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16. Abstract <p>Offsite airport facilities provide ground transportation, baggage and passenger check in, and other transportation services to departing air passengers from a remote location. The purpose of this study was to develop models to determine the airports that might be candidates for such a facility and estimate the percentage of travelers that would choose to use one to access the airport.</p> <p>Offsite airport facility operations were examined in New York, Los Angeles, Zurich, London, and Hong Kong, and passenger data were obtained from surveys distributed at six U.S. airports. A total of 1,700 air-traveler questionnaires were completed at four airports without offsite facilities, i.e., Baltimore/Washington International Thurgood Marshall Airport (BWI), Charlottesville-Albemarle Airport (CHO), Norfolk International Airport (ORF), and Richmond International Airport (RIC), and at two airports with offsite facilities that provide ground transportation only, i.e., Boston Logan International Airport (BOS) and San Francisco International Airport (SFO). The survey results show that 68% of passengers who traveled directly to the airport terminal would consider using an offsite airport facility if available. Of the passengers who currently use an offsite airport facility that provides only ground transportation, almost 70% indicated that their access would be improved by expanded services including baggage and passenger check in. The two main reasons cited for using the offsite airport facilities surveyed in this study were reduced travel time variability (43%) and lower cost (39%).</p> <p>With the data collected at the six airports, two models were developed sequentially to determine the demand for offsite facilities. The airport access quality model was used to establish initial demand by assuming that the likelihood of a viable offsite facility is directly proportional to the difficulty, or resistance, encountered during the current access trip to the airport. This model yielded expected results when tested with a former offsite airport facility. The offsite facility usage model was used to determine the probability of passengers using an offsite facility while accessing an airport and accurately estimated 58% of the test set responses.</p> <p>The airport access quality model develops a value for total resistance and ranks the airports according to the current difficulty encountered by passengers during their access trip to the airport. When applied to three Virginia airports, passengers accessing RIC had the largest total resistance. Accordingly, RIC is considered to have the highest potential demand for an offsite facility.</p> <p>The offsite airport facility usage model was based on flight departure time and variability in ground travel time as predictors of the final demand. For example, the model estimated an offsite airport facility demand of 74% for passengers departing between 8 and 10:30 A.M. when ground travel times vary by 45 min (rounded to the nearest 15-min interval). For passengers departing before 8:00 A.M. and with a ground travel time that varies by no more than 5 min, the models estimated demand at only 26%. The offsite airport facility usage model was also used to identify the zones (defined by zip codes) where potential use of offsite terminals is substantial.</p>			
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**FINAL REPORT**

**AIRPORT OFFSITE PASSENGER SERVICE FACILITIES:  
AN OPTION FOR IMPROVING LANDSIDE ACCESS:  
VOLUME II: ACCESS CHARACTERISTICS AND TRAVEL DEMAND**

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## ABSTRACT

Offsite airport facilities provide ground transportation, baggage and passenger check in, and other transportation services to departing air passengers from a remote location. They were introduced in the United States in the 1950s but did not achieve widespread use. In recent years, interest has been revived in this airport access option because of changes in technology, land use, and air travel conditions. However, potential demand for new offsite terminals is not fully understood. The purpose of this study was to develop models for this research need, which is to determine the airports that might be candidates for an offsite facility and estimate the percentage of travelers that would choose an offsite facility to access the airport.

Offsite airport facility operations were examined in New York, Los Angeles, Zurich, London, and Hong Kong, and passenger data were obtained from surveys distributed at six U.S. airports. A total of 1,700 air-traveler questionnaires were completed at four airports without offsite facilities, i.e., Baltimore/Washington International Thurgood Marshall Airport (BWI), Charlottesville-Albemarle Airport (CHO), Norfolk International Airport (ORF), and Richmond International Airport (RIC), and at two airports with offsite facilities that provide ground transportation only, i.e., Boston Logan International Airport (BOS) and San Francisco International Airport (SFO). The survey results show that 68% of passengers who traveled directly to the airport terminal would consider using an offsite airport facility if available. Of the passengers who currently use an offsite airport facility that provides only ground transportation, almost 70% indicated that their access would be improved by expanded services including baggage and passenger check in. The two main reasons cited for using the offsite airport facilities surveyed in this study were reduced travel time variability (43%) and lower cost (39%).

With the data collected at the six airports, two models were developed sequentially to determine the demand for offsite facilities. The airport access quality model was used to establish initial demand by assuming that the likelihood of a viable offsite facility is directly proportional to the difficulty, or resistance, encountered during the current access trip to the airport. This model yielded expected results when tested with a former offsite airport facility. The offsite facility usage model was used to determine the probability of passengers using an offsite facility while accessing an airport and accurately estimated 58% of the test set responses.

The airport access quality model develops a value for total resistance and ranks the airports according to the current difficulty encountered by passengers during their access trip to the airport. When applied to three Virginia airports, passengers accessing RIC had the largest total resistance. Accordingly, RIC is considered to have the highest potential demand for an offsite facility.

The offsite airport facility usage model was based on flight departure time and variability in ground travel time as predictors of the final demand. For example, the model estimated an offsite airport facility demand of 74% for passengers departing between 8 and 10:30 A.M. when ground travel times vary by 45 min (rounded to the nearest 15-min interval). For passengers departing before 8:00 A.M. and with a ground travel time that varies by no more than 5 min, the models estimated demand at only 26%. The offsite airport facility usage model was also used to identify the zones (defined by zip codes) where potential use of offsite terminals is substantial.

## **FINAL REPORT**

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## **INTRODUCTION**

Options to improve the quality of airport landside access may include expanding existing terminals, widening access roads, constructing new parking facilities, adding curbside drop off/pick up areas (Shriner and Hoel, 1999), and providing operational enhancements such as the use of cell phone lots for drivers picking up passengers. Another option for improving airport landside access is an offsite airport passenger service facility, which serves an airport and its users by providing ground transportation to and from the main terminal, baggage handling, check in, and passenger information. A previous report (Volume I) (Goswami et al., 2008) provided information about the concept, history, and current operations of various types of offsite airport facilities. This report (Volume II) addresses how to estimate demand for offsite airport facilities.

Offsite facilities were first examined in the United States during the early 1950s (Mansel and Mandle, 2000). Most of the remote facilities that initially provided check-in service either have been vacated or serve only as limousine pick-up and drop-of points (Air Transport Association of America, 1976). Previous studies focused on determining a suitable location for such offsite facilities (Kanafani, 1971; Spliseth, 1971); determining the desirability of offsite facilities to improve airport access (Leder, 1970); analyzing the cost-effectiveness of offsite facilities as a means of relieving groundside congestion in major hub cities (Snell, 1971); and conducting a feasibility evaluation of the Marin Airporter offsite facility (Gosling and Novak, 1980). The last source (Gosling and Novak, 1980) estimated the proportion of passengers using an offsite facility based on the ratio of travel time directly to the airport and travel time using the offsite facility.

Increasing landside congestion at major airports has renewed interest in the use of offsite facilities (Gosling, 1987). Yet many of the previous studies evaluated offsite facilities that existed before 1980. Since that time, passenger characteristics have changed (Goswami et al., 2008) and some offsite facilities have closed or modified their services (Berger, 1985; Gosling, 1994, 1997; Sebro, 2007). Through the use of models based on survey data collected at six U.S. airports, this study addressed the passenger demand for offsite facilities in the present context.

## **PROBLEM STATEMENT**

One problem faced by transportation planners is that no modern methods to forecast demand for an airport offsite passenger service facility are available. Without such methods, offsite facilities will lack a process for evaluation and decision making, hindering applications that may be beneficial.

## **PURPOSE AND SCOPE**

The purpose of this study was to develop, calibrate, and test an approach for estimating demand for airport offsite passenger service facilities. *Demand* was defined as the probability that passengers will choose to use an offsite facility. The approach was limited to passenger characteristics such as travel time to the airport, flight departure time (FDT), and the cost of the access trip. Factors other than passenger demand that could influence the viability of an offsite facility, such as the impact of airport parking revenue by introducing offsite terminals (Sherry, 2007), were beyond the scope of this study.

The study focused only on offsite airport facilities used by the departing air passenger, and data gathering efforts were limited to airports where permission to implement surveys was granted.

## **METHODOLOGY**

Four tasks comprised the methodology:

1. A literature review identified suitable performance measures for offsite facilities.
2. Data were collected to determine departing air passenger characteristics.
3. The data from Task 2 and the variables identified in Task 1 were used to develop airport access quality models for use in forecasting airports that were likely candidates for locating an offsite facility.
4. The data from Task 2 were used to develop offsite facility usage models that estimate the percentage of passengers likely to use an offsite facility at a specific airport and to identify promising market segments.

## **Task 1: Identify Performance Measures for Facilities**

The literature review was summarized in Volume I of this study (Goswami et al., 2008). Information about airport access was also obtained through web-based keyword searches, the WorldCat database, the VDOT Research Library, and libraries at the University of Virginia.

The results of the literature review were used to identify passenger performance measures that reflected passenger viewpoints rather than performance measures that reflect the viewpoints of airport owners or airlines. Examples of the former are (1) delay during the airport access trip (Mahmassani et al., 2002); (2) congestion at the curbside (Mahmassani et al., 2001); and (3) uncertain ground access times attributable to highway congestion (Cambridge Systematics Inc., 2004). Examples of performance measures that reflect the viewpoints of airport owners are the lack of landside access capacity (Ndoh and Ashford, 1993) and impacts on the environment (e.g., air emissions) (Airport Land Use Commission, 2005; Gray-Mullen, 2000).

Based on the metrics applicable to passengers, five quantifiable performance measures were selected that are likely to reflect the overall quality of the access trip and the percentage of passengers using an offsite airport facility.

## **Task 2: Determine Air Passenger Characteristics**

### **Data Collection**

Passenger travel data were obtained by a survey of departing passengers and direct observations at the following airports where permission had been granted:

1. Charlottesville-Albemarle Airport (CHO), Charlottesville, Virginia
2. Norfolk International Airport (ORF), Norfolk, Virginia
3. Baltimore/Washington International Thurgood Marshall Airport (BWI), Baltimore, Maryland
4. Richmond International Airport (RIC), Richmond, Virginia
5. Boston Logan International Airport (BOS), Boston, Massachusetts
6. San Francisco International Airport (SFO), San Francisco, California.

In Charlottesville, Norfolk, Baltimore, and Richmond, surveys were conducted within the airport terminal. A booth was established, and departing air passengers were requested to complete a survey (as shown in Appendix A). The surveys were conducted over a 2-day period in 2006 on the following dates: June 15 and 16 (CHO), June 26 and 27 (ORF), August 3 and 4 (RIC), and August 8 and September 8 (BWI).

At Boston and San Francisco, surveys were distributed on buses that provide transportation to the airport from different offsite airport facilities that provide ground transportation only (as shown in Appendix B). (Volume I of this study [Goswami et al., 2008] described seven categories of offsite facilities, and because BOS and SFO provide ground transportation only, they are classified as a Category VI facility as noted in Table 1 of Volume I.)

The BOS surveys were conducted September 18-19, 2006, and the SFO surveys were conducted February 5-7, 2007.

The surveys provided the following data:

- origin in the region (zip code)
- arrival time at airport
- scheduled flight departure time (FDT)
- ground travel time to airport
- perceived variability in ground travel time
- mode to access to airport
- cost of ground travel to the airport
- cost of flight ticket.

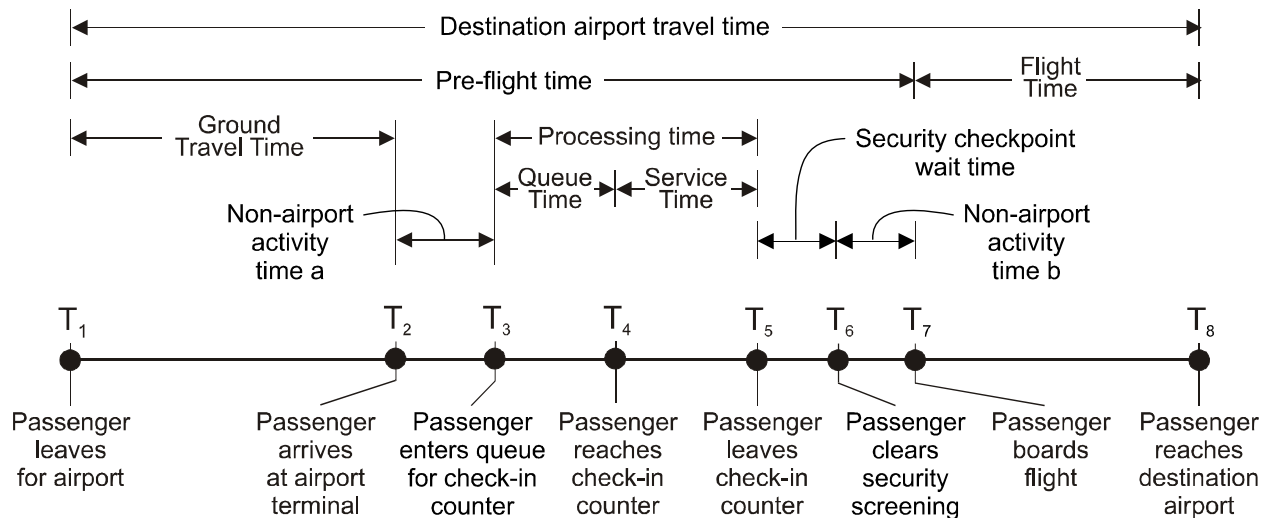
At Charlottesville, Norfolk, Baltimore, and Richmond, in addition to surveys, passenger processing times were collected manually at the terminal. At each airport, two or three data collectors were equipped with stop watches, data entry sheets, or a laptop and provided with a clear view of the queue and the check-in counter. Each data collector independently recorded the time a passenger entered the queue, the time the passenger reached the counter, and the time the passenger left the counter. Observations at each airport were made at different times in a day and at different check-in queues for a period of 2 days to identify the variation in processing times. Two data elements were collected: wait time in the queue prior to check in and service time at the check-in counter.

Average values of security checkpoint wait times were obtained from the Transportation Security Agency (TSA) website (TSA, 2007). Individual values could not be collected as permission was denied to collect data pertaining to security checkpoint times at the terminal.

## **Data Tabulation**

The basis for survey tabulation of passenger time characteristics were based on the following elements as illustrated in Figure 1 (not to scale).

- *Pre-flight time*: time difference between when passengers leave for the airport and the scheduled boarding time
- *Flight time*: time difference between the airport scheduled departure and the scheduled arrival time at the destination airport
- *Destination airport travel time*: summation of pre-flight time and flight time
- *Ground travel time*: time taken to travel from origin to the airport terminal
- *Processing time*: summation of queue (waiting) time and service time at the check-in counter



**Figure 1. Components of Air Passengers' Destination Airport Travel Time**

- *Non-airport activity time*: time spent at the terminal while not engaged in a specific airport/airline procedure
  - *Non-airport activity time* = *Non-airport activity time<sub>a</sub>* + *Non-airport activity time<sub>b</sub>*  
(data pertaining to non-airport activity time<sub>a</sub> were not collected)
  - *Non-airport activity time<sub>a</sub>*: time taken by the passenger to traverse from the terminal door to the check-in queue
  - *Non-airport activity time<sub>b</sub>*: time spent by the passenger at the terminal after clearing security and prior to boarding the flight.

In addition to the average values and variation in these travel time components, three other types of information were extracted from the survey: passengers' willingness to use an offsite facility where none existed, passengers' reason for using the facility if one did exist, and originating zip code of the passenger. The zip codes served to identify areas with a high departing air passenger concentration.

### Missing Data

The surveys were not always fully completed by respondents. Accordingly, a pairwise deletion process was used to address missing data as appropriate. For example, if a survey respondent provided ground travel time, distance to the airport, and access mode but omitted access cost, those computations that required the use of an access cost variable did not included this survey response. If, however, a regression analysis as described in Task 3 was performed where ground travel time was the dependent variable and access mode and distance from the airport were the independent variables, this response was included.

### Task 3: Develop, Validate, and Apply Airport Access Quality Models

An airport access quality model quantifies the difficulty, or resistance, encountered by passengers en route to the airport. If the model indicates that the resistance to direct airport access is low, the airport is probably not a suitable candidate for an offsite facility. If the model indicates that the resistance to direct airport access is high, an offsite facility may potentially improve access. Thus, airport access quality models establish the possibility of demand by suggesting whether or not an airport offsite facility may be a promising option.

#### Development of Resistance Variables

Access resistance was measured using five resistance variables based on the performance measures identified in Task 1 impedance, access cost, ground travel time, processing time, and uncertainty (or ground travel time variability). Table 1 indicates how each resistance variable was obtained using the results of Task 2.

The sequence of steps used to develop airport access quality models were: (1) compute and validate the resistance variables, (2) apply the resistance function, and (3) validate the final airport access quality model.

**Table 1. Resistance Variable Data Source**

<b>Resistance Variable</b>	<b>Source</b>
Impedance	Inferred from question 9 from survey shown in Appendix A
Access cost	Question 8 from survey shown in Appendix A
Ground travel time	Question 3 from survey shown in Appendix A
Processing time	Summation of queue time and service time data collected at check-in counters at airport terminal
Uncertainty	Inferred from Questions 3 and 4 from survey shown in Appendix A

#### Compute and Validate Resistance Variables

For those situations where a survey is not feasible, it is necessary to estimate each variable from data that can easily be measured. For example, rather than asking respondents to provide a value for the “impedance” encountered during a specific trip, the value can be obtained from the ground travel time and the time the respondent left the place of origin (as will be shown in Eq. 11). If a relationship can be established between measured variables (e.g., ground travel time) and the five resistance variables, these relationships can be used to estimate similar variables at other airports where survey data are unavailable.

Accordingly, two approaches for estimating the five resistance variables were used: linear regression and cross classification. For each approach, a relationship was developed between the variables shown in Table 1 and independent variables that could more easily be measured. These relationships were based on 90% of the data collected. The relationships were then “tested” on the remaining 10% of the data to assess the ability of the independent variables to predict the resistance variables.

For example, for the linear regression approach, a relationship between the dependent variable, impedance,  $y_i$ , and the two independent variables, i.e., ground travel time and the time a

respondent left the place of origin ( $x_1$  and  $x_2$ ), was developed based on 90% of the data. Then, the accuracy with which these relationships predicted the remaining 10% of impedances surveyed was determined.

### *Application of Resistance Function*

The concept of the resistance function is derived from the notion of a desirability function developed by Derringer and Suich (1980), which states that the quality of a product with multiple quality characteristics is unacceptable if one of the characteristics lies outside the desired limits. For example, if the “product” is airport access and one of its characteristics is “ground travel time,” the quality of airport access will be unacceptable if the ground travel time exceeds a predefined value, regardless of the value of other quality characteristics. This approach has been widely used for optimizing multiple-response problems (Castillo et al., 1996). The desirability function transforms each estimated response variable  $y_i$  to a desirability value  $d_i$ , such that the desirability values lie between 0 and 1. The value of  $d_i$  increases as the “desirability” of the corresponding response variable increases.

In an airport access application, an increase in a variable such as average access cost ( $y_i$ ) will tend to reduce the desirability of this trip. In order to apply the desirability concept, the term *resistance* is used such that an increase in average access cost would be reflected by an increase the resistance encountered during the trip. In this case, the resistance value  $r_i$  increases as the corresponding resistance variable ( $y_i$ ) increases.

The resistance function in Eq. 1 is used to transform the individual resistance variable ( $y_i$ ) into a resistance value  $r_i$ .

$$r_i = \begin{cases} 0 & y_i \leq y_{\min} \\ \left( \frac{y_i - y_{\min}}{y_{\max} - y_{\min}} \right)^z & y_{\min} < y_i < y_{\max} \\ 1 & y_i \geq y_{\max} \end{cases} \quad (\text{Eq. 1})$$

Note that  $r_i$  is a function of  $y_i$  so that one could formally denote the resistance value as  $r_i(y_i)$  rather than simply  $r_i$ . However, the nomenclature  $r_i$  is used in this report to distinguish the resistance value  $r_i$  from the resistance variable  $y_i$ .

Note also that the value of  $z$  in the superscript of Eq. 1 is specified by the user, where a large value of  $z$  is selected if the user wants  $y_i$  to increase rapidly above  $y_{\min}$ . However, as will be discussed later in the context of Figure 5, a sensitivity analysis showed that  $z$  did not materially affect the study’s results, and thus Eq. 1 used a value of  $z = 1$ .

The total resistance,  $R_{total}$ , of the passenger’s access trip is given by the geometric mean of the individual resistance values ( $r_i$ ) as shown in Eq. 2.

$$R_{total} = (r_1 \times r_2 \times \dots \times r_k)^{1/k} \quad (\text{Eq. 2})$$

The total resistance does not give an absolute value but rather a relative value of the resistance of airport access. For example, if Airport A has a resistance of 0.29, it would be considered to reflect a lower difficulty in access compared to Airport B with a resistance of 0.42. As a consequence, Airport A would be a less likely candidate for an offsite airport facility than would Airport B.

#### *Validation of Airport Access Quality Model*

The East Side Airlines Terminal (ESAT) was used to validate the airport access quality model. Because the model development and calibration did not rely on ESAT data, the ESAT data represented a true test case where the prediction of the models could be compared to the actual performance of ESAT. Volume I of this report (Goswami et al., 2008) provides additional information about ESAT. Data were sought from persons familiar with ESAT, as one of the libraries that had reference materials was destroyed in the September 11, 2001 attack on the World Trade Center, and one source from the literature served as the basis for most of the ESAT data (Gosling et al., 1977).

#### **Task 4: Develop, Validate, and Apply Offsite Facility Usage Models**

An offsite facility usage model predicts the probability that passengers will use an offsite facility. An offsite facility usage model can also be used to identify offsite facility market segments or areas, identified by zip codes, where an offsite facility could be located.

Informally, a probability is the result that will transpire if a certain experiment is repeated an infinite number of times. Formally, this probability relies on the limit as the number of experiments approaches infinity (Ortúzar and Willumsen, 2004). If, for example,  $n_i$  is the number of times a given passenger chooses to use an offsite facility and  $n_o$  is the number of times the passenger chooses not to use an offsite facility, the probability of using an offsite facility  $P_i$  is given by Eq. 3, adapted from Ortúzar and Willumsen (2004).

$$P_i = \lim_{(n_i+n_o) \rightarrow \infty} \frac{n_i}{n_i + n_o} \quad (\text{Eq. 3})$$

In practice, the literature noted that although Eq. 3 presumes multiple experiments, the concept of probability may be extended to a single event (Hogg and Ledolter, 1992) such as the probability of a particular passenger using an offsite facility tomorrow. Whether multiple experiments or a single event is presumed, the basic laws of probability are constant (Hogg and Ledolter, 1992). For example, as per Eq. 3,  $p_i$  and  $p_o$  must sum to 1.0 if those are the only possible outcomes.

However, Eq. 3 suggests that one has greater confidence in seeing evidence of the probability as the total number of experiments  $n = n_i + n_o$  grows larger. For example, if the probability of  $p_i$  is 0.412, if only one experiment is conducted ( $n = 1$ ), the difference between the expected frequency ( $p_i n = (0.412)(1) = 0.412$ ) and the observed frequency ( $n_i = 0$  or 1) will be *at least* 0.412. If  $n = 10$ , then the difference between the expected frequency (4.12) and the

observed frequency (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10) must be *at least* 0.12 (which would result if the observed frequency was 4). If  $n = 1,000$ , it is conceivable that the difference between the expected frequency (412) and the observed frequency (which could be 412) may be zero. Thus, for all probabilities computed in this study, one would expect a greater ability to see the expected frequency as the number of passengers to whom the probability is applied increases.

### Model Development

One of the most common methods for predicting the probability of using a given mode, such as auto or transit, is the mode choice model (Garber and Hoel, 2009). For more than three decades, mode choice models have also been used to forecast the mode passengers will use to access an airport (Gosling, 2008). A particular modeling technique that appeared promising for this study was the binary logit regression model, which can be used to predict the probability of passengers using the offsite facility (Eq. 4).

$$E\{y\} = \Pr(Y = 1 | X = x) = \frac{\exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p)}{1 + \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p)} \quad (\text{Eq. 4})$$

This function can be generalized directly to a situation where there are  $p$  predictor variables, in vector  $\beta$ , i.e.,  $\beta = \beta_0, \beta_1, \dots, \beta_p$ . The reader should note that  $E\{y\}$  where  $Y = 1$  is  $P_{\text{offsite}}$  and that  $E\{y\}$  where  $Y = 0$  is  $P_{\text{non-offsite}}$ . The ratio  $\frac{P_{\text{offsite}}}{1 - P_{\text{offsite}}}$  is called the odds ratio for the event where

$$\frac{P_{\text{offsite}}}{1 - P_{\text{offsite}}} = \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p) \quad (\text{Eq. 5})$$

Eq. 4 may be derived by assuming that the utility of the offsite facility is given by Eqs. 6 and 7, where the vector  $\mathbf{X} = 1$  in Eq. 6 and  $\mathbf{X} = 0$  in Eq. 7.

$$U_{\text{offsite}} = \beta \mathbf{X} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p \quad (\text{Eq. 6})$$

$$U_{\text{non-offsite}} = \beta \mathbf{X} = 0 \quad (\text{Eq. 7})$$

Thus, the probability of using an offsite airport facility is given by Eq. 8,

$$P_{\text{offsite}} = \frac{\exp(U_{\text{offsite}})}{\exp(U_{\text{non-offsite}} + U_{\text{offsite}})} = \frac{\exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p)}{1 + \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p)} \quad (\text{Eq. 8})$$

and the probability of not using an offsite airport facility is given by Eq. 9.

$$P_{\text{non-offsite}} = \frac{\exp(U_{\text{non-offsite}})}{\exp(U_{\text{non-offsite}} + U_{\text{offsite}})} = \frac{1}{1 + \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p)} \quad (\text{Eq. 9})$$

Dividing Eq. 8 by Eq. 9 and using the relationship  $P_{\text{offsite}} + P_{\text{non-offsite}} = 1$  yields Eq. 5.

Taking the natural logarithm of both sides of Eq. 5 yields Eq. 10.

$$\ln\left(\frac{P_{\text{offsite}}}{1-P_{\text{offsite}}}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p \quad (\text{Eq. 10})$$

The logarithm of the odds ratio as shown is called the logit, and the logit transformation produces a linear function of the parameters  $\beta_0, \beta_1, \beta_2, \dots, \beta_p$ . The range of the values of  $P_{\text{offsite}}$  is between 0 and 1, and the range of the values of  $\ln(P_{\text{offsite}}/(1-P_{\text{offsite}}))$  is between  $-\infty$  and  $\infty$ . Logistic regression fitting is carried out by working with the logits, and the method of estimation used is the maximum likelihood method.

As an alternative approach to that shown in Eqs. 4 through 10, a cross-classification model was also implemented.

### *Model Testing*

As noted earlier, the relationships shown in Eqs. 4 through 10 were based on 90% of the data set. The models were tested by evaluating their prediction accuracy on the remaining 10% of the data set.

### *Model Application*

The offsite facility usage model was used for two purposes:

1. *To predict the market segments that might be more likely to use an offsite facility at a given airport.* These market segments are based on the FDT and the variability in ground travel time.
2. *To identify promising zip codes for locating an offsite facility that would serve RIC and BWI.* The identification of such zip codes is based on the assumption that zip codes generating higher proportions of likely offsite facility users are the best candidate locations for an offsite facility. (RIC and BWI had been identified as airports that would be more conducive to an offsite facility than CHO and ORF based on the results of the airport access quality models used in Task 3.)

## **RESULTS AND DISCUSSION**

### **Performance Measures for Offsite Airport Passenger Service Facilities**

Volume I of this study (Goswami et al., 1908) suggested eight potential benefits of offsite airport facilities. Performance measures based on these benefits are given in Table 2. Some benefits apply only to the passenger (e.g., reduction in ground travel time), whereas other

**Table 2. Performance Measures**

<b>Performance Variable<sup>a</sup></b>	<b>Measurable Element<sup>b</sup></b>	<b>Future Potential Benefit</b>
Impedance	Satisfaction of access trip to airport and terminal operations	<ul style="list-style-type: none"> <li>• Passenger satisfaction could improve from reduced baggage handling if allowed to check in at offsite facility</li> <li>• Services offered at offsite facilities could improve overall terminal efficiency, ultimately resulting in higher passenger satisfaction</li> </ul>
Access cost (\$)	Access cost, which includes parking costs, public transportation fare, tolls, and mileage	<ul style="list-style-type: none"> <li>• Passengers could reduce parking costs by avoiding driving to airport and using public transportation from offsite facility</li> </ul>
Ground travel time (min)	Time taken to travel from origin to airport terminal	<ul style="list-style-type: none"> <li>• Reduction in ground travel time delay is possible as passengers would be use dedicated public transportation operating on HOV lanes from offsite facility to airport</li> </ul>
Passenger processing time (min)	Check-in counter queue time and service time	<ul style="list-style-type: none"> <li>• Passengers using offsite facilities could experience reduced delay at check-in counters</li> </ul>
Uncertainty (min)	Perceived variation in ground travel time between origin and airport terminal	<ul style="list-style-type: none"> <li>• Uncertainty could be reduced due to use of public transportation, which would be aided by modern technologies to adhere to strict schedules</li> </ul>
Revenue and Land costs (\$)	Revenue and land cost difference between airport expansion and using an offsite airport facility	<ul style="list-style-type: none"> <li>• Offsite facility could act as substitute for expanding airport terminal and hence reduce demand for new land at airport site</li> </ul>
Volume of automobiles (VMT)	CO, NOx, PM, and VOC emissions	<ul style="list-style-type: none"> <li>• Use of public transportation by departing passengers might help in reducing emissions</li> </ul>
Non-airport activity time (min)	Time spent by air passengers at airport terminal when not involved in required airline/airport activity	<ul style="list-style-type: none"> <li>• Offsite facilities could offer increased amenities to passengers during waiting period</li> <li>• Terminal efficiency could be improved if space needed to hold passenger during non-airport activity time was used for other purposes such as check in, security, etc.</li> </ul>

VMT = vehicle miles traveled; CO = carbon monoxide, NOx = nitrogen oxides, PM = particulate matter, VOC = volatile organic compound.

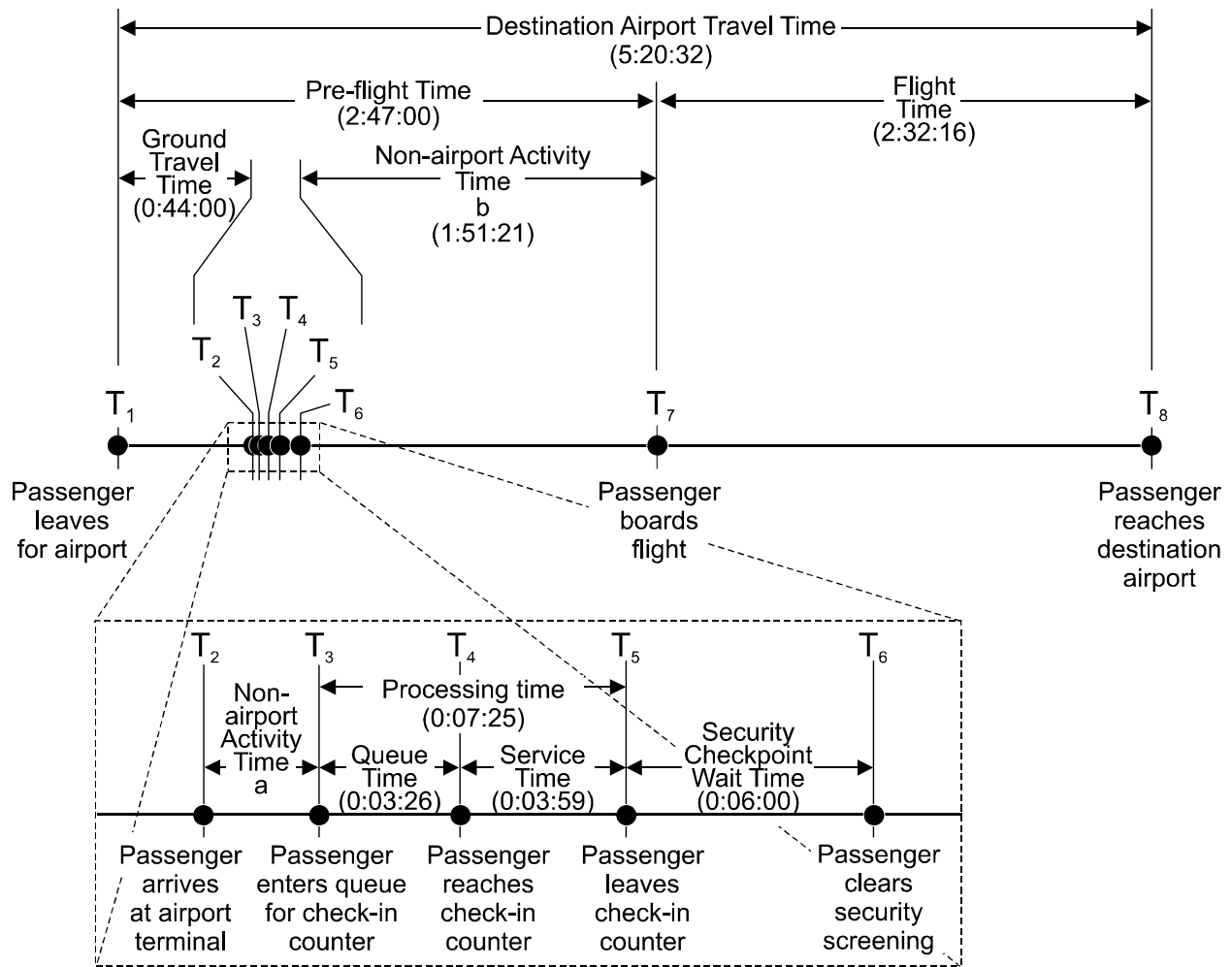
<sup>a</sup>The variable that would ideally be measured if data limitations did not exist (hence the ideal performance measure).

<sup>b</sup>The variable that is measured given existing data limitations (hence the performance measure used in this study).

benefits apply to the airport operator or airline owner (e.g., reduction in land costs) or the general public (e.g., reduction in emissions). The current study describes the process to determine passenger demand for offsite airport facilities,, and, accordingly, its focus was on the first five performance measures because they are direct indicators of passenger demand.

### **Air Passenger Characteristics**

Figure 2 (drawn to scale) depicts travel components for an average passenger departing from BWI. The *destination airport travel time* denotes the length of the entire trip from the instant the passenger leaves his or her home or business to the moment the plane lands at the destination airport. Components of destination airport travel time include the time period during



**Figure 2. Travel Timeline of Passenger Departing from BWI**

which the passenger travels by ground transportation to reach the airport (ground travel time), the time period during which the passenger spends waiting at the originating airport (non-airport activity time), and the time period where the plane is in the air (flight time).

The survey data describe average length for each travel time component in Figure 2, the variation in travel time for individual passengers, the passengers' willingness to use an offsite facility, and the passengers' zip code of origin.

### Mean Travel Times

Table 3 summarizes the findings for two sets of passengers: those arriving directly at the airport, as was the case in Figure 2, and those using an offsite airport facility. The destination airport travel time varies between 4 hr 44 min (CHO) and 9 hr 02 min (SFO). The average flight time varied from 2 hr 32 min (BWI) to 5 hr 55 min (SFO), meaning that on average, the flight time was just 52% of the destination airport travel time.

**Table 3. Summary of Survey Results**

Parameter	CHO	ORF	RIC	BWI	Direct Access: Subtotal	Logan Express: Service to BOS	Marin Airporter: Service to SFO	Indirect Access: Subtotal	All Airports: Total
Average total processing time	4 min	12 min 31 sec	5 min 43 sec	7 min 25 sec	7 min 25 sec	*	*	*	
Average wait time at ticketing queues	1 min 24 sec	8 min 20 sec	2 min 3 sec	3 min 26 sec	3 min 48 sec	*	*	*	
Average service time at ticketing counters	2 min 36 sec	4 min 11 sec	3 min 40 sec	3 min 59 sec	3 min 37 sec	*	*	*	
Number of processing time observations	323	340	346	423	1,432	*	*	*	
Number of surveys collected	96	113	199	244	652	655	425	1,080	1,732
Average ground travel time to airport terminal	28 min	43 min	37 min	44 min	38 min	55 min	1 hr 32 min	74 min	50 min
Predominant mode of access	Auto (58%)	Auto (54%)	Auto (41%)	Auto (34%)	Auto (47%)	Drop off (52%)	Drop off (59%)	Drop off (56%)	
Second most predominant mode	Drop off (26%)	Drop off (21%)	Drop off (31%)	Drop off (24%)	Drop off (26%)	Auto (34%)	Auto (33%)	Auto (34%)	
Average arrival at airport prior to scheduled departure	1 hr 4 min	2 hr 22 min	2 hr 10 min	2 hr 2 min	1 hr 54 min	2 hr 10 min	1 hr 51 min	2 hr	1 hr 56 min
Average pre-flight time	1 hr 32 min	3 hr 3 min	2 hr 45 min	2 hr 47 min	2 hr 31 min	3 hr 37 min	2 hr 58 min	3 hr 17 min	2 hr 47 min
Average non-airport activity time	1 hr 2 min	2 hr 8 min	2 hr 03 min	1 hr 57 min	1 hr 47 min	*	*	*	
Average flight time	3 hr 12 min	2 hr 52 min	2 hr 40 min	2 hr 32 min	2 hr 49 min	3 hr 48 min	5 hr 55 min	4 hr 51 min	3 hr 29 min
Average ticket cost	\$496	\$465	\$463	\$376	\$450	\$439	\$478	\$459	\$453
Average access cost	\$38	\$35	\$37	\$47	\$39	\$25	\$29	\$27	\$35
Willing to use offsite facility	55%	66%	72%	70%	68%	74%	64%	70%	69%
Average destination airport travel time	4 hr 44 min	5 hr 52 min	5 hr 29 min	5 hr 20 min	5 hr 21 min	6 hr 44 min	9 hr 02 min	7 hr 53 min	6 hr 11 min
Average flight time vs. destination airport travel time	61%	47%	47%	46%	50%	52%	61%	57%	52%
Average ground travel time vs. destination airport travel time	11%	12%	12%	14%	12%	17%	19%	18%	14%
Average ground travel time vs. flight time	24%	38%	31%	41%	34%	36%	39%	38%	35%
Average non-airport activity time vs. flight time	55%	107%	114%	106%	96%	*	*	*	
Average non-airport activity time vs. destination airport travel time	27%	39%	43%	41%	38%	*	*	*	

CHO = Charlottesville-Albemarle Airport, ORF = Norfolk International Airport, RIC = Richmond International Airport, BWI = Baltimore/Washington International Thurgood Marshall Airport, BOS = Boston Logan International Airport, SFO = San Francisco International Airport.

Thus, the time not spent in the air, i.e., the pre-flight time, is a substantial portion of the passenger’s journey, with an average of 2 hr 47 min per airport. The largest component of this pre-flight time was non-airport activity time (with an average duration of 1 hr 47 min) followed by ground access time (with an average duration of 50 min). The processing time was relatively small (with an average duration of slightly more than 7 min).

Two differences between the airports without offsite facilities and with the offsite facilities are also noted. The ground travel time for airports with offsite facilities (average of 74 min) is greater than the ground travel time for airports without offsite facilities (average of 38 min). Passengers using the airports with offsite facilities had longer flights (average duration of 3 hr 29 min) compared to passengers who used airports without such facilities (average duration of 2 hr 49 min).

### Variation in Travel Times

Table 3 summarizes average values for each travel time component. For example, the average passenger arrived 1 hr 56 min ahead of his or her scheduled departure time, but this average value masks variation in individual passengers: some passengers arrived 10 min prior to departure and some arrived 9 hr prior to departure. This section discusses the variation in airport arrival time, ground travel time, processing time at the check-in counters, security time, and non-airport activity time.

#### *Variation in Airport Arrival Time*

Table 3 showed the average *arrival at airport prior to scheduled departure*, which was calculated by subtracting the passenger’s scheduled boarding time from the stated time of arrival at the terminal. Table 4 repeats this average value for each airport and shows the coefficient of variation. (The coefficient of variation is calculated as the standard deviation divided by the mean.) The lower coefficient of variation for BOS and SFO when compared to RIC, ORF, and BWI indicates that passengers’ ground travel time is less variable at the two airports where an offsite facility exists (BOS and SFO) than at an airport where no such facility exists (BWI, ORF, and RIC). One possible explanation is the use of HOV lanes by the buses at BOS and SFO, which should reduce this variation, or uncertainty, in ground travel time. A different possible

**Table 4. Arrival Time at Airport Prior to Scheduled Departure**

<b>Airport</b>	<b>Mean</b>	<b>Median</b>	<b>Coefficient of Variation</b>
CHO	1 hr 4 min	1 hr	46%
ORF	2 hr 22 min	2 hr	66%
RIC	2 hr 10 min	1 hr 47 min	65%
BWI	2 hr 2 min	1 hr 45 min	54%
BOS	2 hr 12 min	2 hr 5 min	49%
SFO	1 hr 54 min	1 hr 48 min	45%

CHO = Charlottesville-Albemarle Airport, ORF = Norfolk International Airport, RIC = Richmond International Airport, BWI = Baltimore/Washington International Thurgood Marshall Airport, BOS = Boston Logan International Airport, SFO = San Francisco International Airport.

explanation is the variation in congestion levels, which is supported by the fact that CHO has the second lowest coefficient of variation in Table 4, no HOV lanes, and likely the lowest level of traffic congestion of the six airports studied.

#### *Variation in Ground Travel Time*

When passengers are using an offsite facility, the ground travel time has three components: ground travel time from origin to the facility, transfer time at the facility, and ground travel time from the facility to the airport. For example, based on the data obtained from the survey (Appendix B) for the Marin Airporter offsite facility, Table 5 shows the mean and coefficient of variation for the first component: the ground travel time from the top five originating zip codes to the corresponding offsite facility serving SFO. Table 6 shows comparable information for the remaining two components: the transfer times at the offsite facility and the ground travel times from the offsite facility to SFO.

**Table 5. Variability in Ground Travel Time from Origin to Marin Airporter Terminal**

Marin Airporter Terminal Accessed at	Originating Zip Code	Ground Travel Time to Marin Airporter Terminal	
		Mean	Coefficient of Variation
San Rafael	94901	14 min 32 sec	91%
San Rafael	94903	11 min 31 sec	41%
Manzanita	94941	7 min 34 sec	49%
Larkspur	94904	18 min 50 sec	110%
Novato	94947	33 min 37 sec	91%

**Table 6. Transfer Time and Ground Travel Time from Marin Airporter Terminal to San Francisco International Airport**

Marin Airporter Terminal at	Transfer Time		Ground Travel Time to San Francisco	
	Mean	Coefficient of Variation	Mean	Coefficient of Variation
Novato	10 min 41 sec	60%	1hr 15 min	23%
San Rafael	12 min 20 sec	52%	54 min 14 sec	15%
Larkspur	14 min 3 sec	64%	52 min 38 sec	14%
Seminary Drive	10 min 30 sec	60%	45 min 47 sec	17%
Manzanita	10 min 20 sec	65%	48 min 17 sec	15%
Sausalito	14 min 12 sec	76%	44 min 16 sec	18%

#### *Variation in Processing Time*

Table 3 showed that the average time to process a passenger at the check-in counters was relatively low (e.g., 5 min 43 sec at RIC) compared to the other travel time components. Table 7 shows that these processing times were highly variable (e.g., a 90% coefficient of variation at RIC).

#### *Variation in Security Time*

The TSA provides the average, median, and maximum wait times of passengers at security gates for various airports (TSA, 2007). Table 8 shows that these average times are relatively low (e.g., a 2-min average at RIC). The reader should note the large deviation between

**Table 7. Processing Time<sup>a</sup>**

<b>Airport</b>	<b>Mean</b>	<b>Median</b>	<b>Coefficient of Variation</b>
CHO	4 min	3 min 5 sec	74%
ORF	12 min 31 sec	8 min 38 sec	104%
RIC	5 min 43 sec	3 min 50 sec	90%
BWI	7 min 25 sec	5 min 52 sec	71%

CHO = Charlottesville-Albemarle Airport, ORF = Norfolk International Airport, RIC = Richmond International Airport, BWI = Baltimore/Washington International Thurgood Marshall Airport.

<sup>a</sup>Processing time is the summation of queue time and service time at ticketing counters

**Table 8. Security Checkpoint Wait Time**

<b>Airport</b>	<b>Average</b>	<b>Median</b>	<b>Maximum</b>
CHO	4 min	4 min	10 min
ORF	5 min	4 min	21 min
RIC	2 min	2 min	12 min
BWI	6 min	5 min	28 min
BOS	4 min	3 min	36 min

CHO = Charlottesville-Albemarle Airport, ORF = Norfolk International Airport, RIC = Richmond International Airport, BWI = Baltimore/Washington International Thurgood Marshall Airport, BOS = Boston Logan International Airport.

the average and maximum values; e.g., although the average wait time at BWI was 6 min, the maximum wait time was 28 min).

### *Variation in Non-Airport Activity Time*

After completing the security screening process, passengers have additional time prior to boarding the flight. This non-airport activity time is not only comparable to the actual flight time but is also a major portion of the total pre-flight time. The two data elements used to calculate the non-airport activity time—processing time and arrival at airport prior to scheduled departure—were collected using different methods. Thus, a given passenger’s processing time cannot be matched with his or her arrival at airport prior to departure. Hence the non-airport activity time was determined by simulating 50 combinations of linking the two data elements. Based on these simulations, the mean and median of non-airport activity times are shown in Table 9 (truncated to the lowest minute).

### **Willingness to Use an Offsite Facility**

As shown in Appendices A and B, one survey question was whether airport passengers would be willing to use an offsite facility (for surveys conducted at BWO, CHO, ORF, and RIC, which were not served by an offsite facility) or whether passengers would be interested in additional services at their offsite facility (for surveys conducted at BOS and SFO, which were served by offsite facilities providing only transportation).

**Table 9. Non-Airport Activity Time<sup>a</sup>**

<b>Airport</b>	<b>Mean</b>	<b>Median</b>	<b>Coefficient of Variation</b>
CHO	1hr 1min <sup>b</sup>	57 min 17 sec	49%
ORF	2 hr 8 min	1 hr 50 min	75%
RIC	2 hr 2 min	1 hr 37 min	68%
BWI	1 hr 57 min	1 hr 42 min	57%

CHO = Charlottesville-Albemarle Airport, ORF = Norfolk International Airport, RIC = Richmond International Airport, BWI = Baltimore/Washington International Thurgood Marshall Airport.

<sup>a</sup>Time spent by passengers at terminal while not engaged in required airport/airline procedure.

<sup>b</sup>Example: The 95% confidence interval showed that lower bound for CHO mean time was 1 hr 1min 35 sec and upper bound was 1 hr 1 min 45.5 sec. Thus, the truncated value 1 hr 1min is within this 95% confidence interval.

### *Surveys Conducted at Airports without Offsite Facilities*

At the four airport terminals without an offsite facility, passengers were asked if they would be willing to use an offsite facility in the future, provided that the facility was suitably located and would provide check-in, baggage handling, and transfer to the airport. Overall, 68% of the passengers indicated they would use such a facility. Responses varied slightly by airport: 72% (RIC), 70% (BWI), 55% (CHO), and 66% (ORF) indicated they would use such a facility.

### *Surveys Conducted at Airports with Offsite Facilities*

Passengers on buses transferring them from offsite facilities to BOS and SFO were asked if they would like to have check-in and baggage handling in the future. Of these passengers, 74% of passengers using the Logan Express service at BOS indicated that they were in favor of additional services at the existing locations, and 64% of the passengers using the Marin Airporter service to SFO indicated the same.

These passengers were also asked why they preferred to use the offsite airport facility rather than accessing the airport directly. Table 10 shows the reasons passengers gave for using the offsite facility. Of the 963 passengers surveyed, 183 (19%) indicated that the only reason for using the offsite facility was that it reduced the variability in ground travel time compared to accessing the airport directly. 45 passengers (5%) cited all four reasons for using the offsite facility: shorter travel time, lower cost, reduced uncertainty of ground travel time, and convenient parking. Overall, 418 passengers (43%) perceived that reduced variability was at least one of the reasons that they preferred to use the offsite facility.

## **Geographic Distribution of Passengers**

Some areas of a region may contribute a disproportionately large share of airport passengers. For example, at RIC, passengers arrived from 84 zip codes, but 19% of the zip codes (16 zip codes) accounted for 50% of the passengers. At CHO, three zip codes accounted for 48% of the passengers. Table 11 shows the market share of the top three passenger-generating zip codes for each airport. Figure 3 and Figure 4 show the three zip codes in the Charlottesville-Albemarle region and in the Richmond metropolitan area that generate the highest number of passengers at CHO and RIC, respectively.

**Table 10. Offsite Airport Facility Preference**

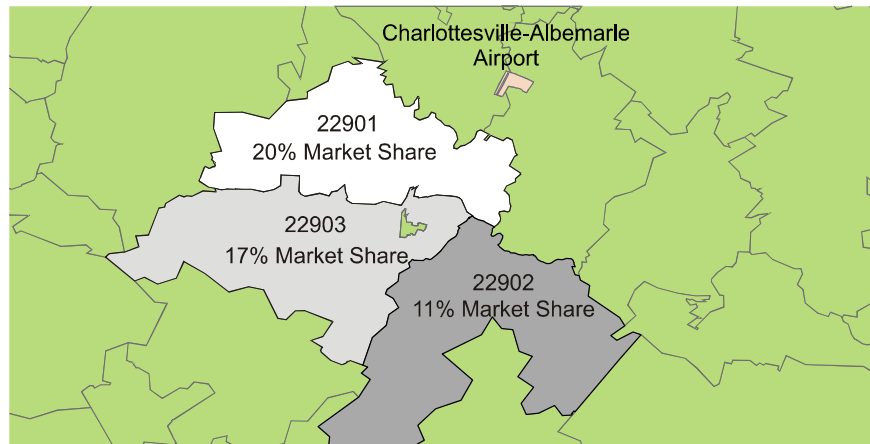
No. of Passenger Responses	Shorter Travel Time	Lower Cost	Reduced Variability	Convenient Parking
183			√	
179		√		
134	√			
132				√
49			√	√
45	√	√	√	√
42		√		√
39		√	√	
39	√		√	
32	√			√
29	√	√	√	
18	√	√		
18	√		√	√
16		√	√	√
8	√	√		√
% of Total	34%	39%	43% <sup>a</sup>	36%

<sup>a</sup>The percentage of passengers indicating reduced variability as one of the reasons for using offsite facility was calculated in the following manner: 963 responses were obtained; 418 indicated reduced variability as one reason for using facility (e.g., for 183 respondents, reduced variability was only reason, for 49 respondents, reduced variability and convenient parking were each cited as a reason). The ratio of 418/963 is 43%.

**Table 11. Passenger Origins in Region**

Airport	Top 3 Passenger-Generating Zip Codes	Cumulative Market Share of Top 3 Zip Codes	% of Zip Codes Generating 50% of Passengers
CHO	22901, 22902, 22903	48%	15%
ORF	23454, 23321, 23060	17%	25%
RIC	23112, 23220, 23185	14%	19%
BWI	21401, 21212, 21044	9%	27%
BOS	01701, 02184, 01801	8%	16%
SFO	94901, 94903, 94941	32%	6%

CHO = Charlottesville-Albemarle Airport, ORF = Norfolk International Airport, RIC = Richmond International Airport, BWI = Baltimore/Washington International Thurgood Marshall Airport, BOS = Boston Logan International Airport, SFO = San Francisco International Airport.



**Figure 3. Top Three Passenger-Generating Zip Codes for Charlottesville-Albemarle Airport**











































































