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DEPARTMENT OF COMPUTER SCIENCE
COLLEGE OF SCIENCES
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA 23529

DATA LINK PERFORMANCE ANALYSIS FOR LVLASO EXPERIMENTS

By
Dr. Ravi Mukkamala, Principal Investigator

FINAL REPORT

For the period June 1, 1998 – September 30, 1998

Prepared for
NASA Langley Research Center
Attn.: Mr. R. Todd Lacks, Grant Officer
Mail Stop 126
Hampton, VA 23681-0001

Under
NASA Research Grant NAG-1-2102
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Submitted by
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800 West 46th Street
Norfolk, VA 23508

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1. Introduction

Low-visibility Landing and Surface Operations System (LVLASO) is currently being prototyped and tested at NASA Langley Research Center. Since the main objective of the system is to maintain the aircraft landings and take-offs even during low-visibility conditions, timely exchange of positional and other information between the aircraft and the ground control is critical. For safety and reliability reasons, there are several redundant sources on the ground (e.g., ASDE, AMASS) that collect and disseminate information about the environment to the aircrafts. The data link subsystem of LVLASO is responsible for supporting the timely transfer of information between the aircrafts and the ground controllers. In fact, if not properly designed, the data link subsystem could become a bottleneck in the proper functioning of LVLASO. Currently, the other components of the system are being designed assuming that the data link has adequate capacity and is capable of delivering the information in a timely manner.

During August 1-28, 1997, several flight experiments were conducted to test the prototypes of subsystems developed under LVLASO project. The background and details of the tests are described in the next section. The test results have been collected in two CDs by FAA and Rockwell-Collins. Under the current grant (NAG-1-2102), we have analyzed the data and evaluated the performance of the Mode S datalink.

In this report, we summarize the results of our analysis. Much of the results are shown in terms of graphs or histograms. The test date (or experiment number) was often taken as the X-axis and the Y-axis denotes whatever metric of focus in that chart. In interpreting these charts, one need to take into account the vehicular traffic during a particular experiment.

In general, the performance of the data link was found to be quite satisfactory in terms of delivering long and short Mode S squitters from the vehicles to the ground receiver. Similarly, its performance in delivering control messages from the ground control to the vehicles (aircrafts) was also satisfctory.

The report is organized as follows. In Section 2, we describe the background information for the LVLASO and the system flight experiments. Section 3 contains formats of the performance data that was analyzed during our research. Section 4 describes different experiments flight experiments and their setup. Section 5 analyzes each of the graphs produced in this report. Finally, Section 6 has a summary of observations that we make based on our research.

2. Background

The NASA TAP (Terminal Area Productivity) program is focused on providing technology and operating procedures to obtain clear-weather capacity in instrument-weather conditions at airports, while also improving safety. The goal of the Low Visibility Landing and Surface Operations (LVLASO) System Flight Experiment is to meet a Level I milestone of the TAP program. This was accomplished by:

1. Demonstrating a prototype LVLASO system to relevant stakeholders

2. Validating selected simulation findings and operational concepts
3. Assessing the performance and suitability of the prototype as compared to:
    - The draft operational requirements of the Advanced Surface Movement Guidance and Control System(A-SMGCS)
    - The requirements of NASA's conceptual LVLASO system.

The LVLASO System Flight Experiment was conducted at Atlanta's Hartsfield International Airport (ATL). This experiment brought together government and industry partners from NASA, the FAA, Rockwell Collins, Cardion, Project Management Enterprises, Volpe Center, Trios Associates, and St. Cloud University. These partners have each contributed to the LVLASO system development.

LVLASO is investigating technology to improve the safety and efficiency of aircraft movements on the surface movement area during the operational phases of landing, roll-out, turnoff, inbound taxi, outbound taxi, and takeoff. The prototype LVLASO system will provide enhanced guidance and situational awareness information to the flight crew. This will be done through a head-up display (HUD) and a head-down LCD airport map. These displays will be integrated with onboard sensors and datalinks, as well as ground subsystems to provide relevant surface data. These displays will operate in one of two modes: (1) during high-speed roll-out and runway exit, the Roll-Out Turn-Off (ROTO) display symbologies will be engaged; (2) during taxi, the Taxi Navigation and Situational Awareness (T-NASA) displays will be engaged. NASA will provide a Boeing 757 equipped with the prototype HUD and head-down LCD airport map. The 757 will also be equipped with an Extended Mode-S transponder unit.

The LVLASO ground system that supports the onboard system of the 757 is a combination of both proven and prototype systems. It includes the following elements:**ATIDS/CAPTS** - provides surveillance(position and ID) of aircraft and ground vehicles equipped with 1090MHz ADS-B and MODE A/C/S transponders. Interfaces implemented by Cardion and the FAA.

- **ASDE-3** radar - provides surveillance(position only) of all aircraft or vehicles operating on the airport surface movement area. Interfaces implemented by the FAA.
- **AMASS** - provides:
    - tracking of ASDE-3 targets
    - data fusion of ATIDS target data with ASDE-3 track data and ADS-B reports from the 757 to improve accuracy and reliability of surveillance data
    - safety logic to detect runway incursions.
        - Interfaces implemented by the FAA.
- **DGPS reference** - provides differential correction determination for navigation and surveillance. Implemented by Rockwell-Collins.
- **Datalink manager** - provides:
    - traffic data and runway status to the 757 aircraft. Implemented by Project Management Enterprises and Rockwell-Collins.

    - differential corrections to the 757 aircraft and any other GPS-equipped vehicles. Implemented by Project Management Enterprises and Rockwell-Collins.
    - ATC instructions and flight crew acknowledgments. Provided by Cardion and the FAA.
- **ARTS** - provides ASR-9 radar position/ID of airborne aircraft near the airport. Interfaces implemented by Cardion and the FAA.
- **Controller Interface(CI)** - allows a test controller to mimic normal voice instructions in parallel, and then transmit these instructions digitally for display in the flight deck of the 757. Implemented by St. Cloud State University.
- **GPS survey system** - collects DGPS data independently during the test. This data will be post-processed to provide an accurate "truth" position data. Provided by NASA.
- **Video telemetry system** - the ground components of the video telemetry system allowing observation of in-flight activities from the ground. Provided by NASA.

To verify the functionality of the these systems, two additional mobile units were utilized. A van provided by Rannoch Corporation was equipped with the following equipment:

- **ATIDS Receiver/Transmitter unit** - provide the capability to receive ADS-B transmissions from the aircraft's ADS-B unit.
- **Mobile Master Workstation** - record ADS-B transmissions received by the ATIDS Receiver/Transmitter.

A van provided by Trios Associates, Inc. was equipped with an Extended Mode-S transponder unit. This unit contains a Mode-S radio, GPS receiver, and an air datalink processor. The Mode-S transponder is provided by the FAA.

To analyze the outcome of the planned testing of the LVLASO system at ATL, aircraft state data and datalink data was electronically recorded for post-processing. Audio data was recorded to capture pilot comments regarding the LVLASO system. All surveillance data was recorded at the ground stations.

The LVLASO system tests were performed both during the day and at night. A majority of the tests are scheduled at night to best approximate low visibility conditions. A variety of tests were performed during two separate testing sessions at ATL. These sessions took place from August 1-7 and August 18-23. These tests included different combinations of test vehicles(vans/plane) and a variety of surface movements and flight patterns. There were ten test variables:

- TOD = D (day), N (night)
- HUD = Y (on), N (off)
- LCD = Y (installed), N (not installed)
- Left Seat = Gn (guest pilot n), Nn (NASA pilot n) (left seat pos)
- Cycle = Y (takeoff, circle, land), N (taxi only)
- Route Track= Y (follow taxi route), N (deviate from taxi route as instructed)
- Traffic = P (near-peak conditions), Q (non-peak conditions)

- Surv = A (ASDE radar), F (sensor fusion)
- AFDS = A (autoland), F (manual) (autopilot flight director station mode)
- PID Exit = A, MHI, MLO

The tests have been defined based on the goals of the testing and constraints placed on the deployment in terms of time and operational costs. There are 64 total tests, with 59-64 being optional. Here is a summary of the tests:

- 24 tests include flight (18 night, 6 day)
- 34 taxi-only tests (18 night, 16 day)
- 24 tests include ROTO (6 day, 18 night)
- 58 tests include T-NASA (22 day, 36 night)
  - 24 tests do not use the HUD (12 day, 12 night)
  - 30 tests do not use the map LCD (6 day, 24 night)
  - 16 use both HUD and LCD (10 day, 6 night)
- 4 guest pilots will be used. Each will perform 9 tests.
- NASA pilots would perform 22 tests (11 each for two NASA pilots) from the left seat.

3. Data Formats

In this section, we have included the formats of the performance data that we used to analyze the data link performance. The data as well as the formats are available in two CDs (one from FAA and one from Rockwell-Collins).

3.1 ATIDS Input File Format

The following is the format of a typical input data string:

ID$, ModeA$, FlghtID$, TailNo$, time#, MEast#, MNorth#, MHeight#, mvalid!, Multtype$, Multresl$, Retries, NoSol3d, San3d, NoSol2d, San2d, tqused$, RxselRank$, RTdetect$, Mergeflag!, Geast#, Gnorth#, gvalid!, GPSresl$, ModeC#, ModeCtime#, GroundBit!, Teast#, Tnorth#, Talt#, EastVel#, NorthVel#, quality!, status!, trkStatus!, intend!, SanityR#, Statdist#

The following is a description of the data that is recorded during an input extraction when using the MWS15a MasterWorkstation software version.

The top of the file contains two lines that are used for text input prior to extraction of the file. This is followed by the system configuration settings during the extraction. These are defined by the letter "C" at the first position of each line. The number of lines that describe the system settings can vary depending on the site parameters. Though this file has 58 lines of system settings the number will be different if for example the number of W/S steps was increased.

C Test file extraction C 2/13/95 C ----- SITE PARAMS ----- C RT_count= 3 C RT 0 east= -2969.2 north= -2931.1 height= 75.0 C retry_time= 17c417c4 status= 17c4 retry_count= c4 mtl= 23 C RT 1 east= 1913.4 north= 4494.3 height= 100.0 C retry_time= 17c417c4 status= 17c4 retry_count= bf mtl= 23 C RT 2 east= 2910.4 north= -2852.7 height= 148.0 C retry_time= 47614770 status= 4772 retry_count= 61 mtl= 71 C ref lat=

39.5 lon= -74.6 C max range= 20.0 C ref xponder east= -2375.4 north= -526.4 alt= 140 C ref xponder ModeS= 20c0 ModeA= 3335 C region 0 start east= -1000.0 north= -1000.0 stop east= 1000.0 north= 1000.0 C region 1 start east= 0.0 north= 0.0 stop east= 0.0 north= 0.0 C rcvr file= rcvr.sel C ----- ATMOSPHERE PARAMS ----- C baro pressure= 28.0 alt correct= -1800.0 trans alt= 1000 C ----- SYSTEM PARAMS ------ C format version= 12345678 date= Jan 26 1995 time= 11:25:03 C stars pair tol= 0.6 us valid spacings:125 175 us C whisper s forced_rt= TRUE rt_to_use= 0 rate= 2.000000 C whisper s num_steps= 2 delay time= 1 ms window time= 8 ms C whisper s def pair spacing= 130 alt= 135 usec toggle= FALSE enable= TRUE C whisper s step 0 p1_p3_p4= 54 s1= 55 mtl=-78 C whisper s step 1 p1_p3_p4= 53 s1= 54 mtl=-77 C multilat accuracy= 10.0 max_iter= 100 mode= MULTILAT C multilat forced_triad_enable= FALSE forced_triad= 0 in english= 012 C filter_data max_alt= 0.0 uf= 16 ID1= 0 ID2= 0 enables = FALSE FALSE FALSE FALSE C ref_rt= 0 C format filter= DF 11 ATCRBS C region 0 uf= 11 df= 11 rate= 0.4 enable= FALSE C region 0 message= AABBCCDDEEFF77 C region 1 uf= 11 df= 11 rate= 1.0 enable= FALSE C region 1 message= FFEEDDCCBBAA23 C broadcast data: rate= 1.0 power= 54 dBm uf= 21 rt= 0 C all call data: rate= 1.0 power= 54 dBm rt= 0 C dgps data: power= 54 dBm rt= 1 num_times_to_send= 2 diversity= TRUE C altitude uplink data: tentative rate = 0.1 normal rate = 0.1 C altitude uplink data: enable= FALSE uf= 4 df= 4 C identity uplink data: rate = 0.1 enable= FALSE uf= 5 df= 5 C forced rt data: enable= FALSE rt= 0 C range reset data: enable= FALSE rt_offset = 100 interval= 10 s C max_echo_wait_interval= 100 msec retries= 5 C interrogator id 2 C mode S select mode target ID= 000000 C coast interval= 1500 msec C init criteria m= 4 n= 8 drop criteria= 6 mask= 3f C tracker enable= TRUE C uplink operating range= 300000.0 C capts mode= NONE user= MWS C dgps enable= FALSE C num_regions_enabled= 1 C cleanup_cluster_age= 30 msec cleanup_degen_cluster_age= 25 msec C downlink retry interval= 80 msec C max_tentative_time= 5000 msec C max_select_tries= 4 max_region_tries= 2 C listen delay= 0 msec window= 8 C capts_display_filter_enable= FALSE D 8384 0 27 3417516617 414847 2 1 58 00 20 c0 00 00 00 D 3039 2073 0 3494882015 415623 1 0 D 8384 0 27 3512547983 415798 0 1 58 00 20 c0 00 00 00 Ua 21 415799 1 58 00 20 c0 00 00 00

Right after the last line of system parameters the input primitive reports are stored. This file at operator request can record information on uplinks (broadcast, region, automatic altitude, automatic ID). The data for each report has the following information. **D** - Line designation (**D** - downlink, **G** - DGPS broadcast, **Ua** - Altitude Uplink, **Ui** - ID Uplink, **Ur0** - Region 0 Uplink, **Ur1** - Region 1 Uplink) **8384** - Target ID in decimal (1235 in Octal) This happens to be an ATCRBS report **0** - Target reported altitude (grey code) **27** - Target Type (**0** - ATCRBS time spacing 125 microseconds, **1** - ATCRBS time spacing 130 microseconds, **2** - ATCRBS time spacing 135 microseconds, ..., **14** - ATCRBS time spacing 195 microseconds, **15** - ATCRBS time spacing 200 microseconds, **16** - Mode S DF = 0 or UF 0, **20** - Mode S DF = 4 or UF 4, **21** - Mode S DF = 5 or UF 5, **27** - Mode S DF = 11 or UF 11, **32** - Mode S DF = 16 or UF 16, **33** - Mode S DF = 17 or UF 17, **36** - Mode S DF = 20 or UF 20, **37** - Mode S DF = 21 or UF 21 **3417516617** - 10 nanosecond time stamp (32 bits) **414847** - MWS Log time in Milliseconds **2** - R/T # (source of reply) **1** - Confidence bit **58 00 20 c0 00 00 00** - Mode S message (if Mode S target type otherwise empty) If line designation is one of the uplinks formats then the data in each line will be the following: **Ua** - Line Designation (see above for explanation) **21** - Target Type (see above for explanation this would be UF 5) **415799** - MWS time log of interrogation **1** - R/T # (source of interrogation) **28 00 20 c0 00 00 00** - Mode S Uplink message

3.2 ATIDS Output File Format

The following is the format of a typical output data string:
ID$, ModeA$, FlghtID$, TailNo$, time#, MEast#, MNorth#, MHeight#, mvalid!, Multtype$, Multresl$, Retries, NoSol3d, San3d, NoSol2d, San2d, tqused$, RxselRank$, RTdetect$, Mergeflag!, Geast#, Gnorth#, gvalid!, GPSresl$, ModeC#, ModeCtime#, GroundBit!, Teast#, Tnorth#, Talt#, EastVel#, NorthVel#, quality!, status!, trkStatus!, intend!, SanityR#, Statdist#
The following is a description of the data that is recorded during an output extraction when using the MWS16f Master Workstation software version.
The top of the file contains the system configuration settings during the extraction. These are defined by the letter "C" at the first position of each line. The number of lines that describe the system settings can vary depending on the site parameters. Though this file has 58 lines of system settings the number will be different if for example the number of W/S steps was increased.
C ----- SITE PARAMS ----- C RT_count= 5 C RT 0 east= 3147.3 north= 1209.4 height= 1045.0 C retry_time= 17201720 status= 1720 retry_count= b3 mtl= -68 C RT 1 east= 7001.5 north= 3922.2 height= 1050.0 C retry_time= 20174d17 status= 7017 retry_count= 17 mtl= -68 C RT 2 east= 25.6 north= 4853.1 height= 1150.0 C retry_time= 176e1761 status= 1763 retry_count= 65 mtl= -68 C RT 3 east= -5524.9 north= 4639.6 height= 1070.0 C retry_time= 74176517 status= 2017 retry_count= 17 mtl= -68 C RT 4 east= -1708.6 north= 1030.2 height= 1138.0 C retry_time= 74176517 status= 2017 retry_count= 17 mtl= -74 C ref lat= 33.6 lon= -84.4 C ref xponder east= -227.1 north= 4847.7 alt= 1150.0 C ref xponder ModeS= 808080 ModeA= 10000 C region 0 start east= -1000.0 north= -1000.0 stop east= 1000.0 north= 1000.0 C region 1 start east= 0.0 north= 0.0 stop east= 0.0 north= 0.0 C rcvr file= atl100.RWO C baro pressure= 30.0 alt correct= 100.0 trans alt= 10000 C ----- SYSTEM PARAMS ------ C stars pair tol= 0.6 us valid spacings: us C whisper s forced_rt= TRUE rt_to_use= 0 rate= 1.000000 C whisper s num_steps= 1 delay time= 10 ms window time= 20 ms C whisper s def pair spacing= 185 alt= 195 usec toggle= FALSE enable= FALSE C whisper s step 0 p1_p3_p4= 54 s1= 55 mtl=-78 C multilat max_iter= 5 mode= 2D C multilat solution range cutoff = -3.0 nmi C multilat forced_tuplet 0 enable= FALSE is_3d= FALSE C triad= 0 in english= 012 quartet= 6 in english= 0123 C multilat disregard_tuplet 0 enable= FALSE is_3d= FALSE C triad= 0 in english= 012 quartet= 6 in english= 0123 C multilat forced_tuplet 1 enable= FALSE is_3d= FALSE C triad= 0 in english= 012 quartet= 6 in english= 0123 C multilat disregard_tuplet 1 enable= FALSE is_3d= FALSE C triad= 0 in english= 012 quartet= 6 in english= 0123 C multilat forced_tuplet 2 enable= FALSE is_3d= FALSE C triad= 0 in english= 012 quartet= 6 in english= 0123 C multilat disregard_tuplet 2 enable= FALSE is_3d= FALSE C triad= 0 in english= 012 quartet= 6 in english= 0123 C multilat forced_tuplet 3 enable= FALSE is_3d= FALSE C triad= 0 in english= 012 quartet= 6 in english= 0123 C multilat disregard_tuplet 3 enable= FALSE is_3d= FALSE C triad= 0 in english= 012 quartet= 6 in english= 0123 C multilat forced_tuplet 4 enable= FALSE

is_3d= FALSE C triad= 0 in english= 012 quartet= 6 in english= 0123 C multilat disregard_tuplet 4 enable= FALSE is_3d= FALSE C triad= 0 in english= 012 quartet= 6 in english= 0123 C mode_s_filter_data id = a4806f enables = TRUE FALSE C ref_rt= 2 C format filter= DF 11 DF 17 Unknwn Md S C region 0 uf= 11 df= 11 rate= 0.4 enable= FALSE C region 0 message= AABBCCDDEEFF77 C region 1 uf= 11 df= 11 rate= 1.0 enable= FALSE C region 1 message= FFEEDDCCBBAA23 C broadcast data: rate= 1.0 power= 54 dBm uf= 21 rt= 0 C all call data: rate= 1.0 power= 54 dBm rt= 0 C dgps data: power= 54 dBm rt= 1 num_times_to_send= 2 diversity= TRUE C altitude uplink data: tentative rate = 0.2 normal rate = 0.2 C altitude uplink data: enable= FALSE uf= 4 df= 4 C identity uplink data: rate = 0.1 enable= FALSE uf= 5 df= 5 C forced rt data: enable= FALSE rt= 0 C range reset data: enable= FALSE rt_offset = 120000 interval= 1800 s C max_echo_wait_interval= 300 msec retries= 2 C interrogator id 2 C mode S select mode target ID= 000000 C coast interval= 2000 msec C init criteria m= 4 n= 8 drop criteria= 6 mask= 3f C tracker enable= TRUE C uplink operating range= 300000.0 C capts mode= NONE user= MWS C dgps enable= TRUE C num_regions_enabled= 0 C cleanup_cluster_age= 70 msec cleanup_degen_cluster_age= 35 msec C downlink retry interval= 80 msec C max_tentative_time= 5000 msec C max_select_tries= 4 max_region_tries= 2 C listen delay= 0 msec window= 10 C capts_display_filter_enable= FALSE 111111, 0, COLLINS, , 1868224, -132.4, 4877.6, 1000.4, 1, 3D, 2_SOL, 1, 0, 0, 0, 0, 1234, 1, 1f, 1, -137.4, 4836.7, 1, G_NOTYP, 0.0, 0, 0, -138.3, 4839.0, 1000.4, -0, -1, 4, 3, 3, 0, 2.2e+003, 8.5e+000 **111111**, - Target ID (Mode S or Mode A) in Hex. Mode A code will be scrambled. **0**, - Mode A code unscrambled (OCTAL) **COLLINS**, - Flight Identification , - Tail Number (If available, otherwise a blank space) **1868224**, - MWS Log time in Milliseconds **-132.4**, - Multilateration East coordinate calculation in feet **4877.6**, - Multilateration North coordinate calculation in feet **1000.4**,- Multilateration Height coordinate calculation in feet (if 3D was used) **1**, - Multilateration quality (1 = valid report, 0 = not valid report) **3D**, - Algorithm used for multilateration calculation (2D, 3D or --) **2_SOL**, - How many position solutions the algorithm used determined (2_SOL, 1_SOL, 0_SOL, COAST, 0-TRI) **1**, - # of position calculations attempted **0**, - # of 3D position calculation attempted which had no solution **0**, - # of 3D position calculation attempted which failed sanity window **0**, - # of 2D position calculation attempted which had no solution **0**, - # of 2D position calculation attempted which failed sanity window **1234**, - Receiver triad/Quartet used for final position calculation **1**, - Priority of triad/quartet used in receiver selection table (1 = highest accuracy) **1f**, - Receiver reporting bit map (1f in hex means all 5 R/Ts detected) **1**, - Merge flag (1 - means that one or more corrupted reports were recovered in this report **-137.4**, - GPS or DGPS East position in feet **4836.7**, - GPS or DGPS North position in feet **1**, - GPS or DGPS quality (1 = valid report, 0 = not valid report) **G_NOTYP**, - GPS result **0.0**, - Mode C altitude in feet (if available) **0**, - Mode C altitude time (last time that valid Mode C was received) **0**, - Ground Bit (1 - yes, 0 - no) Indication that airplane is on the ground **-138.3**, - Tracker East position in feet **4839.0**, - Tracker North position in feet **1000.4**, - Tracker altitude position in feet **-0**, - East velocity (ft/sec) **-1**, - North velocity (ft/sec) **4**, - Tracker Quality flag [data used for updating tracker] (0=coast, 1=bad, 2=Mult, 3=GPS, . 4=DGPS) **3**, - Track Status (0=drop track, 1=Tentative, 2=Initial, 3=Firm) **3**, - Track state (0=No position, 1=First report, 2=Second report, 3=Positional Velocity) **0**, - Track Intend

(0 - level, 1 = Maneuver) **2.2e+003**, - Sanity Window radius **8.5e+000** - Statistical distance (squared) .

3.3 Rockwell-Collins Data Format

This data is collected by the ARINC datalogger on the NASA aircraft. It has the following format (e.g., r057r49.dat).

```
0123456789012345678901234567891234567890
202963  1066.079 1-1  273  0A5580
     1     0.006 1-2  350  00004D

0-5 Word #
6-6 blank
7-15 time (3 decimals)
16-16 blank
17-19 B-C
20-21 blank
22-24 label
25-26 blank
27-32 data


ARINC datalogger report on 08/05/97 07:29:07 from log file: R057B.LOG.

 Logging start time:  Tue Aug 05 07:10:58 1997
 Logging stop time:   Tue Aug 05 07:28:44 1997
 Total words: 202963
 Total time:  1066.0 seconds

 Board summary:
   CEI-200 at D000, i/o 380, 16K:  recvd   202963, lqst        0
      Equipment IDs per channel: 1-B 2-0 3-0 4-0 5-0 6-0 7-0 8-0

   Word     Time B-C Label  Data
```

4. Flight Experiment Data

The data collection was conducted at following locations:

ATIDS	- All Inputs are logged in one file. - The Output is logged in one file.
AMASS	- All Inputs are logged in one file.
DataLink Manager	- The Input is logged in one file. - The Output is logged in one file.

In addition, Rockwell-Collins collected ARINC data on the NASA aircraft.

4.1 FAA Surface Surveillance Data File Names

All Log files have been zipped to enable them to fit on one CD. There is one Zip File per machine per test.

	ZIP File Names	File Names	File Types	File Formats
ATIDS	cpsxx.zip	Input File = cpsxx.in Output File = cpsxx.out	ascii text	Input Output
AMASS	amsxx.zip	File = amsxx.log	binary	Input
DataLink Manager	dlxx.zip	Input File = damxx.txt Output File = dl1xx.txt	ascii text	Input Output

xx = test number

4.2 Test Matrix

Test No.	TOD	HUD	LCD	Left Seat	Cycle	Route Track	Traffic	Surv	AFDS	PID Exit
1	D	N	N	G1	N	Y	P	F	-	-
2	D	N	Y	G1	N	Y	P	F	-	-
3	D	Y	Y	G1	N	Y	P	A	-	-
4	N	N	N	G1	N	Y	P	F	-	-
5	N	N	Y	G1	N	Y	P	F	-	-
6	N	Y	Y	G1	N	N	Q	F	-	-
7	N	Y	N	G1	Y	Y	Q	F	A	MHI
8	N	Y	N	G1	Y	Y	Q	F	A	A
9	N	Y	N	G1	Y	Y	Q	F	A	MLO
10	D	N	N	G2	N	Y	P	F	-	-
11	D	N	Y	G2	N	Y	P	F	-	-
12	D	Y	Y	G2	N	Y	P	F	-	-
13	N	N	N	G2	N	Y	P	F	-	-
14	N	N	Y	G2	N	Y	Q	F	-	-
15	N	Y	Y	G2	N	N	Q	F	-	-
16	N	Y	N	G2	Y	Y	Q	F	A	MHI
17	N	Y	N	G2	Y	Y	Q	F	A	A
18	N	Y	N	G2	Y	Y	Q	F	A	MLO
19	D	N	N	G3	N	Y	P	F	-	-
20	D	N	Y	G3	N	Y	P	F	-	-
21	D	Y	Y	G3	N	Y	P	F	-	-
22	N	N	N	G3	N	Y	Q	F	-	-
23	N	N	Y	G3	N	Y	Q	F	-	-
24	N	Y	Y	G3	N	N	P	F	-	-
25	N	Y	N	G3	Y	Y	Q	F	A	MHI
26	N	Y	N	G3	Y	Y	Q	F	A	A

27	N	Y	N	G3	Y	Y	Q	F	A	MLO
28	D	N	N	G4	N	Y	P	F	-	-
29	D	N	Y	G4	N	Y	P	F	-	-
30	D	Y	Y	G4	N	Y	P	F	-	-
31	N	N	N	G4	N	Y	P	F	-	-
32	N	N	Y	G4	N	Y	Q	F	-	-
33	N	Y	Y	G4	N	N	Q	F	-	-
34	N	Y	N	G4	Y	Y	Q	F	A	MHI
35	N	Y	N	G4	Y	Y	Q	F	A	A
36	N	Y	N	G4	Y	Y	Q	F	A	MLO
37	D	N	N	N1	N	Y	P	F	-	-
38	D	N	Y	N1	N	Y	P	A	-	-
39	N	N	N	N1	N	Y	P	F	-	-
40	N	N	Y	N1	N	Y	P	F	-	-
41	N	Y	Y	N1	N	Y	P	F	-	-
42	N	Y	N	N1	Y	Y	Q	F	A	MHI
43	N	Y	N	N1	Y	Y	Q	F	A	A
44	N	Y	N	N1	Y	Y	Q	F	A	MLO
45	D	Y	Y	N1	Y	Y	P	F	A	MHI
46	D	Y	Y	N1	Y	Y	P	F	A	A
47	D	Y	Y	N1	Y	Y	Q	F	A	MLO
48	D	N	N	N2	N	Y	P	F	-	-
49	D	N	Y	N2	N	Y	P	F	-	-
50	N	N	N	N2	N	Y	Q	F	-	-
51	N	N	Y	N2	N	Y	Q	F	-	-
52	N	Y	Y	N2	N	Y	Q	F	-	-
53	N	Y	N	N2	Y	Y	Q	F	A	MHI
54	N	Y	N	N2	Y	Y	Q	F	A	A
55	N	Y	N	N2	Y	Y	Q	F	A	MLO
56	D	Y	Y	N2	Y	Y	Q	F	A	MHI
57	D	Y	Y	N2	Y	Y	P	F	A	A
58	D	Y	Y	N2	Y	Y	P	F	A	MLO

4.3 Test number and Dates

Test #	Date
45	Aug. 2
51,53,54,55,56a	Aug. 4
49,56b,58	Aug. 5
40n,40s,41,42,43,44,5 2	Aug. 6
38,46,57	Aug. 7
46c	Aug. 18
4,5,6,7,8	Aug. 19
9,13,14,15,15	Aug. 20
17,18,22,23,24	Aug. 21
25,26,27,32,33	Aug. 22
31,34,35,36	Aug. 23

5. Results

In this section, we describe the results that we obtained after analyzing the flight experiment data. The results are summarized in terms of graphs or histograms.

5.1 Figure R1: Traffic during different experiments: This graph summarizes the number of vehicles information during different experiments. For each experiment, it displays the number of vehicles in the downlink (present during the experiment at some point or the other), in the uplink, the maximum number of vehicles present at any given instant in time, and the average number of vehicles present at any given instant in time. From this graph, we can identify experiments of high-traffic and of low-traffic. In all cases, there were more vehicles in the downlink than in the uplink.

5.2 Figure R2: Duration of experiments: This graph shows the duration of each experiment that we analyzed. The duration ranged from 1000 seconds to 2400 seconds.

5.3 Figure R3: Number of attempts per Ui message: This figure illustrates the percentage of Ui messages that needed one, two, three, or four attempts. Since the messages that needed more than 4 attempts were insignificant, these are not plotted here. Clearly, in all experiments at least 80 percent of the Ui messages were received in one attempt. In experiments 6,13a, 13b, 14, 25, and 46, significant number of them required two attempts or more.

5.4 Figure R4: Number of attempts per Ua message: This graph illustrates the percentage of Ua messages that needed one, two, or three attempts before successfully reaching the destination. Clearly, in all cases at least 90 percent of the messages were delivered in the very first attempt. Significant percentage of messages requiring more than one attempt were observed in experiments 6, 13a, 13b, 14, 24, 26, and 45.

5.5 Figure R5: Number of attempts per Us message: This figure illustrates the percentage of Us messages needing 1-15 attempts per message. Clearly, most messages are successfully received within 1 or 2 attempts. A few however require higher number of attempts before successful reception.

5.6 Figure R6: Number of attempts per CPDLC message: This figure illustrates the distribution of the number of attempts made for a single control-pilot message to be sent. While most were delivered and responded to in 2 attempts or less, there were some messages that took as much as 25 attempts.

5.7 Figure R7: Confidence levels for Interarrival times of long squitters (NASA): (Type 33): This graph characterizes the interarrival times in terms of confidence interarrivals. The chart has three levels: 90%, 95%, and 99%. The 99.99% confidence level was included in the table but not in the graph. Clearly, in all cases 90% of the squitters were received within 1 second of the previous squitter. In fact, in most of the experiments, the interarrival time was just 0.65 sec or less in 90% of the cases. 95% of the squitters were received within 1.2 seconds. Only in one case (Experiment # 56b), 95% of the squitters were received within 3.65 sec of the previous ones. Except in one case (#56b), 99% of the squitters were received within 3.8 seconds of the previous ones.

5.8 Figure R8: Confidence interval for interarrival times of short squitters (NASA): This graph illustrates the 90%, 95%, and 99% confidence intervals for interarrival times of short squitters corresponding to the NASA vehicle. Clearly, the 90% interval is less than 5 seconds. In fact, in the majority of the cases it is less than 2.5 seconds. The 95% interval however is slightly larger and extends up to 9 sec. Once again in the majority of cases it is about 3.5 seconds. The 99% interval extends up to 25 seconds. The 99.99% interval is not plotted but is included in the chart.

5.9 Figure R9: Distribution of interarrival times of short squitters (NASA): This graph shows the average interarrival times for the NASA vehicle for short squitters. The X-axis represents the experiment sequence number.

5.10 Figure R10: Distribution of interarrival times of short squitters (other vehicles): This graph shows the average interarrival times for the vehicles other than the NASA vehicle for short squitters. The X-axis represents the experiment sequence number.

5.11 Figure R11: Interarrival times for Long Squitters (NASA): (Type 33): This illustrates the average interarrival times for long squitters for the NASA aircraft. On the average, a squitter is sent every 0.5 seconds or two per second. However, due to the collisions all transmitted squitters may not reach the target successfully. From the figure, it may be observed that the intersquitter times range from 0.47 sec. to 0.85 sec. But most are in the 0.5-0.6 sec. range. The outliers occur on data categories 13a, 56, and 57.

5.12 Figure R12: Us Traffic -- Number of vehicles: This shows the number of vehicles involved in us messages for each experiment. The traffic was as low as 1 to as high as 81. Only a few high-traffic experiments seem to be present in these experiments.

5.13 Figure R13: Us Traffic -- Number of messages: This graph displays the number of Us messages transmitted during each experiment and the number of vehicles that were involved in the Us messages. The number of messages sent ranges from 44 to 997. The number of vehicles range from 1 to 81 (Figure R12).

5.14 Figures R14: Figure R14-1: Histogram of Intersquitter arrivals (NASA) Short squitters---Low Traffic: This illustrates the intersquitter times received from the NASA aircraft (A71A99) under low-traffic conditions. For example, consider the traffic for experiment 55. While the majority of the squitters had an intersquitter time of less than 600 msec, the rest had intersquitter times up to 3 sec. Only one squitter arrived after 24 seconds of the previous one.

Similar results for experiment #43 are in Figure R14-2. Here, all squitters had an interarrival time of less than 1.9 seconds. As before, the majority arrived within 600 msec of the previous ones.

Figure R14a shows the number of vehicles sending us messages under three low-traffic instances: experiments 43, 55, and 8.

Figure R14b shows the number of us messages sent by the vehicles shown in Figure R14a.

5.15 Figures R15: Squitter interarrivals--High Traffic: Figures R15-1 through R15-3 illustrate the intersquitter times received from the NASA aircraft (A71A99) under high-traffic conditions. For example, consider the traffic for experiment 13b. While the majority of the squitters had an intersquitter time of less than 600 msec, the rest had intersquitter times up to 2.6 seconds. Only one intersquitter time was found to be 31.2 seconds.

Figure R15-2 illustrates the same for experiment 13a. The observations are similar to the one for experiment 13b. Similar results for experiment 24 are in Figure R15-3.

Figure R15a graphs the number of vehicles under three high-traffic instances with Us-type messages: experiments 13a, 13b, and 24. Figure R15b graphs the number of Us messages sent under high-traffic: experiments 13a, 13b, and 24.

5.16 Figure R16: Distribution of duration of vehicles: Low-traffic: This corresponds to a sample distribution of duration of vehicles under low-traffic. For example, consider the data for experiment #43 (Date: Aug. 6). There were only 7 vehicles, and most of them were present for 1.4 seconds. Only one vehicle (AB90AB1) was present for 61.8 seconds.

The traffic for experiment #08 is another example. Here, 13 vehicles were present during the experiment. Most vehicles had a duration of 1.5 sec. maximum duration was 6.3 sec.

The traffic for experiment #55 is another example of low traffic. There were 14 vehicles with a minimum duration of 1.2 seconds to a maximum duration of 8.5 seconds.

5.17 Figure R17: Distribution of duration of vehicles-high traffic: This figure summarizes the traffic pattern under high-traffic conditions. In Experiment #13b, there were 94 vehicles. The duration of vehicles ranged from 1 second to 11 seconds.

During Experiment #24, there were 110 vehicles. The duration of vehicles ranged from 1 second to 10 seconds.

6. Summary of Observations

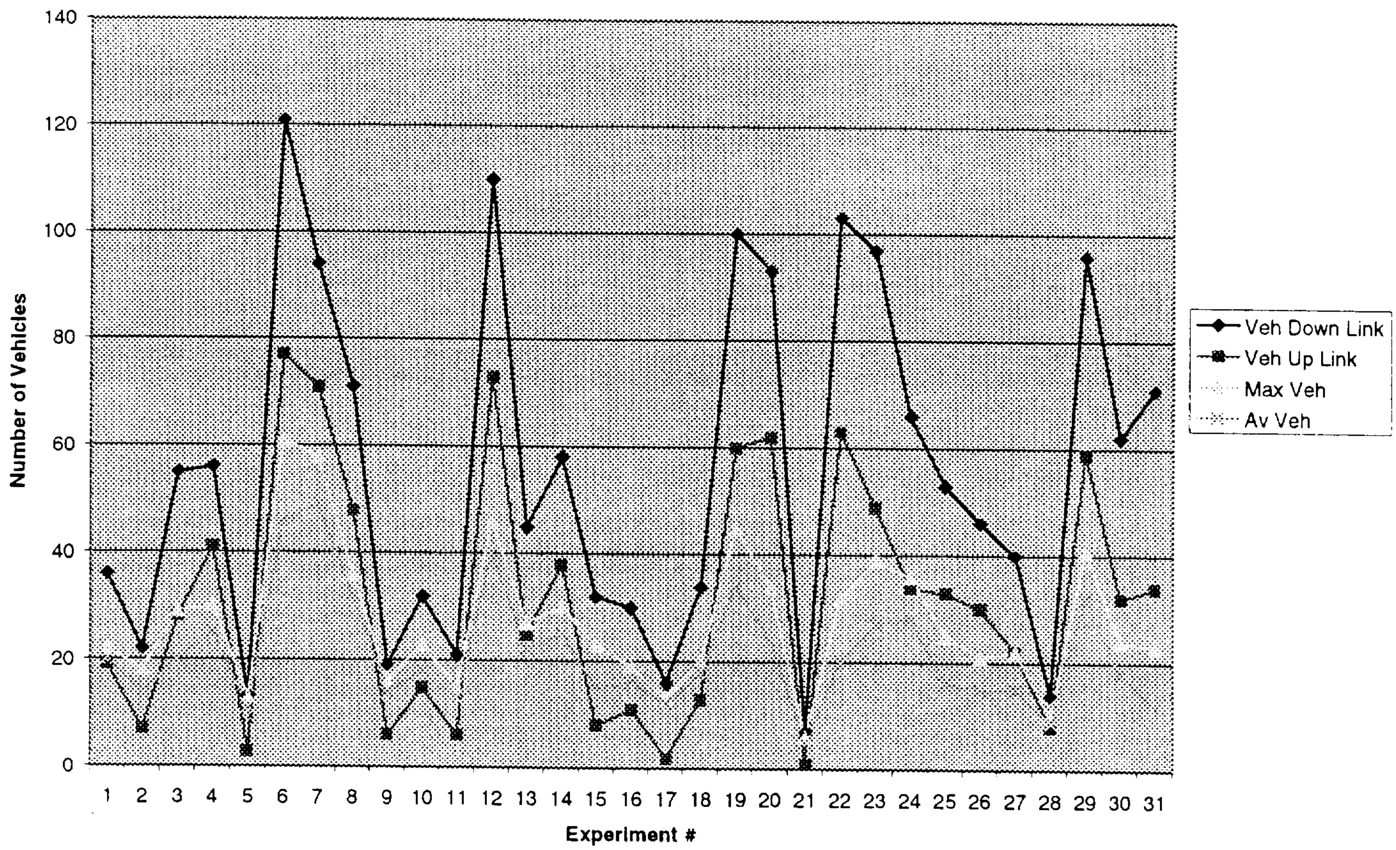
From the analysis of the data collected during Aug. 1-28, 1997 at Atlanta's Hartsfield International Airport, we make the following observations regarding the traffic and data link performance.

- The percentage of attempts needed to send Ui messages in one attempt was over 80% in all cases. In fact, there appeared to be no correlation between the number of vehicles (in uplink or downlink) and the number of attempts needed to send a Ui message. From here we conclude that the traffic that was present during the trials was well below the saturation point for the datalink system. Few cannot, however, extrapolate these results to determine the traffic at the saturation point at which the number of attempts would start increasing and showing a correlation with the traffic. There was also no correlation with the duration of the experiment and the number of vehicles that were present during an experiment.

- The results for the number of attempts for Ua messages were similar. In fact, 90% or more Ua messages were delivered in one attempt. This also confirms the observation that the vehicular and message traffic was well below saturation load for the datalink.
- The results for the Us message were somewhat intriguing. Some of the messages needed as many as 15 attempts prior to correct reception. Once again there was no correlation between the traffic and the distribution of number of attempts needed. On the average, about 50% of the Us messages were delivered in 1 attempt. The reason for such high number of retries per message warrants further investigation.
- The performance of long squitters (type 33) was quite satisfactory. While the actual average interarrival time of generation was 0.5 sec, 95% of the squitters arrived within 1 sec of the previous. From here we can conclude that the collision was not a major factor in the performance of the system.
- The performance for the short squitters (type 27) had a much higher variance across the experiments. The expected rate of generation of short squitters is 1 per second. The 90% confidence level for most cases was 2.5 sec. However, some had it as high as 5 sec. As before, we did not find any correlation between the traffic and the longer interarrival times.
- The average interarrivals of short squitters for other vehicles (i.e., excluding NASA) was averaged at 1.5 sec. This is an acceptable measure.
- The average interarrival times of long squitters for the NASA vehicle were between 0.5 and 0.6 sec. There were only two outlier values at 0.85 sec.

In summary, the results indicate that the datalink system has not saturated with the load presented during the experiments. The performance was quite satisfactory. However, it may not be possible to predict its performance in an actual system where hundreds of vehicles may need to be handled simultaneously.

Figure R1 : Traffic During different Experiments



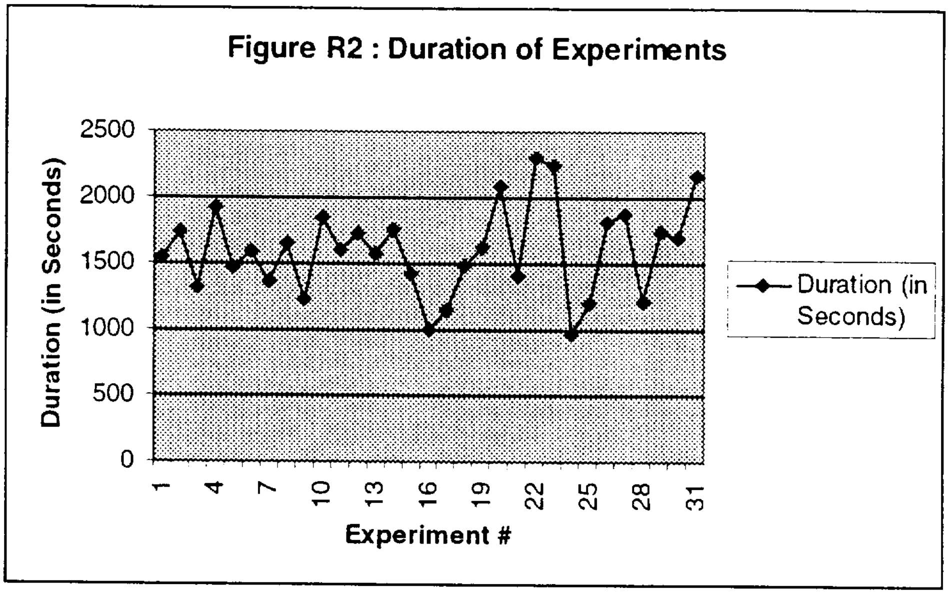


Figure R2 : Duration of Experiments
2500
2000
1500
1000
500
0
Duration (in Seconds)
1
4
7
10
13
16
19
22
25
28
31
Experiment #
Duration (in Seconds)

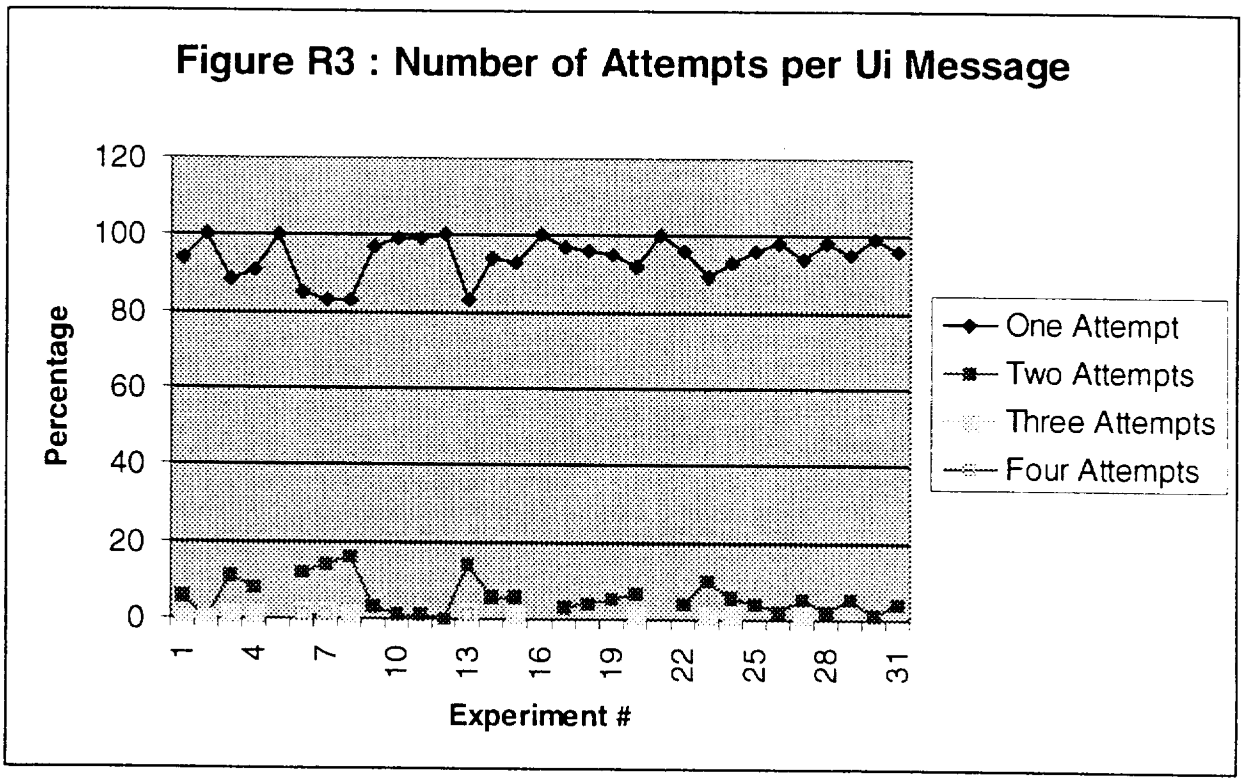
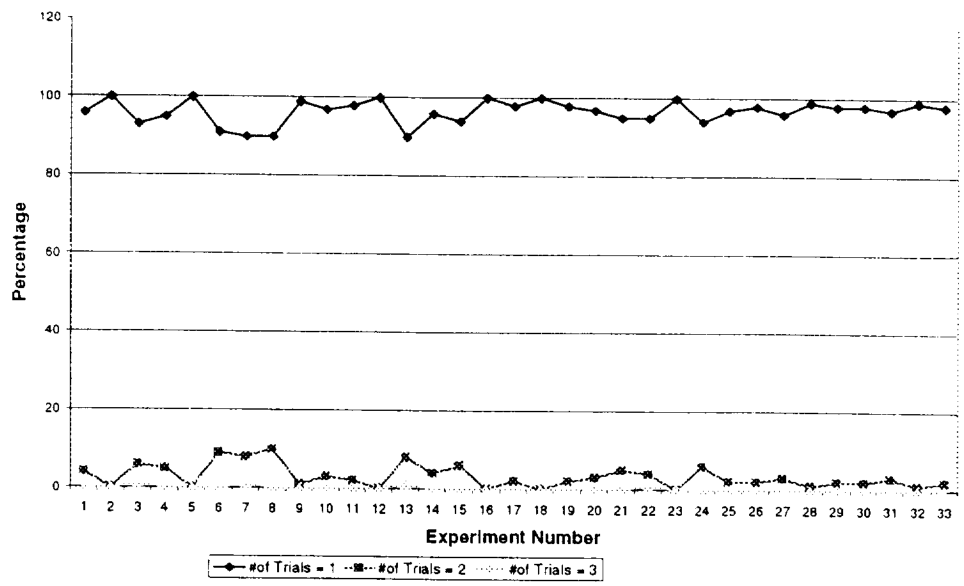


Figure R3 : Number of Attempts per Ui Message
120
100
80
60
40
20
0
Percentage
1
4
7
10
13
16
19
22
25
28
31
Experiment #
One Attempt
Two Attempts
Three Attempts
Four Attempts

Figure R4 : Number of Attempts per Ua Message



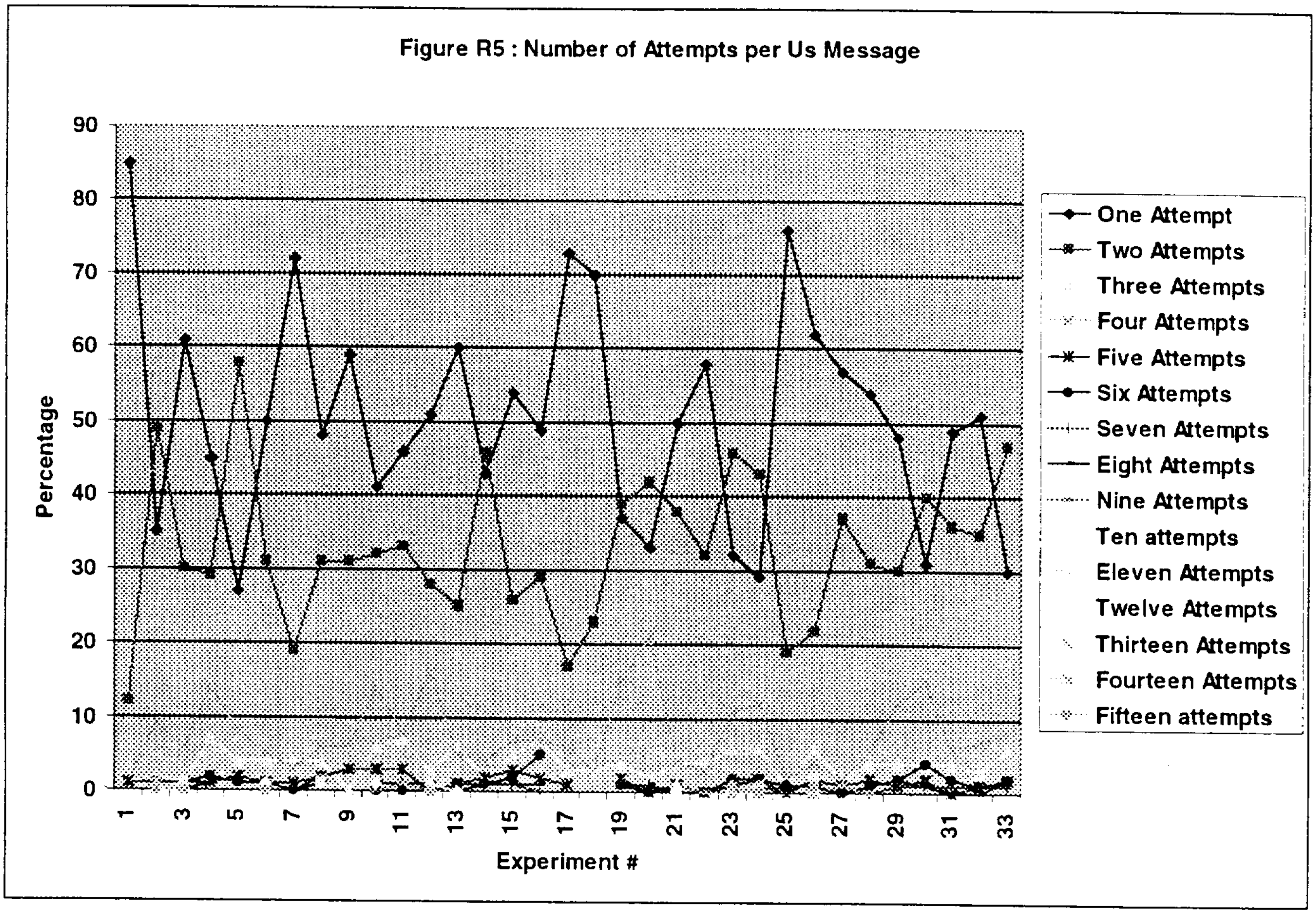


Figure R5 : Number of Attempts per Us Message
90
80
70
60
50
40
30
20
10
0
Percentage
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
Experiment #
One Attempt
Two Attempts
Three Attempts
Four Attempts
Five Attempts
Six Attempts
Seven Attempts
Eight Attempts
Nine Attempts
Ten attempts
Eleven Attempts
Twelve Attempts
Thirteen Attempts
Fourteen Attempts
Fifteen attempts

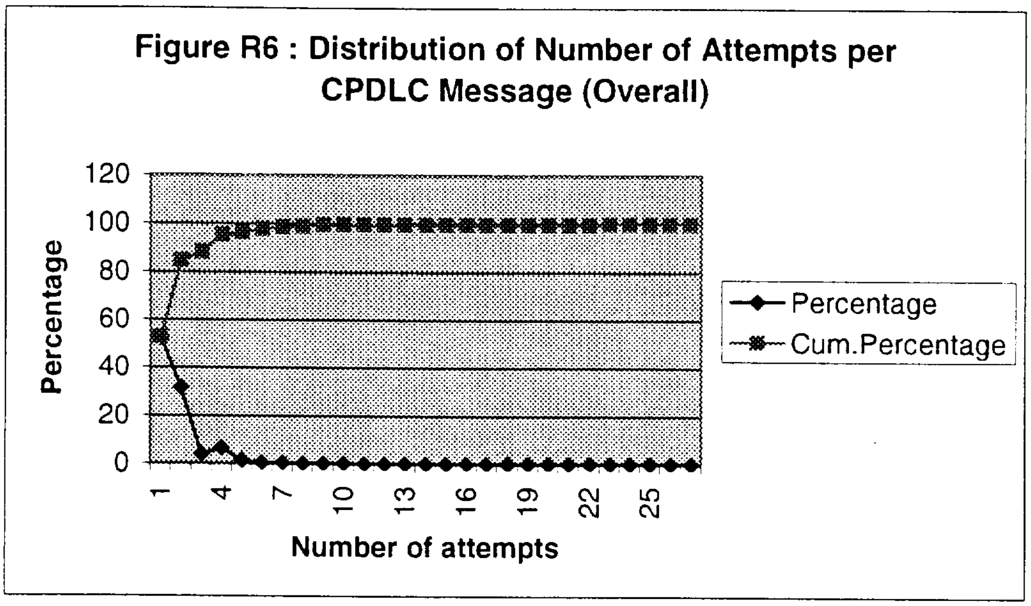


Figure R6 : Distribution of Number of Attempts per CPDLC Message (Overall)
120
100
80
60
40
20
0
Percentage
1
4
7
10
13
16
19
22
25
Number of attempts
Percentage
Cum.Percentage

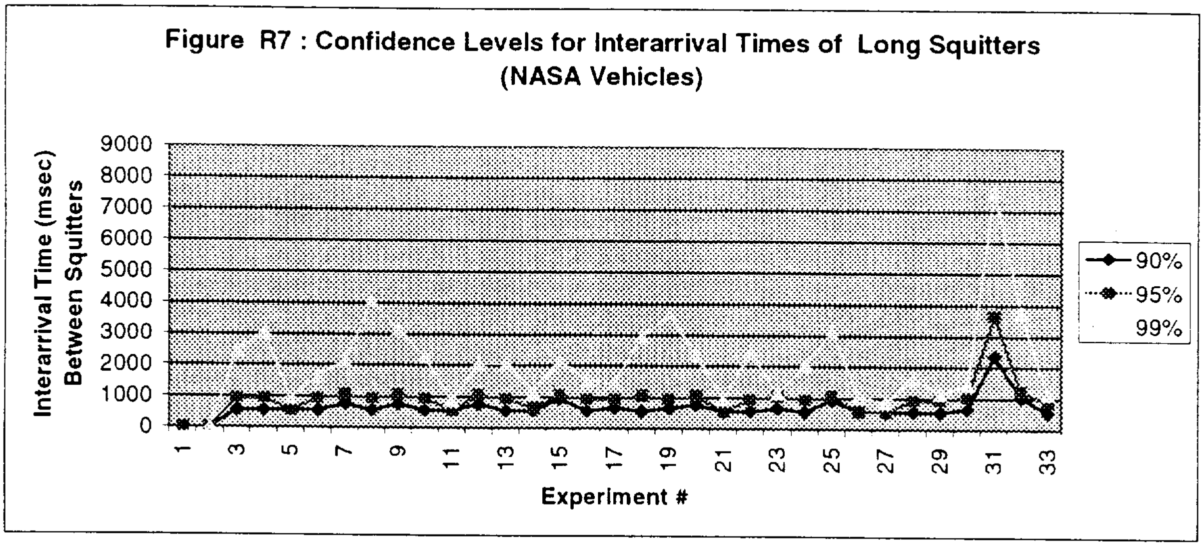


Figure R7 : Confidence Levels for Interarrival Times of Long Squitters
(NASA Vehicles)
Interarrival Time (msec)
Between Squitters
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
Experiment #
90%
95%
99%

Figure R8 :Confidence Interval for Interarrival Times(Short Squitters)

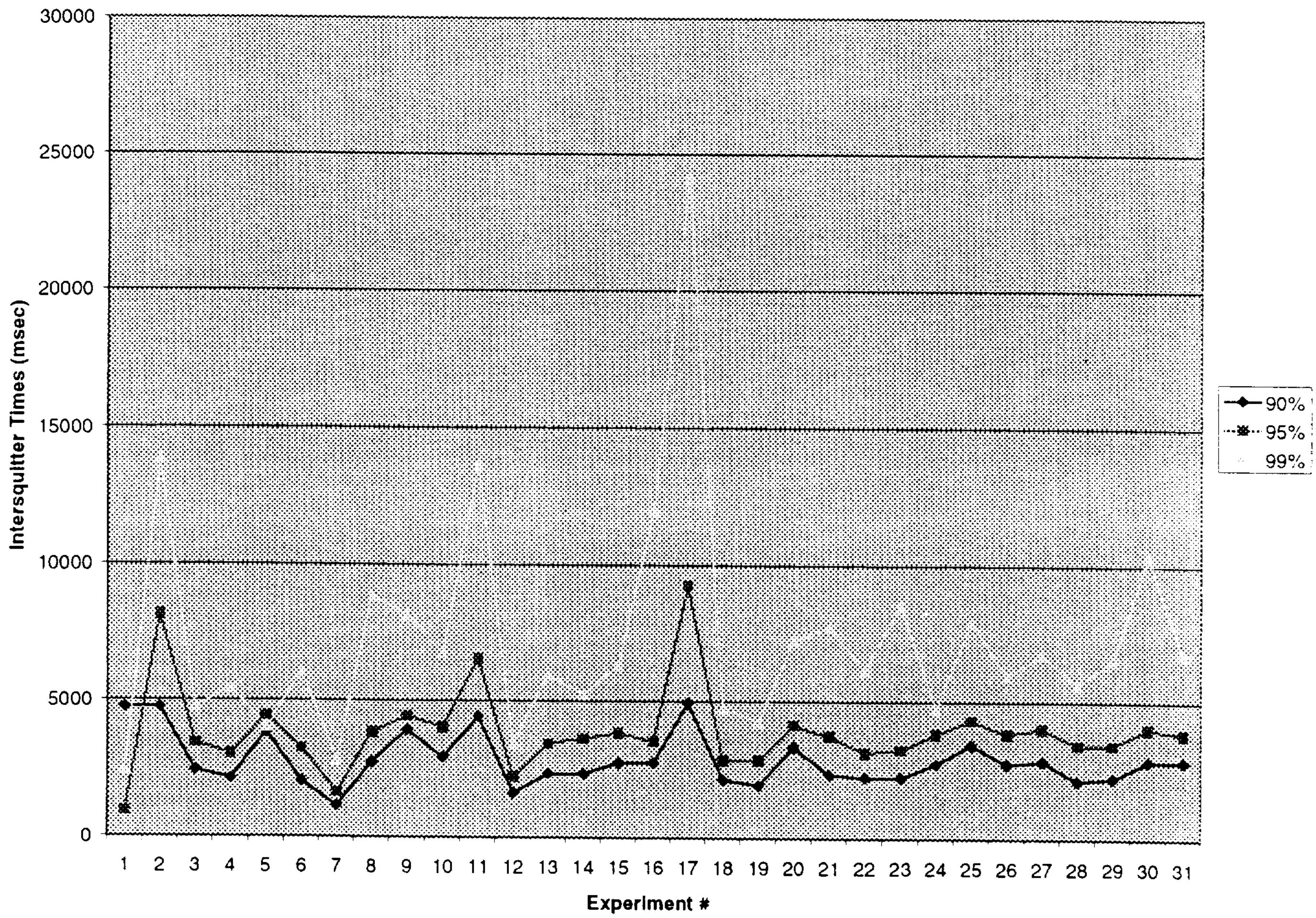


Figure R9 : Interarrival of Short Squitter Arrivals(NASA)

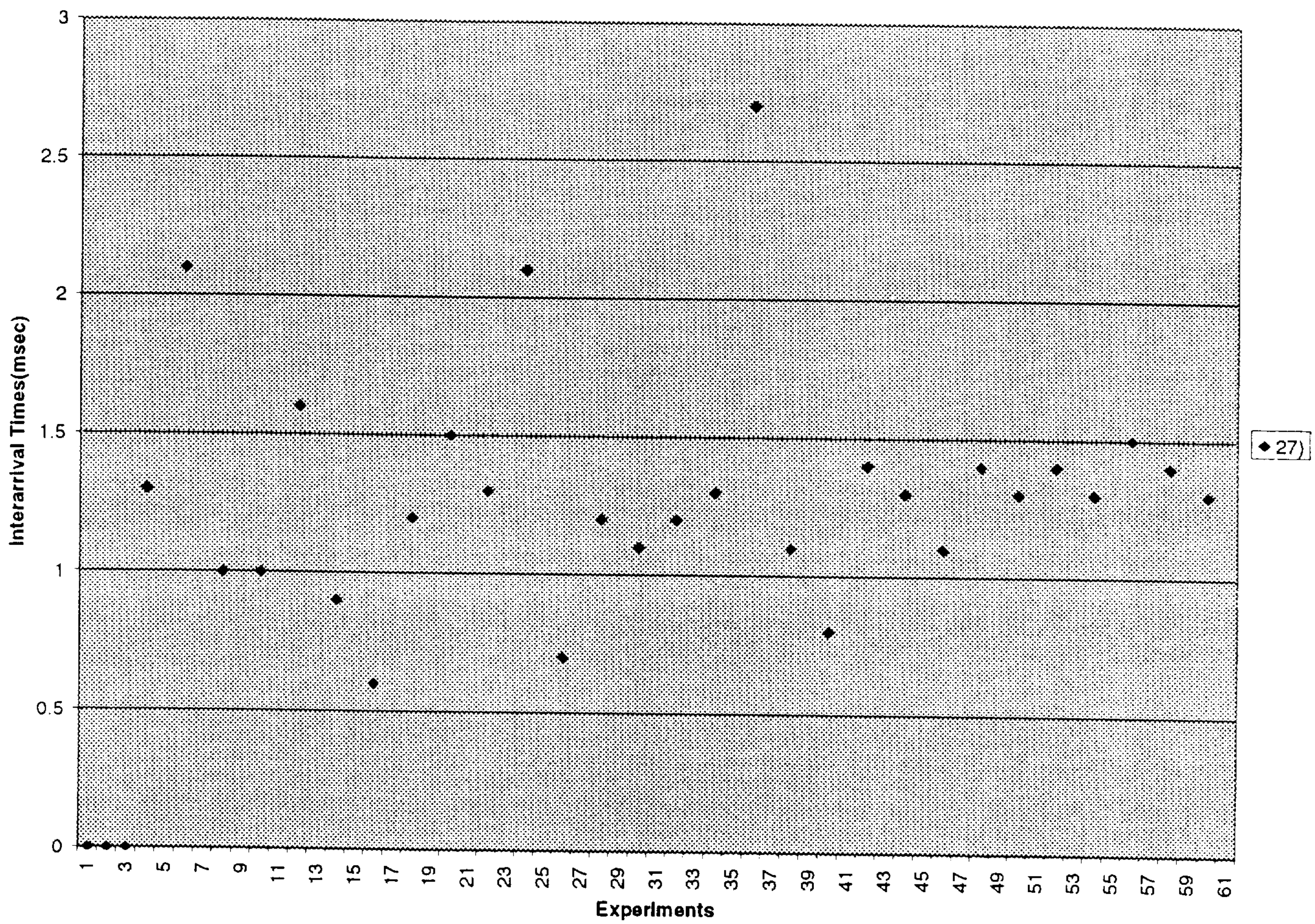


Figure R10 : Interarrival of Short Squitter Arrivals (Other Vehicles)

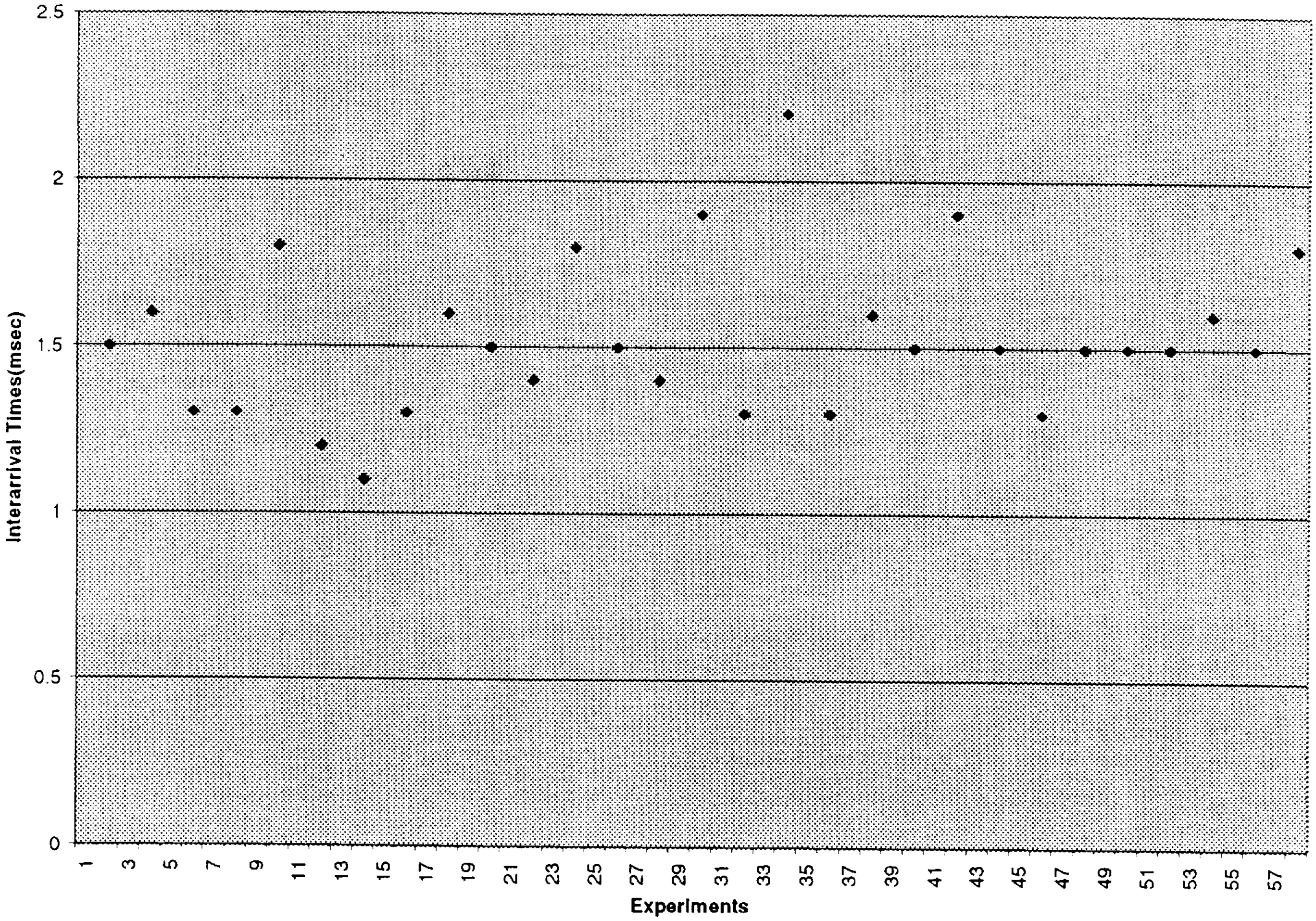


Figure R11 : Interarrival Times of Long Squitter Arrivals (NASA)

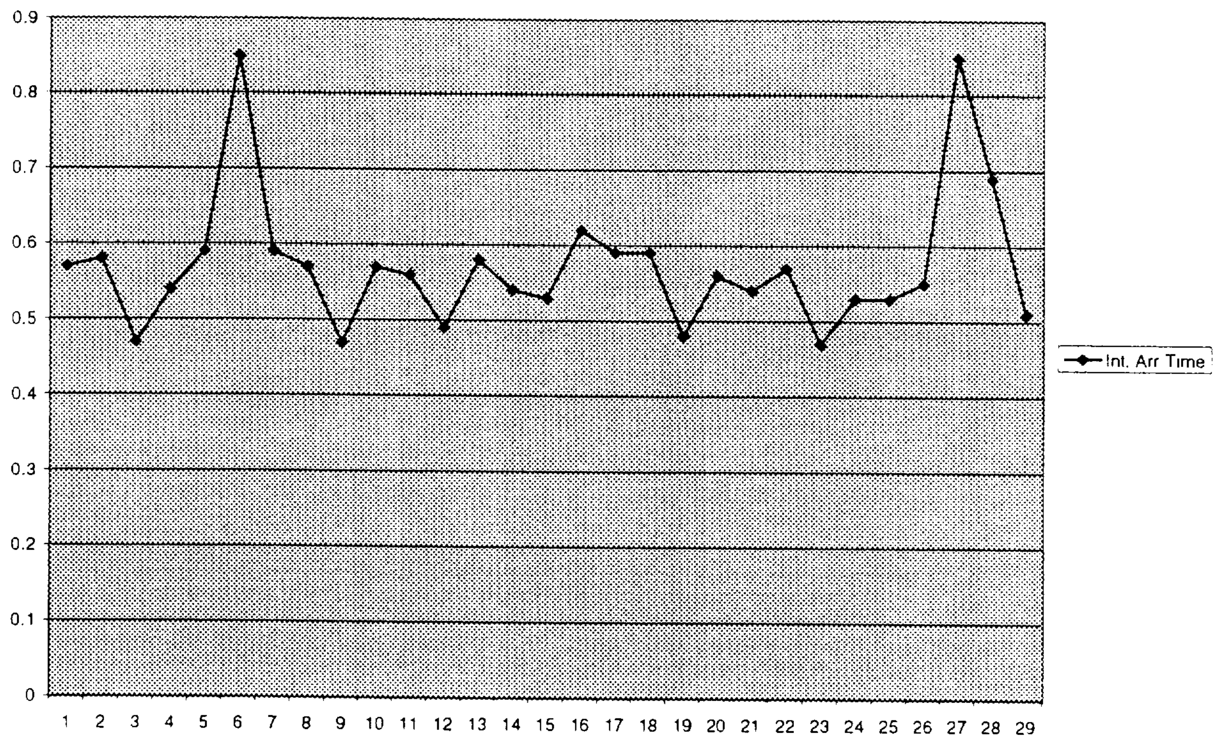


Figure R12 : US Traffic - Number of Vehicles

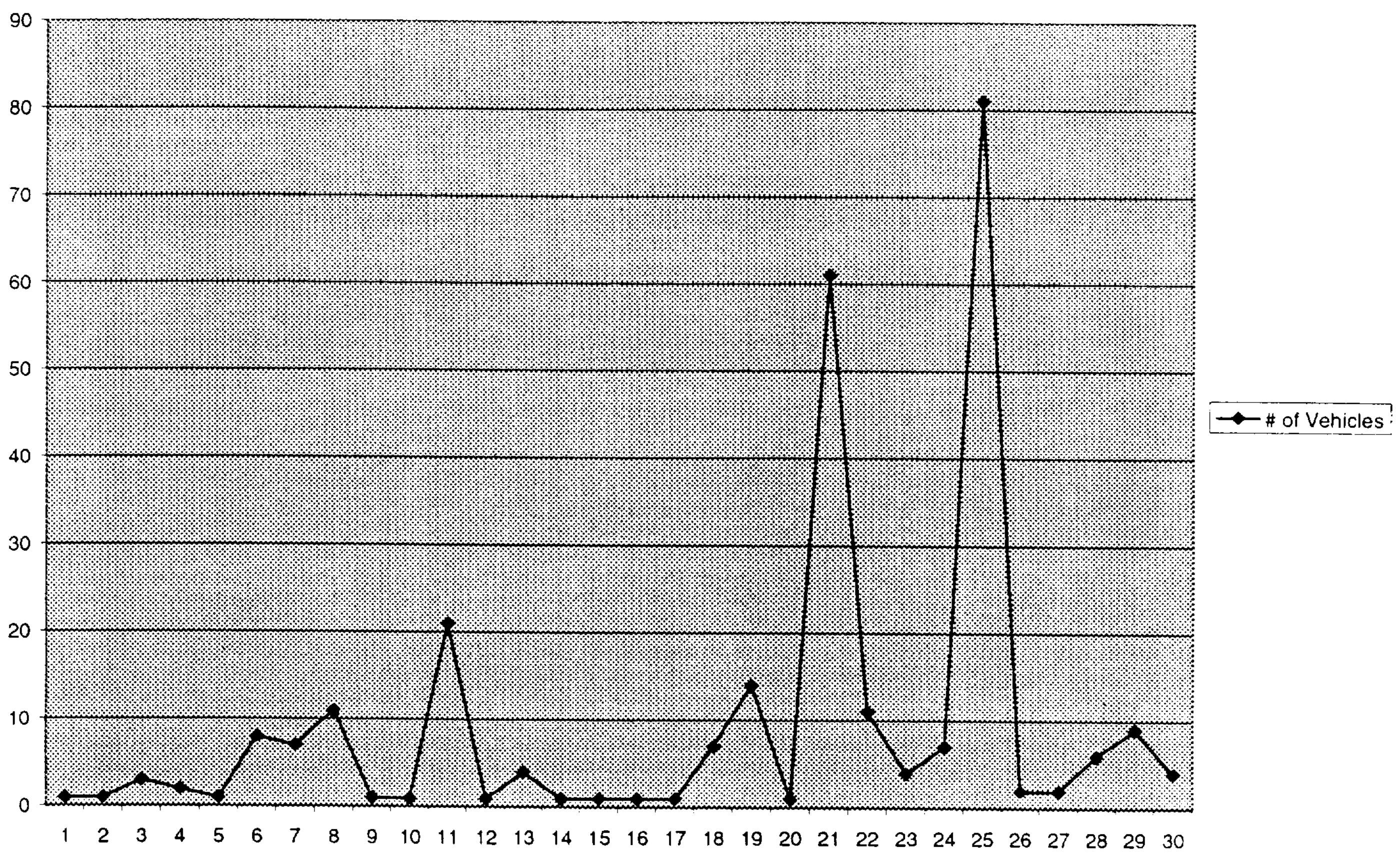


Figure 14-1: Histogram of InterSquitters (NASA) Low Traffic (55)

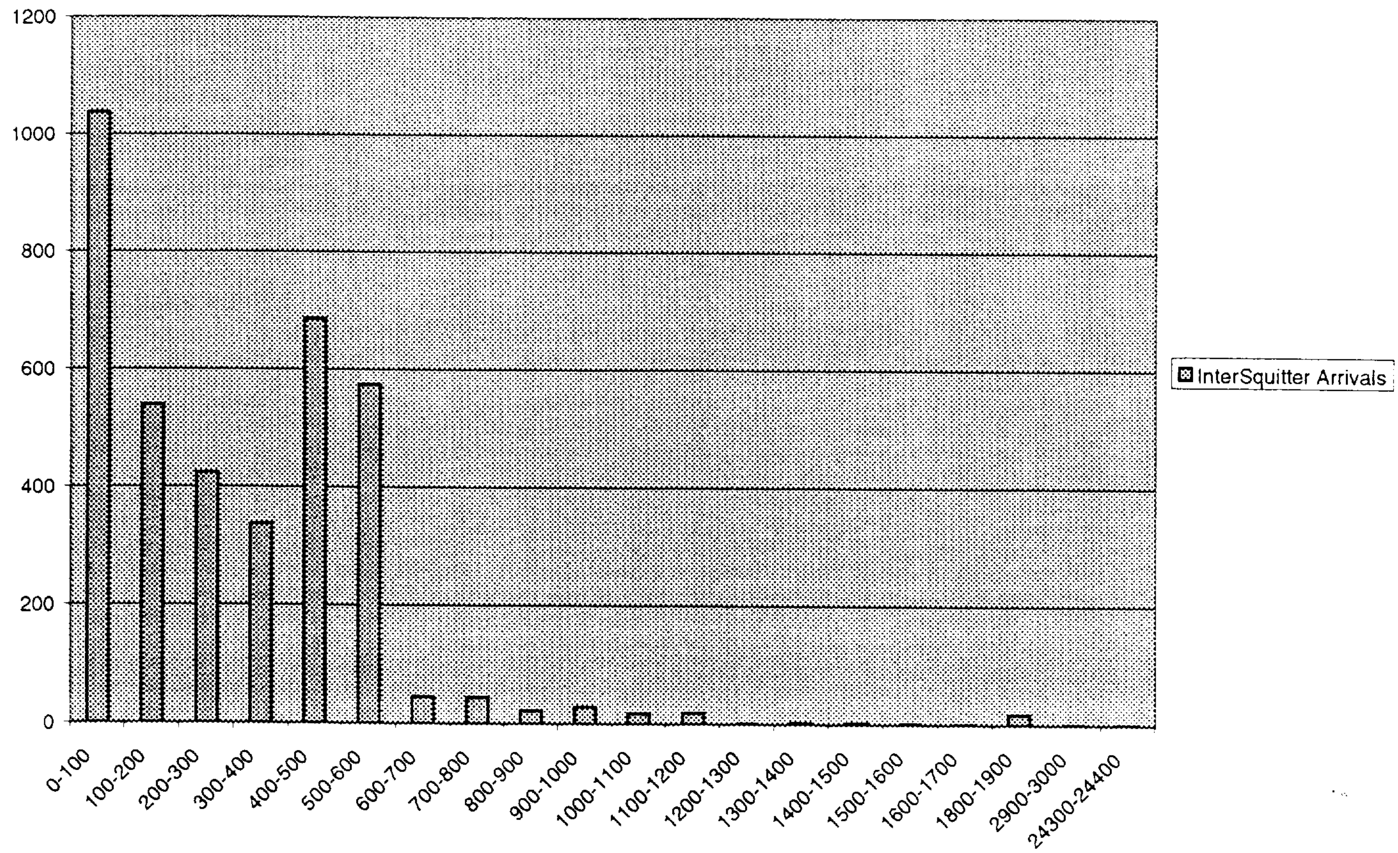
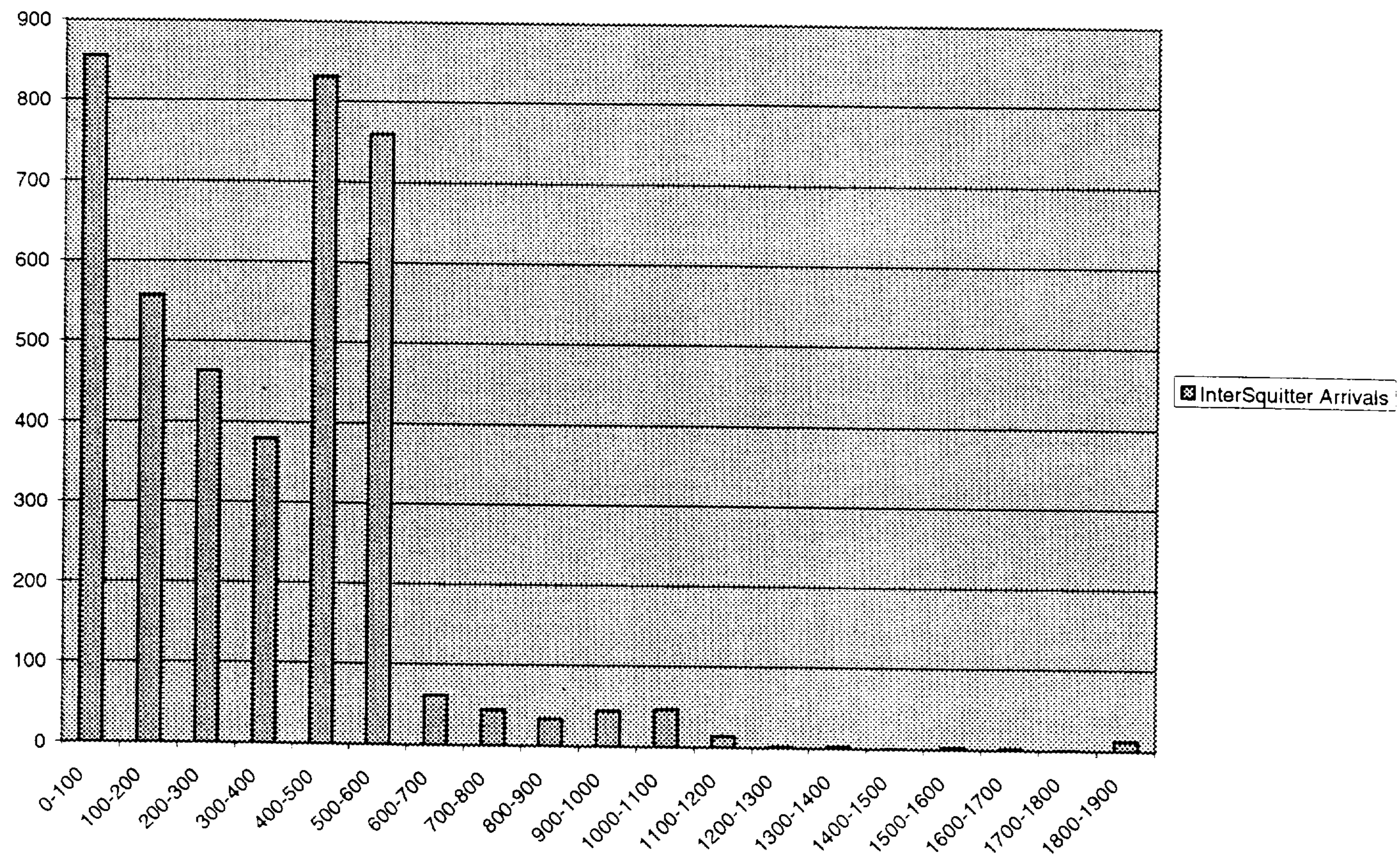


Figure R14 - 2 : Histogram of InterSquitters(NASA) Low Traffic (43)



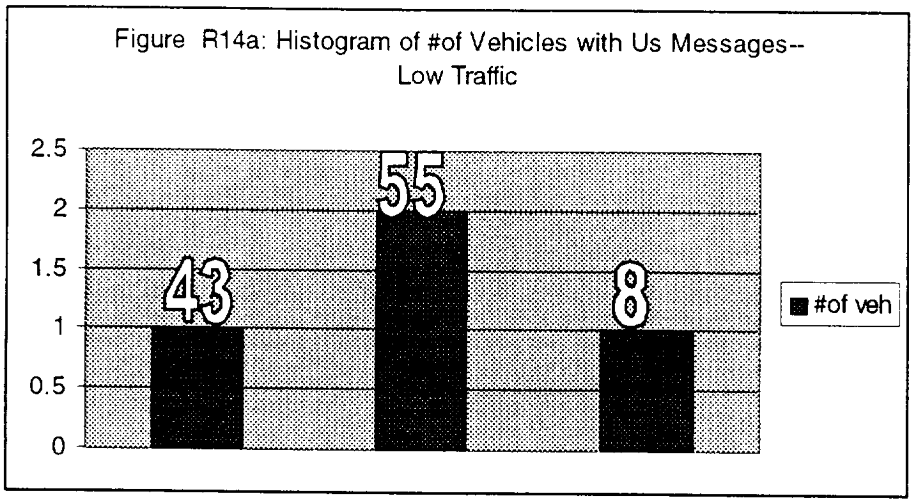


Figure R14a: Histogram of #of Vehicles with Us Messages--
Low Traffic
2.5
2
1.5
1
0.5
0
43
55
8
#of veh

Figure R14B : Histogram of Us Messages Sent (Low Traffic)

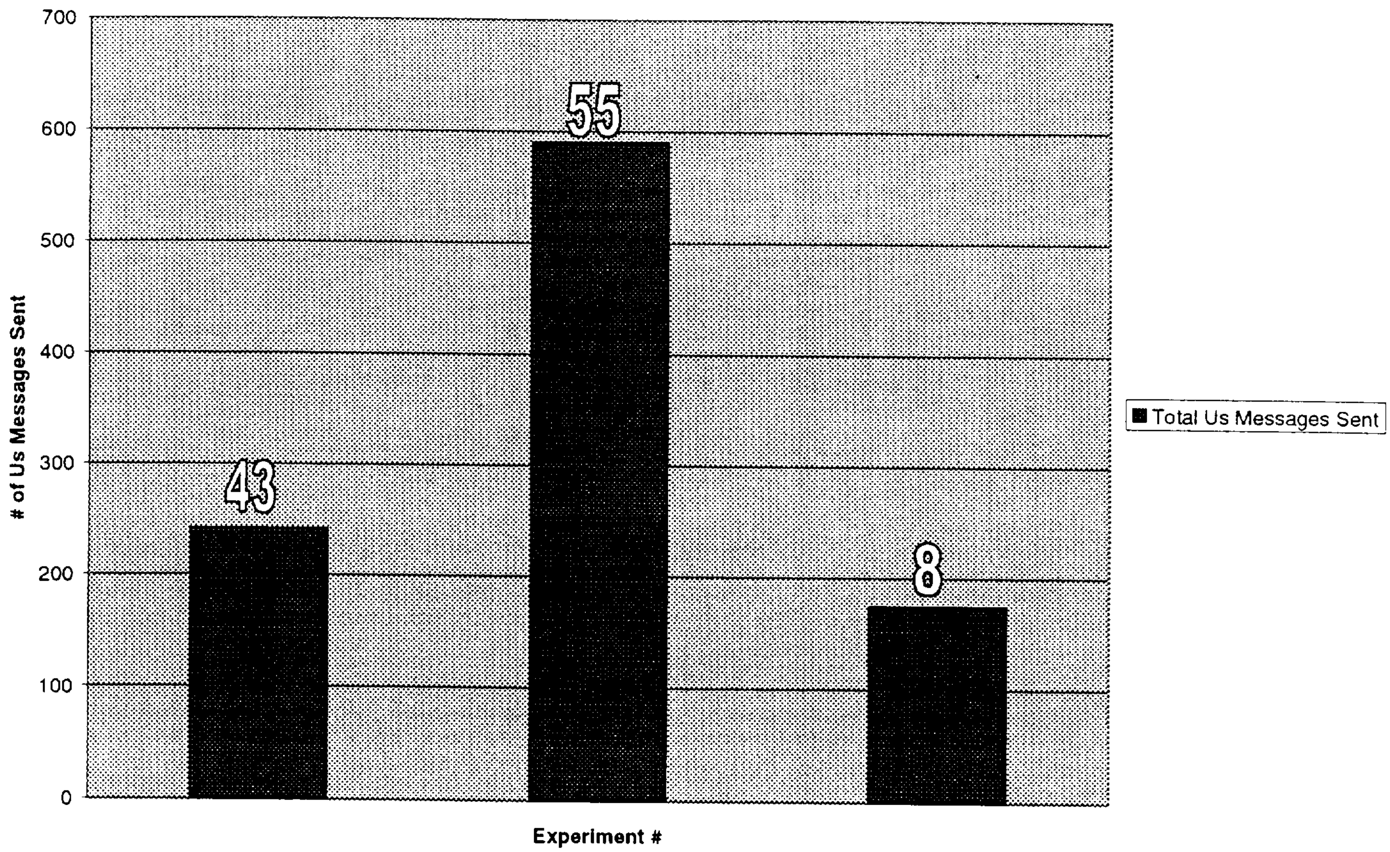


Figure R15-1: Histogram of InterSquitters (NASA) High Traffic (13b)

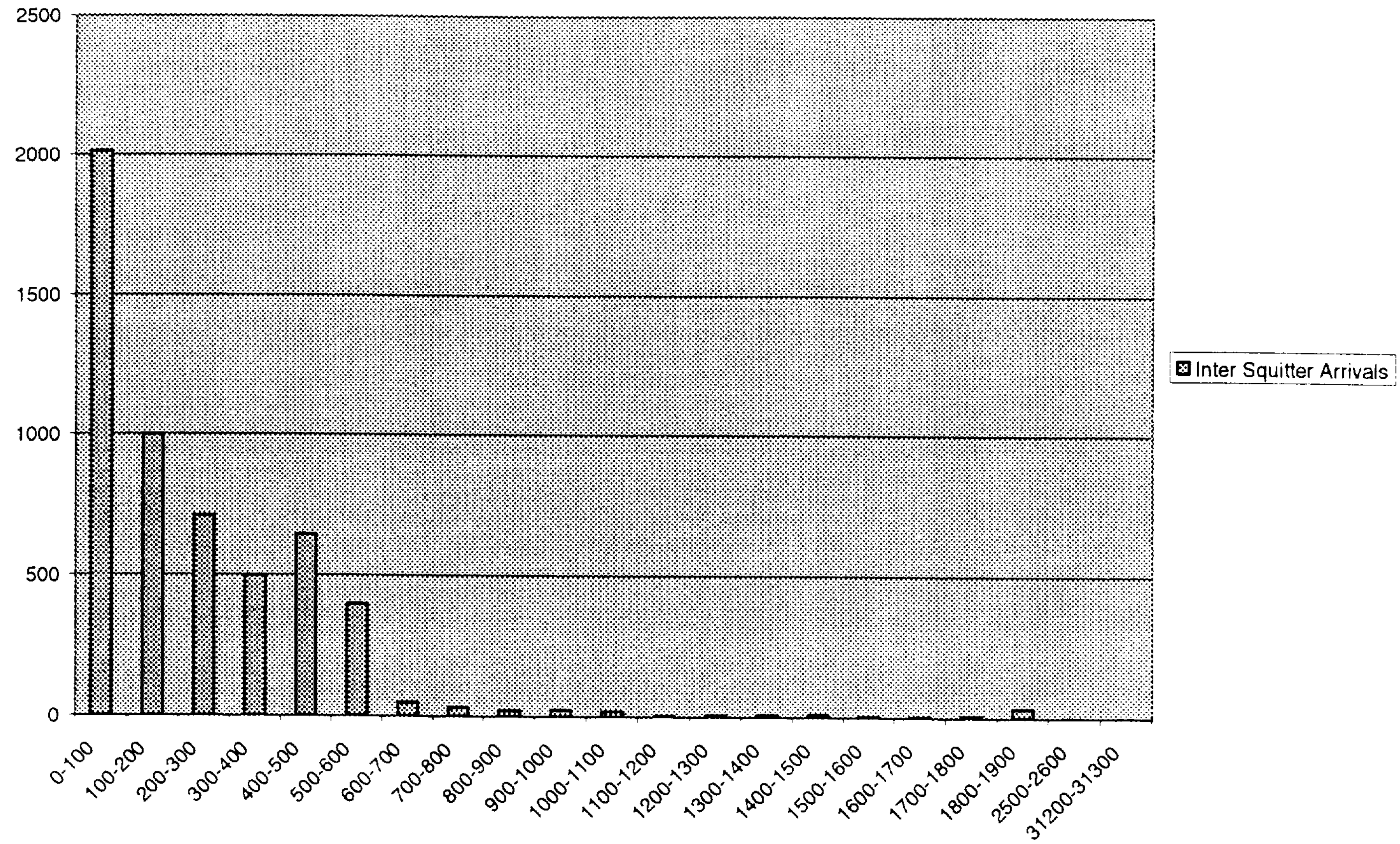


Figure R15-2: Histogram of Squitters (NASA) High Traffic (13a)

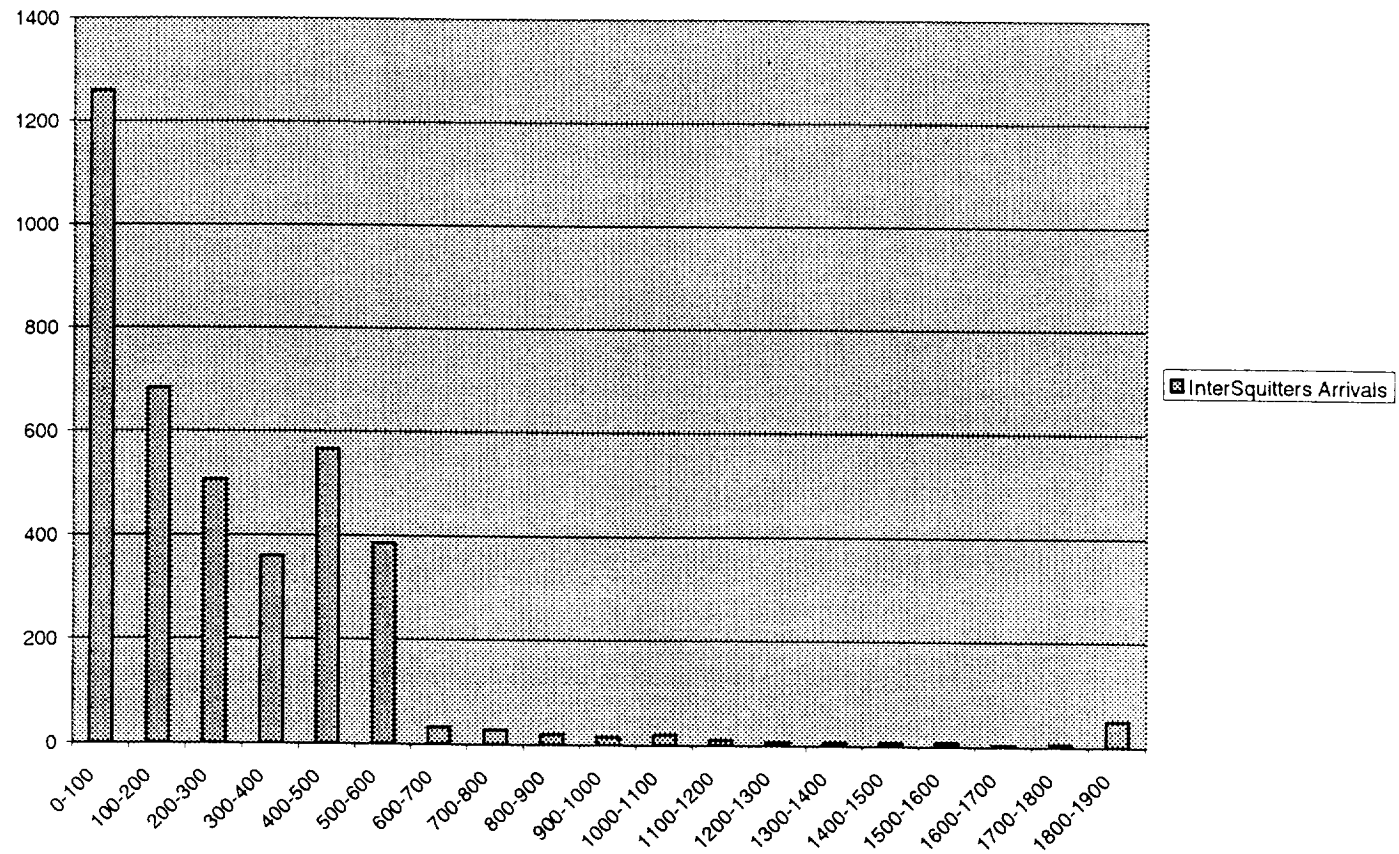
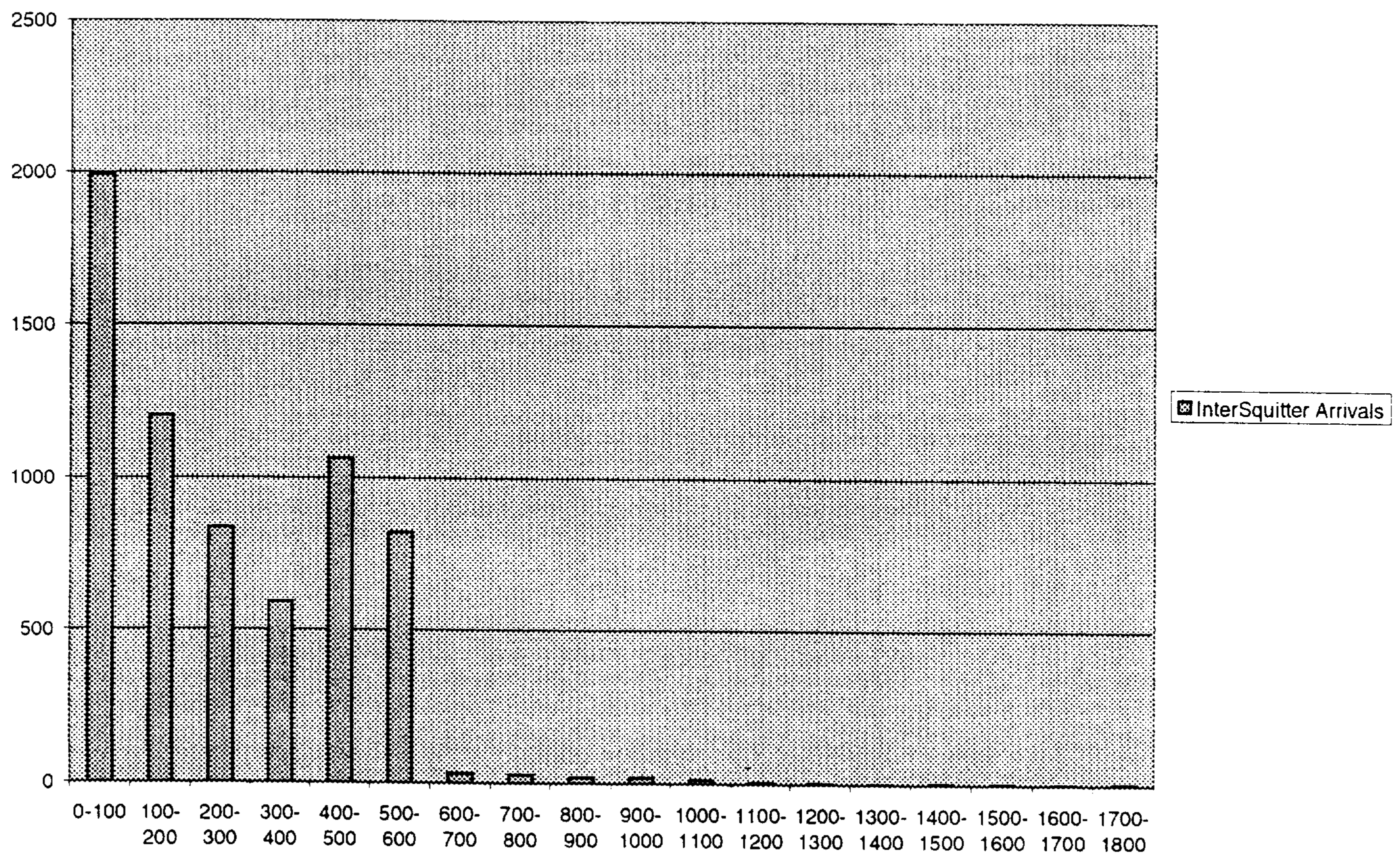


Figure R15 - 3: Histogramof InterSquitters (NASA) High Traffic (24)



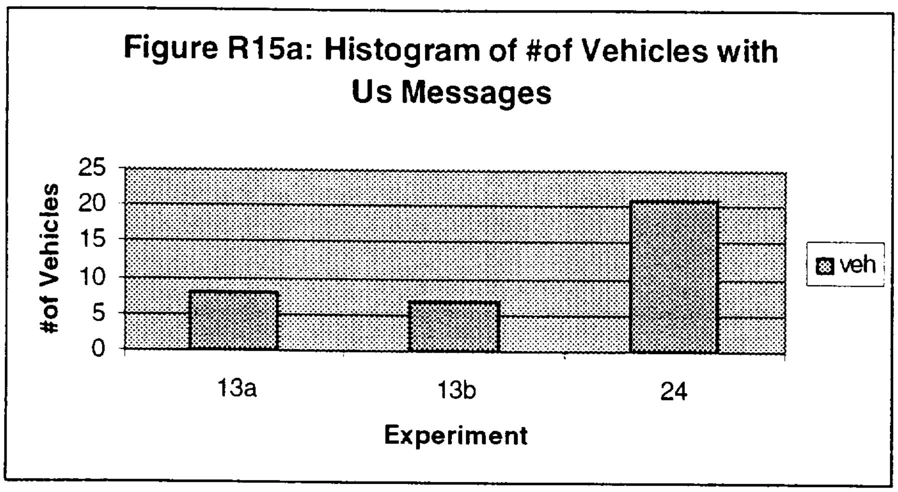


Figure R15a: Histogram of #of Vehicles with Us Messages
25
20
15
10
5
0
#of Vehicles
13a
13b
24
Experiment
veh

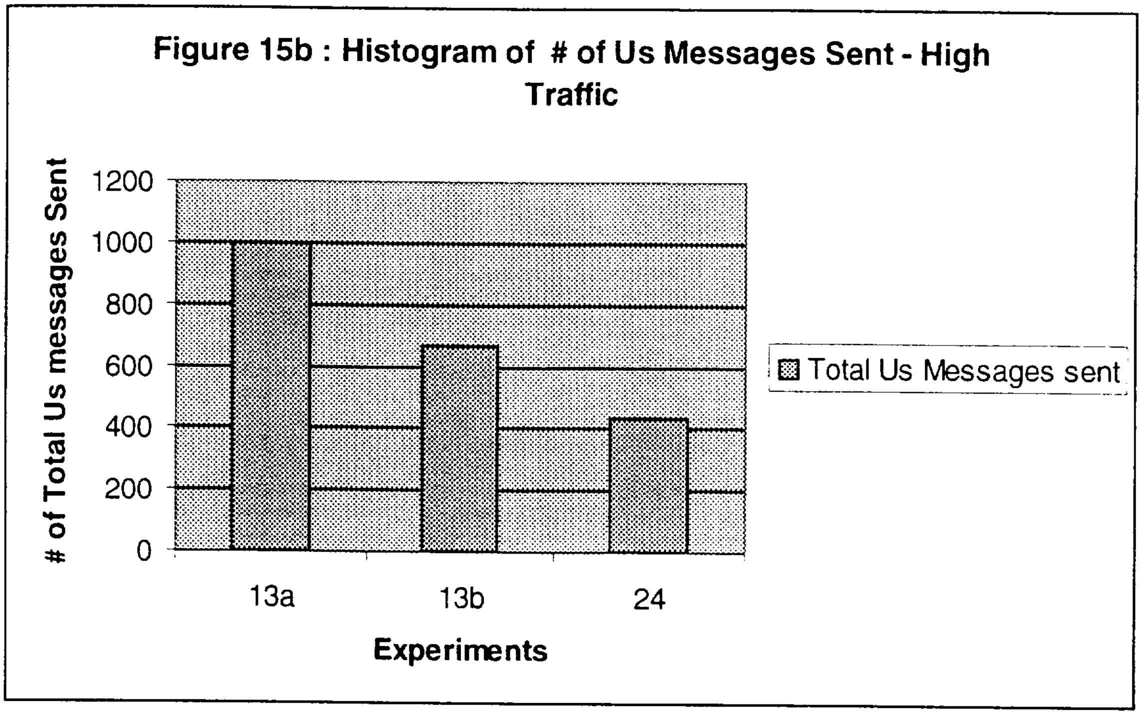


Figure 15b : Histogram of # of Us Messages Sent - High Traffic
# of Total Us messages Sent
1200
1000
800
600
400
200
0
13a
13b
24
Experiments
Total Us Messages sent

Figure R16: Distribution of Duration of Vehicles - Low Traffic(08)

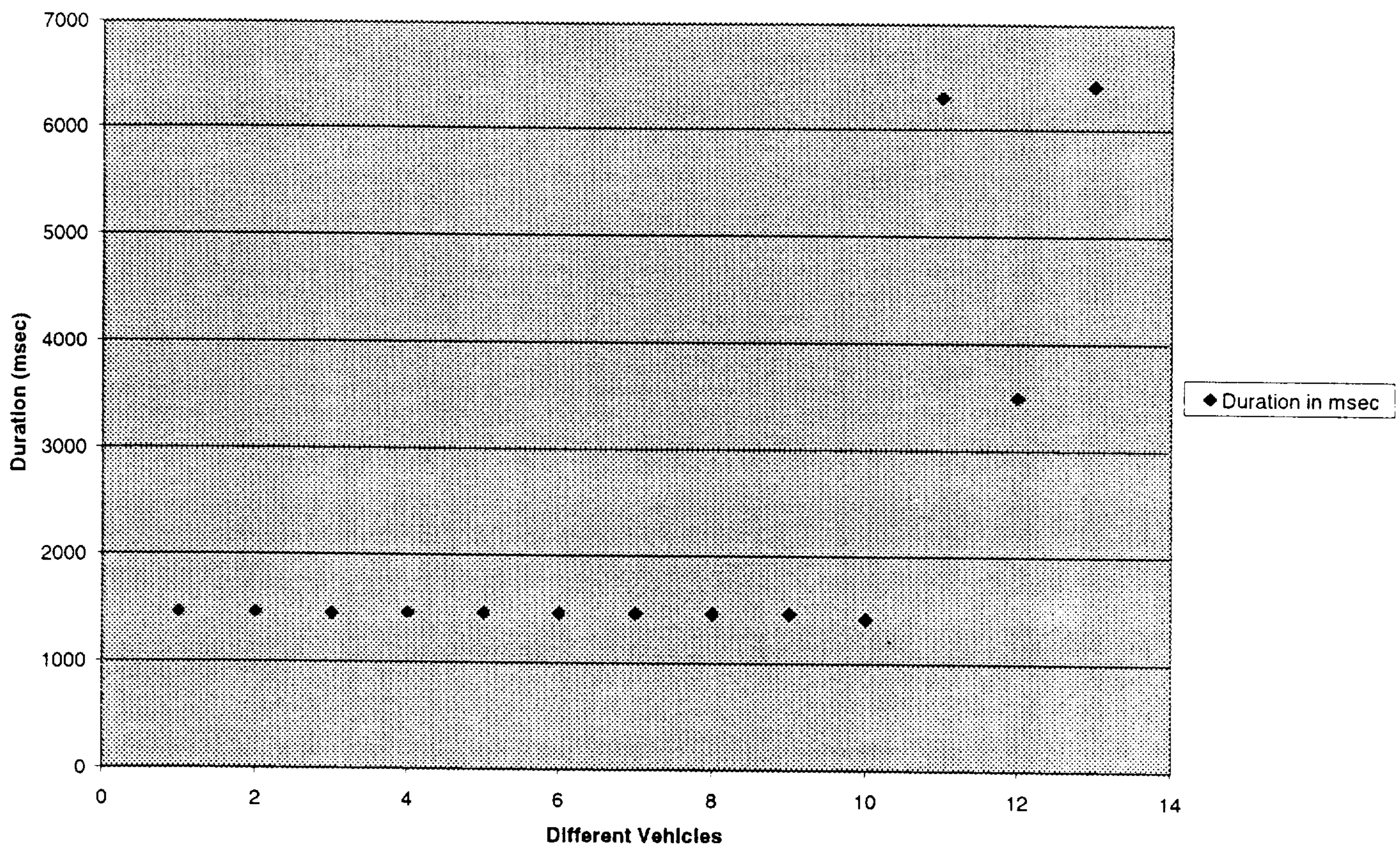


Figure R16-2: Distribution of Duration of Vehicles -Low Traffic(43)

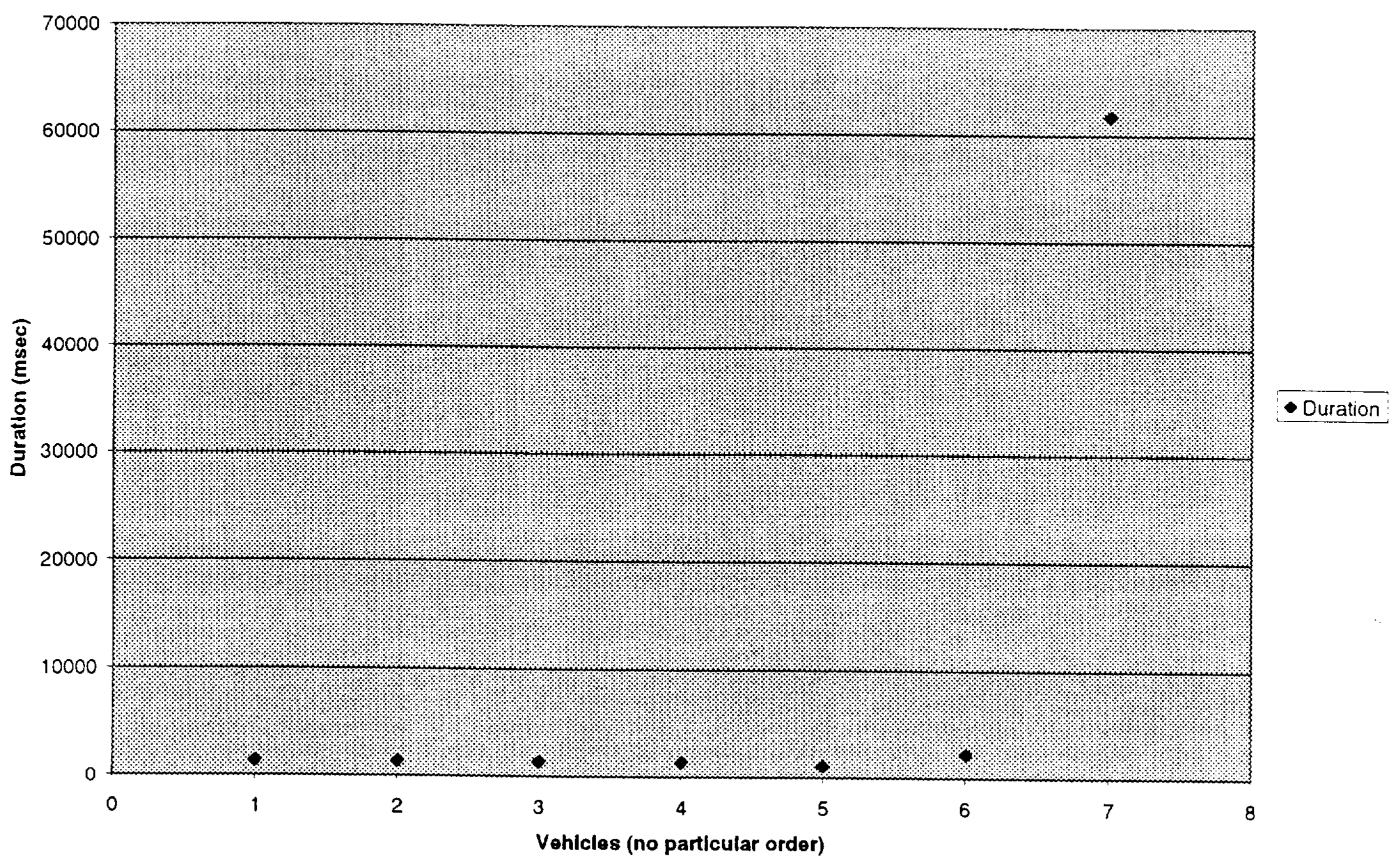


Figure R16-3 : Distribution of Duration of Vehicles - Low Traffic(55)

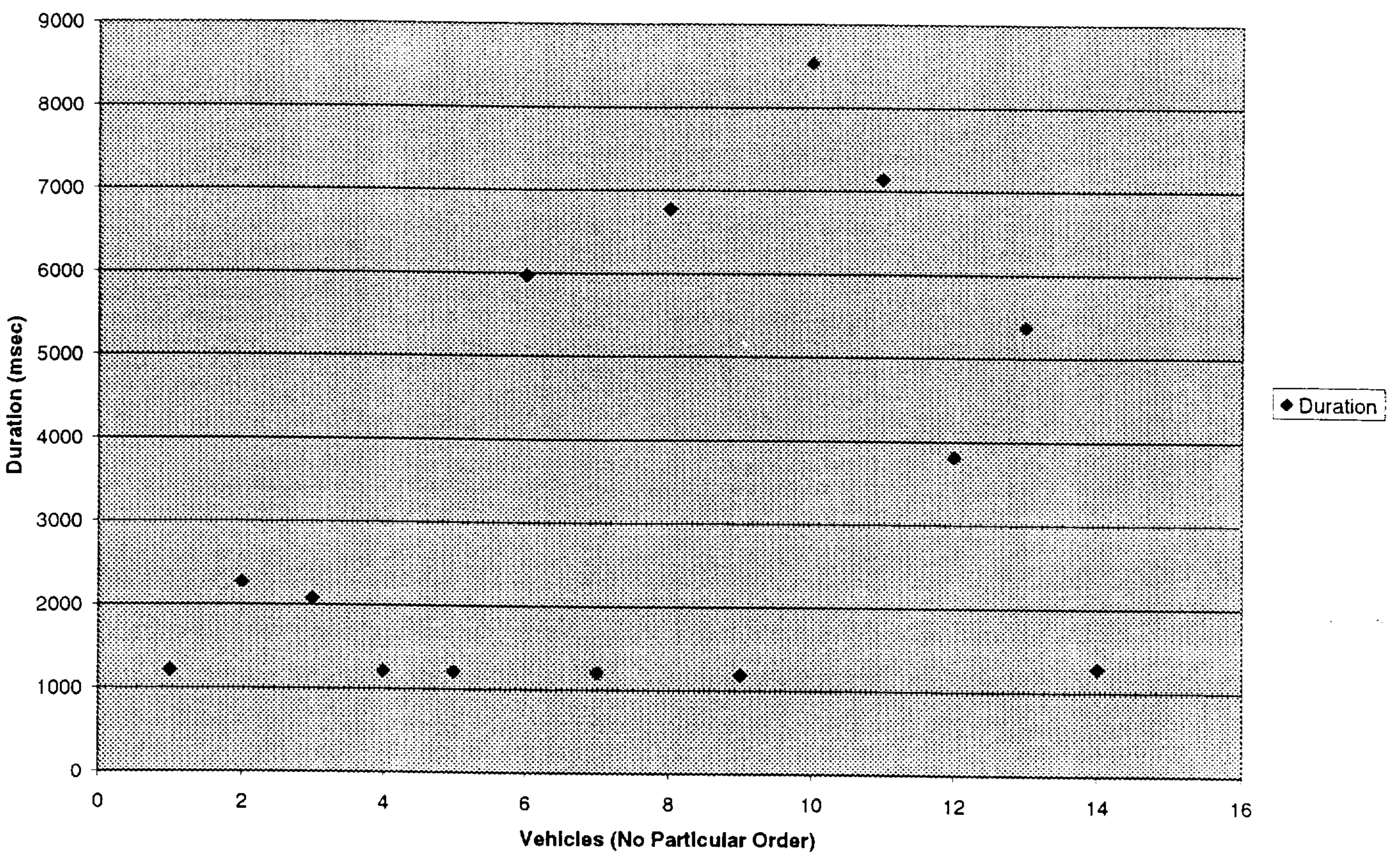


Figure R17-1 : Distribution of Duration of Vehicles - High Traffic(13b)

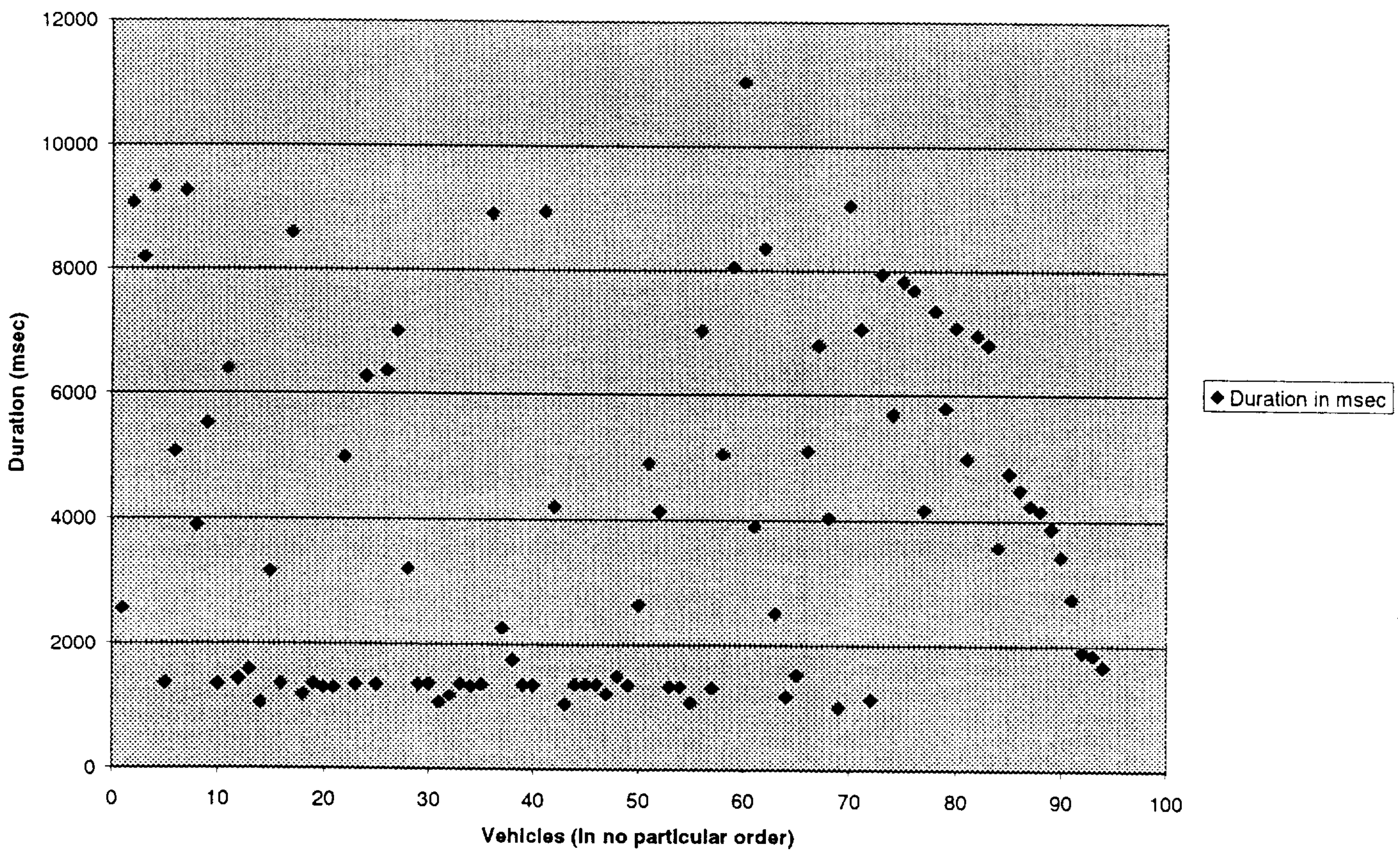


Figure R17-2 : Distribution of Duration of Vehicles : High Traffic(24)