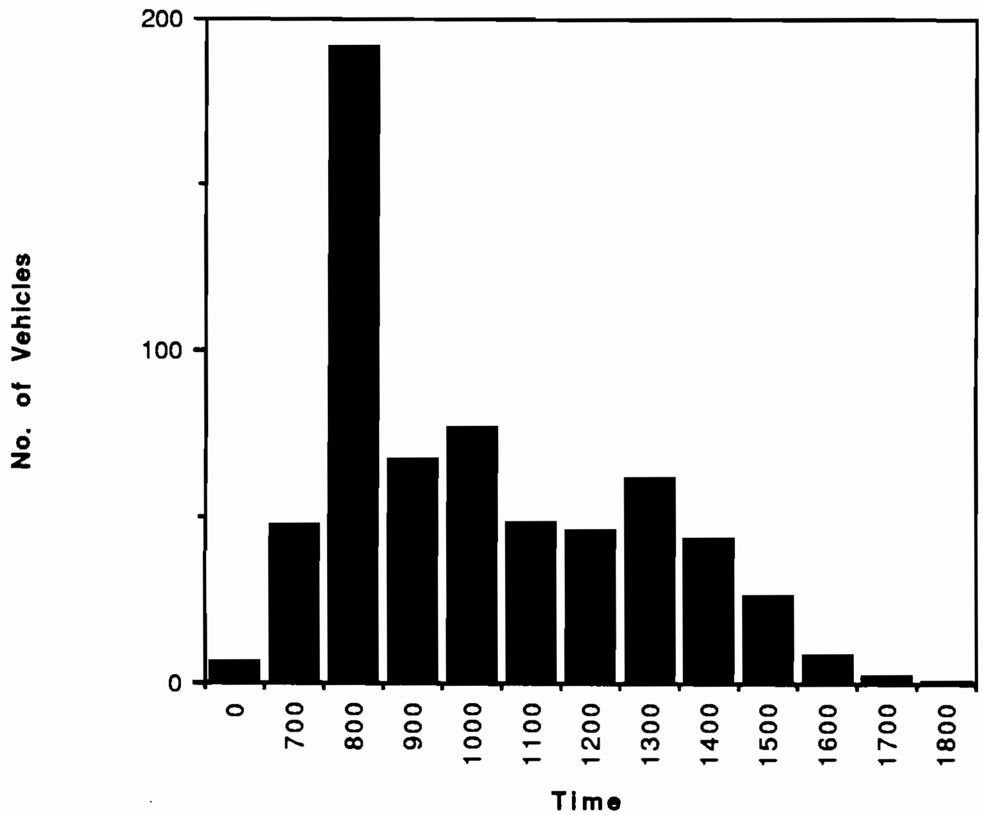
Arr. Distribution Dist.23 '87-'88



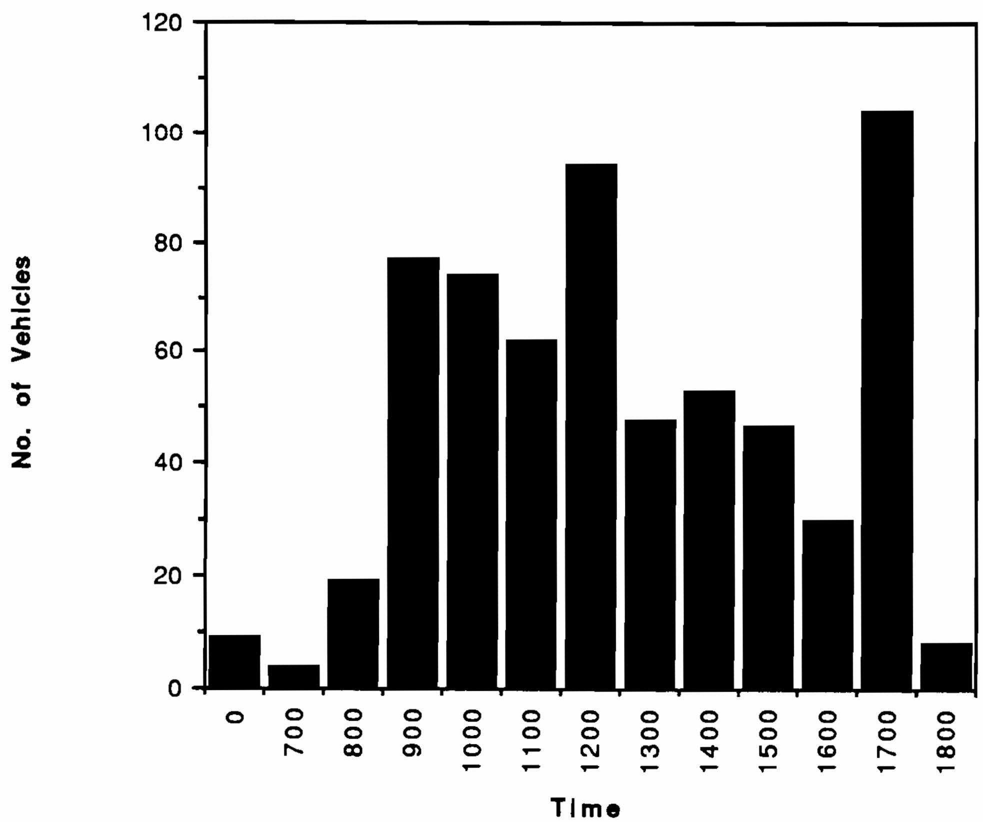
Dep. Distribution Dist.23 '87-'88



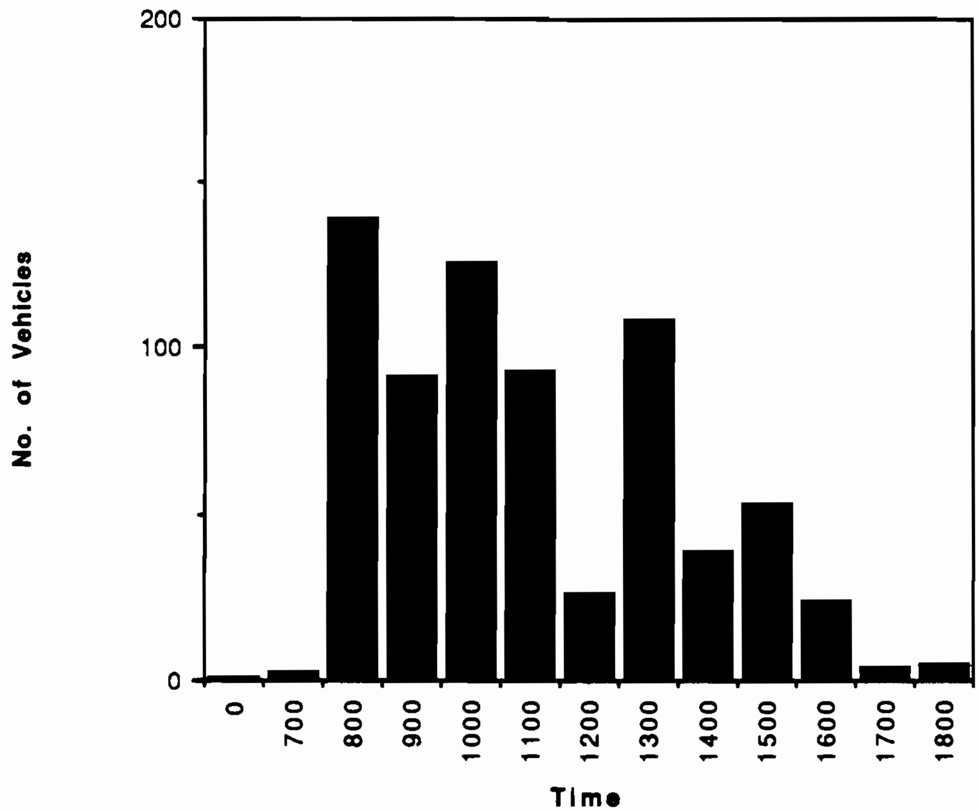
Arr. Distribution Dist.24 '87-'88



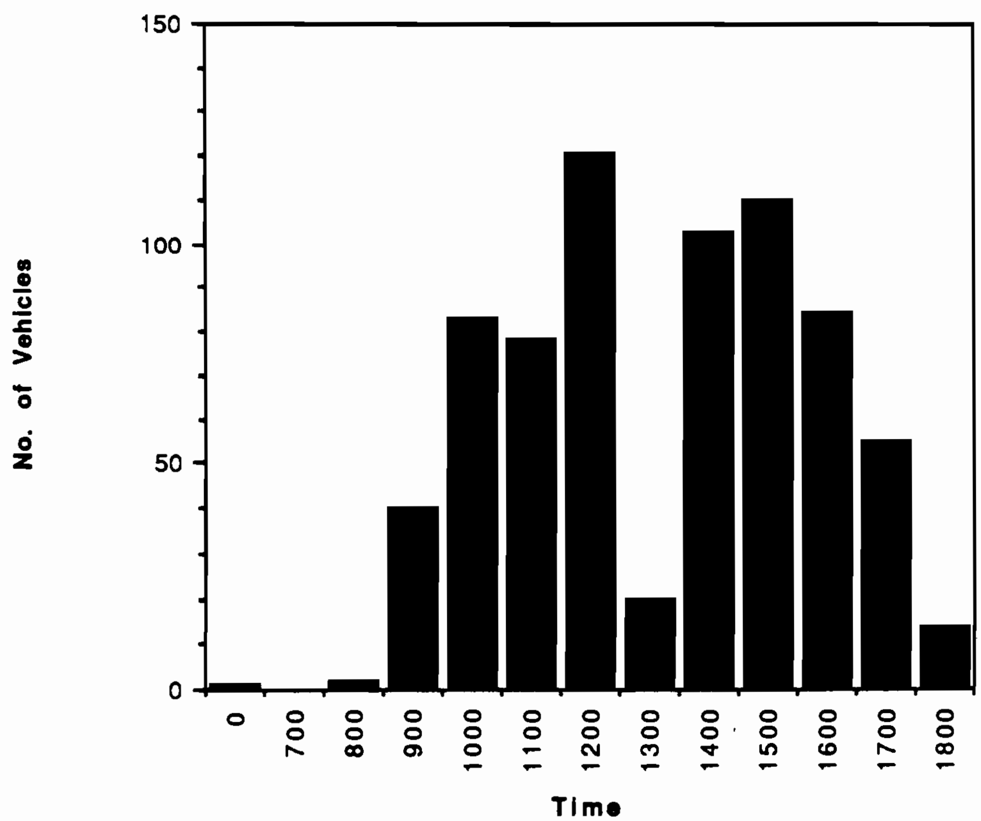
Dep. Distribution Dist.24 '87-'88



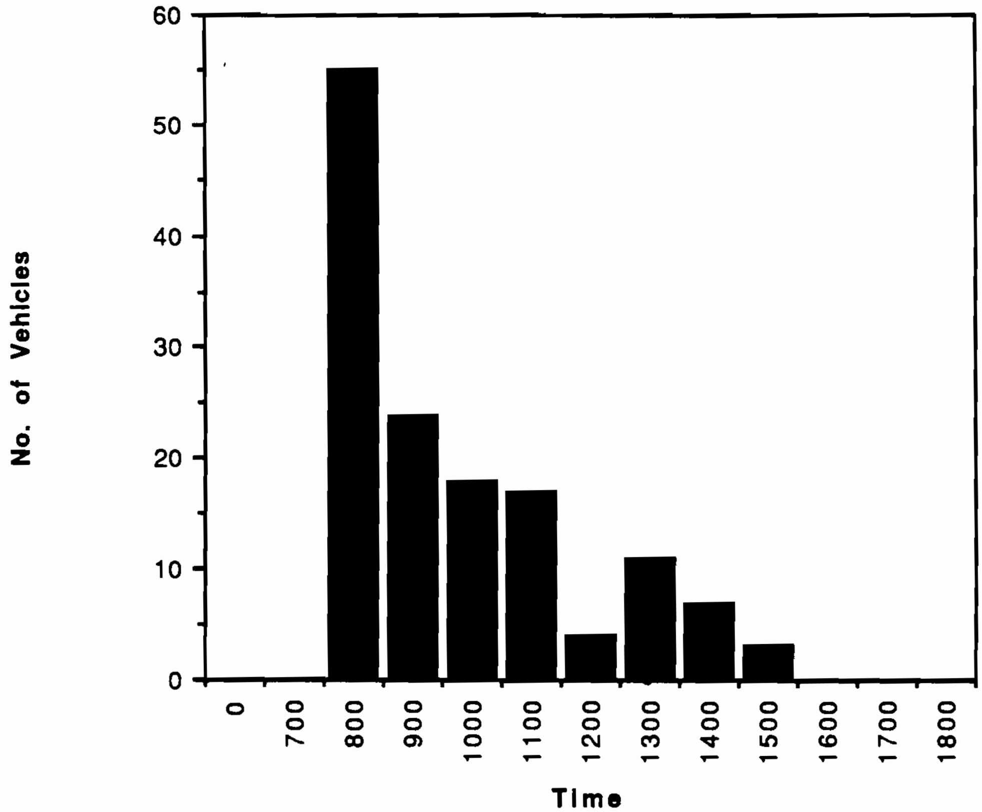
Arr. Distribution Dist.25 '87-'88



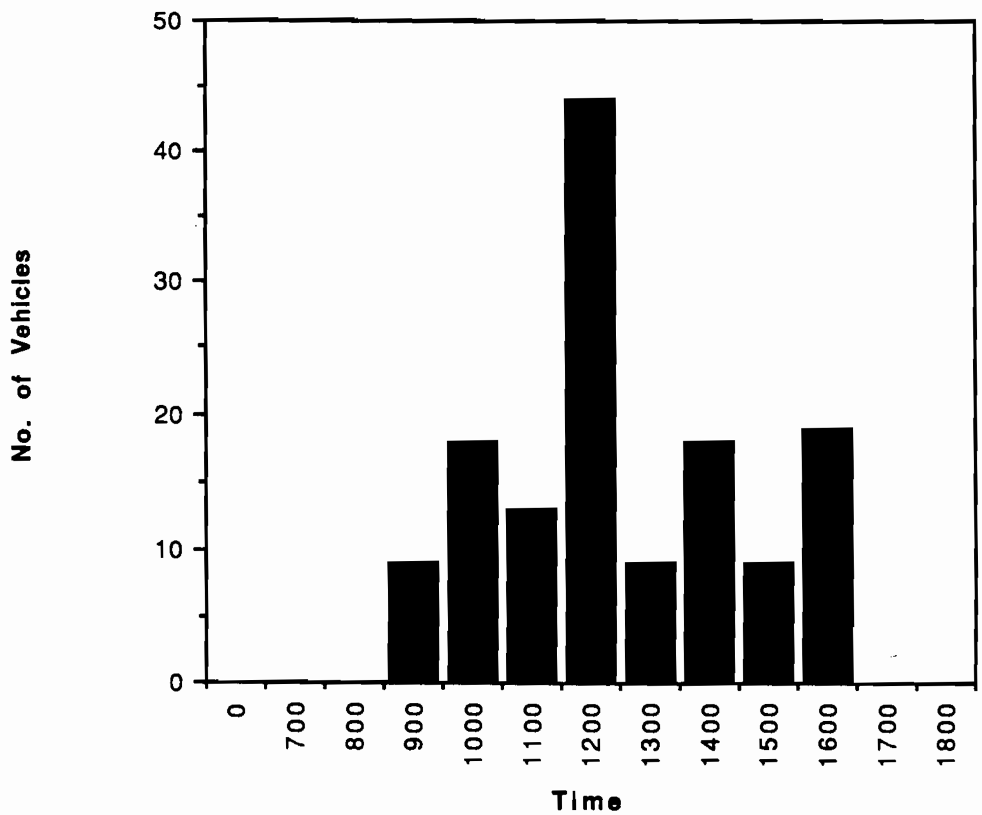
Dep. Distribution Dist.25 '87-'88



Arr. Distribution Dist.29(22?) '87-'88



Dep. Distribution Dist.29(22?) '87-'88



APPENDIX D. EQUIPMENT OPERATING SYSTEM REPAIR REASON/FUNCTION CODES

ARGUMENT VALUES	RESULT VALUES
(001)	(FUEL&OIL-ISSUES&PURCH.)
(002)	(MISC. REPAIR PARTS)
(010)	(PREVENTIVE MAINTENANCE)
(012)	(PM, PERIODIC INSPECTION)
(013)	(PM, ANNUAL INSPECTION)
(014)	(OIL ANALYSIS)
(015)	(STATE INSPECTION)
(016)	(ENGINE DIAGNOSIS AND ANAL)
(017)	(WASHING & CLEANING)
(020)	(ENGINE)
(021)	(ENGINE, HEAD GASKET AND A)
(022)	(ENGINE, BELOW HEAD GASKET)
(023)	(ENGINE, OIL AND FILTER)
(024)	(ENGINE, IGNITION SYSTEM)
(025)	(ENGINE, COOLING SYSTEM)
(026)	(ENGINE, AIR INTAKE SYSTEM)
(027)	(ENGINE, FUEL SYSTEM)
(028)	(ENGINE, EXHAUST SYSTEM)
(029)	(ENGINE, EMISSION CONTROL)
(030)	(TRANSMISSION)
(031)	(TRANSMISSION ASSEMBLY (AU)
(032)	(TRANSMISSION ASSEMBLY (MA)
(033)	(TRANSMISSION, POWER SHIFT)
(034)	(CLUTCH COMPONENTS)

ARGUMENT VALUES	RESULT VALUES
(035)	(PTO AND PTO DRIVESHAFT)
(036)	(LUBRICATION, FLUID AND FI)
(040)	(SPECIAL FUNCTIONAL REP.)
(041)	(MATERIAL BUCKET)
(042)	(BOOMS)
(043)	(CORE DRILL DERRICK & COMP)
(044)	(AERIAL DEVICES/DIGGER DER)
(045)	(PROFILER AND RECLAIMER DR)
(046)	(HEATING SYSTEMS)
(047)	(MOWER, GEARBOXES AND DRIV)
(048)	(COCO PADS/SCRAPERS)
(049)	(AIR COMPRESSORS)
(050)	(ELECTRICAL SYSTEM)
(051)	(ELECTRICAL WIRING)
(052)	(LIGHTS, LAMPS, ETC.)
(053)	(INSTRUMENTS, INCLUD HOUR)
(054)	(WARNING LIGHTS)
(055)	(STARTER)
(056)	(GENERATOR/ALTERNATOR)
(057)	(ARROW BOARDS)
(058)	(BATTERY)
(059)	(ON-BOARD COMPUTER/ANALYZE)
(060)	(BODY, CAB, & CHASSIS)
(061)	(CAB MAINTENANCE)
(062)	(SHEET METAL AND FIBERGLAS)
(063)	(UPHOLSTERY)
(064)	(ROPS)

ARGUMENT VALUES	RESULT VALUES
(065)	(FRAME, WELDING, REPAIRING)
(066)	(STRUCTURAL WORK)
(067)	(AIR CONDITIONER)
(068)	(CAB HEATER)
(069)	(SPEEDOMETER)
(070)	(HYDRAULICS)
(071)	(PUMPS)
(072)	(LINES, HOSES AND PIPING)
(073)	(RESERVOIRS)
(074)	(CYLINDERS)
(075)	(CONTROL VALVES)
(076)	(FILTER)
(077)	(MOTORS)
(078)	(HYDRAULIC DIAGNOSIS & ANA)
(080)	(BRAKES)
(081)	(ADJUSTING BRAKES)
(082)	(BRAKE DRUMS, ROTORS, LINI)
(083)	(BRAKE SYSTEMS AND LINES)
(084)	(BRAKE BOOSTER SYSTEM)
(085)	(MASTER CYLINDER)
(086)	(WHEEL CYLINDERS)
(087)	(AIR COMPRESSOR AND GOVERN)
(088)	(ELECTRIC BRAKES)
(089)	(VALVES)
(090)	(TIRES)
(091)	(TIRE REPLACEMENT, NEW)
(092)	(TIRE REPLACEMENT, RECAP)

ARGUMENT VALUES	RESULT VALUES
(093)	(TIRE AND TUBE REPAIR)
(094)	(BALANCING)
(095)	(TIRE ROTATION)
(096)	(TIRE CHAINS)
(097)	(TUBE REPLACEMENT)
(100)	(WHEELS)
(101)	(WHEEL - RIM REPAIR OR REP)
(110)	(SUSPENSION)
(111)	(FRONT SUSPENSION)
(112)	(REAR SUSPENSION)
(113)	(SHOCK ABSORBERS AND STRUT)
(120)	(STEERING)
(121)	(STEERING LINKAGE)
(122)	(MANUAL STEERING GEAR & SY)
(123)	(POWER STEERING GEAR AND S)
(124)	(HYDRAULIC PUMP SYSTEM)
(125)	(STEERING COLUMN UNIT)
(126)	(ALIGNMENT)
(127)	(STEERING KNUCKLE ASSEMBLY)
(128)	(CONSTANT VELOCITY JOINT)
(129)	(HYDROSTATIC STEERING SYST)
(130)	(AUXILIARY ENGINE)
(131)	(ENGINE, HEAD GASKET AND A)
(132)	(ENGINE, BELOW HEAD GASKET)
(133)	(ENGINE, OIL AND FILTER)
(134)	(ENGINE, IGNITION SYSTEM)
(135)	(ENGINE, COOLING SYSTEM)

ARGUMENT VALUES	RESULT VALUES
(136)	(ENGINE, AIR INTAKE SYSTEM)
(137)	(ENGINE, FUEL SYSTEM)
(138)	(ENGINE, EXHAUST SYSTEM)
(139)	(ENGINE, EMISSION CONTROL)
(140)	(AUXILIARY TRANS. & DRIVE)
(141)	(TRANSMISSION ASSEMBLY)
(142)	(AUXILIARY DRIVE SHAFT)
(143)	(LUBRICATION, OIL AND FILT)
(144)	(AUXILIARY CLUTCH)
(150)	(FINAL DRIVE)
(151)	(SINGLE DRIVE AXLE)
(152)	(TANDEM DRIVE AXLE)
(153)	(AXLE SHAFT REPLACEMENT)
(154)	(PROPELLER SHAFT)
(155)	(UNIVERSAL JOINTS & CARRIE)
(156)	(HYDROSTATIC DRIVE SYSTEM)
(157)	(HYDRAULIC MOTORS)
(158)	(WHEEL HUB, BEARING AND SE)
(159)	(DRIVE CHAINS AND DRIVE BE)
(160)	(NON-DRIVE AXLES)
(161)	(WHEEL HUB, BEARING AND SE)
(170)	(MODS & ATTACHMENTS)
(171)	(MODIFICATIONS)
(172)	(ATTACHMENTS)
(180)	(SPECIAL REP. - NOT COVERE)
(181)	(RADIO)
(182)	(CRUISE CONTROL)

ARGUMENT VALUES	RESULT VALUES
(183)	(COMPLETE PAINT JOB)
(190)	(COMPLETE EQUIP. OVERHAUL)
(200)	(TRACK AND ROLLERS)
(201)	(TRACK REPAIR AND ADJUSTME)
(202)	(LINK REPAIR AND/OR REPLAC)
(203)	(TRUNNIONS)
(204)	(STEEL ROLL (ROLLERS))
(205)	(PADS (GROUSERS, ETC.))
(206)	(DRIVE SPROCKETS)
(207)	(IDLERS AND ROLLERS)
(208)	(TRACK ADJUSTORS)
(209)	(UNDERCARRIAGE REPAIRS & A)
(210)	(BODY, BOX, AND BED REPAIR)
(211)	(DUMP BOX)
(212)	(FLATBED AND STAKE SIDES)
(213)	(UTILITY BODY)
(214)	(TRAILER DECKS)
(215)	(TANKS)
(220)	(WEARING SURFACES)
(221)	(BROOM CORES, WAFERS, ETC.)
(222)	(MOWER BLADES)
(223)	(PLOW AND MOTORGRADER BLAD)
(224)	(SCARIFIER AND RIPPER TEET)
(225)	(AUGER BITS)
(226)	(BUCKET CUTTING EDGE)
(227)	(CUTTING TEETH AND BITS)
(228)	(DIAMOND BLADES)

ARGUMENT VALUES	RESULT VALUES
(229)	(WEAR PLATES &/OR PADS)
(230)	(MATERIAL HANDLING SYSTEMS)
(231)	(SPREADER DRAG CHAINS)
(232)	(SPROCKETS AND SPINNERS)
(233)	(CONVEYOR BELTS AND ROLLER)
(234)	(PUMPS (PAINT, ASPHALT))
(235)	(PAINT AND BEAD GUNS)
(236)	(SPRAY BARS)
(237)	(AUGERS (LAYDOWN MACHINES))
(238)	(STRIPER CONPRESSOR AND PI)
(240)	(ACCIDENT DAMAGE)
(241)	(ACCIDENT DAMAGE, STATE EX)
(242)	(ACCIDENT DAMAGE, REIMB OU)
(243)	(ACCIDENT DAMAGE, REIMB EM)
(244)	(ACT OF GOD)
(250)	(WARRANTY REPAIRS)
(251)	(PICKUP AND DELIVERY)
(252)	(IN-HOUSE & CHARGED BACK)
(260)	(MARINE COMPONENTS)
(261)	(AIR COMPRESSORS)
(262)	(PROPELLOR SHAFT)
(263)	(STUFFING BOX COMPARTMENT)
(264)	(RUDDER COMPARTMENT)
(265)	(RADIO REPAIRS)
(266)	(RADAR REPAIRS)
(267)	(PUMPS)
(268)	(HYDRAULIC RUDDER AND CONT)

ARGUMENT VALUES	RESULT VALUES
(270)	(INSPECTION AND TESTING)
(280)	(MAKE-READY CHARGES)
(290)	(ENHANCEMENTS)