BWI TERMINAL ACCESSIBILITY STUDY

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This study details the landside accessibility of the BWI airport. The accessibility of the airport is examined from each of the access facilities. Included in the study are the terminal garage, ESP parking lot, all satellite lots and terminal curbside drop-offs.

The study confirms much of what most informed people “know” about landside access of the airport, but does contain some information that is surprising. The garage provides the most rapid average access followed by the ESP lot. The satellite lots provide the highest average access times. Terminal curbside drop-off is studied separately and displays a very high variance.

The use of the lower roadway for morning rush hour shuttle delivery of passengers drastically reduces access times for the lots affected. This practice yields results that are quantified as well. The congestion of the upper level roadway provides a major drag on access and this is quantified for the various lots during different periods of day and days of week.

In addition, forecasting techniques are used to determine what average access times might be after an increase in passenger usage of access facilities. These forecasts show that, given no changes in other conditions, all access facilities could face unacceptable access times with as little as a 25-50% increase in passenger use of the access facilities.</td></tr>
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1 Introduction

One of the largest problems that airports face is getting passengers from the ground transportation network (highways and access roads) to the terminal. Unlike airside traffic, groundside traffic is not tightly regulated and human behavior plays a large role in how efficiently the system runs. Airports generally supply several means of access to the terminal building, and in developing plans for future development and improvement of airport grounds, it is important to take into account the trends in terminal access.

There are two important factors that influence the access time of passengers: groundside congestion, and volume relative to capacity at access facilities. In the future, terminal accessibility will be made more difficult by any increases in groundside volume that accompanies expected airside growth. It is important for airport officials to have a solid grasp of what the terminal access problem may look like in the future. This document presents a detailed look at the accessibility of BWI's terminal building during a two-week period in January 2000.

The accessibility of the airport is studied under a broad variety of conditions. The survey includes data from heavy peak activity periods as well as light off-peak periods. Accessibility of the airport is examined taking into account the effects of these factors. This allows some broad conclusions to be made about future accessibility to the airport. The facilities that were included in the study are the main parking garage, the ESP parking lot, and the satellite lots (blue, green and Amtrak). In addition, the terminal roadway was studied for the accessibility for drop-off passengers.

This report is divided into five sections. Section 2 contains the methodology for the data collection, the statistical evaluation and the forecasts. Section 3 contains the results of the study. Both summary results and the detailed results of the estimations are presented. Section 4 contains the conclusions from the study and Section 5 contains some recommendations for future study and action by airports to accommodate future growth. The Appendix contains information about the data, the data analysis procedure, and other information regarding the study.

2 Methodology

The study presented here had three components. The first component was data analysis; the second component was statistical evaluation; and the third component was probability function estimation and forecasting. The methodology for each component is described here.

2.1 Data Collection Methodology

The survey was conducted over a two-week period in early January 2000. The first day of the study was Monday, January 3 and the last day of the study was Sunday, January 16. As was necessary for our study, this is a relatively busy period at the airport. The first two days of the study saw very high volume, as holiday traffic was still quite high. The last weekend of the study also saw high volume as the Washington Redskins football team had an away playoff game. In fact, the satellite lots were closed for a considerable period over this last weekend of the study and the Amtrak lot was used for satellite parking customers.

Thirty-three students from Morgan State University conducted the survey. The survey began shortly after 6 a.m. and finished around 8 p.m. on weekdays and ran from 7 a.m. to 7 p.m. on weekends. Staffing levels were higher during peak periods (6 a.m. to 9 a.m. and 3 p.m. to 7 p.m.).

The methodology of the survey was simple. The goal was to collect data on the time it takes passengers to access the terminal from the various access facilities. Surveyors performed one of three tasks. The first task was to hand out survey cards to passengers as they entered an access facility. The second task was to collect the survey cards as the passengers entered the terminal building. The third task was to time drop-off trips through the terminal roadway. A diagram is included in the Appendix depicting the location of the ticket dispensers and collectors.

The methodology for handing the tickets was as follows. There were four sets of tickets – one for each of the lots we anticipated to study. The tickets were color-coded: yellow for garage, cream for ESP, blue for the blue lot satellite, and green for the green lot satellite. On the day that the Amtrak lot was in use, we used the blue tickets because that lot was closed and not scheduled to open. Figure 2-1 shows an actual ticket from the garage lot (this is actual size).

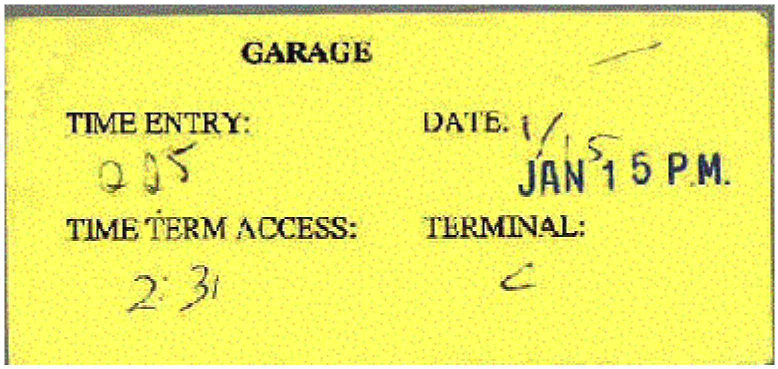

Figure 2-1

The surveyor at the ticket booth filled out the top half of the ticket and handed it to the passenger as they collected their garage ticket (same for all lots). The date stamp was added later for data entry procedures. The passenger was asked to hand the ticket to a survey worker at the terminal door. Figure 2-2 and Figure 2-3 show the process of handing out tickets.

Figure 2-2

Figure 2-3 illustrates one of the problems we encountered doing the study; cars seemed to exhibit a lemming-like behavior. Even in the presence of open lanes, the cars would back up in the lane that we were operating. It appeared that drivers thought the surveyors were handing out some important piece of information. The surveyors were forced to conduct cars away from the lanes at times. Compounding this problem was another problem demonstrated in Figure 2-3. Despite the presence of 6 lanes for cars to enter the garage, it was common to have as many as four non-functioning lanes at any particular time. Figure 2-3 shows three lanes closed. This was usually because the machines were out of tickets or malfunctioning.

These problems reduced the effectiveness of our surveyors, as they needed to stop handing out tickets and direct traffic on numerous occasions. This will be discussed in further detail in the recommendations section.

Figure 2-3

During peak periods, the number of ticket dispensers was increased to allow a greater sample of tickets during high-volume access times. The number of tickets dispensed was less than originally desired due to closures of the satellite lots for extended periods during the study. Obviously, these closures affected the accessibility of the airport. While recognizing the effect of these closures on access times, they cannot actually be analyzed or quantified. Tickets were dispensed at the entrance to the access facilities and it is not possible to account for lost time driving to closed satellite lots and then continuing on to other parking lots (namely the Amtrak lot).

In addition, the original goal was to account not only for parking, walking and shuttle time, but also for queuing time to enter the facilities. This was not possible and thus any time lost waiting in line to take a ticket is *not* accounted for in this study. Queuing time is longer during peak periods. Thus, it is possible to state that the results showing longer access times during peak airport hours understates the difference in access time during these periods. If this difference is significant, then the results of the forecasting may understate access times during peak periods in the future (with higher airside volumes).

The collection of tickets was performed at the terminal curbside. Again, the survey was unable to capture any additional queuing inside the airport caused by congestion or increased activity. Figure 2-4 shows the collection of a garage ticket at the terminal curbside. As can be seen, the collection point is immediately outside the terminal doors. So, all time lost to congestion in the lots, search for parking spaces and congested walkways are already incurred at this point. The surveyor collecting the ticket marked the terminal access time and the terminal accessed on the ticket after collecting it from the passenger.

Figure 2-4

The collection of satellite tickets was very similar except that it was necessary to meet the shuttle buses as they pulled up to the terminal curbside. Figure 2-5 shows an example of satellite ticket collection. The surveyors were not able to collect every ticket for a variety of reasons. Many of the passengers did not understand what was being done and either left tickets in their cars or did not pause to hand over their tickets upon entry. In addition, during extremely heavy traffic, the flow of tickets was often too heavy to collect every one.

Figure 2-5

The methodology for collecting data on the drop-off passengers is simple and intuitive. A detailed diagram is provided in the Appendix to help understand what was timed. The basic idea was to capture how long it took passengers to access the airport once they were on the terminal roadway. We could not pick up any queuing time that was incurred prior to entry to the terminal roadway.

Once a car entered the terminal roadway, three times were recorded. The time from when the car entered the terminal roadway until it pulled to the curb to discharge the passenger; the time from when the car pulled to the curb to when the car tried to re-enter the terminal roadway traffic; and the time from when the car tried to re-enter the terminal roadway traffic until it left the terminal roadway. The exact locations that we used for entrance and exit from the terminal roadway are given in the diagram in the data appendix.

The three times are denoted as access time, standing time and exit time. The access and exit times are combined and termed travel time. Travel time is used in the analysis.

2.2 Statistical Methodology

The first set of results is statistical summaries. In many cases the methodology is self-explanatory. In order to make judgments about the comparative length of time between two different access facilities or two different sub-samples of entry times, a standard test for the difference between two means was utilized. The form of this test is

$$t = \frac{\bar{x}_2 - \bar{x}_1}{\sqrt{s_2^2/n_2 + s_1^2/n_1}}$$

Where $\bar{x}_1$ is the mean of the first sample, $\bar{x}_2$ is the mean of the second sample, s_1^2 is the variance of the first sample, and s_2^2 the variance of the second sample. *t* is distributed normally with mean 0 and variance 1. This distributional result is subject to both samples having more than 30 observations $(n_1, n_2 > 30)$. When this last assumption is not met, it is necessary that the data come from a normal distribution.

This test is robust to changes in the underlying distribution of the data for large sample sizes (often $n \geq 30$). In small samples, this test is only valid for data from normal distributions. In our case, the data do not come from normal distributions (see the results from the probability estimations in Section 3) and, thus, for small samples this test is not correct. It is rare that we are examining samples of less than 30 and these are clearly marked in the results section.

2.3 Regression Methodology

The regression analysis carried out for this report is simple ordinary least squares regression analysis. While there are drawbacks to the regression analysis performed (see the recommendations for a description of these problems), the results of the regression analysis are useful for two reasons. First, they provide insight into the interaction between the variables, which allows analysis of how various factors influence access times. Second, the regression results provide parameters for the forecasting section.

For each of the regressions, the following model was utilized:

$$\tau_t = \alpha + \beta_d d_t + \beta_h h_t + \beta_u u_t + \varepsilon_t$$

Where τ is the access time in minutes, α is the constant in the regression, β are the coefficients in the regression, d is a set of variables representing the day of the week, h is a set of variables representing the time of day, and u is a set of variables describing the utilization rate of the lot.

The access time is measured as the time it takes to go from the ticket booth at the parking lot to the terminal curbside. The constant in the regression can be considered the average access time under the base scenario.[1] In most of the regressions that follow the base scenario is Wednesday during late morning. The days of week variables are a set of dummy variables that represent each day of the week except the base case (Wednesday in most cases). The time of day variables are a set of dummy variables that represent different periods of the day. The periods of day are morning rush hour, late morning, midday, early afternoon, late afternoon rush hour and evening. The exact times for each of these are given in

[1] The effect minus the impact of the utilization variables. The utilization variables are not used in deviation from mean form and thus the constant includes the impact of these variables evaluated at their means.

Time of Day Variables					
A.M. Rush	**Early A.M.**	**Midday**	**Early P.M.**	**P.M. Rush**	**Evening**
6 a.m.	8 a.m.	11 a.m.	1 p.m.	3 p.m.	6 p.m.
8 a.m.	11 a.m.	1 p.m.	3 p.m.	6 p.m.	8 p.m.

Table 2-1

The regression is carried out estimating the parameters as follows:

$$\beta = (X'X)^{-1}X'Y$$

Where

$$\beta = \begin{pmatrix} \alpha \\ \beta_d \\ \beta_h \\ \beta_w \\ \beta_u \end{pmatrix}, X = \{1, d, h, w, u\}, Y = \tau$$

The coefficients in this regression represent the increase (or decrease) in average access time for that particular variable relative to the base case. This is explained in detail in the results section.

2.4 Forecasting Methodology

One of the important results presented in this study is the forecast of accessibility under certain potential future scenarios. The methodology for the forecasting is quite simple. Various potential growth rates for airport usage and volume rates are analyzed given the results of the probability distribution estimations. These figures are inserted into the estimated distributions and the various access times calculated. The results are graphed in various forms to show the access times over various scenarios. These results are fully explained in the results section.

Forecasting, while often looked upon as “witchcraft”, is a very refined concept. The forecasting done here *does not* predict future traffic levels or even access times. Instead, the methodology employed here is to predict access times as a function of *potential* future air and groundside volumes at BWI. Due to the limited scope of this study, only simple forecasting methods were employed. If the airport considers accessibility in the future to be a serious issue, further study is strongly recommended in this area. As section 3.3 shows, the future accessibility of the airport could be quite unsatisfactory if certain scenarios “play out”. This study does not attempt to place probabilities on the various scenarios. That is the role of a true forecasting study.

3 Results

This section contains the results of the study. The first part of this section contains the standard descriptive data analysis. Frequencies, means and other descriptive variables are presented. In addition, tests for the differences in some access times and other statistics are tested. The second part of this section contains the results from the regression analysis. The third part of this section contains the results from the forecasting procedure. There are many graphs and tables in this section, which were kept in the main body of the report for easy reference to the description of the results.

3.1 Statistical Results

The data analysis in this study consisted primarily of finding average access times across varying conditions, and looking at the frequency of access times and observations across varying classes. The results are presented by access facility. Table 3-1 contains some summary statistics about the data itself. This table shows the number of tickets collected by the access facility as well as return rates of these facilities.

Scope of BWI Accessibility Study	
Number of Man-Hours Collecting Data	2,100
Number of Survey Tickets Dispensed	35,400
Number of Survey Tickets Collected	12,268
Number of Drop-Offs Timed	2,396
Number of Garage Tickets Dispensed	26,150
Number of Garage Tickets Collected	9,054
Number of Satellite Tickets Dispensed	8,350
Number of Satellite Tickets Collected	2,999
Number of ESP Tickets Dispensed	900
Number of ESP Tickets Collected	215
Minutes of Walkway Usage Data Collected	4,843

Table 3-1

While individual facilities varied, the average collection rate of the tickets was about 35 percent. The satellite tickets were more successfully collected than any other access facility. This was in part because the passengers arrived in groups and the surveyors could meet the bus and capture a number of tickets at one time. It is also probable that the passengers using the satellite lot were less time-sensitive and thus more willing to take the few seconds it required to turn the ticket in to a surveyor. The individual access facility summaries will be handled in their subsections below.

3.1.1 ESP Results

The ESP lot is the lowest volume access facility at BWI airport. The number of observations for this lot is quite low for several reasons. The first is that the lot has low volume. The second is that the travelers who use this lot were often less willing to take the time to receive the card and turn it in to the surveyors. The last reasons is that the ESP lot volume is so low for much of the day that we did not hand out tickets there except for a short time most days. Figure 3-1 shows the distribution of tickets collected by date for the ESP lot. Figure 3-2shows the distribution of tickets collected by time of entry for the ESP lot. Figure 3-3 shows the distribution of access times for the ESP lot. Table 3-2 contains the summary statistics for the access times from the ESP lot.

Summary Statistics for the ESP Lot			
# Of Observations	**Average Access Time**	**Minimum**	**Maximum**
215	9.6698	2	26
Variance	**10 %tile**	**25 %tile**	**50 %tile**
11.4932	6	8	10
75 %tile	**90 %tile**	**95 %tile**	**99 %tile**
11	13	15	19

Table 3-2

Table 3-2 indicates that only a few tickets were obtained from this facility. The access times for this facility were surprisingly high in variance. While a rapid access facility, access to the terminal from this facility is subject to terminal roadway congestion. Even so, 50 percent of passengers arrived at the terminal within exactly 8 and 11 minutes. Due to the small number of observations, can be said about the high variance for this lot. It should also be noted that any observation with an access time greater than 30 minutes was discarded. This will be discussed more fully in the data appendix.

Not many tickets were handed out at the ESP facility during the highest volume days (January 3 and January 4). It is not possible to state that we have observed the behavior of this lot under high volume conditions. This, combined with the small number of observations, makes the results for this lot difficult to compare and forecast.

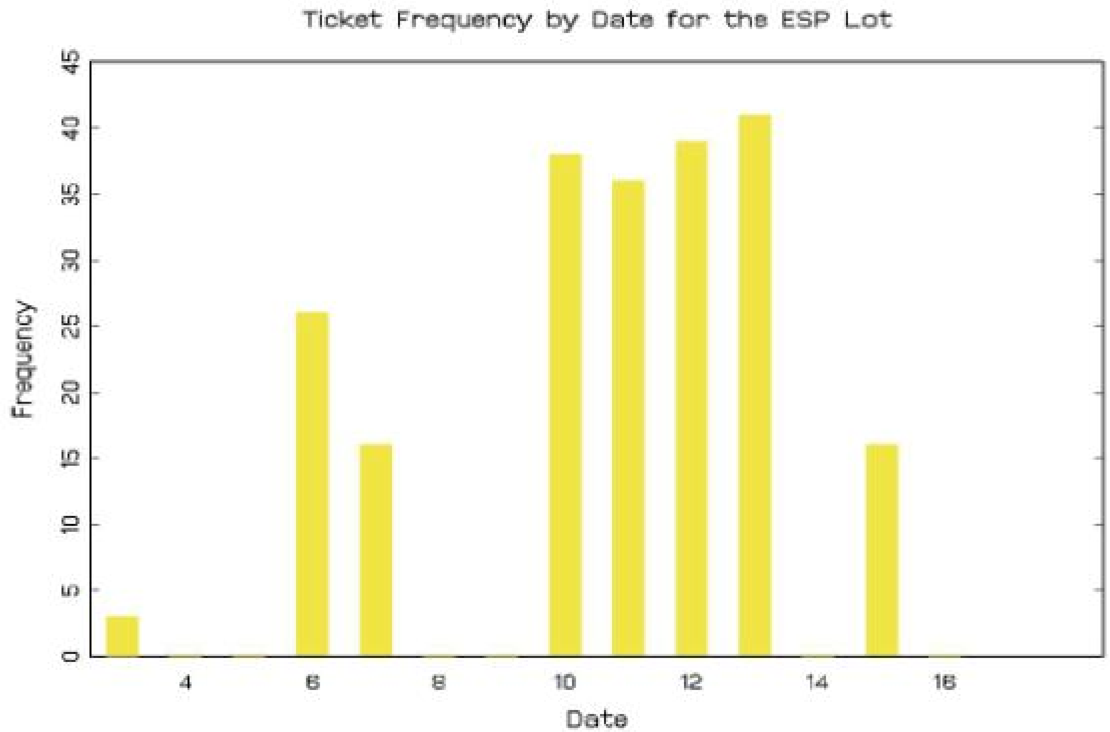

Figure 3-1

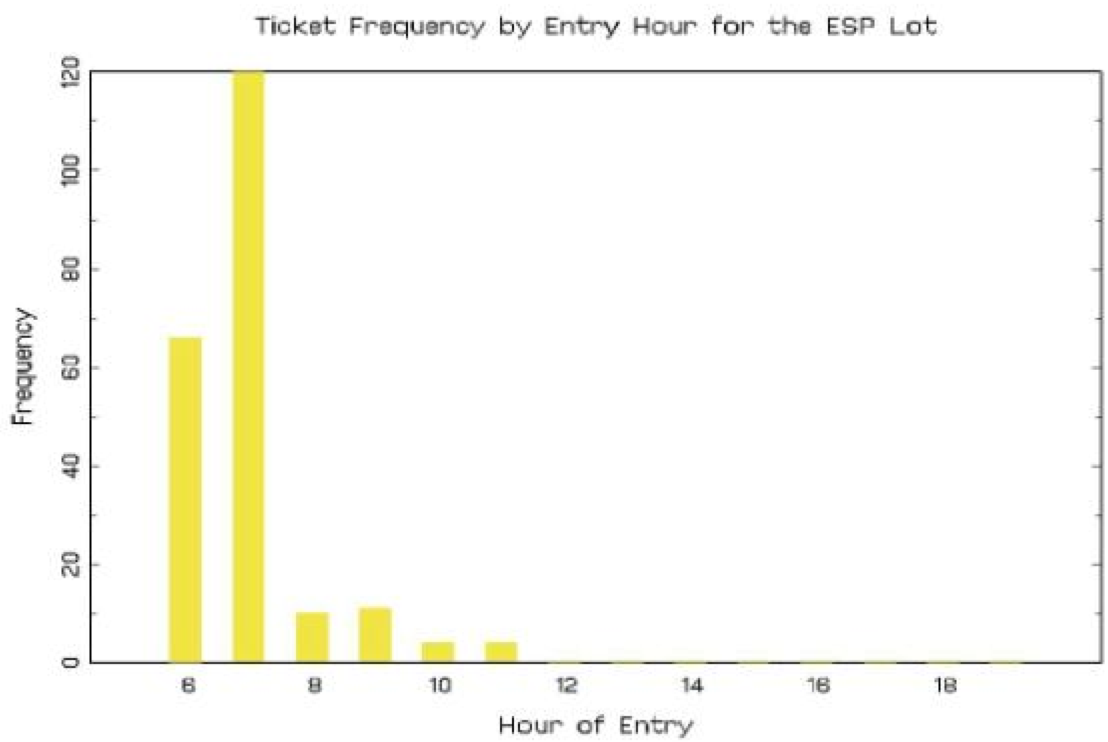

Figure 3-2

Nearly all of the observations from this facility were obtained during the morning rush hours. This is because the lot observes its peak use during this time. The steep decrease in observations after 8:00 a.m. is partially attributable to the decrease in facility usage after this hour and partially attributable to the surveyors not handing out tickets at this facility throughout the day.

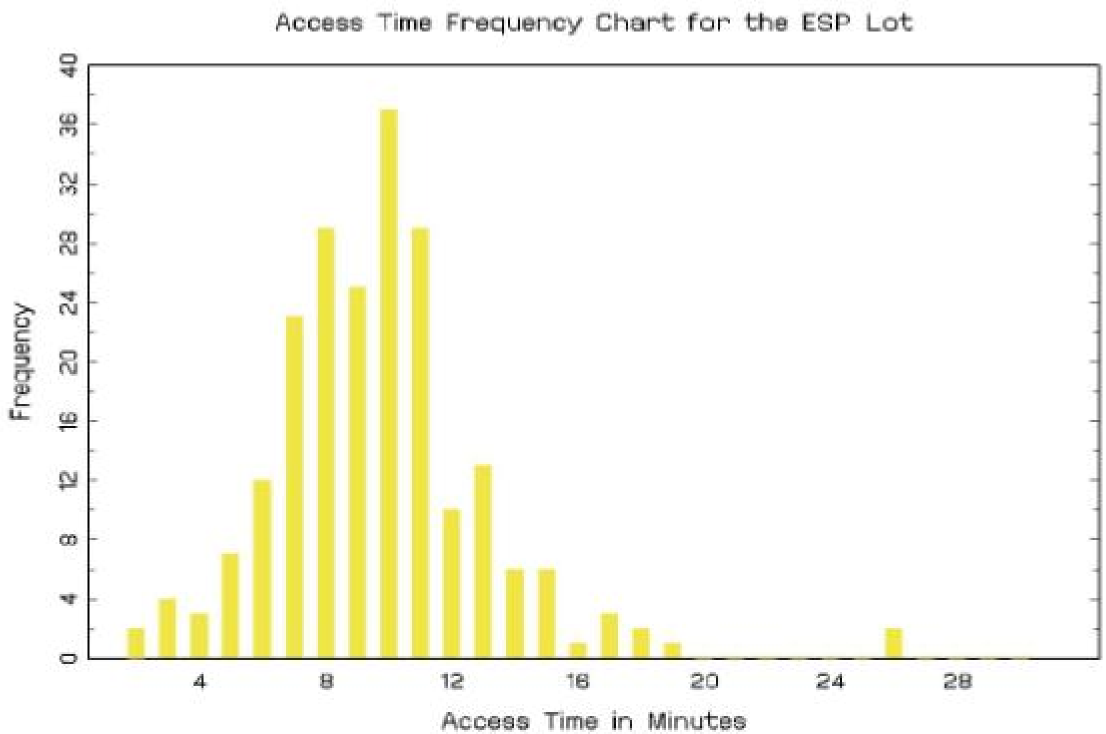

Figure 3-3

It is clear from Figure 3-3 that the access time for the ESP lot has high variance. While there is a peak at 10 minutes (the mean), there is a broad range of access times from this lot.

Table 3-3 shows the average access time by day of week. The access times are relatively constant. The low number of observations makes differentiating these differences very difficult. It does appear that access times are higher on Mondays and lower on Fridays. The tests below will cast more light on this.

Average Access Time for the ESP Lot by Day of Week			
Monday	**Tuesday**	**Wednesday**	**Thursday**
10.463415	9.5833333	10.025641	9.4179104
Friday	**Saturday**	**Sunday**	
8.1875000	9.5000000	.	

Table 3-3

Table 3-4 shows the average access time by hour of day. Again, the small number of observations makes differentiating these figures difficult. However, rush hour access was faster than off-peak access. While this might seem counter-intuitive, there is a good reason for this. During the early morning rush hour, there are almost no arriving flights at the airport. Thus, the lower level roadway (arrivals) is nearly deserted. During this period, the shuttles from the ESP lot and the satellite lots use the lower roadway to avoid congestion. It appears to work from the small number of observations obtained. These figures do not include any queuing time before arriving at the ESP lot ticket dispenser.

Average Access Time for the ESP Lot by Time of Entry	
Early a.m. Rush Hour	**Late a.m. Off-Peak**
9.4462	11.1034

Table 3-4

The average access times were tested to determine if they were truly different over days of the week or times of day. The results are shown in Table 3-5 and Table 3-6. Table 3-5 shows the results for the tests across days of week. It must be remembered that the Friday, Saturday, and Sunday tests are subject to the low number of observation problems mentioned in the methodology section.

T-Tests for Difference in ESP Access Times Across Days of Week						
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
Monday	0.00	1.00	0.57	*1.51*	***2.48***	0.39
Tuesday	1.00	0.00	0.52	0.21	*1.41*	0.03
Wednesday	0.57	0.52	0.00	0.92	**2.05**	0.22
Thursday	*1.51*	0.21	0.92	0.00	*1.48*	0.03
Friday	***2.48***	1.14	**2.05**	*1.48*	0.00	0.53
Saturday	0.39	0.03	0.22	0.03	0.53	0.00

Table 3-5

The numbers in *italicized print* are significant at the 10 percent level, those in **bold print** are significant at the 5 percent level, and those in ***bold italicized*** print are significant at the 1 percent level. The low number of observations may be contributing to the inability to differentiate between access times by day of week. Despite the low number of observations on Friday, it does appear that access times are lower on Fridays. The test used is not technically valid for the number of observations on Friday, but the results are strong and they match intuition. Business travel is lowest on Friday morning and we would expect more rapid access that day.

Table 3-6 shows the results for the tests across hour of day.

T-Tests for Difference in Means Across Times of Day		
	A.m. Rush	**Mid-Morning**
A.m. Rush	0.00	*1.63*
Mid-Morning	*1.63*	0.00

Table 3-6

Again, the italicized print represents a statistic that is significant at the 10 percent level. Table 3-6 indicates that the early rush hour access times are lower than those for later in the morning. The small number of observations does provide a bit of doubt about this conclusion, but it does appear that the difference is significant. This provides evidence that utilizing the lower level roadway does save time accessing the terminal. The savings appear to be at least three minutes (it is impossible to see the savings directly). More will be said of this after the drop-off data are examined.

3.1.2 Satellite Results

The Satellite lots included in this study are the blue lot, the green lot, and for one day the Amtrak lot. Results are presented for each of these lots individually and for the combined group. The number of observations for these lots is sufficient to allow relatively reliable testing between the different lots as well as the days of the week and times of day.

Table 3-7 contains the summary statistics for access from the satellite lots. It is immediately clear that the number of observations was roughly equal between the two main satellite lots.

Summary Statistics for the Satellite Lots					
# Of Observations		**Average Access Time**	**Minimum**	**Maximum**
Blue	1419	19.2051	1	45
Green	1476	21.9085	1	45
Amtrak	84	18.3810	4	45
Total	2979	20.5213	1	45
Variance		**10 %tile**	**25 %tile**	**50 %tile**
Blue	41.0630	12	15	18
Green	43.2804	14	17	21
Amtrak	43.4917	12	14	17
Total	44.1099	13	16	20
75 %tile		**90 %tile**	**95 %tile**	**99 %tile**
Blue	23	28	32	39
Green	26	31	34	40
Amtrak	22	25	27	45
Total	24	29	33	40

Table 3-7

The three lots also have very similar average access times. More observations were obtained during high volume periods for the green lot than the blue lot and this may account for part of this difference. More will be said about the relationship between access time from the blue and green lots below. The Amtrak lot was only used for a Saturday afternoon and, as will be seen below, access times are lower on weekends.

For the combined lots, 50 percent of passengers arrived at the terminal within exactly 16 to 24 minutes. This low variance was a surprise. There are many factors that affect the efficiency of using the satellite facilities. This means of access is highly susceptible to terminal roadway congestion. More will be said about dealing with terminal roadway congestion in the recommendations below. Finally, any observation with an access time in excess of 45 minutes was discarded. This is fully described in the Appendix.

Figure 3-4, Figure 3-5 and Figure 3-6 show the distribution of tickets collected by date for each of the lots except Amtrak, which were only collected on Saturday, January 15. Note that Figure 3-6 is for all three-satellite lots (Amtrak included).

Figure **3-7**, Figure 3-8, Figure 3-9, and Figure 3-10 show the distribution of tickets collected by hour of entry for each of the lots. It should be noted that the Amtrak lot is not examined in detail because there are only observations for this lot on one day. It is included in the total satellite figures and analysis.

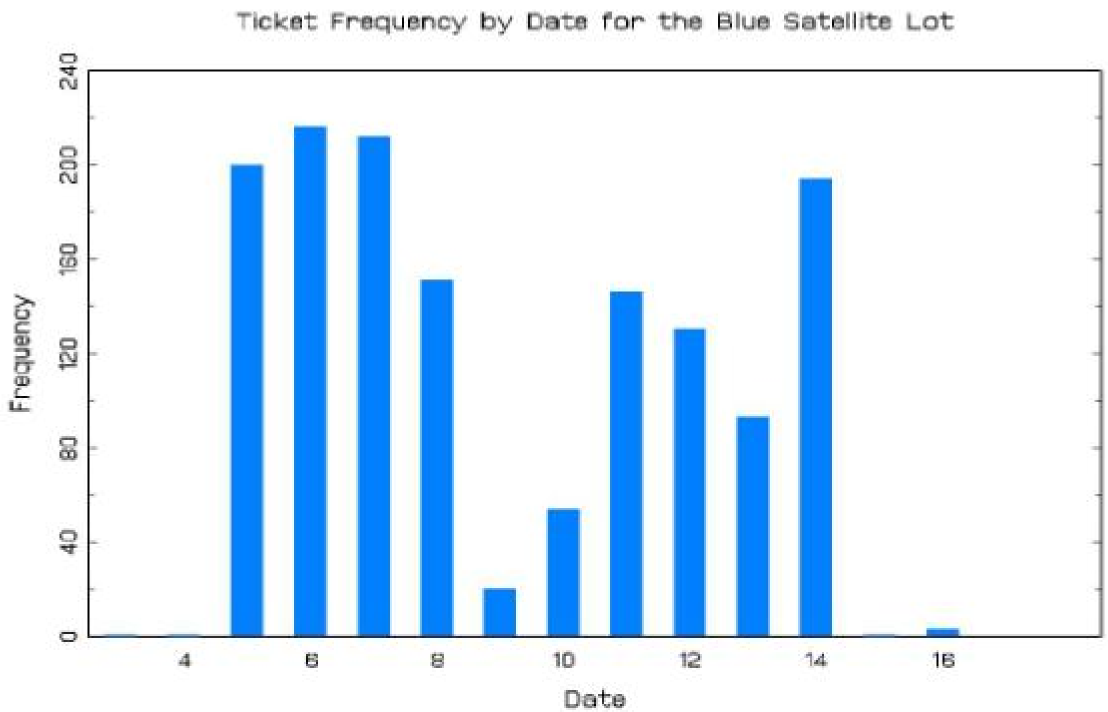

Figure 3-4

The blue lot was closed for the entire day January 3, 4 and 15. On days, this lot was closed for parts of the day. The large number of satellite lot users on Fridays is apparent from this graph.

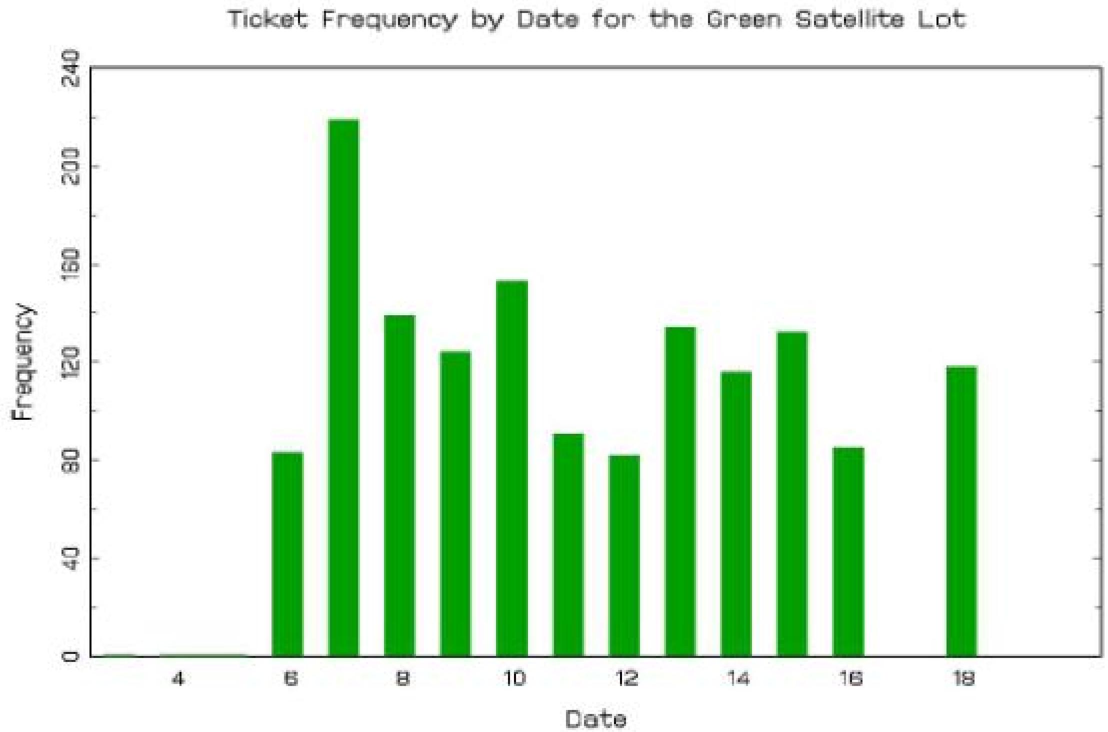

Figure 3-5

The green lot was closed the entire day on January 6 and for almost the entire day on January 15. The green lot was not collected with nearly the frequency of the blue lot when both lots were opened and thus the ticket collection numbers are less telling.

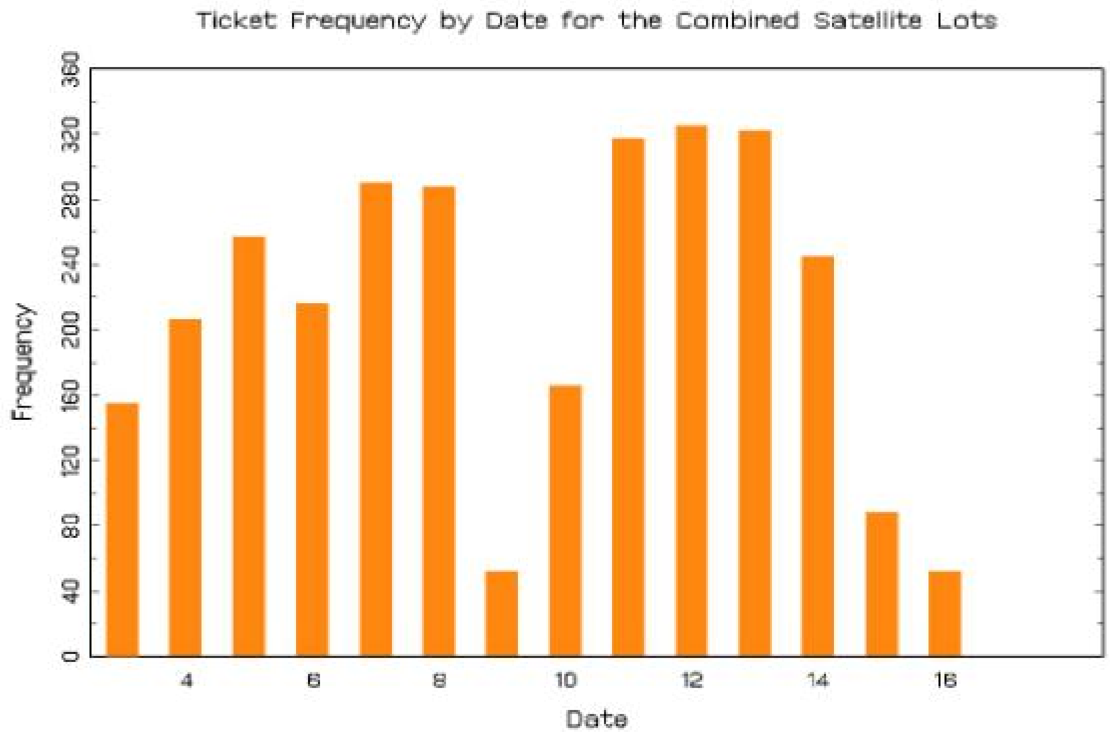

Figure 3-6

The large number of satellite lot users toward the end of the week is evident from this graph. The low figure for January 9 was partially due to low satellite usage and partially attributable to low staffing of surveyors that day. The increased use of the satellite lots during the second week is quite obvious from these figures. A good part of the reason for this increase is that the Washington Redskins played an away playoff game the last weekend of our study. In fact, the satellite lots were totally filled and the Amtrak lot was used for most of the day on January 15.

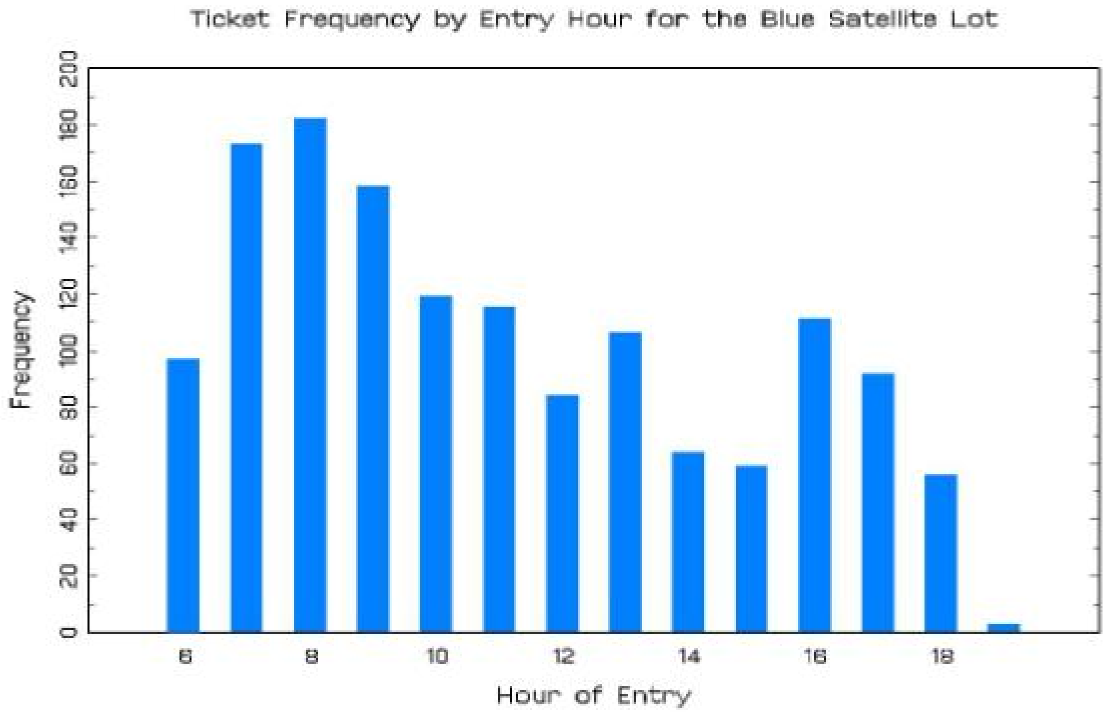

Figure 3-7

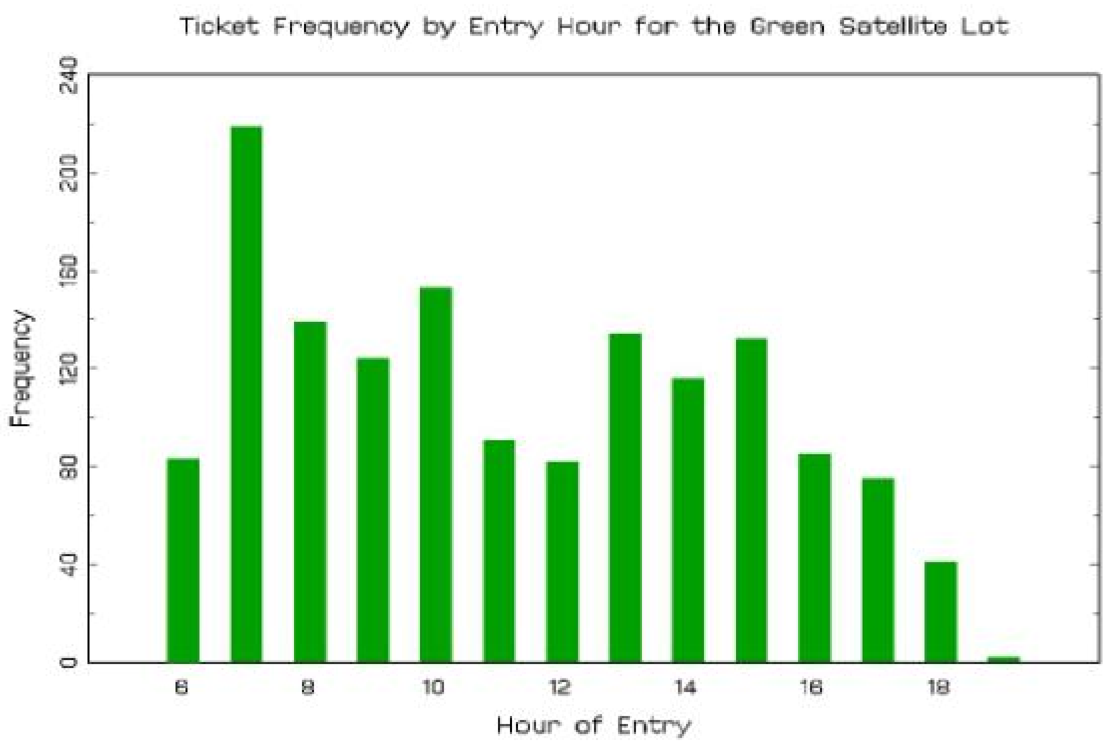

Figure 3-8

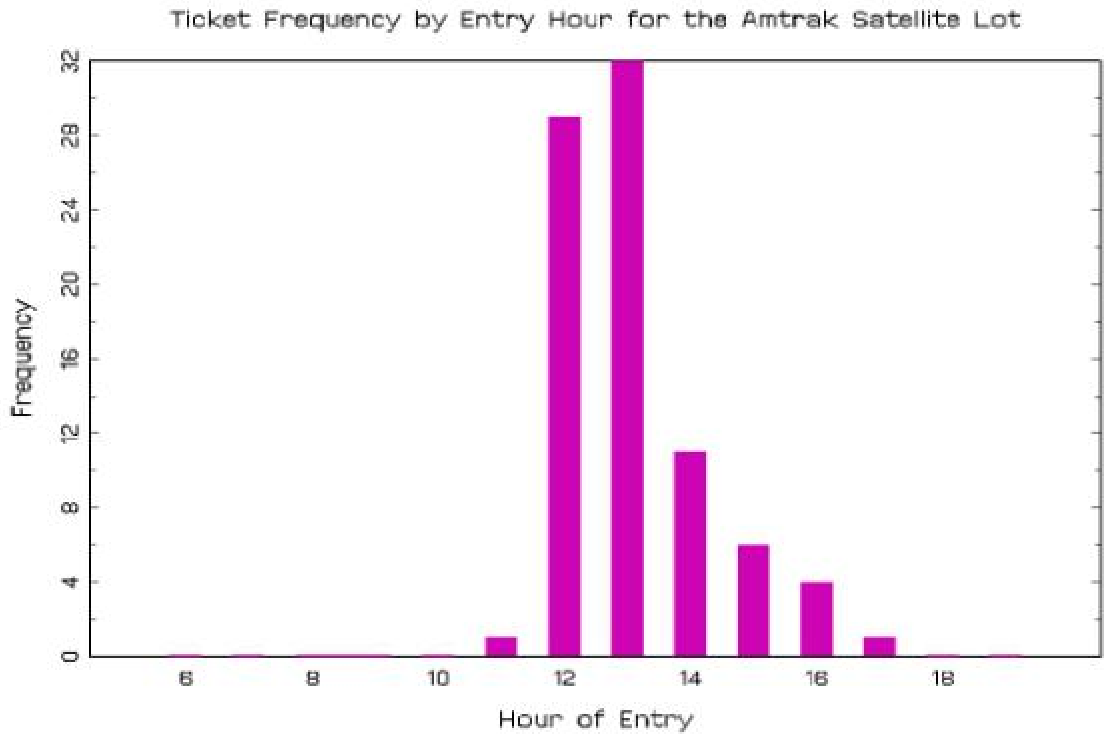

Figure 3-9

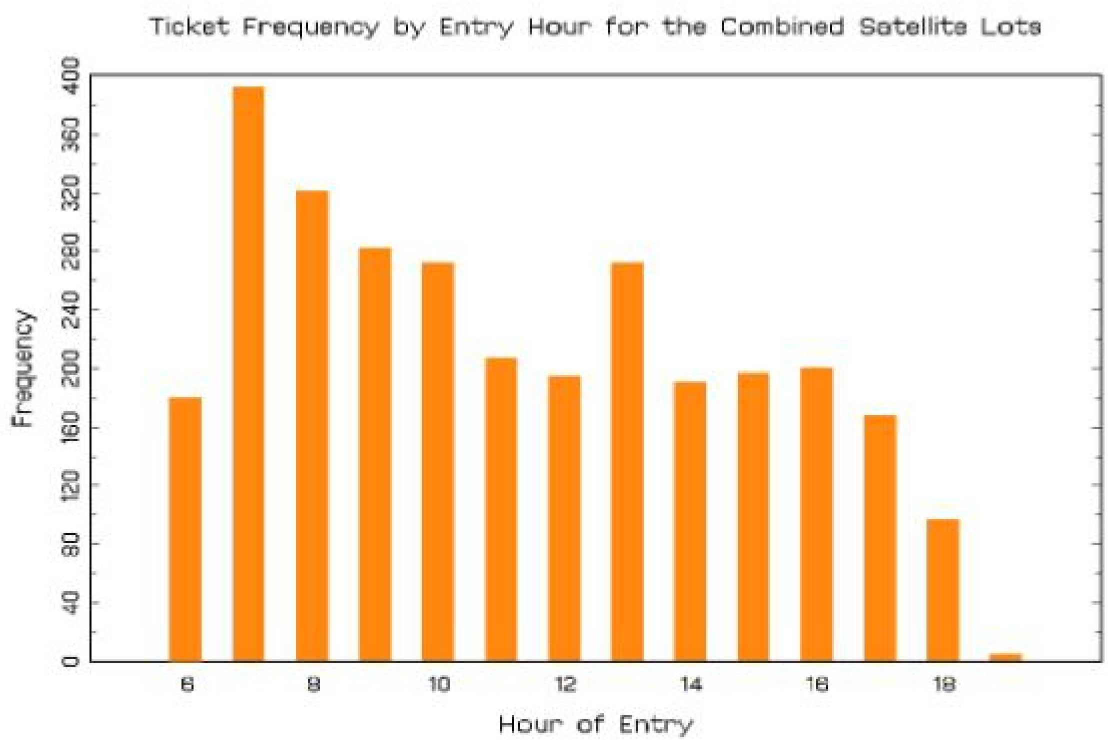

Figure 3-10

The hour of entry data are a bit deceiving for the satellite lots. Remember that staffing levels of the study were highest in the early morning hours. While this is a high volume period for the satellite lot, the afternoon hours also receive very high traffic volumes. Any frequency data are affected by staffing levels. This is not true for average access time data.

Figure 3-11, Figure 3-12, Figure 3-13 and Figure 3-14 show the distribution of access times for each lot and for the whole group of satellite lots.

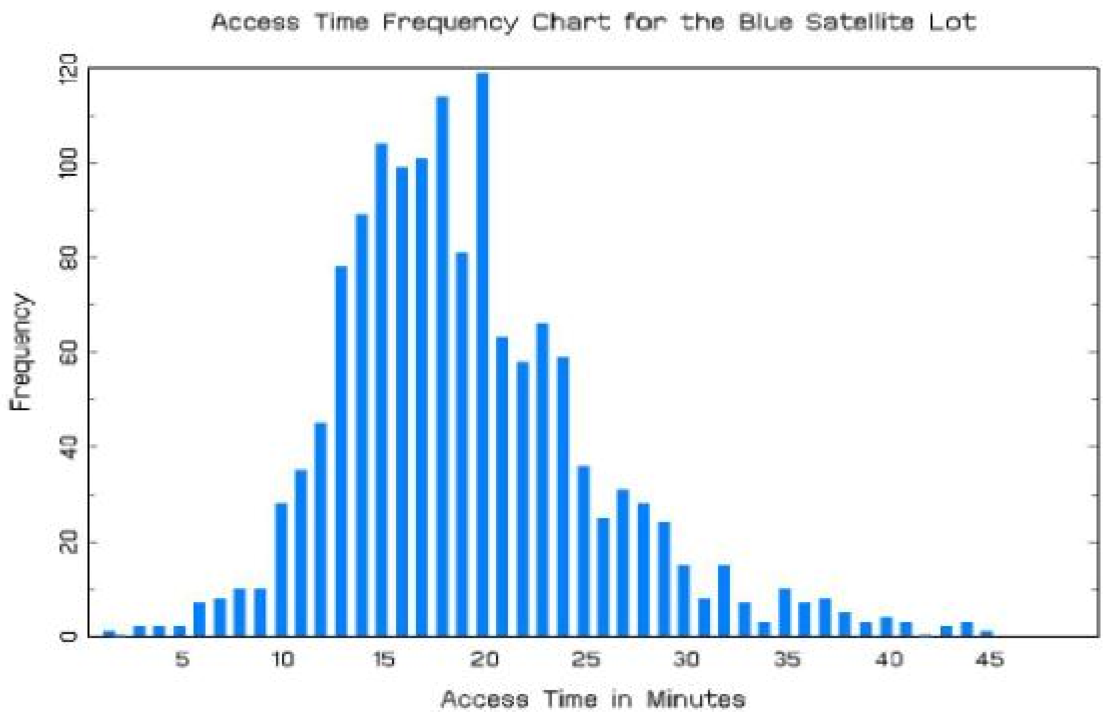

Figure 3-11

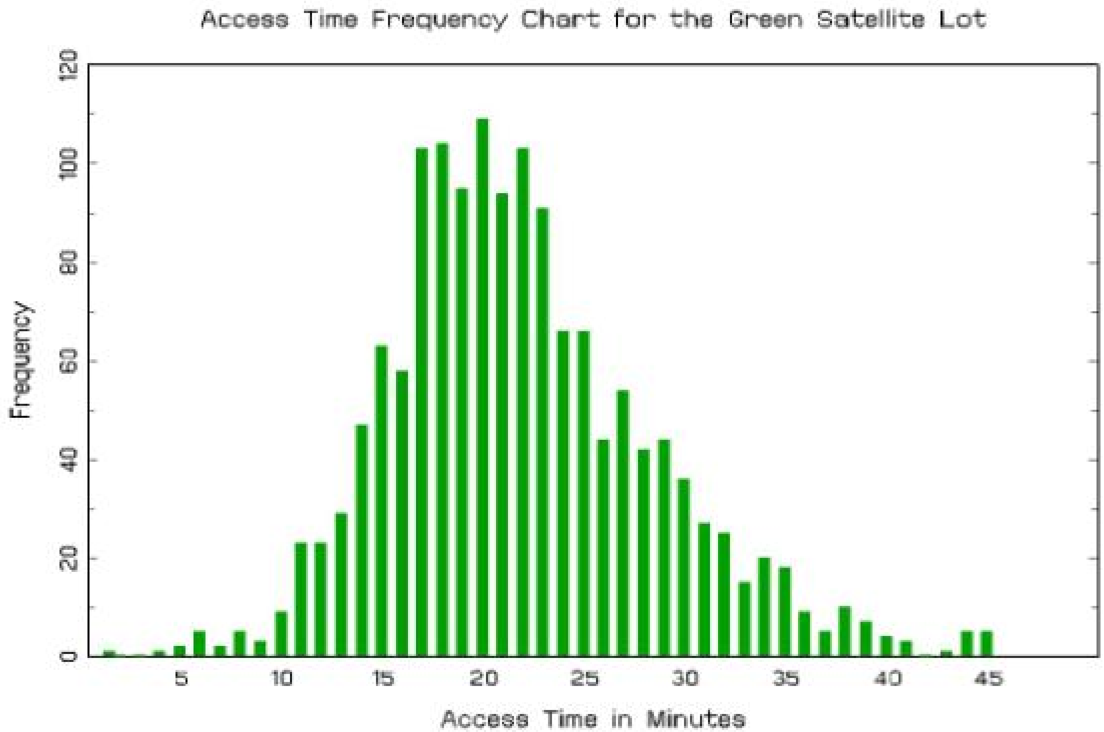

Figure 3-12

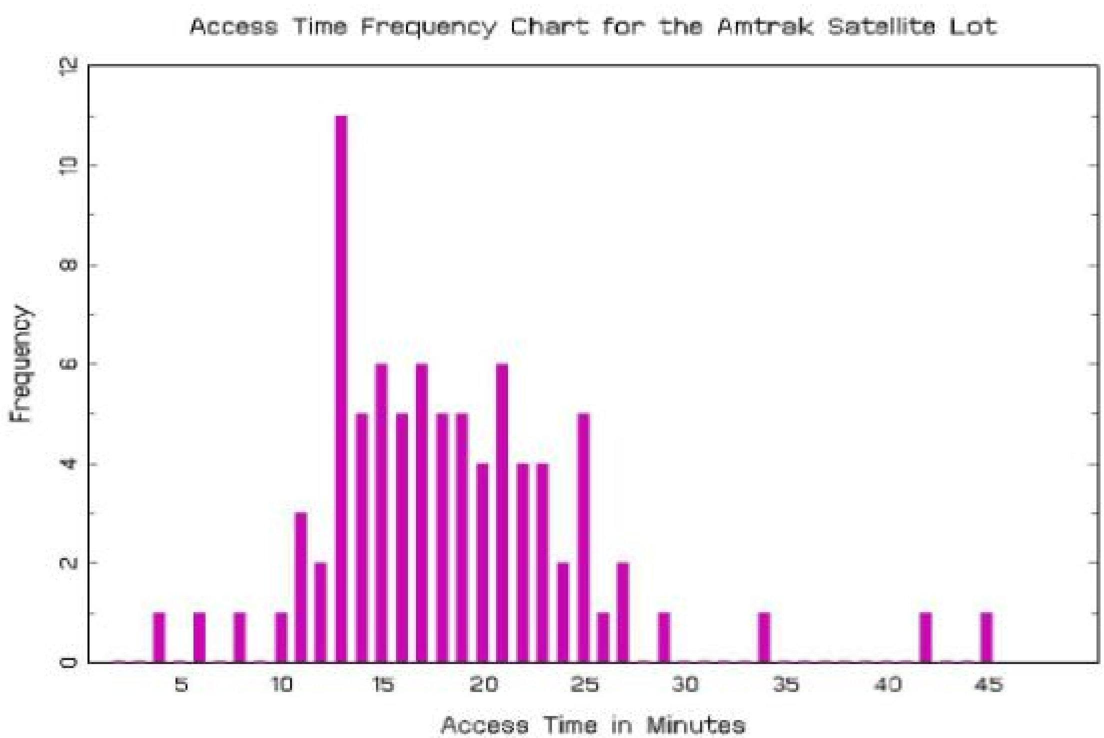

Figure 3-13

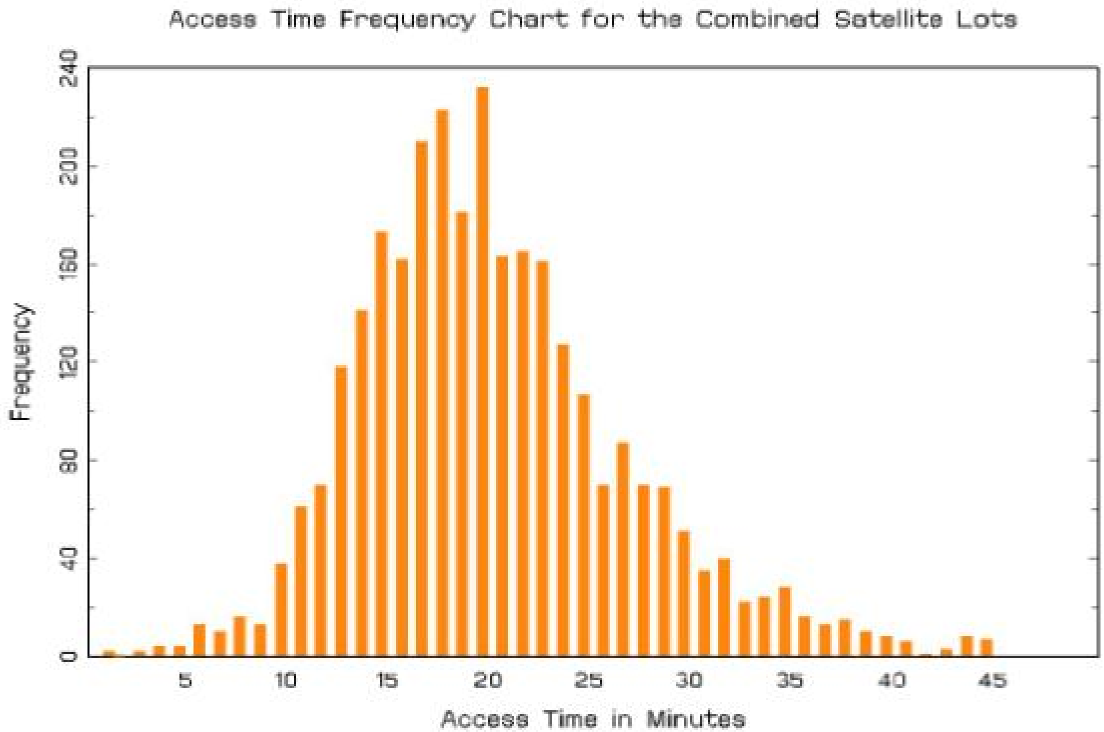

Figure 3-14

The access time graphs show a clear pattern. The access time for each lot was close to 20 minutes. For each of the lots, this was a nearly central mean – meaning that the 50th percentile user also accessed the lot in approximately 20 minutes. There is a slight skewing of the access times to the right and this is evident in each of the graphs (as well as the fact that the median is slightly lower than the mean for all three lots).

Table 3-8 shows the average access time by day of week. It is obvious that there is variance across the week.

Average Access Time for the Satellite Lots by Day of Week				
	Monday	**Tuesday**	**Wednesday**	**Thursday**
Blue	19.759259	18.171233	18.669697	19.398058
Green	21.573034	21.408488	22.948413	22.825328
Amtrak	.	.	.	.
Total	21.267913	20.504780	20.522337	20.856877
	Friday	**Saturday**	**Sunday**	
Blue	20.408867	17.423841	20.000000	
Green	22.953488	20.007092	21.160494	
Amtrak	.	18.380952	.	
Total	21.022430	18.606383	20.903846	

Table 3-8

It appears that access from the Green lot is slower than from the Blue lot. The regression and forecasting results confirm this. While it is possible that there are conditions that adversely affected the Green lot and not the Blue lot during this period, that is not likely. It appears that access from the Green lot is about 1-3 minutes slower than the Blue lot on average. The regression results confirm that the access from the Green lot is slower.

Table 3-9 shows the average access time by hour of day. The early morning rush hour shows the lowest average access time with the exception of the evening off-peak hours. Again, similar to the ESP lot, the use of the lower level roadway seems to be quite effective in avoiding congestion. The highest access times are found to be in the afternoon. This is not surprising given that tourist traffic (the passenger most likely to use satellite parking) is a larger percentage of departing passengers during these hours. In addition, the upper level roadway congestion enters the access times from the satellite lots during this period (unlike the early morning when the satellite shuttles utilize the lower roadway). The averages will be tested below to determine if they actually are different across time of entry.

Average Access Time for the Satellite Lots by Time of Day			
Early a.m. Rush Hour		Late a.m.	Midday
Blue	18.1667	18.5645	19.026316
Green	19.9260	21.3708	22.393519
Amtrak	.	24.000000	18.344262
Total	19.1136	19.8845	20.494647
Early p.m.		**Late p.m. Rush Hour**	**Evening**
Blue	22.626016	20.837438	18.016949
Green	24.092742	23.981250	19.186047
Amtrak	17.941176	19.200000	.
Total	23.358247	22.182065	18.509804

Table 3-9

The differences in average access time are tested across both the day of week and the time of day. These results are presented for individual satellite lots (except Amtrak) and for the satellite group as a whole. These results are presented in Table 3-10, Table 3-11 and Table 3-12.

T-Tests for Difference in Means Across Days of Week – Blue Lot							
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Monday	0.00	*1.54*	1.10	0.36	0.64	*1.37*	0.16
Tuesday	1.54	0.00	0.94	**2.19**	***4.00***	0.51	*1.52*
Wednesday	1.10	0.94	0.00	*1.50*	***3.58***	0.86	1.14
Thursday	0.36	**2.19**	1.50	0.00	**1.95**	*1.35*	0.51
Friday	0.64	***4.00***	***3.58***	**1.95**	0.00	**2.04**	0.35
Saturday	*1.37*	0.51	0.86	*1.35*	**2.04**	0.00	*1.42*
Sunday	0.16	*1.52*	1.14	0.51	0.35	*1.42*	0.00

Table 3-10

We can see that it appears that access from the blue lot was slower on Friday than any other day. In addition, it appears that access is slower on Thursday than on Tuesday. This does fit with our prior belief that access will be slower later in the week as the lots fill and weekend travelers begin to use the lot with greater frequency.

T-Tests for Difference in Means Across Days of Week – Green Lot							
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Monday	0.00	0.30	**2.26**	**1.90**	**1.78**	***2.41***	0.56
Tuesday	.30	0.00	***3.07***	***2.53***	**2.22**	***2.54***	0.38
Wednesday	**2.26**	*3.07*	0.00	0.20	0.01	***4.85***	***2.56***
Thursday	**1.90**	*2.53*	0.20	0.00	0.16	***4.29***	**2.24**
Friday	**1.78**	**2.22**	0.01	0.16	0.00	***3.80***	**2.11**
Saturday	***2.41***	***2.54***	***4.85***	***4.29***	***3.80***	0.00	*1.57*
Sunday	0.56	0.38	***2.56***	**2.24**	**2.11**	*1.57*	0.00

Table 3-11

The results here also support slower access from the satellite lots later in the week. Wednesday, Thursday and Friday are much slower access times than the rest of the week. The weekend is the fastest access time for this lot. These results are highly significant and so should be expected to remain even with the added variables in the regression analysis below.

T-Tests for Difference in Means Across Days of Week – All Lots							
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Monday	0.00	*1.56*	*1.52*	0.80	0.47	***5.23***	0.55
Tuesday	*1.56*	0.00	0.05	0.89	1.26	***4.85***	0.70
Wednesday	*1.52*	0.05	0.00	0.84	1.21	***4.84***	0.66
Thursday	0.80	0.89	0.84	0.00	0.38	***5.35***	0.08
Friday	0.47	1.26	1.21	0.38	0.00	***5.56***	0.20
Saturday	***5.23***	***4.85***	***4.84***	***5.35***	***5.56***	0.00	3.89
Sunday	0.55	0.70	0.66	0.08	0.20	3.89	0.00

Table 3-12

The only strong result for all lots combined is that Saturday access is much faster than other days. This may be due to the use of the Amtrak lot the last Saturday of the study. The difference in time from day to day is not strongly significant when all satellite lots are examined together. More can be said of this in the regression analysis section once more explanatory variables are added in the regression analysis section below.

The tests are also carried out between the blue and green lots for dates that both were active. This is still not conclusive and the regression analysis will provide more insight into this. The tests are presented in Table 3-13. The access time on the 5th is lower for the green lot than the blue lot. For every other date it is lower for the blue lot. Every date, except the 5th, this difference in access time is significant at the 90 percent confidence level or greater. For seven of the ten dates that both lots were in operation the difference is significant at the 99 percent level. It should be noted that there are some dates with small numbers of observations and results from these dates must be treated a bit more carefully. However, as stated above, it appears that access from the blue lot is faster than from the Green lot. In fact, the difference in access time appears to be larger when evaluated date by date than when examined by day of week. This implies that the conditions were actually more favorable to rapid access for the Green lot than the Blue lot during the entire sample period.

T-Tests for Differences in Blue and Green Lots' Access Time by Date				
January 5	**January 7**	**January 8**	**January 9**	**January 10**
0.59	***3.20***	***3.61***	*1.36*	*1.37*
January 11	**January 12**	**January 13**	**January 14**	**January 16**
4.01	***7.50***	***5.04***	***4.90***	***7.83***

Table 3-13

The results for differences in access times across time of day are given in Table 3-14, Table 3-15 and Table 3-16. Again, they are presented for each lot separately and then for the all satellite lots combined.

T-Tests for Difference in Blue Lot Access Times Across Times of Day						
	A.M. Rush	**Late A.M.**	**Midday**	**Early PM**	**PM Rush**	**Evening**
A.M. Rush	0.00	**2.17**	**1.75**	***5.97***	***4.64***	0.23
Late A.M.	**2.17**	0.00	0.18	***4.39***	***2.68***	*1.50*
Midday	**1.75**	0.18	0.00	***4.37***	***2.69***	*1.31*
Early PM	***5.97***	***4.39***	***4.37***	0.00	**2.04**	***4.83***
PM Rush	***4.64***	***2.68***	***2.69***	**2.04**	0.00	***3.41***
Evening	0.23	*1.50*	*1.31*	***4.83***	***3.41***	0.00

Table 3-14

The differences in access time are fairly significant for most times of day for the Blue lot. The early morning rush and the evening off-peak times definitely experience lower access times than the rest of the day. The late morning and midday access times are less than the afternoon (both peak and off-peak) times. These differences are nearly all significant at the 95 percent or the 99 percent level of confidence.

T-Tests for Difference in Green Lot Access Times Across Times of Day						
	A.M. Rush	**Late A.M.**	**Midday**	**Early PM**	**PM Rush**	**Evening**
A.M. Rush	0.00	***4.50***	***4.27***	***7.83***	***5.79***	1.03
Late A.M.	***4.50***	0.00	0.13	***3.01***	**2.30**	***2.99***
Midday	***4.27***	0.13	0.00	***2.72***	**2.10**	***3.01***
Early PM	***7.83***	***3.01***	***2.72***	0.00	0.15	***4.63***
PM Rush	***5.79***	**2.30**	**2.10**	0.15	0.00	***4.21***
Evening	1.03	***2.99***	***3.01***	***4.63***	***4.21***	0.00

Table 3-15

The results for the Green lot are nearly identical to those from the Blue lot. The early morning rush and evening off peak access times are significantly different from the rest of the day.

Again, the late morning and midday access times are lower than those for the afternoon. All of these differences are significant at the 95 percent or 99 percent level. The results for the differences in access time by time of day seem a bit stronger for the Green Lot than for the Blue Lot.

T-Tests for Difference in all Satellite Lots Access Times Across Times of Day						
	A.M. Rush	**Late A.M.**	**Midday**	**Early PM**	**PM Rush**	**Evening**
A.M. Rush	0.00	***4.87***	***3.85***	***10.39***	***6.92***	1.11
Late A.M.	***4.87***	0.00	0.65	***5.62***	***2.89***	***3.64***
Midday	***3.85***	0.65	0.00	***6.02***	***3.35***	***3.15***
Early PM	***10.39***	***5.62***	***6.02***	0.00	**2.16**	***7.32***
PM Rush	***6.92***	***2.89***	***3.35***	**2.16**	0.00	***5.38***
Evening	1.11	***3.64***	***3.15***	***7.32***	***5.38***	0.00

Table 3-16

Again, the early morning rush hour and the evening off-peak access times are significantly lower than the rest of the day. In addition, the late morning and midday access times are significantly lower than the afternoon access times. These differences are all significant at the 99 percent confidence level.

3.1.3 Garage Results

The main garage is the highest volume access facility at the BWI airport (with the possible exception of drop-offs at the terminal curbside whose volumes are not measured). The number of observations for this lot is very high. Due to the high number of observations for this access facility it is expected that the information about the access relationships will be most clear for this facility. However, this facility seems to be the lowest variance facility at the airport and thus it appears that the variables have the smallest effect on access times for the garage.

Table 3-17 contains the summary statistics for the access times from the garage lot. The average access time for this lot is the lowest of any facility at the airport (with the exception of direct passenger drop-off at the terminal). The variance however, is the highest relative to the average access time (again with the exception of drop-offs). This may imply that this lot is the most susceptible to the factors that lead to congestion delay. More will be said of this with the regression results.

Summary Statistics for the Garage Lot			
# Of Observations	**Average Access Time**	**Minimum**	**Maximum**
9170	7.9479	1	30
Variance	**10 %tile**	**25 %tile**	**50 %tile**
14.1094	4	5	7
75 %tile	**90 %tile**	**95 %tile**	**99 %tile**
10	12	15	22

Table 3-17

The percentile figures show that 50 percent of the passengers arrive at the terminal in within exactly 5 and 10 minutes. In addition, 95 percent of passengers arrive at the terminal within 15 minutes. Of course, this does not take into account any queuing delay before the passengers arrive at the garage ticket dispensers.

Figure 3-15 shows the distribution of tickets collected by date for the garage lot. Again, the frequencies displayed on these charts reflect not only the volume of traffic in the lot but also our efforts to hand out and collect tickets. This chart should not be interpreted as showing a 40 percent reduction in garage usage in the second week. The usage in the second week was lower, but not by this much. The chart demonstrates that a large number of tickets were collected every day of the survey from this facility.

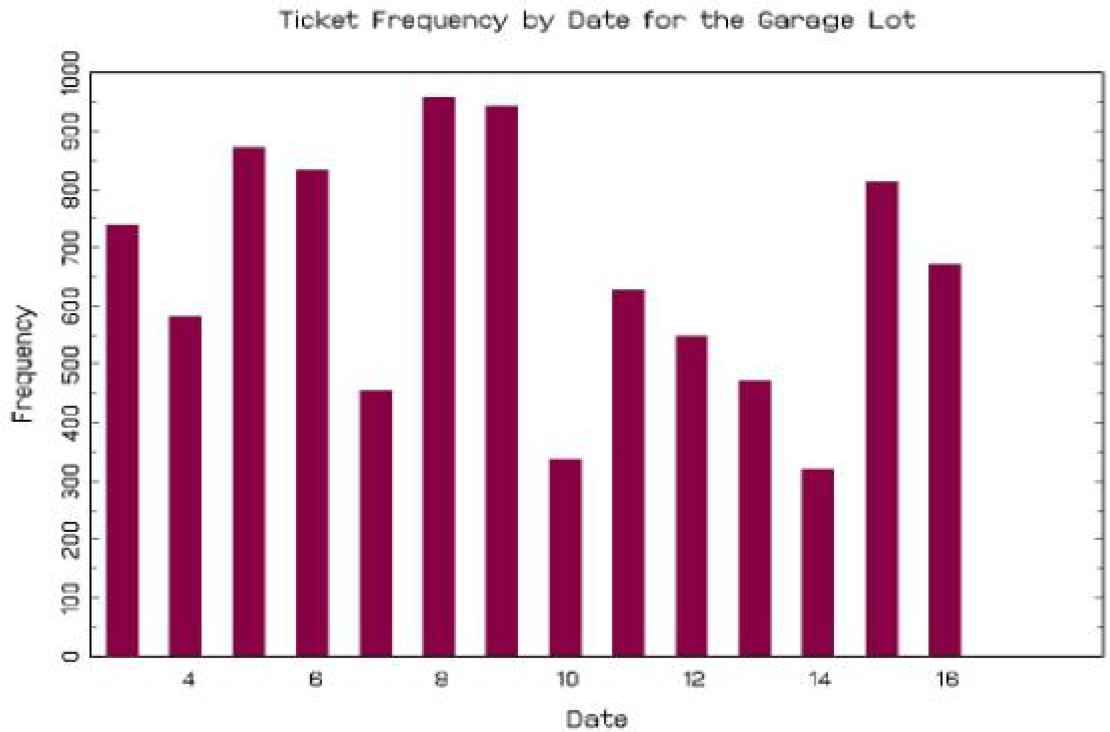

Figure 3-15

Figure 3-16 shows the distribution of tickets collected by time of entry for the garage lot. This figure indicates that we did collect tickets from every part of the day. In fact, our collection of garage tickets, unlike the other access facilities, was relatively constant throughout the day. The higher number of tickets from 7:00 to 9:00 a.m. reflects both a higher volume of traffic during those hours and a higher staffing level during those hours. The marked decrease in tickets collected after 7:00 p.m. reflects a much lower volume of arrivals in the garage facility accompanied by the fact that we began to wrap up our operations during this hour.

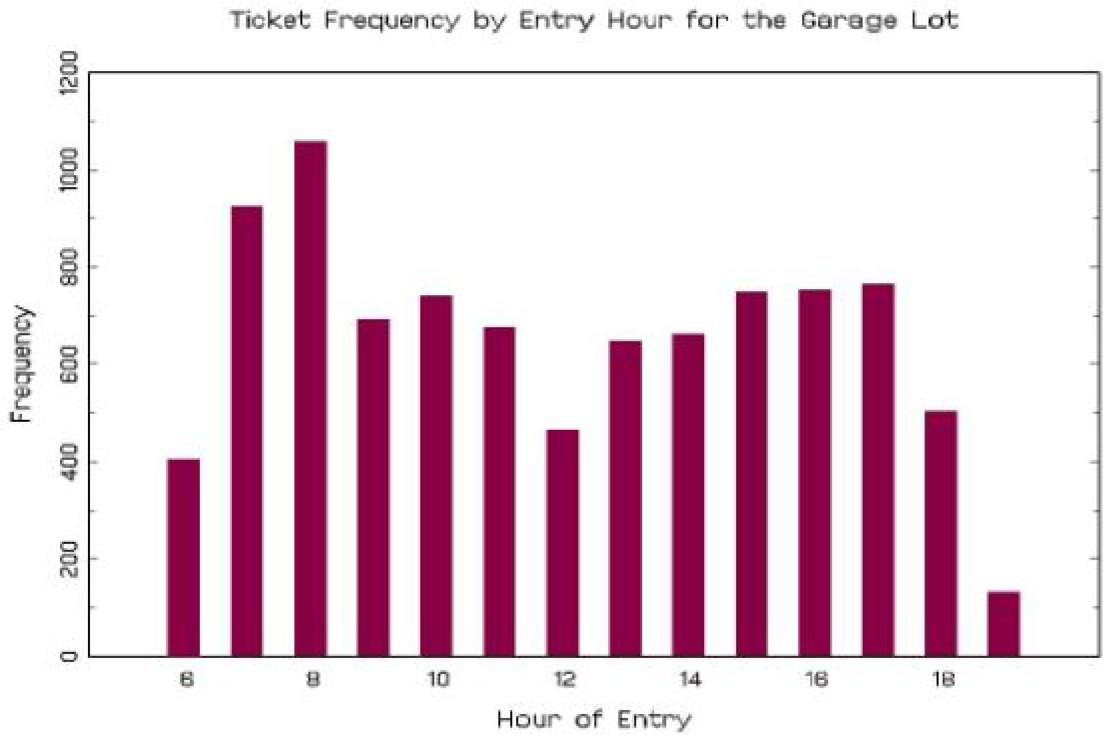

Figure 3-16

Figure 3-17 shows the distribution of access times for the garage lot. As can be seen, the distribution is quite steep. This means that a very large percentage of passengers accessed the terminal in close to the same amount of time. More importantly, there is a large tail to the right-hand side of the distribution. This means that despite low average access times, there are a significant number of people who do not access the terminal nearly as quickly. We cannot discern between those that took more time getting out of their cars and those that were delayed due to congestion in the garage. The regression analysis will cast a bit more light on this question. As in the case of ESP lot access, we discarded observations with access times greater than 30 minutes.

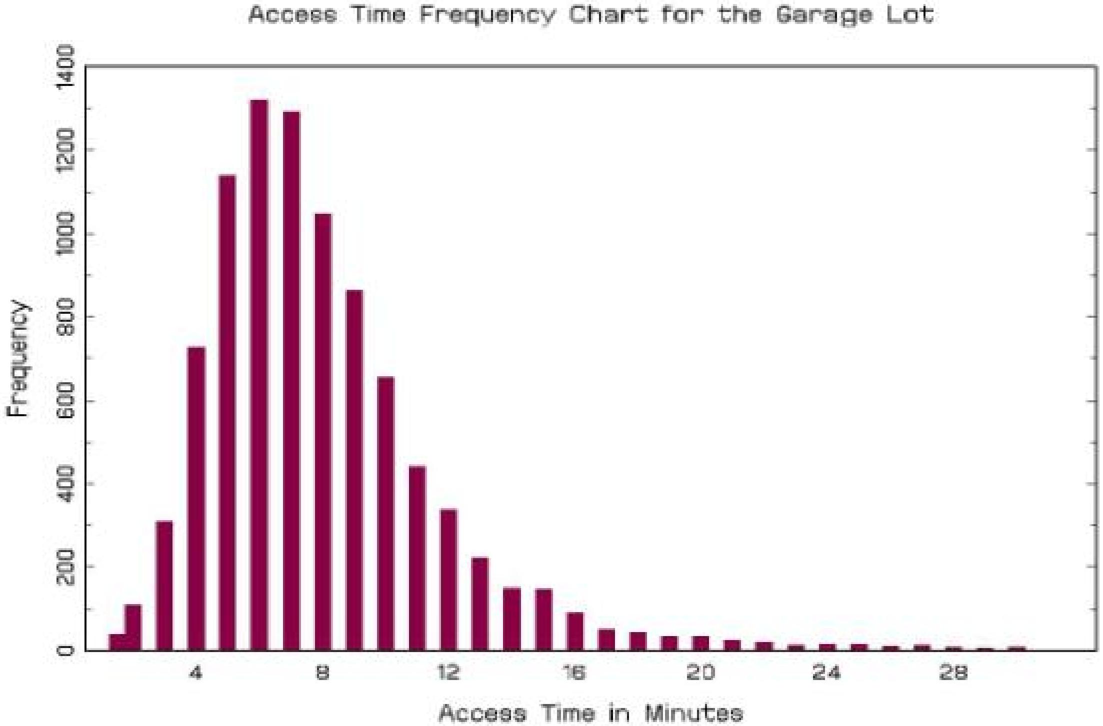

Figure 3-17

Table 3-18 shows the average access time by day of week. There is a marked increase in the average access time during the middle of the week. This is primarily caused by the facility becoming full. The regression results will cast more light on this relationship.

Average Access Time for the Garage Lot by Day of Week			
Monday	**Tuesday**	**Wednesday**	**Thursday**
7.5929368	8.9925620	8.4105634	8.3478927
Friday	**Saturday**	**Sunday**	
7.9251613	7.3337098	7.3552387	

Table 3-18

Table 3-19 shows the average access time by hour of day. The relationship between rush hour access time and off-peak access times is less dramatic than might be expected. However, some of the affect of off-peak diminished congestion is mingled with the fact that the garage becomes more full during the day and then less full in the evening. Also, the type of passenger using the facility may differ between time periods. For example, if the early morning rush hour passengers are mostly business travelers who are familiar with the facility and moving quickly they would have lower access times in general. If late morning or early afternoon travelers are mostly tourist travelers who are less familiar with the facility and generally in less of a hurry, they would have higher access times in general. It was impossible for us to discern the type of passenger during the study. The regression analysis will provide much more information about the congestion effect on garage access times.

Average Access Time for the Garage Lot by Time of Entry		
Early A.M. Rush Hour	**Late A.M.**	**Midday**
7.57304	7.8296	7.9910233
Early PM	**Late PM Rush**	**Evening**
8.4897236	8.2730871	7.2668760

Table 3-19

Table 3-20 shows the results for the tests across days of week.

T-Tests for Difference in Means for the Garage Lot Across Days of Week							
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Monday	0.00	***8.48***	***5.05***	***4.64***	**1.79**	**1.72**	*1.57*
Tuesday	***8.48***	0.00	***3.92***	***4.32***	***6.13***	***12.20***	***12.01***
Wednesday	***5.05***	***3.92***	0.00	0.43	***2.83***	***8.14***	***7.96***
Thursday	***4.64***	***4.32***	0.43	0.00	***2.46***	***7.60***	***7.43***
Friday	**1.79**	***6.13***	***2.83***	***2.46***	0.00	***3.68***	***3.54***
Saturday	**1.72**	***12.25***	***8.14***	***7.60***	***3.68***	0.00	0.18
Sunday	*1.57*	***12.01***	***7.96***	***7.43***	***3.54***	0.18	0.00

Table 3-20

The differences in access times are all statistically significant. With the exception of a few, all are significant at the 99 percent level. So, we can conclude that access is faster on weekends than the rest of the week; access is faster on Monday than the rest of the weekdays; Tuesday is the slowest access day; midweek access is slower than Monday and Friday access.

This fits with the idea that garage access times are impacted by how full the garage is at the time of entry. The garage tends to fill up early in the business week and then empty toward the end of the week. This relationship will be explored in more detail in the regression analysis.

Table 3-21 contains the results of the tests for difference in access times across times of day.

T-Tests for Difference in Garage Lot Access Times Across Times of Day						
	A.M. Rush	**Late A.M.**	**Midday**	**Early PM**	**PM Rush**	**Evening**
A.M. Rush	0.00	***4.53***	***3.11***	***7.52***	***6.01***	**2.00**
Late A.M.	***4.53***	0.00	0.92	***2.40***	0.96	***4.92***
Midday	***3.11***	0.92	0.00	***3.21***	**1.87**	***3.95***
Early PM	***7.52***	***2.40***	***3.21***	0.00	*1.53*	***6.98***
PM Rush	***6.01***	0.96	**1.87**	*1.53*	0.00	***5.87***
Evening	**2.00**	***4.92***	***3.95***	***6.98***	***5.87***	0.00

Table 3-21

Again, we can see that most of the differences are significant at the 99% level. The evening off-peak access times are faster than the rest of the day. The next quickest access times are in the early morning rush hour. The rest of the day travelers experience elevated access times. The early afternoon period is the slowest time for access from the garage lot. These significance levels imply that the utilization rate of the garage could play a major role in congestion. Even in periods when entry volume is lower, access times are higher as the garage lot becomes more full. More will be said on this after the regression analysis.

3.1.4 Drop-Off Results

The results for the drop-off data are potentially the most interesting in the study. Drop-off accessibility is very sensitive to congestion on the terminal roadway. In addition, we were able to capture some of the queuing time for passengers accessing the terminal by being dropped off at the terminal curbside. While potentially the most interesting results, the drop-off data is also the most complex. The results are presented for total travel time rather than total time including dwell time at the curb.

This is done for several reasons. One of the main reasons is that there is a strong possibility of endogenous behavior in the drop off data. A good example of this is that when there was a congested roadway, many passengers chose to disembark at Terminal A. One reason for this is that the passengers may have felt that they could walk to Terminal C (or whatever their destination terminal) faster than waiting for the queued traffic to move that far. Obviously, the total travel time will reflect the congestion more accurately than just the access time for these cases. The surveyors did not record the terminal the passenger accessed, merely the terminal at which they were dropped off. This was done because the surveyors had no means of determining if a passenger entered one terminal and walked to another once entering the airport.

Table 3-22 contains the summary statistics for the drop-off data.

Summary Statistics for the Drop-Off Observations			
# Of Observations	**Average Access Time**	**Minimum**	**Maximum**
2345	95.4486	14	720
Variance	**10 %tile**	**25 %tile**	**50 %tile**
4756.7142	42	57	76
75 %tile	**90 %tile**	**95 %tile**	**99 %tile**
111	166	215	411

Table 3-22

These data are in seconds instead of minutes. There is a very high degree of variance in the amount of time it takes to get through the terminal roadway. This only includes the time that the vehicle was attempting to drive and not the standing time at the curb. The percentile data show that 50 percent of the passengers took between 57 and 111 minutes to drive through the terminal roadway. This translates to from just under 1 minute to just under 2 minutes. The interesting thing to note is that the 95th percentile travel time is over three and a half minutes, almost three times the median travel time. The 99th percentile travel time is nearly twice as long as the 95th percentile travels time. There is a very steep congestion curve associated with drop-off activity. Unfortunately, the lack of reliable airside data makes it impossible to truly measure the affects of congestion on drop-off access times.

Figure 3-18 contains the frequency of drop-off observations by date. It can be seen that more drop-off data were collected later in the survey. This is a result of two factors. The first is that the scheduling of survey workers better allowed this later in the sample. The second factor is that the number of drop-off observations collected is an inverse function of the time it takes for a car to travel through the terminal roadway. While some surveyors were able to follow more than one car at a time, most surveyors timed a single vehicle through the roadway at a time. Thus, on days when travel time through the roadway was affected by congestion, fewer observations were obtained. The terminal roadway was more congested early in the study than later in the study and thus this contributed to the lower number of observations on these dates.

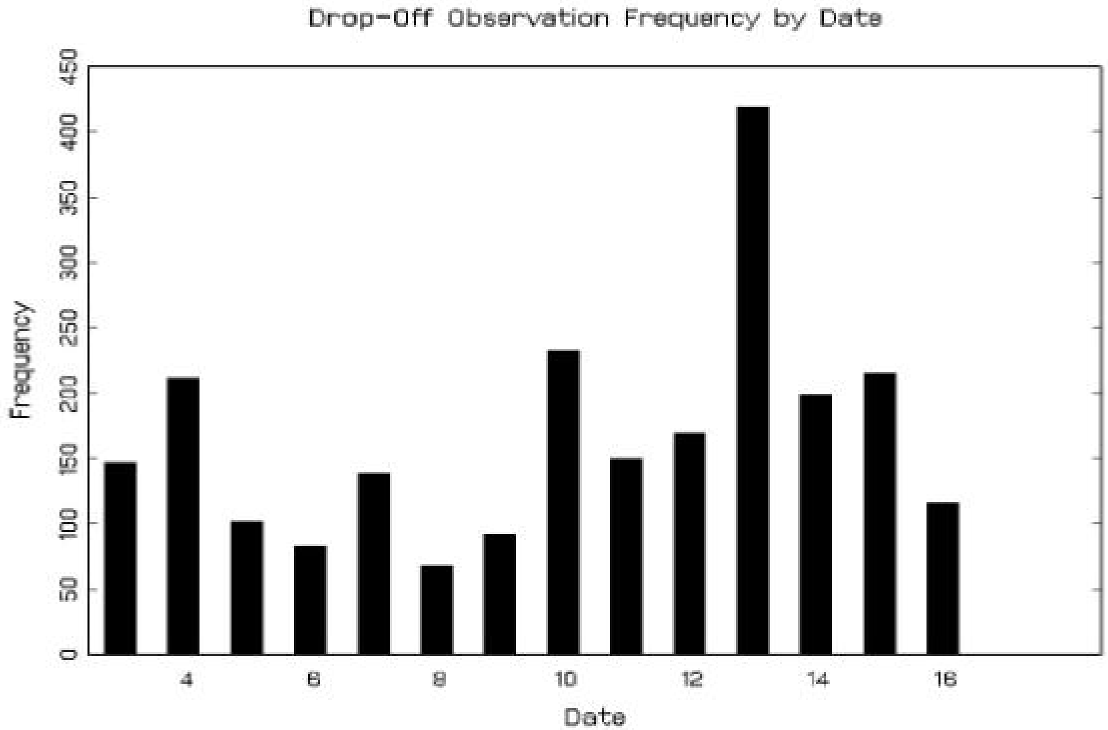

Figure 3-18

Table 3-23 contains the average travel time through the terminal roadway by day of week. Note that the normal pattern of higher travel times during the week is less noticeable in this table. The drop-off observations were not always obtained uniformly throughout the day and thus the regression analysis is needed to interpret this data. Weekend travel time is in fact lower than weekday travel time, once the time of day is taken into account. The regression results explain this in more detail.

Average Travel Time for the Drop-Off Observations by Day of Week			
Monday	**Tuesday**	**Wednesday**	**Thursday**
81.0159	103.5770	93.8662	97.2308
Friday	**Saturday**	**Sunday**	
88.8634	104.2807	83.8795	

Table 3-23

Figure 3-19 contains the frequency of drop-off observations by hour of day. It can be seen that the collection of drop-off observations was relatively uniform through the day. This is not true for individual days. In other words, while the number of observations per hour was relatively constant for the duration of the survey, there were some days with many observations in the early morning and few later in the day, while other days had most of their observations at another time. Figure 3-18 and Figure 3-19 show that both every day and every time of day are well represented in the sample.

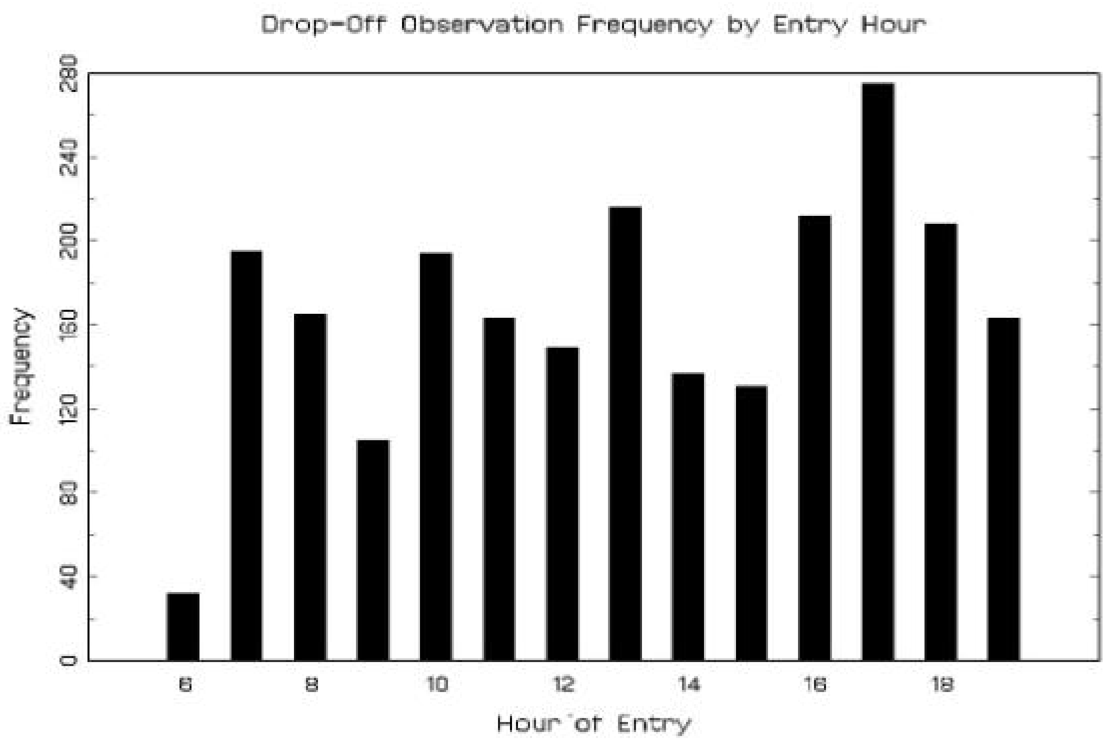

Figure 3-19

Table 3-24 shows the average access times by time of day. It is immediately clear that travel times are very sensitive to time of day. The terminal roadway is highly congested during several periods of the day. The early morning rush hour and most of the afternoon are heavy periods for the upper level roadway. The difference in travel times is quite large and immediately evident from the table. There is nearly a 60 percent increase in travel time from the evening hour (a very uncongested period on the upper roadway) and the morning rush hour (a very congested period on the upper roadway).

Average Access Time for the Drop-Off Observations by Time of Entry		
Early A.M. Rush Hour	**Late A.M.**	**Midday**
113.1389	88.3243	95.5942
Early PM	**Late PM Rush**	**Evening**
108.3457	108.7707	76.5735

Table 3-24

Figure 3-20 contains the distribution of travel time for the drop-off observations. The grouped nature of the data provides a meaningful way to look at the data, but it also makes the data susceptible to changing boundaries of the groups. The selection of 10-second intervals was arbitrary and is used for illustrative purposes only. None of the analysis on these data is done using the grouped data.

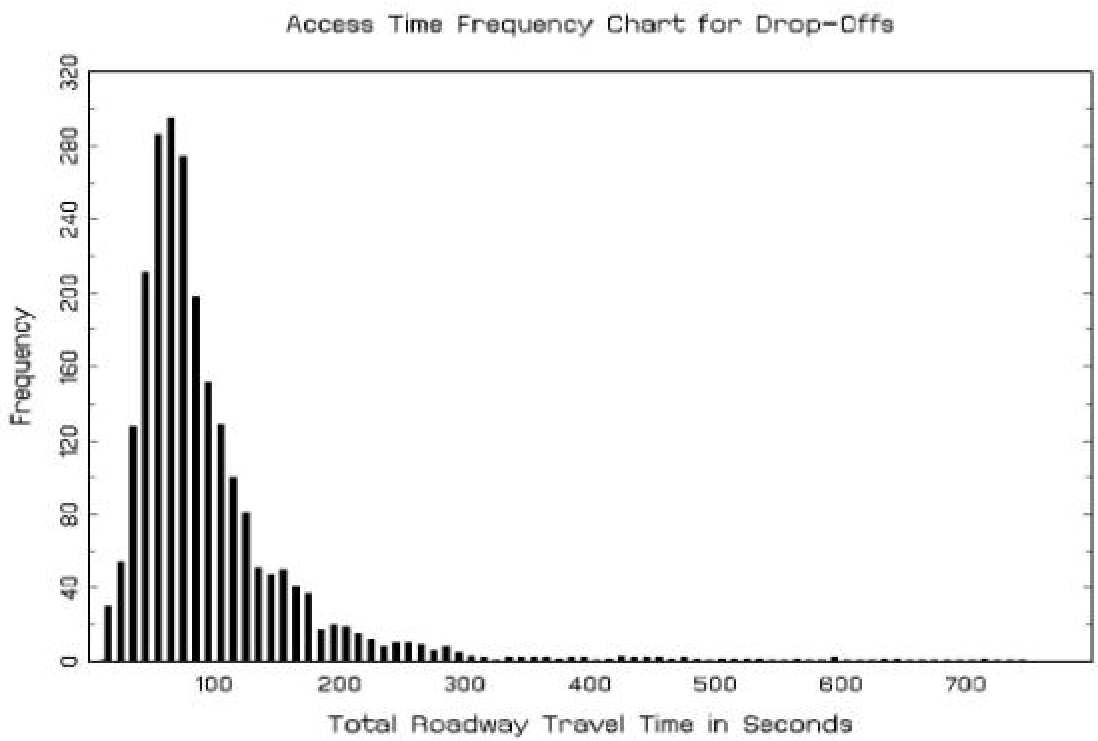

Figure 3-20

3.2 Regression Results

The access times were analyzed using regressions. The regressions modeled access time as a function of several control variables. The general form of the regression was given in the methodology section. The first set of variables was the days of the week. The base day was Wednesday. Thus the coefficients of all the days of the week variables are the relative change in access time relative to Wednesday. The second set of variables was the hours of the day. The base time period was midday. Thus the coefficients on time of day are the relative change in access time relative to midday. The utilization variables were the percentage utilization rate of the lot, the number of entries during the hour, the number of exits during the hour, and all the second order and cross terms among these three variables.

The effect of these variables is described in detail for each of the access facilities below. The general fit and descriptiveness of the regressions are categorized in Table 3-25

Goodness of Fit and Descriptive Statistics for the Regression Analysis				
Regression	**Number of Observations**	**Number of Variables**	**Adjusted R-squared**	**F-Statistic**
ESP	214	16	.0810	***2.26***
Blue Satellite	1418	21	.0752	***6.76***
Green Satellite	1476	21	.0898	***8.28***
Amtrak (Satellite)	83	4	.0106	.29
All Satellites	2895	21	.1052	***18.02***
Garage	9183	21	.0518	***26.07***
Drop-Off	2283	12	.0092	***2.93***

Table 3-25

The adjusted R-Squared and F-Test figures suggest that the regression analysis provides a reasonably good fit to the data. The low R-squared figures are typical of a cross-sectional data set where much variance is truly exogenous.[2] At the boundaries of the data (near the minimum

[2] While the trends and averages can be predicted well with this type of regression model, the individual actions of the passengers can be very different and none of this variance is explained in a regression of this type. A passenger who sprints from their car to the shuttle will have a very different access time from a passenger who reads the fine print on their ticket, does last minute packing, stows miscellaneous materials in the car's truck and then strolls to the shuttle stop. The regression is not designed to pick up the variance caused by these actions and thus the R-squared figures will be low. The high F-statistic shows that the means of the access times under different conditions are well represented by this regression.

and maximum values), the descriptive power of the regression is considerable weaker. This is examined in detail in the forecast section and in the recommendations section. All of the regressions pass the test for having a relevant model at the 1% level with the exception of the Amtrak lot (which only had 83 observations and one day of use). All of the results below use heteroskedastic consistent standard errors. There is reason to believe that the variance of the error term is correlated with the congestion variables so this correction is used to ensure that the inference is correct.

3.2.1 ESP Results

The results of the regression for the ESP access times are given in Table 3-26. Note that there are no entries for Sunday or time of day slots after morning rush hour. This is because there were no observations from this lot after the late morning period (which is the base case) and no Sunday observations for this lot.

Regression Results for the ESP Lot *			
Variable	**Estimate**	**Variable**	**Estimate**
Intercept	0.38313	Lot Entrances	-0.27327
Monday	*-2.55656*	Lot Exits	**1.73342**
Tuesday	0.26302	Utilization Squared	-0.00166
Thursday	1.0296	Entrances Squared	*0.00266*
Friday	-1.92685	Exits Squared	-0.00953
Saturday	-3.86613	Utilization*Entrances	-0.00161
Morning Rush Hour	-3.50314	Utilization*Exits	**-0.03159**
Lot Utilization	0.48536	Entrances*Exits	0.00718

Table 3-26

* Estimates in ***Bold Italics*** are significant at the 1 percent level, estimates in **Regular Bold** are significant at the 5 percent level, and estimates in *Italics* are significant at the 10 percent level.

The first thing to note about these results is that they should be regarded carefully due to the low number of observations from this lot. While many regressions with more than 200 observations would be considered very well specified, the large variance in the individual observations makes this a very different matter. There are an average of 35 observations per day of the week and an average of just fewer than 20 observations per day of week – time period. While this is a large enough number of observations to obtain results, the high variance in the data implies that results must be treated with a bit of caution.

Note that only two of the coefficients are significant at the 95 percent level. This is a product of the high variance and the low number of observations. This makes the forecasting procedure later in the report tricky.

The base scenario for the ESP regression is Wednesday during late morning hours. All other coefficients are relative to this period. For example, the regression shows that access to the airport from the ESP lot is about 2.5 minutes faster than on Wednesday. Note that this seems to conflict with the fact that access time on Monday is actually about .4 minutes slower on Mondays than on Wednesdays. This is caused by the fact that the regression controls for all other variables. After accounting for the effects of the utilization variables, Mondays were faster than Wednesdays, *ceteris Para bus*. This implies that the lot utilization conditions were much less favorable on Monday than on Wednesday, yet the difference in access time was small. Of course, the low number of observations and the high variance in the observations may contribute to these figures. The signs of the figures appear to be significant; however, the levels of the coefficients may be slightly overstated or understated.

The same interpretation is possible for the other days of the week and the morning rush hour time period. The morning rush hour time period is quite remarkable. According to the regression results, there is a 3.5-minute savings in time during this period. This is during the heaviest usage period for the lot and for the terminal roadway. It is quite possible that the usage of the lower roadway accounts for this difference. The use of the lower roadway for unloading passengers during this heavy use period probably saves more than the 3.5 minutes reflected here since, without this strategy, the coefficient on this variable would likely be positive.

The coefficients on the lot utilization variables tell an interesting story. The lot utilization figure (percentage of lot spaces filled) has a positive impact on access time. The more cars in the lot, the longer it takes to access the airport. The number of vehicles entering the lot has a positive affect also (note that the first-order coefficient is negative but the second-order coefficient is positive). The number of vehicles exiting the lot also seems to have a positive affect on access time. The second order terms are interesting in all of these cases. The utilization rate has a positive, but declining affect, on the access time. This means that as the lot fills the affect changes. At moderate levels of lot usage, the effect of more vehicles in the lot is strong and each new car adds quite a bit more time to the access time. As the level of usage increases, the affect is still positive but it declines. Meaning that each vehicle added to the lot adds access time but not as much as the last vehicle. The opposite is true for vehicles entering the lot. Each extra vehicle entering the lot adds time to the access time of the other vehicles. As more and more vehicles enter the lot at the same time, each new vehicle adds more time to the access time of the other vehicles. This relationship is also true for the number of exiting cars.

This seems to point to a process where the vehicles parked in the lot and those that enter and leave the lot add to the access time of the other passengers. The moving vehicles affect the access of the other passengers in a manner that increases the access time and each new vehicle adds more to the access time than the last. This is a convex relationship. The parked vehicles seem to have a concave relationship. Each additional parked vehicle adds time to the access time of other passengers but each new-parked vehicle adds less time than the last

3.2.2 Satellite Results

The results for the satellite regressions are presented in Table 3-27. Note that the regression for the Amtrak lot has only a few variables. This is because there were tickets collected for this lot only on one day (a Saturday) and there are no lot capacity and utilization figures for this facility. There are a large number of observations for both the Blue and Green lots (as well as the combined Satellite lots) so the figures are fairly robust.

The first point to note is that the lot utilization figures do not fully capture the congestion in these lots. This is particularly clear in the Green Lot. Note that Wednesday access from the Green lot was particularly slow. This is seen in the negative coefficients of the other day of week variables. This could be caused by one of several factors. It is possible that there was a very slow access on one of the Wednesdays of the study. This could be either because of terminal roadway congestion, or a problem with bus frequency on one particular Wednesday. It remains possible that Wednesday is a very slow day to access the terminal from the Satellite lots.

Though this is not the most likely reason for this (though lot utilizations do build through the week and then diminish for the weekend).

Regression Results for the Satellite Lots *

Variable	Blue Lot Estimates	Green Lot Estimates	Amtrak Lot Estimates	Total Satellite Estimates
Intercept	***11.76222***	**27.72583**	***18.34426***	***11.94423***
Monday	0.38	**-1.39813**	---	-0.289486
Tuesday	-0.44511	**-1.24919**	----	*-0.60144*
Thursday	0.22777	***-2.04032***	----	**-0.89003**
Friday	0.20975	-3.08452	----	***-1.4002***
Saturday	*-0.93337*	*-2.3127*	----	***-1.12728***
Sunday	-0.7013	***-3.78978***	----	***-2.01502***
Morning Rush Hour	**-1.58564**	***-4.013***	----	***-2.99609***
Late Morning	-0.68706	***-2.27719***	***5.65574***	***-1.45153***
Early Afternoon	***3.33266***	0.8402	-.40309	***2.11055***
Afternoon Rush	**1.54021**	*1.49394*	0.85574	***1.51422***
Evening	-0.03007	*-2.5368*	----	-1.0346
Lot Utilization	0.02518	-0.18108	----	**0.06199**
Lot Entrances	***0.10905***	0.02324	-----	***0.09979***
Lot Exits	-0.01256	0.05979	----	0.01426
Utilization Squared	0.000535	0.00149	----	***0.00049***
Entrances Squared	***-0.000266***	**-0.0001904**	---	***-0.000258***
Exits Squared	-0.000199	0.0002684	----	0.000287
Utilization*Entrances	***-0.000662***	0.0003419	----	***-0.000456***
Utilization*Exits	0.000176	-0.00129	---	**-0.000914**
Entrances*Exits	**0.000358**	-0.0000318	----	**0.000299**

Table 3-27

* Estimates in ***Bold Italics*** are significant at the 1 percent level, estimates in **Regular Bold** are significant at the 5 percent level, and estimates in *Italics* are significant at the 10 percent level.

Beginning with the day of week variables, it is immediately obvious that weekend access is much quicker than weekday access from the satellite lots. For the Blue lot, the weekend access is about a full minute faster than weekday access (with the exception of Tuesday which was a fast access day for the Blue lot). The Green Lot follows a similar pattern. Weekend access is between one and three minutes faster than weekday access. The full satellite regression (accounting for both lots) shows that weekend access is between one-half and two minutes faster than weekday access. There is no clear pattern across lots for the weekday access speeds. For the Blue lot, Tuesday was much faster than Wednesday and the rest of the week was slightly slower. For the Green Lot, Thursday and Friday were faster than Monday and Tuesday and Wednesday was the slow day. For the combined regression the Green results seem to dominate (this is perhaps caused by the much slower access time on Wednesdays from the Green lot compared to any other lot and day).

The time of day variables show a more consistent pattern across lots. For both the Blue and Green lots (and thus for the combined lots as well), the early morning rush hour provided the fastest access to the terminal. This period was one and one-half minutes faster than midday for the Blue lot, four minutes faster for the Green lot, and three minutes faster for the combined lots. The afternoon periods were the slowest for all the lots as well. The early afternoon was five minutes slower than the morning rush hour for all lots. The afternoon Rush hour was three minutes slower than the morning rush hour for the Blue lot, five and one-half minutes lower for the Green lot, and four and one-half minutes slower for the combined lots. The rest of the day provided less dramatic results. Both the late morning and evening periods were slightly faster than midday for both lots. The results show larger time differences for the green lot, but these are not terribly significant because there was a larger degree of variance in the Green lot access times.

The utilization variables had results that were approximately as expected. Surprisingly, the Green lot had a negative coefficient on lot utilization but this was not a large figure and did not overwhelm the other (cross-term and squared-term) affects. In general, the fuller the lot, the longer the access times and the more cars entering the lot, the longer the access times. This is consistent with congestion causing slow-downs for access to the airport. The shape and level of these effects will be explored in the forecasting section. More will be said of these relationships in the forecasting section below.

3.2.3 Garage Results

The results of the regression for the Garage lot are given below in Table 3-28.

Regression Results for the Garage Lot *			
Variable	**Estimate**	**Variable**	**Estimate**
Intercept	***3.7518***	Evening	***-0.78684***
Monday	***0.52007***	Lot Utilization	**0.04839**
Tuesday	***0.93918***	Lot Entrances	0.000632
Thursday	0.10693	Lot Exits	**0.00489**
Friday	0.02187	Utilization Squared	8.07E-05
Saturday	*-0.2502*	Entrances Squared	3.38E-06
Sunday	**-0.33539**	Exits Squared	6.3E-07
Morning Rush Hour	**-0.40882**	Utilization*Entrances	-2.1E-05
Late Morning	0.08699	Utilization*Exits	*-3.22E-05*
Early Afternoon	0.18085	Entrances*Exits	-5.28E-06
Afternoon Rush	***-0.10627***		

Table 3-28

* Estimates in ***Bold Italics*** are significant at the 1 percent level, estimates in **Regular Bold** are significant at the 5 percent level, and estimates in *Italics* are significant at the 10 percent level.

The number of significant coefficients is much higher for the Garage lot regression. This is partially a result of the very high number of observations for this lot. It may also be due to the fact that the behavior of passengers that use the garage is more uniform. The first explanation is more likely given the low R-squared of the regression.

The day of week variables suggest that early in the week, access times are poor relative to the conditions in the garage. The garage tends to fill up later in the week and so the conditions are worse late in the week than early in the week. Access times vary by less than a minute between almost all days. The weekend access times are faster than the weekday access times and this difference is significant. The slowest day, relative to conditions in the garage, is Tuesday and the fastest day, relative to conditions, is Sunday.

The time of day variables show that the garage occupancy variables have not picked up 100 percent of the effect. The early morning period and the evening period are the fastest access times (relative to conditions in the garage). These are the periods when the garage is the least full. It should be noted that passengers were not timed for their exit from the terminal. Exiting the garage is likely to take more time in the evening, even if entering the airport is rapid at this time. The daytime periods (late morning, midday, early afternoon and the afternoon rush hour) are nearly identical in their access times. The fastest of these is the afternoon rush hour and the slowest the early afternoon. The difference between these two is well under one-half a minute. Note that airport access times increase throughout the day until the afternoon rush hour. This coincides with garage lot utilization, which seems to peek in the late afternoon as well.

The lot utilization variables tell a story similar to that for the other lots. All three of the utilization figures had a positive affect on access time (made accessing the terminal building take longer). In addition, each of these had a positive second order term, meaning that the relationship is strengthened over time. This means that each new car (parked in, entering, or leaving the garage) adds more time to other passengers' access times than the last. Each of the cross-terms had a negative coefficient. This means that while each variable increases the access time for passengers, they have mitigating affects on each other.

This means that while more cars parked in the garage increases access time, the more cars leaving the garage, the lower this affect. The same is true for each variable with respect to the other variables. Much more will be said on this in the forecasting section.

3.2.3 Drop-Off Results

The results of the regression for the drop-off observations are presented in Table 3-29 below.

Regression Results for the Drop Off Observations *			
Variable	**Estimates**	**Variable**	**Estimates**
Intercept	***160.9468***	Sunday	*19.40334*
Monday	***50.31377***	Morning Rush Hour	**34.3473**
Tuesday	***51.01221***	Late Morning	**20.94381**
Thursday	10.51536	Early Afternoon	7.51608
Friday	***35.65874***	Afternoon Rush Hour	9.17859
Saturday	**28.04425**	Evening	15.29175

Table 3-29

* Estimates in ***Bold Italics*** are significant at the 1 percent level, estimates in **Regular Bold** are significant at the 5 percent level, and estimates in *Italics* are significant at the 10 percent level.

The first important fact to note about this regression is that the access times are measured in seconds instead of minutes. In addition, the times estimated here is total travel time through the terminal roadway (explained in Section 2 above). The other measures were of less interest.

While the correlation between travel time and dwell time could be of interest, there is no good idea, which is the causal relationship, and so it is not included in the regression.[3] This regression points to the relationship that we are seeking in this study.

Looking at the days of the week variables we see that Monday and Tuesday are significantly slower than the rest of the week. Almost one minute slower (on an average of about three minutes). This is primarily caused by the very heavy volume on the first two days of the study (January 3rd and 4th), which were a Monday and a Tuesday. Unfortunately, there was no data available to us for the airside traffic during the study period. This would have allowed a more precise look at the congestion caused by airside activity.

The time of day variables show a pattern we might expect. The midday period is the fastest for accessing the terminal through the terminal roadway. The morning rush hour is about ½ minute slower and other busy roadway periods are about 15 seconds slower. Note that this should affect the satellite lots during these periods. The fact that satellite access during the morning rush hour was significantly less than the rest of the day implies that using the lower roadway has significantly reduced satellite access times during this period.

3.3 Forecasting Results

Forecasts are generated using the lot utilization figures in order to determine what might happen to access times as utilization rates increase. The forecasts are carried out for two different scenarios. The first scenario is the "best case" scenario (BCS) and the second scenario is the "worst case" scenario (WCS). The BCS is where the forecasts are presented for the fastest day and time of day. The WCS is where the forecasts are presented for the slowest day and time of day. There is no attempt to link the utilization rates to actual forecasts of airport usage.

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[3] It is possible that longer dwell times cause traffic to slow down through the terminal. However, it is also possible that longer travel times cause passengers to dwell longer. The opposite is also possible. We found a positive correlation between the variables. A regression was run with dwell time as an explanatory variable but it had little predictive power and introduced causality problems that seemed to overwhelm any additional information that might be gained.

In addition, the forecasts merely present information on the average access times under these conditions. No inference should be drawn about the variance of these access times. In other words, if the average access time for the garage is 10.5 minutes under certain conditions today and the forecast shows that an average access time of 13 minutes will result under some set of conditions in the future – this does not give us any information about the variance of access times in the future scenario. The distribution will likely spread (yielding, for example, a 95 %tile access time further above the average access time than today) – but the forecasting techniques do not allow us to conclude this.

3.3.1 ESP Results

The ESP lot had very few observations in the sample, and so the forecasts are the most suspect. The lack of observations creates two problems. First, the forecasts have a high degree of error from the large variances in the coefficients. Second, the forecasts do not allow us to look very far outside the current data because the fit was poor away from the center of the data. Table 3-30 shows the figures used in the forecasts.

Statistics and Boundaries of ESP Lot Forecasting Data					
	Current Data			**Forecast Ranges**	
	Minimum	**Average**	**Maximum**	**Minimum**	**Maximum**
Lot Utilization %	30	65	82	0	85
Cars Entering	17	64	116	0	145
Cars Leaving	1	6	15	0	30
Day of Week	Saturday	-	Thursday	-	-
Time of Day	A.M. Rush	-	Late A.M.	-	-

Table 3-30

During periods that we have observations for the ESP lot, the lot utilization ranged from 30 to 82 percent. The forecasts allowed this variable to range from 0 to 85 percent. The number of cars entering the lot per hour during our study ranged from 17 to 116. The forecasts allow this number to range from 0 to 145. The number of cars leaving the lot ranged from 1 to 15 during our study. The forecasts allow this number to vary between 0 and 30.

Due to the small number of observations several difficulties were encountered in these forecasts. First, it was not possible to allow the lot utilization rate to vary significantly above current levels. This was true of all facilities, but in the other facilities capacity was reached at some point in the sample and that was expected to be a cap to the figure. In addition, when examining the forecasts with large numbers of cars leaving the lot per hour (above ten), the forecasts began to take on a strange shape. This is a result of the low number of observations and the fact that the number of cars leaving the ESP lot during the morning hours was never much above 10. The forecasts presented here are for the scenarios where five cars are leaving the lot per hour.

The best-case scenario is Saturday during the morning rush hour and the worst-case scenario is on Thursday during the late morning period. These forecasts do not necessarily coincide with these periods, but represent the BCS and WCS forecasts from the data collected. Figure 3-21 shows the BCS forecast of access times. As can be seen, there is a small area where negative access times are predicted. Note that these are at an extreme level of the data (near or below the minimums for both variables included in the forecasts.

The increasing relationship is clear for both variables in this forecast. Note that if only one car is entering the lot, the access time increases from about 0 (for lot utilizations below about 45%) to 21 minutes when the lot is near the maximum observed in the data. For cars entering the lot the relationship is less strong. This is most likely a result of the endogenous nature of the shuttles. If more cars are entering the ESP lot, more shuttles will be run thus reducing this element of congestion somewhat. However, looking at an empty lot, access times increase from 0 minutes to 13 minutes as the number of cars entering moves from 0 to the maximum observed level (116).

The “saddle” shape of the curve is typical of relationships that have synergies. The synergy here is that as more cars enter the lot, access time is slowed except for the potential for shuttles to be more rapid. In addition, the saddle shape is exaggerated due to the lack of data away from the center of the data. During typical periods in the BCS, today’s access times range from five to nine minutes. The forecasts show that these access times could approach 20 minutes with heavy utilization.

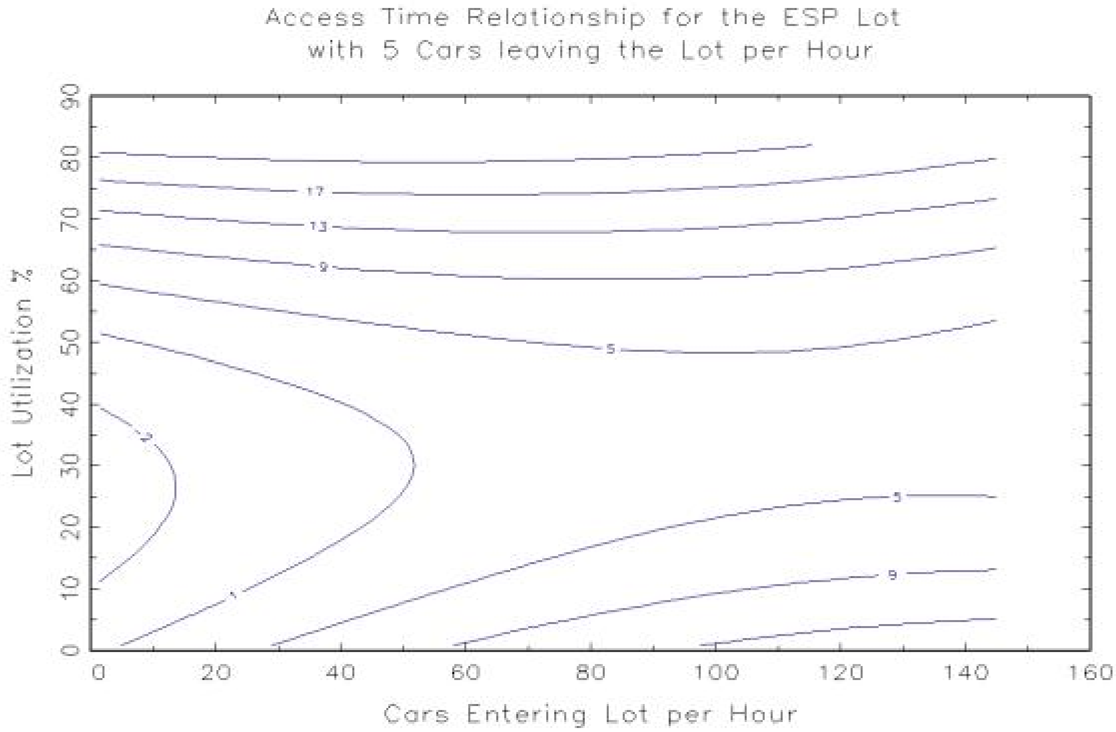

Figure 3-21

Figure 3-22 contains the forecasts for the WCS. Note that the shape is identical except for the values of the isotime lines. These are about seven minutes higher than in the BCS. The relationships remain the same, but the level of access times is much higher. During "bad" periods with current conditions, access times range from 12 to 16 minutes. The forecasts show that these figures could approach 30 minutes with full lots and high numbers of entries.

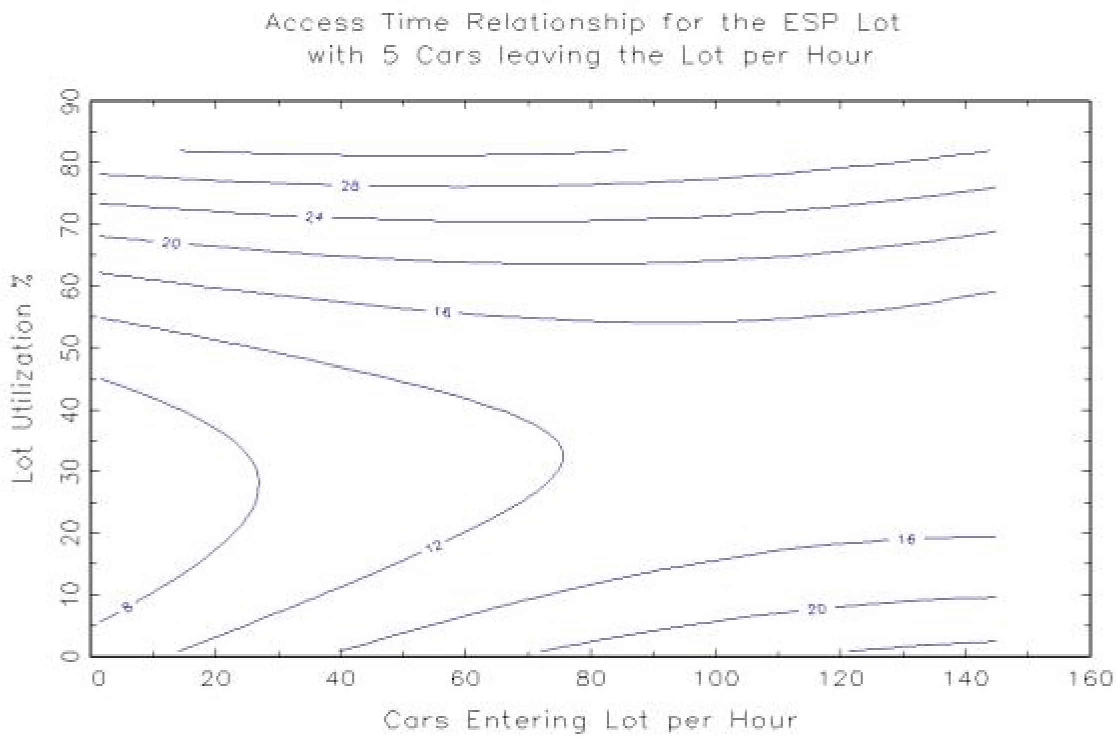

Figure 3-22

Figure 3-23 shows the surface plot that is identical to Figure 3-22. This is the WCS surface plot. The saddle shape to the access time forecasts is clear in this figure. Note the high access times predicted at the boundaries of the forecast numbers. The figure merely helps “see” the last two figures.

The saddle shape also shows one potential problem with the ESP forecasts. Most of the observations for the ESP lot were from the “middle” of the forecast range. The red region represents access times less than approximately 15 minutes. Almost all of our observations are from this range. The portions of the forecasts that are in the dark blue range are at the border of the observed data range and the portions in the green range are outside the observed data. This does not mean that the forecasts are wrong, just that they must be looked at a bit more skeptically than those that follow.

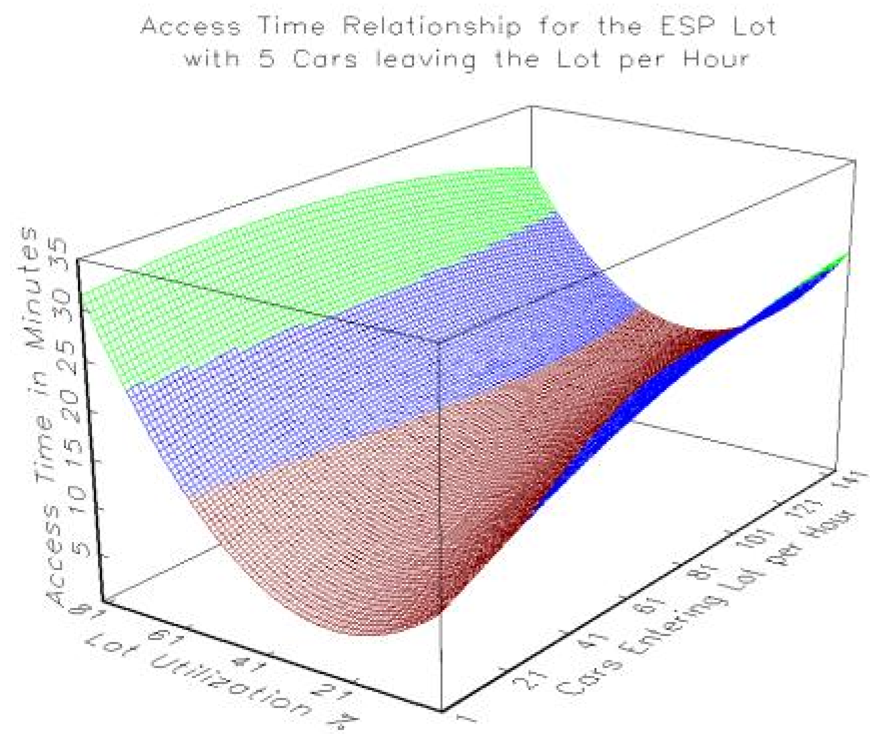

Figure 3-23

3.3.2 Satellite Results

The satellite results are presented for both the Blue and Green lots as well as for the two lots combined. The results are about as similar as the statistical and regression results above. Table 3-31 contains the figures used in the forecasts.

The first fact that is noteworthy here is that the maximum lot utilizations exceed 100 percent for both lots. These figures are obtained from the parking management printout and were checked for obvious errors. While it does not seem possible to have 125 percent of the lot being used, there was no means of correcting this data consistently. Obviously, lot capacities were not examined at levels above what was observed in the data.

The ranges for the other variables are approximately in line with the ratios from the ESP lot. Entering vehicles are examined up to about 25 percent above maximum levels observed in the data and exiting vehicles are observed over a range that extends beyond that (though these are not included in the presentation of results in most cases).

Statistics and Boundaries of Satellite Lot Forecasting Data					
Blue Lot					
	Current Data			**Forecast Ranges**	
	Minimum	**Average**	**Maximum**	**Minimum**	**Maximum**
Lot Utilization %	21	63	107	0	108
Cars Entering	0	96	263	0	375
Cars Leaving	0	23	114	0	263
Day of Week	Saturday	-	Monday	-	-
Time of Day	A.M. Rush	-	Early PM	-	-
Green Lot					
	Current Data			**Forecast Ranges**	
	Minimum	**Average**	**Maximum**	**Minimum**	**Maximum**
Lot Utilization %	60	88	125	0	125
Cars Entering	0	49	237	0	344
Cars Leaving	0	17	95	0	263
Day of Week	Sunday	-	Wednesday	-	-
Time of Day	A.M. Rush	-	PM Rush	-	-
Combined Satellite Lots					
	Current Data			**Forecast Ranges**	
	Minimum	**Average**	**Maximum**	**Minimum**	**Maximum**
Lot Utilization %	21	76	125	0	125
Cars Entering	0	72	263	0	375
Cars Leaving	0	20	114	0	263
Day of Week	Sunday	-	Wednesday	-	-
Time of Day	A.M. Rush	-	Early PM	-	-

Table 3-31

Figure 3-24 shows the forecasts for the Blue lot under the BCS when there are 131 cars leaving the lot per hour (the 75 %tile). The forecasts show the relationship that might be expected with the exception of the upper right-hand corner of the figure. At very high volumes and utilization rates, the access times diminish. This is most likely an artifact of trying to forecast outside the data range.

The relationship between utilization rate and access time is generally increasing. At very low levels, access times are as low as about 10 minutes (when there are only a few cars entering the lot). As the utilization rate climbs toward the lowest observed in the sample (21 percent) the average access time is about 15 minutes. As the lot utilization increases to the mean of the sample (63 percent) the average access time increases to about 25 minutes. In the BCS, the peak average access time is around 27 minutes and this occurs at near full occupancy with very few entries into the lot.

As the number of entries into the lot increases the access time increases at low occupancy rates but decreases at moderate to high occupancy rates (above 40 or 50 percent). This is likely to be caused by the increased shuttle rate when lot entries are high. If the lot were empty, access times increase from about 6 minutes to about 17 minutes as the number of entries per hour increases from 0 to 375. However, if the lot is 60 percent full (about the average), the access times decrease from about 27 minutes at very low entry rates to about 22 minutes at average to high entry rate levels and do not decrease much after that. This implies that the returns to traffic (in terms of increased shuttle frequency) are rapidly exhausted at moderate utilization levels.

Figure 3-25 contains the BCS for when 263 cars exit the lot per hour. Note that the graph has changed in shape. The highest access times are now found when the lot is full and there are few entries. The decreasing access times at high levels of utilization combined with high entry levels is reduced to a very small corner of the region. In fact, this region lies totally outside the range of data observed in the study.

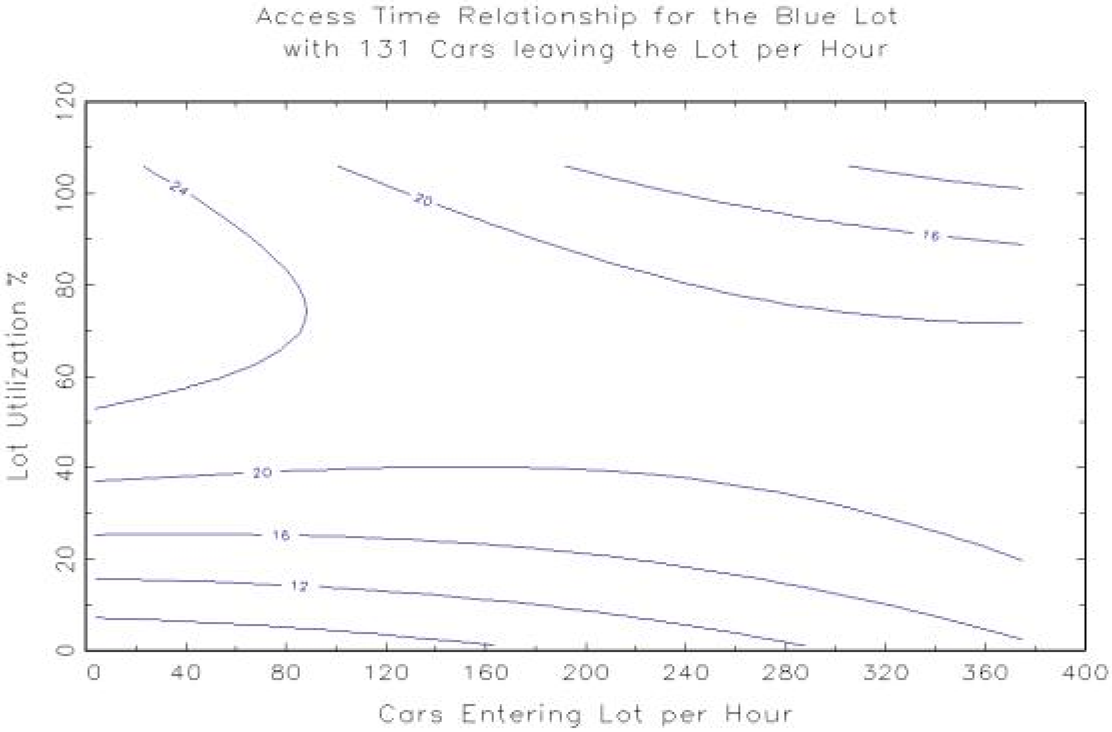

Figure 3-24

The negative predicted access times for a very small sliver of low utilization ands entry rates is an artifact that can be dismissed just as the upper corner. Again, the lot utilization is much more important for access time than the number of cars entering the lot per hour. The main difference in this figure is that the peak average access time reaches about 30 minutes. It is important to note that this occurs with few entries and a full lot. This is consistent with how we know the shuttles run, and the fact that utilization rate was extremely important for predicting access time. This data point is within the observed range and many observations fit this pattern.

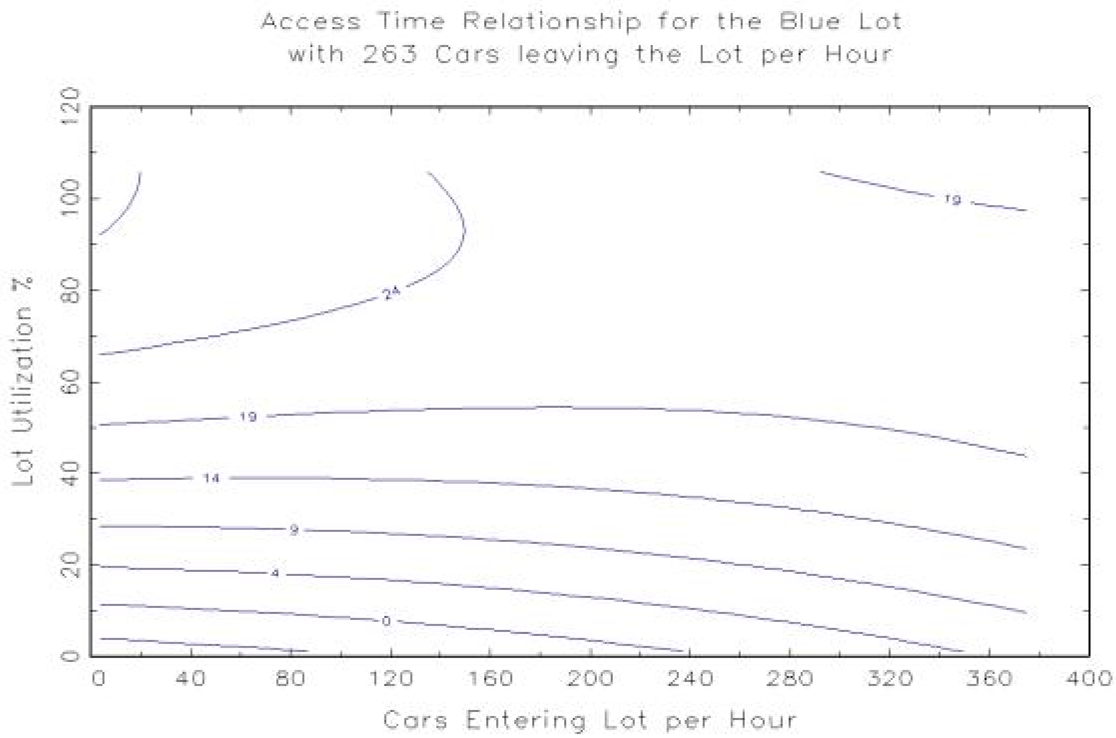
Access Time Relationship for the Blue Lot
with 263 Cars leaving the Lot per Hour
Lot Utilization %
Cars Entering Lot per Hour
0
20
40
60
80
100
120
0
40
80
120
160
200
240
280
320
360
400
24
19
19
14
9
4
0

Figure 3-25

Figure 3-26 and Figure 3-27 show the same graphs as those in Figure 3-24 and Figure 3-25 except that these two figures are for the WCS. The only difference is the access times. Instead of average access times peaking at 27 and 30 minutes (respectively), the average access times peak at about 33 and 37 instead. The rest of the relationships are identical.

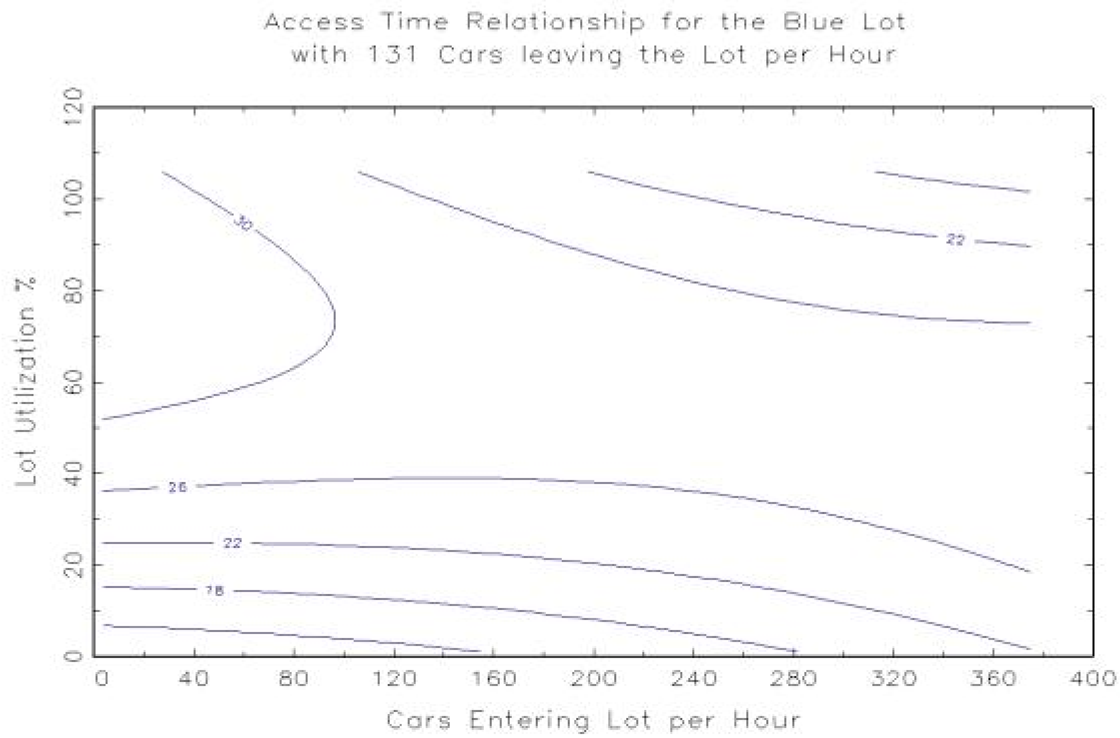

Figure 3-26

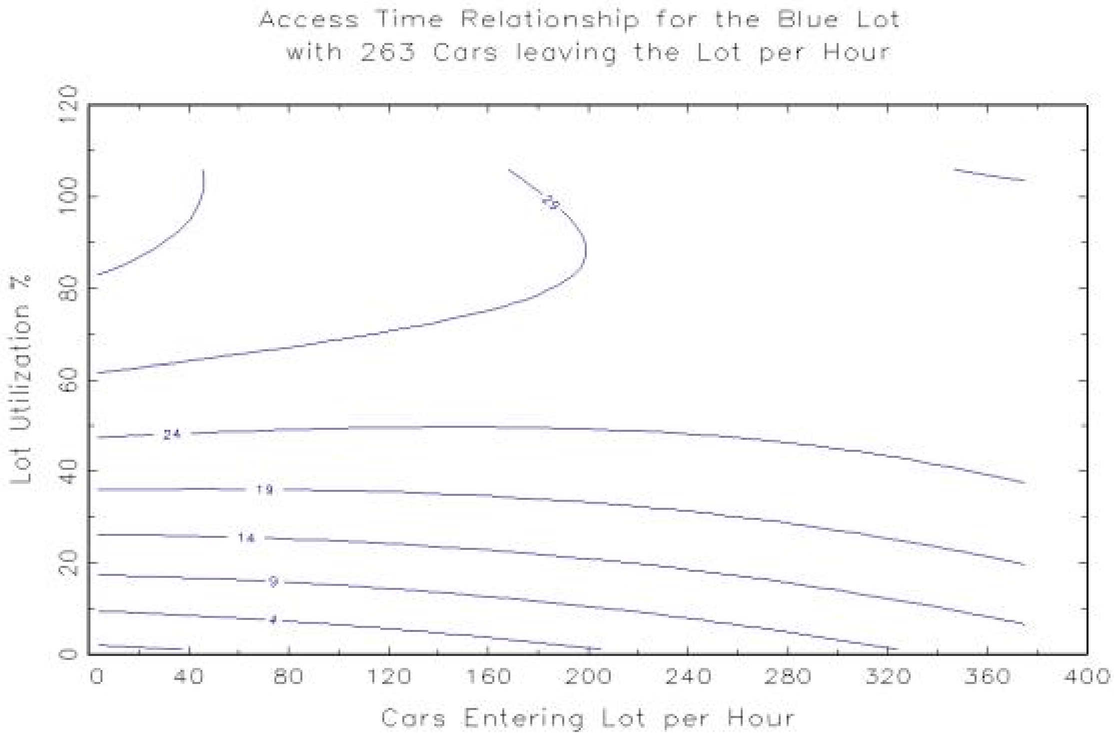

Figure 3-27

Figure 3-28 shows the same forecast as Figure 3-27, but in a surface plot. The saddle shape is clearly visible in this figure. Note that while the majority of data fell into the dark and dark blue portions of this figure, there were a sizeable number of observations from the green area. This curve may understate the affect of increased lot utilization due to the fact that capacities were reached in the data and some of the congestion caused by this was not measured. For example, if a passenger tried to use the Blue lot and it was full – they likely proceeded to another lot. This time (which does count as access time) was not included in the study because they do not get a ticket until they arrive at the lot where they are going to park.

Given this, the slight downward slope to the figure as lot entries increase and the downward slope at the highest lot utilization percentages may be a result of some of the queuing and access time not being included in the studied time. There was no reasonable way to collect data on this type of lost time for the passenger.[4]

[4] To include this time in the data it would have been necessary to track a passenger from the second they entered the airport grounds. There does not seem to be an unobtrusive means of collecting this data. It is likely that any study

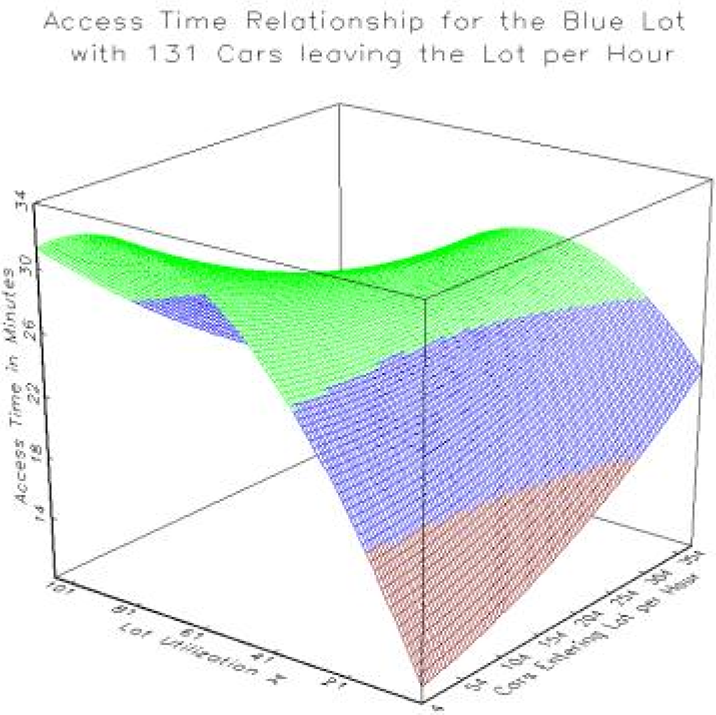

Figure 3-28

Figure 3-29 and Figure 3-30 show the forecasts for the Green lot. Note that both of these forecasts are performed with no traffic leaving the lot. This is due to the fact that the number of cars leaving the Green lot was very low during our study. At higher levels of cars leaving the lot, the access times increase dramatically in the forecasts. As can be seen from Figure 3-29, in the BCS the access times increase as the number of cars entering increases. There is a slight downward trend in access times as the lot utilization approaches capacity but this is weaker at high levels of entering traffic. The access times vary from about 16 minutes to about 26 minutes for moderate lot utilizations.

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of airport access time will suffer from this type of understatement of access time under certain congested conditions. The recommendations contain a few suggestions for trying to account for this time in future studies.

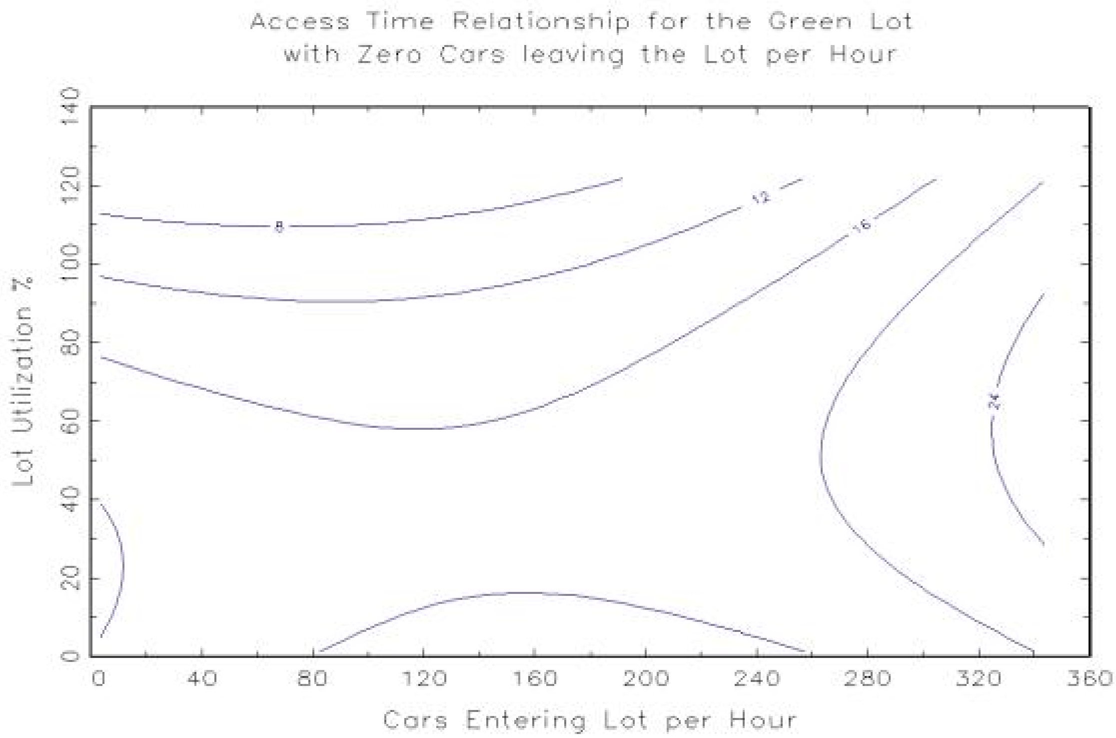

Figure 3-29

Figure 3-30 shows the same trend with a slightly more pronounced saddle for the WCS. The access times in the WCS vary from about 20 minutes to about 30 minutes for moderate lot utilization rates.

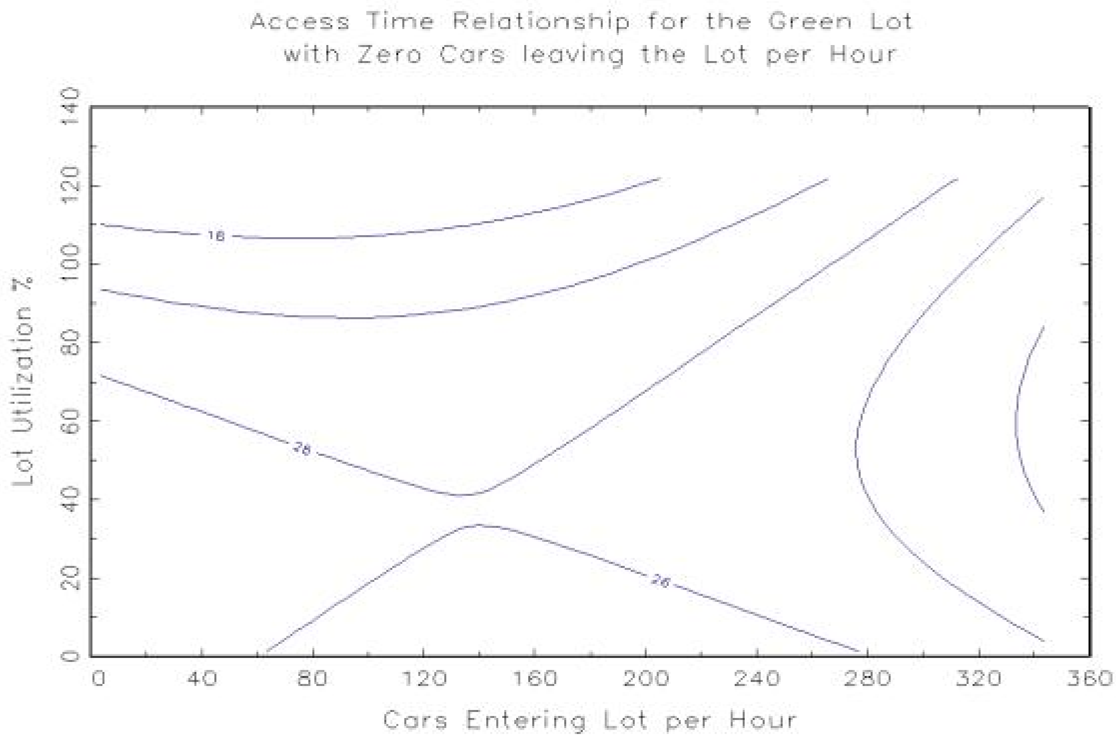

Figure 3-30

Figure 3-31 shows the same data as are in Figure 3-30, except in a surface plot. Note the pronounced saddle shape with increasing access times as more passengers enter the lot.

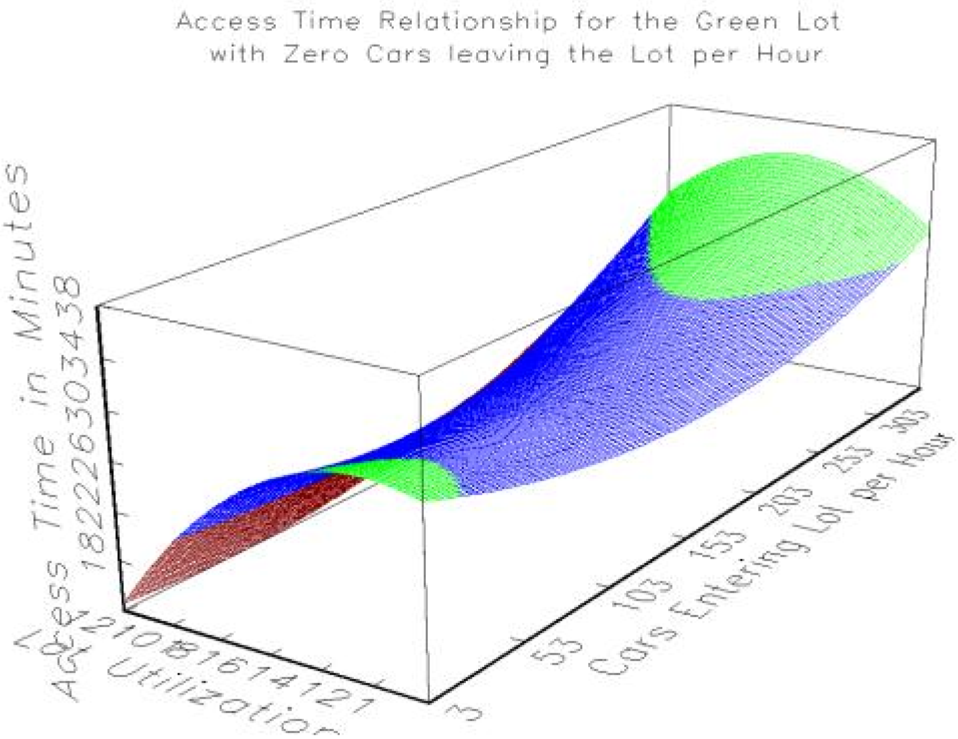

Figure 3-31

Figure 3-32 and Figure 3-33 show the forecasts for the combined satellite lots. As in the Green Lot, all the figures are for no cars leaving the lot. The reasons are the same as for the green lot – drastic increases in predicted access times as more cars leave the lot. The access times vary from approximately 8 minutes to approximately 23 minutes in the BCS (ignoring the upper right-hand corner). In the WCS, the access times range from approximately 16 minutes to 31 minutes (again, ignoring the upper right-hand corner). Figure 3-34 shows the WCS in a surface plot. The concave saddle shape is very clear in this graph.

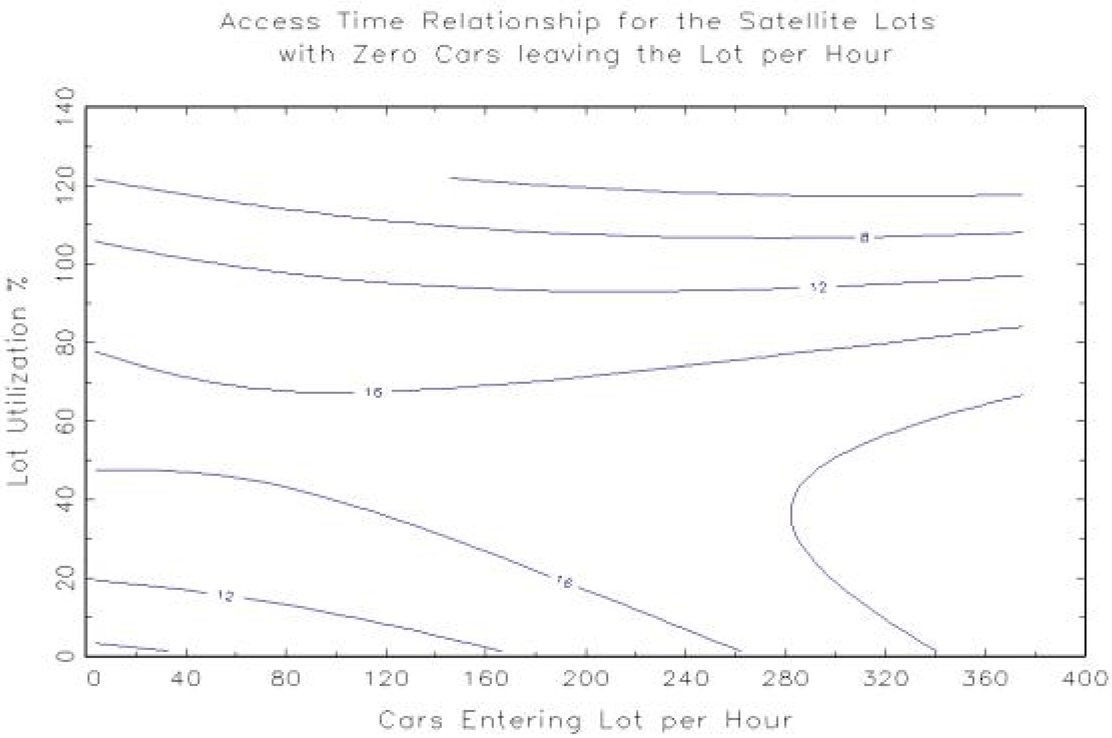

Figure 3-32

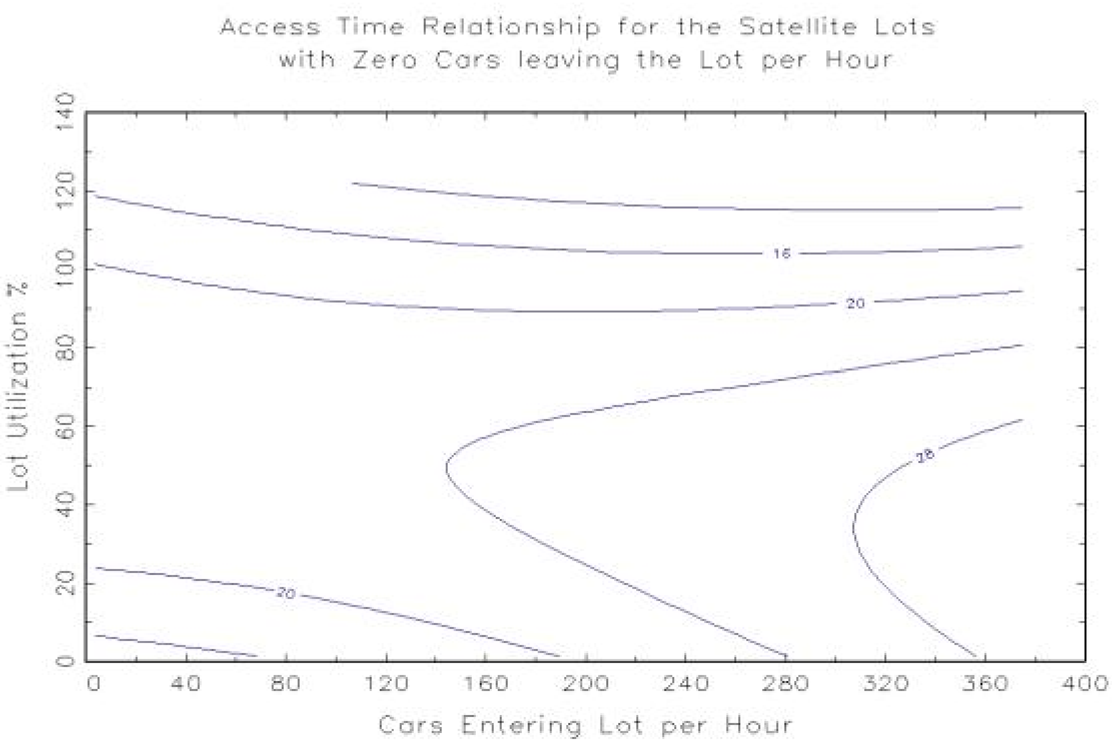

Figure 3-33

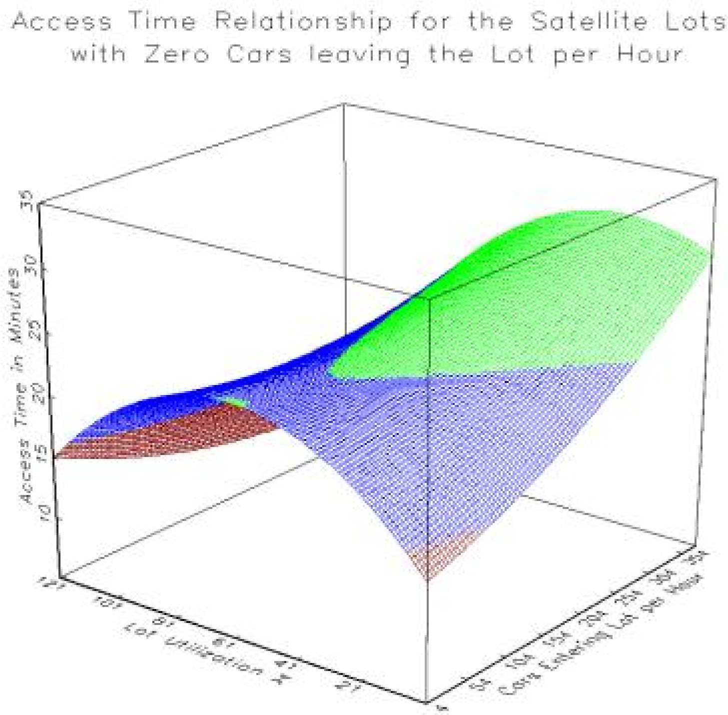

Figure 3-34

3.3.3 Garage Results

Table 3-32 contains the data used in the forecasts for the Garage Lot.

Statistics and Boundaries of Garage Lot Forecasting Data					
	Current Data			**Forecast Ranges**	
	Minimum	**Average**	**Maximum**	**Minimum**	**Maximum**
Lot Utilization %	22	66	107	0	107
Cars Entering	0	459	951	0	1189
Cars Leaving	0	393	1021	0	1532
Day of Week	Sunday	-	Tuesday	-	-
Time of Day	Evening	-	Early PM	-	-

Table 3-32

Figure 3-35, Figure 3-36, Figure 3-37 and Figure 3-38 show the forecasts for the Garage lot. Figure 3-35 shows the BCS with 255 cars leaving the lot per hour (the 25 percentile of observed values) while Figure 3-36 shows the BCS with 970 cars leaving the lot per hour (the 95 percentile of observed values). The first case shows average access times varying from 4 minutes to 10 minutes while moving from the lower left-hand corner to the upper right-hand corner. This means that if the garage lot is relatively empty and not many cars are entering the lot, the average access time is four or five minutes. However, if the lot is very full and there are lots of cars entering the lot, the average access time is 9 or 10 minutes. The lot being full seems to have a slightly larger affect on access time than the number of cars entering the lot. Recall however, that queuing to obtain the ticket at the entrance to the garage is not included in this time.

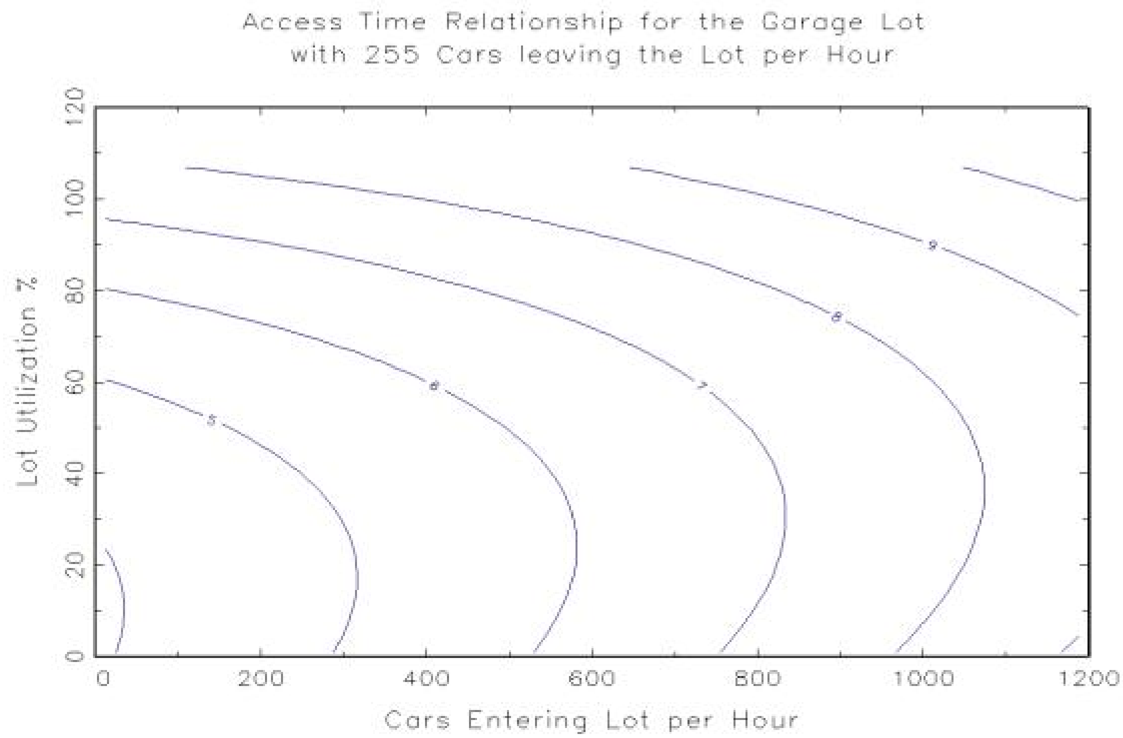

Figure 3-35

The second case shows a similar pattern, but with entering cars having the larger affect on access times. The lowest access times seem to fall in the middle of the lot utilization values and for very few cars entering the lot. At these values the average access time is approximately six and one-half minutes. The highest access times seem to fall when the lot is relatively empty but there are many cars entering the lot. The average access time is approximately 10 ½ minutes at these values. The fact that entering cars has the larger affect in this case shows that there is a cross-effect from the number of cars leaving the lot. If only a few cars leave the lot, the "fullness" of the lot is more important than how many cars are entering for average access time (up to the queuing time not accounted in the data). When many cars leave the lot, the number of cars entering the lot is more important than how full the lot is. This is a logical (but not necessary) relationship.

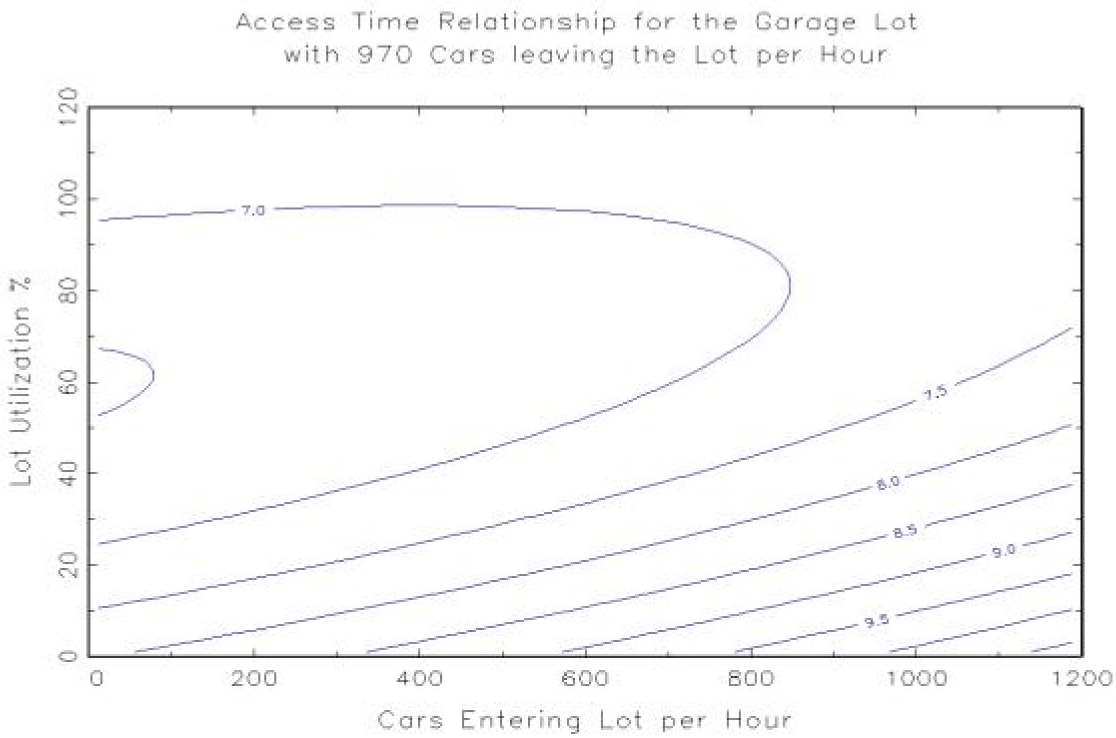

Figure 3-36

Figure 3-37 and Figure 3-38 show the same two cases under the WCS. The average access times increase from 4-10 minutes to 6-12 minutes and from 6 ½ - 10 ½ minutes to 8 ½ - 12 ½ minutes respectively. Other than that the relationships and shapes are identical.

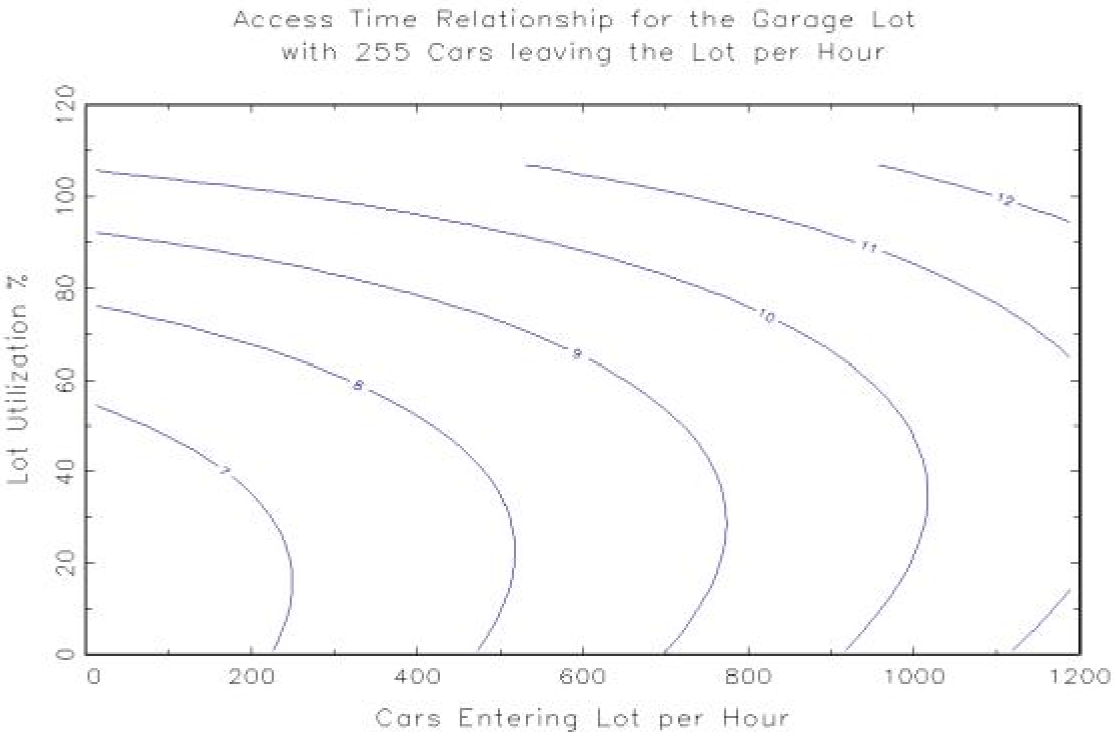

Figure 3-37

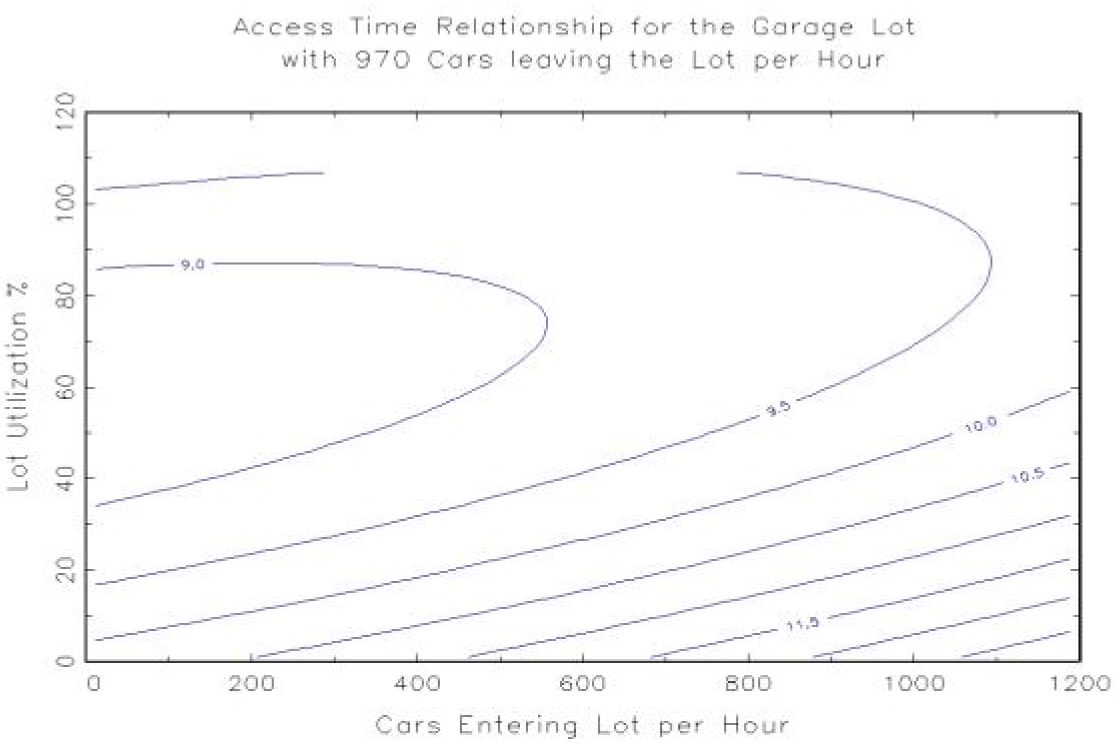

Figure 3-38

Figure 3-39 and Figure 3-40 are presented as surface plots. Unlike the other lots, there are many observations from each portion of this surface represented in the data. The majority of observations fall into the dark blue category since this contains the center of the data. Note that the shift from lot utilization % to cars entering per hour as the dominant variable affecting access times is reflected in the shape of the surface. In Figure 3-39, the surface slopes up toward the back. In Figure 3-40, the surface slopes up toward the right corner. This is reflecting the shift in importance of the two variables as the number of cars leaving the lot increases.

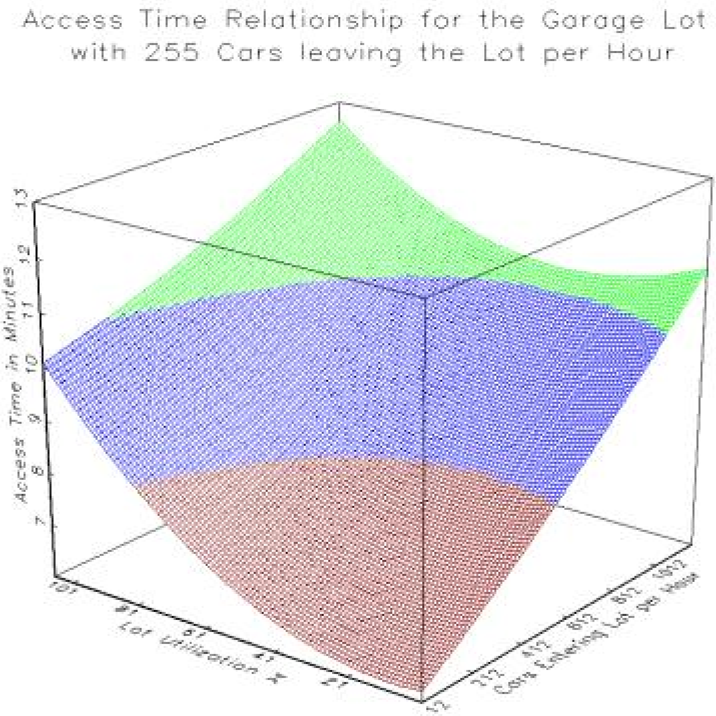

Figure 3-39

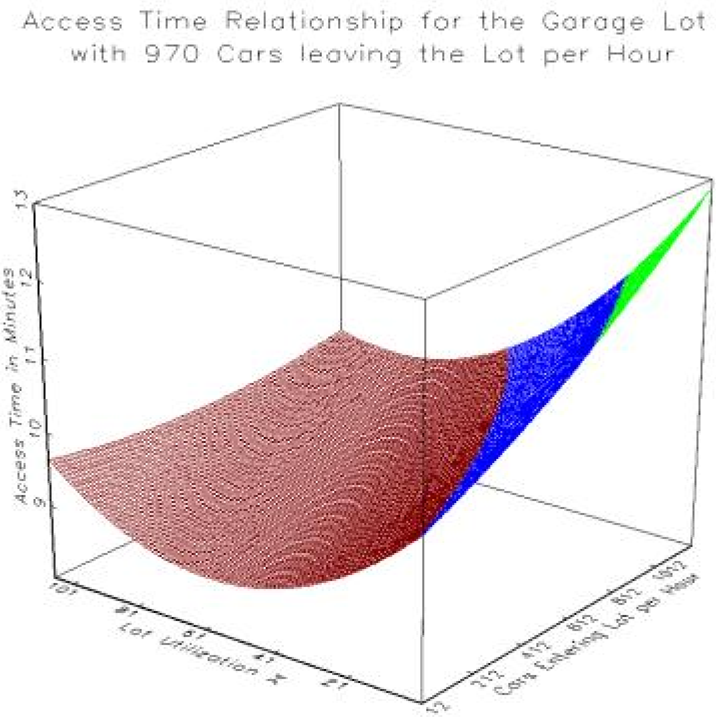

Figure 3-40

4 Conclusions

The study found strong evidence that congestion does affect the access times of passengers arriving at the BWI airport. While most of the average access times were quite low, it was definitely observed that during peak periods significant delays could be experienced in accessing the airport. During the period of the study there were large ranges of access times that varied from quite low during off-peak hours to moderately long during peak congestion periods.

A few tables are presented here to give a flavor of the results presented in the study. Table 4-1 shows the range from the 25th percentile to the 75th percentile access time observed for each access facility as well as the range of average access times under different lot conditions for the forecasts from the best-case and worst-case scenarios.

Range of Access Times and Forecasts				
Lot	**ESP**	**Garage**	**Blue Lot**	**Green Lot**
25 %tile time	8	5	15	17
75 %tile time	11	10	23	26
Low BCS	<0	3	<0	5
Low WCS	<0	5	<0	14
High BCS	21*	12	31	54
High WCS	29*	15	37	63

Table 4-1

Under most conditions presently encountered at the BWI airport the average access times remain relatively low.[5] However, the forecasts point to certain scenarios that could lead to significant increases in access times in the future. It is important for the airport to monitor the progress of the accessibility of the airport as growth occurs (or changes are made to the access structure of the airport) if rapid access is a goal of the airport. The low end of the ranges are a bit tricky to interpret. For the ESP lot, the forecasts did not behave well outside of the current levels of usage and even the high end estimates are of concern. The results are presented in the table but are not discussed. For the Blue lot, the low end estimates are for ranges of usage well outside the current levels. The upper end was for observations not that far outside the current usage levels. The same is true for the Garage and Green lots.

The forecasts presented above show a possibility that access times could grow to what might be deemed unacceptable levels. The forecasts show that average access times could grow considerably if access conditions change. The average access times for the garage lot could increase to as much as 12 or 15 minutes. This would reflect a 50 – 90 percent increase in the average access time. It should be noted that these types of access times were observed during congested periods at the airport.

The Blue lot could experience average access times of 31 to 37 minutes. This would reflect a 60 – 90 percent increase in the average access times. Again, average access times of 30 minutes were not rare during heavily congested periods at the airport. The forecasts for the Green Lot

[5] The term "low" for access times should be interpreted as compared to the public statements made by the airport. For example, information given by the BWI airport concerning satellite parking implies that passengers should allow 45 minutes to access the terminal from the satellite parking lot. Average access times under 25 minutes would be considered rapid in this context. This is not to say that this is low in comparison with other airports.

show that average access times could increase to 54 to 63 minutes. Again, the upper end of these estimates might be inflated due to the use of means rather than distributions (see recommendations below). But this would reflect a 170 – 215 percent increase in the average access times. The "best worst case" scenario for the Green lot found an average access time of 33 minutes - about a 65 percent increase in access times over current conditions. This is in line with the best-case scenario for the Blue lot and does represent an average access time that was observed under current congested conditions at the airport.

While the methodology and data only allow a glimpse at future access times, the data show a compelling trend toward congestion affects. If airside volume continues to grow at the airport, there will be increased pressure placed on the groundside facilities. Such pressure will be evidenced in increased access times without measures being taken to increase capacity (in terms of flow, not parking) or the ability of the facilities to handle higher volumes. In addition, as congestion occurs, it is likely that the distribution of access times will become more "spread". This means that the variance of access times will increase. As this occurs, the passengers experiencing slow access times will be further removed from the average passenger than today. Currently, for the Blue satellite lot, the average access time is approximately 19 minutes. The current 95th percentile observation is 32 minutes. This means that the 95th percentile passenger is 13 minutes "behind" the mean passenger. This "gap" will likely increase as congestion becomes a larger problem. Suppose that the average access time for the Blue lot does increase to 31 minutes. In addition, suppose that the "gap" between the mean and the 95^{th} percentile passenger increases to 23 minutes (this is probably optimistic). This means that the 95^{th} percentile passenger will now take 55 minutes to access the airport.

These figures are chosen for illustrative purposes and no attempt has been made to link the forecasts in this study to particular growth rates in airside volumes. The figures point to the need to study and understand congestion, as well as to the need for distributional studies like one proposed in the recommendations. Understanding the congestion affects will allow the airport to properly plan and monitor expansions of services on the groundside of the terminal.

This study has provided a detailed view of the accessibility of the airport at current usage rates and a glimpse at what access times might be under certain scenarios when growth occurs. This points to the need for future study to determine the likelihood of the forecasting results and to link these results to airside volume. In addition, the airport can use these figures and methodology to update access relationships as changes are made to the groundside of the airport.

5 Recommendations

This study shows certain relationships that might be of concern to the airport in the future. In order to better understand these relationships and to better analyze the potential for congestion delay, further study is needed. Several recommendations are presented here. It is important to note that the scope of this study did not include reviewing procedures or growth plans of the airport. In addition, this was a study that had a very limited scope and thus does not allow precise forecasting of certain events.

First, the current practice of taking satellite and ESP passengers to the lower roadway of the terminal during peak morning hours seems to be very effective. As pointed out, the gains in time may be diminished by any increase in time it takes passengers within the terminal as a result of debarking from the shuttle at the lower level. It may be necessary to study the flow of passengers within the terminal to determine these effects. It would seem that passengers would much prefer being dropped on the lower roadway, but the airport may wish to conduct some sort of survey to determine passenger reaction to this practice. Also, it might be worth examining the possibility of expanding this type of service to other times of day. The upper level roadway is quite crowded for much of the afternoon. It is quite possible that it is faster to use this means of passenger delivery to the terminal for much of the day. Because there is no reserved lane on the upper roadway, it seems that such a practice could save time for much of the day.

Another recommendation for guaranteeing rapid access to the terminal is to ensure that all of the ticket dispensers are working more of the time. It was common; see Figure 2-3, for multiple lanes to be closed at the satellite and garage lots. While this is not of large concern for much of the day – the closures did affect access times during peak hours.

A third recommendation is that the data in this study should be linked to airside data. This was not feasible in this study. It would be much more desirable to use the airside traffic as a predictor of access times than the lot utilizations. This additional dimension added to the forecasting would provide two important benefits. First, this would allow a direct link to airport traffic – the true measure of congestion versus growth. Second, this allows an extra dimension to explain the access times, which would greatly improve the forecasts.

The fourth recommendation is to obtain information on the distribution of access times. The results in this study present only average access times. While they conveys important information, it may be important to understand the behavior of the 25th percentile, 75th percentile, 90th percentile or some other reference access time. It is not necessary that these other benchmarks follow the trends of the average access times. It would be very possible that the average access times were faster for the Blue Satellite lot than the Green Satellite lot under almost every condition (which is true) while the Green Satellite lot had lower 95th percentile access times for most of these conditions (not true in this case but possible). A study that examines the entire distribution of access times provides much more information about how passengers access the airport. The National Transportation Center at Morgan State University has sponsored a small study to look at this very issue using the data already collected from this project. Studies of this sort will greatly improve the state of knowledge concerning the behavior of access times and congestion.

The last recommendation is that the MAA continue with studies of this sort. With a major groundside expansion in progress, it is important for the MAA to understand the impact of the changes on accessibility to the terminal building. Future studies could be refined drastically from the information obtained in this study. Both broad studies (such as this one) or specific studies (aimed at studying one particular access facility) can be carried out. The largest cost of these studies is the collection of data. In the case of this study, roughly 85 percent of the cost was data collection. By using the results of this study, finely refined studies are possible at a greatly reduced cost of data collection.

A Appendix

This appendix contains details about the data and other methodological information that is of more concern from a scientific point of view and thus detracted from the flow of the report. The elements of the appendix are in no particular order.

Observations Discarded: There were some observations that needed to be discarded. While an attempt was made to correct as many observations as possible, there were times that is was impossible to salvage an observation. These fell into two categories. The first was negative observations and the second was prolonged entry observations. The negative observations occurred when a passenger seems to have accessed the terminal before arriving at the lot. This is obviously not possible. While sometimes these errors could be corrected (usually by noting that the entry time was wrong by one hour), other times no correction could be made. Access times that were negative were discarded.

The prolonged access time observations were more difficult to handle. It is impossible to account for how long a passenger stayed at their car in the lot. Obviously this is different for each passenger. Of course, this is true at all times of day and every day, so the affects of this are diminished in a large sample. However, there is a point where it becomes obvious the passenger did not proceed directly through the process. The amount of time allowed for access from the ESP and Garage lots was 30 minutes. The amount of time allowed for access from the satellite lots was 45 minutes. In all cases, there were only a few observations discarded and they were quite uniformly distributed over a long period. In the case of the satellite lots approximately 1 percent of the tickets (28) were discarded. A few of these may be legitimate observations; others (including one ticket with an access time of 147 minutes) are obvious errors. Including these observations may improve future study looking at high percentile access times but would have distracted from the accuracy of predictions concerning average access times – the goal of this study.

Study Locations: shows the airport grounds and the location of the ticket dispensers and collectors. The dispensers are identified by the black lines leading to the entry to each of the lots. The collectors are identified by the light blue lines that lead to the terminal curbside.

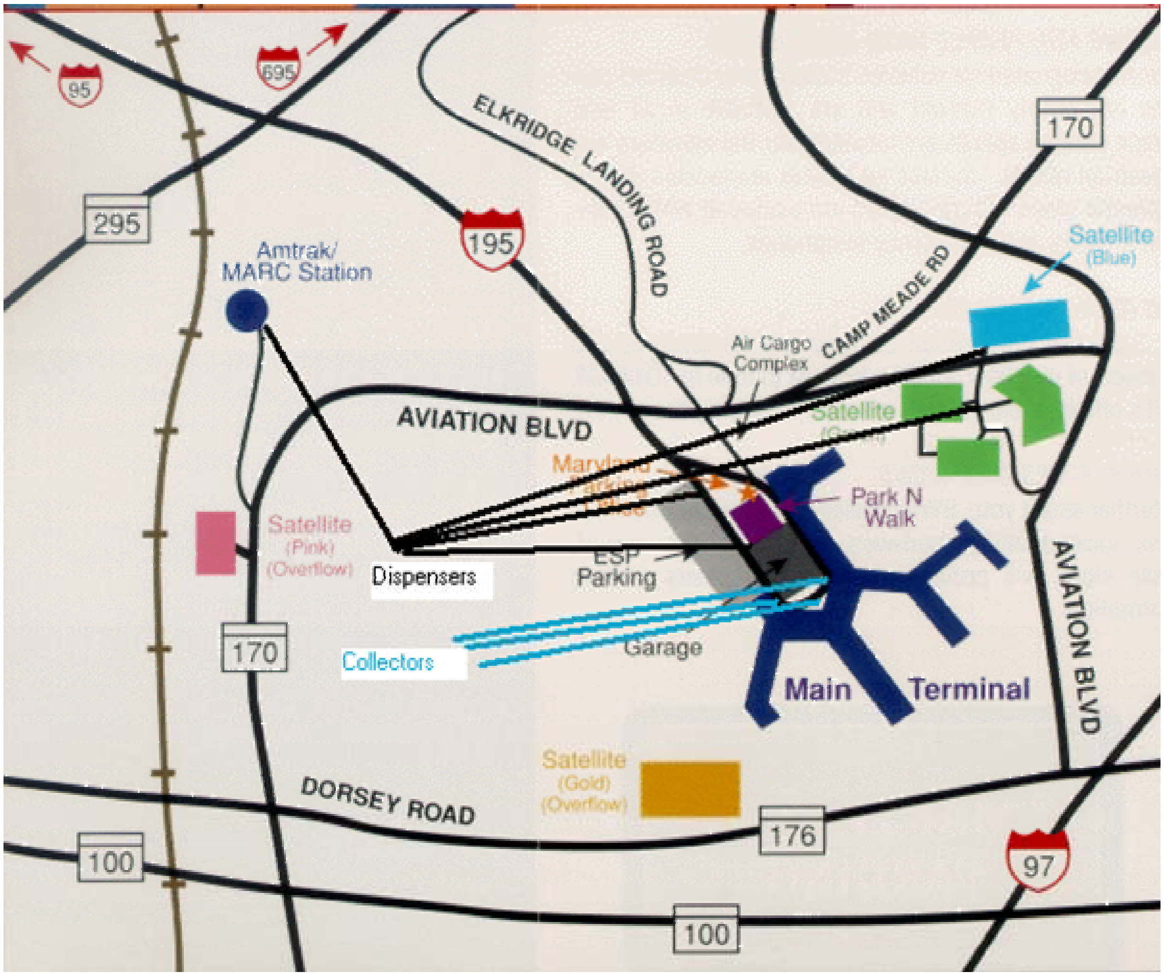

Figure A-1

Figure A-2 shows the points used for timing cars for the drop-off observations. The red lines indicate where the vehicles entered and exited the field of vision of the surveyor. While it is possible for some congestion to be present before and after these timing points, it was not practical to obtain observations beyond these points. Any attempt to gain information outside these points would require greater resources or require a drastic reduction in the number of vehicles timed.

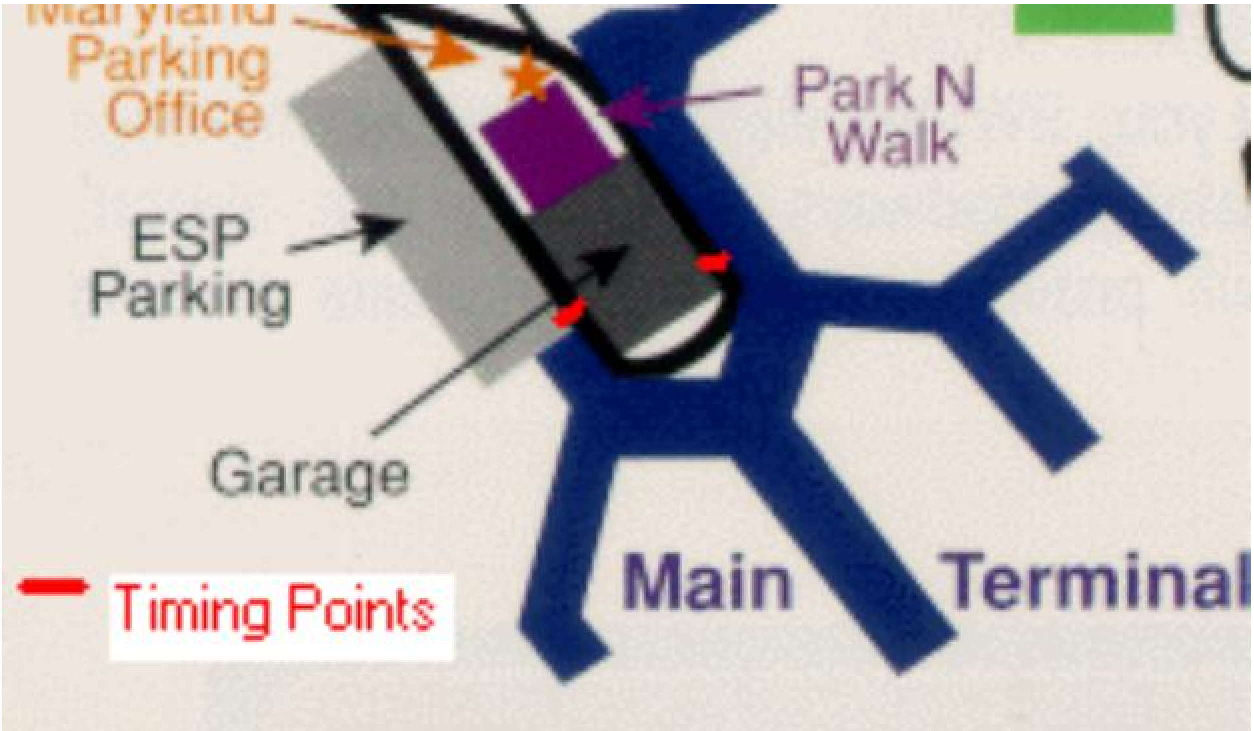
Parking
Office
Park N
Walk
ESP
Parking
Garage
Main Terminal
Timing Points

Figure A-2