Shuttle Transit System Evaluation Methodology: Performance, Characterization, and Optimization

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ABSTRACT

In this study, a unique methodology was developed to analyze the performance of a small to medium sized or university shuttle system. The goal was to develop an inexpensive, quick, and practical means to evaluate such a shuttle system’s performance, ridership demand characteristics and needs, and provide for service scenario optimization. A user intercept survey and on-board performance audit were used to collect statistical, origin-destination (O-D), ridership, and stop utilization data for a case study. The comprehensive and practical data allowed for complete characterization of system performance and passenger demand, and the development of a model that compared the current system and alternate operational patterns as a function of average passenger travel time given the actual demand. Several studies have sought to analyze and optimize small shuttle systems. However, our study is unique in that the methodology can be used for any small transit system analysis providing quick data collection, beneficial visual outputs of the data for decision makers, and actual passenger travel times within the analytical model.

The results from the analytical model provided insight on the operations of the case study. Information found included ways to reduce average travel time, average wait time, number of routes, and owners’ costs as well as ways to increase ridership. While the results presented are for a particular university’s transit system, this methodology can be applied to examine potential service improvements of any small to medium shuttle system.
INTRODUCTION

Performance evaluations are used in many fields to ensure people and services are working efficiently. These are specifically beneficial to public transit as they ensure passengers are receiving the highest possible level of service while minimizing the owner’s financial liabilities. An ideal performance evaluation is inexpensive, repeatable, versatile, expeditious, and able to evaluate several outcomes simultaneously. This study endeavors to develop such a performance evaluation methodology applicable to small to medium scale transit systems that islogistically simple and economically practical. The methodologies will be tested by application to the UC Berkeley Bear Transit Campus Shuttle Service as a case study.

Many studies have been performed to examine the operation of similar shuttle systems. Some of these studies suggested that providing real-time shuttle locations eliminates the need to alter service (1, 2), but these failed to evaluate if these strategies provide passengers with an improved level of service. Other studies examine how shuttle speed, passenger loads and on-time performance can be used to assist operators in targeting section of the system that needs improvement (3). Improving the passenger travel time within the system and eliminating high-cost routes maximizes the level of service for customers and minimizes the operators’ costs (4, 5, and 6). Eliminating or altering routes based on these analyses can help to improve performance and economic stability of the system (7). Advanced tools like genetic algorithms have been used to determine the most efficient routes in an attempt to optimize service (8). However, these studies assume the existence of origin-destination distribution data (O-D) and offer no method for attaining this data other than by use of a regional survey, which may not be applicable to a small or medium sized system. Determining this vital information is not trivial. Individual GPS devices (9) and on-board surveys (10) have been used in the literature to develop this kind of O-D data with some success. The former method is quite expensive and impractical for smaller systems, while the latter is rarely combined simultaneously with an audit of system performance.

Little research has been done on cost-effective methods of data collection for the purpose of analyzing passenger information and system operations simultaneously. We developed a system of analysis applicable to any small or medium shuttle system by successfully implementing a novel two-pronged data collection process to analyze the current system and several alternative routes. The first data collection process is an intercept survey of passengers to better understand their current trip origin-destination (O-D) information, motives for using the shuttle, and basic demographics. The second is an audit of service performance, ridership, stop utilization, and route timings. These two methods combine to give a complete understanding of the system in terms of both rider demand and their characteristics as well as the system performance in terms of average ridership travel time given the actual ridership demand, origins, and destinations.

A literature review precedes the methodology section that includes the data collection details, as well as descriptions of all the analyses and their outcomes for decision makers. The case study section reveals the outcomes for a particular application, and the conclusions summarize the findings. The Appendices show an example survey and a listing of the code for a MatLab program used on the shuttles for the performance audit part of the data collection process.

METHODOLOGY

Analysis Metrics and Data Needs

The study team sought to serve several objectives: (a) understand passenger trip spatial and temporal patterns: O-D data, which could be used to produce quantified actual and relative passenger demand for each shuttle stop pair; (b) identify the penetration rates of captive or convenience passengers in the shuttle system: evaluating stated shuttle usage patterns, and asked directly; (c) characterize demographics of passengers: age category, campus affiliation, and gender; (d) estimate ridership levels by time of day and by each line: count actual passenger activity by stratified sample; (e) determine average running time and
dwell time of the current operations: time of door open, door closed at each stop also reveals travel times
in between stops; and (f) compare several service scenarios for optimal level of service and costs:
minimize both average passenger travel time, given the actual travel demand distribution, and operating
costs in the form of number of physical shuttles required. The sum of these objectives would allow the
evaluation of the current system performance and identify any potential changes that could better serve
the passengers or reduce operating costs. The study team determined that the objectives could be met
through the combination of two data collection efforts, a passenger intercept survey and an audit.
The survey would address objectives (a), (b), (c) and (d), while the audit would address objectives
(d) and (e) as well as enable system on-time evaluation. For example, objective (a) is satisfied by the O-D
portion of the passenger survey. However, since every single passenger did not fill out a survey,
quantifying demand outcomes such as (d) had to be done with the performance audit where passengers
were actually counted at each stop. In order to accomplish objective (f), access and egress estimates as
well as O-D distributions from the passenger survey data were combined with travel time estimates from
the performance audit to form the model inputs.

Data Collection
It was required, given the research team’s typically small budget and timeline, that the data collection
methodology be quick, inexpensive, practical, anonymous, and incredibly powerful. Since the case study
for our methodology was to be a university campus shuttle service, it was also important that the data
collection process be completely anonymous so that the study qualified for exempt status with the
university Internal Review Board (required for all research involving human subjects). This allowed for
the approval of the study to proceed in a markedly faster timeline and for the data collection stage of the
research to be enacted right away. The following passenger intercept survey and system performance
audit methodology was developed with these goals in mind.

Passenger Survey
A passenger intercept survey was developed and administered for a University shuttle service case study.
The passenger intercept survey consisted of 10 questions printed in black and white on one side of a
single letter-sized page. A random sample of survey collection periods was stratified by line, peak or off-
peak, and Monday/Wednesday or Tuesday/Thursday in response to class scheduling. Fridays were
excluded for expected atypical class schedules and travel. To collect origin-destination (O-D) data, one of
the questions consisted of a map of the campus for survey respondents to identify the starting point of
their current trip, their access and egress points to the shuttle system, and their final destination. The
collected access and egress distances are typically elusive to transit planners when they are designing
public transportation services. In our analysis of the operations, we were able to use a more accurate
average access/egress distance for average travel time calculations. The survey also allowed us to collect
key demographics including gender and university affiliation along with key trip frequency information
including number of times per day and days per week for using the system. An initial question on the
survey established if this was the first time the respondent was filling out the survey. This was impor-
tant for knowing when to include a survey for passenger characterizations, and when to exclude as a double.
Volunteers staffed each shuttle with one sitting directly behind the driver and the other near the
rear door. The front volunteer addressed passengers as they boarded by handing them a survey and
saying, “Please fill this out while you are on the shuttle”. Although it is tempting to ask each passenger if
they would like to fill out a survey, each passenger has to respond by thinking of whether or not they do,
and most often, they don’t want to. It’s best not to ask any questions. The carefully designed simple
instruction also informs the passenger that they are to fill it out now, and not later or submit the survey by
mail or Internet. The volunteer in the back area of the shuttle collected surveys from those exiting the
rear door and also approached those who refused to take a survey at the front door (there are always a
few) to explain the study and personally request their participation.
Summary statistics of the survey responses provided many of the desired outcomes (see actual survey example at: http://www.cee.mtu.edu/~lidicker/). Other aspects of the survey data became inputs to models or other bivariate analyses.

Performance Audit
To perform the audit of our case study shuttle system, stratification of the data was similar to that of the survey data. A MATLAB program was developed to simplify data input, and data collectors used a laptop to run this program on the shuttles (MATLAB code available for free download at http://www.cee.mtu.edu/~lidicker/). Data collectors rode the shuttles and recorded the time the doors opened and closed (accurate to the second) and the number of passengers boarding and alighting at each stop. Data collectors could also note disabled passengers boarding, bicycle rack usage, and exterior causes of delay such as congested traffic or road construction. These simple statistics provided stop arrival time (for on-time performance evaluation), average stop times, time between each pair of stops (travel times for each O-D pair), total system loop time, number of passengers boarding for each stop in the system, number of passengers alighting for each stop of the system, and the number of passengers on the shuttle at any given time all stratified by route, day of week, and peak-off peak. Many of these outcomes were transformed into averages for study objective outcomes and many were used as inputs for the analytical models.

Analytical Model: Alternative Routes
The information collected in the survey and audit were combined for use in an analytical model that compared the operation of the current system configuration and schedule with proposed scenarios by determining the average trip time for passengers in the system for each scenario. This metric together with the system operating cost can be used to assess the performance of a transit system (11). The total trip time for each passenger consists of three parts: the average time to access/egress the shuttle system from the passengers’ origins and destinations (survey data), the average waiting time for the shuttle (audit data), and the average in-vehicle travel time (audit data) (12). Thus, the trip time for a particular passenger \( i \) using a specific line \( j \) can be written as:

\[
T_i^j = E_i^j + W_i^j + \sum_{m \in M} t_m + \sum_{n \in N} d_n
\]

where:
- \( E_i^j \) is the average access/egress time per passenger using route \( j \),
- \( W_i^j \) is the average waiting time per passenger using route \( j \),
- \( t_m \) is the average travel time on link \( m \) (between two consecutive stops),
- \( M \) is the set of links between the origin and destination stop,
- \( d_n \) is the time the shuttle spends stopped at stop \( n \)
- \( N \) is the set of stops that a passenger travels between on his trip.

CASE STUDY: BEAR TRANSIT SHUTTLE SYSTEM
In search of a performance evaluation and service improvements, The Department of Parking and Transportation (DPT) requested an analysis of The University of California Berkeley’s (UCB) campus shuttle system, Bear Transit. This is a frequently used, free service to students, faculty, and staff of the university. UCB has a built-out urban campus on a hillside just east of Downtown Berkeley. The elevation change from Downtown to the highest point on campus (generally West to East) is approximately 65m. However, traveling in the North-South direction incurs a negligible change in elevation. A Bay Area Rapid Transit (BART) station in Downtown provides regional rail transit access...
from neighboring towns and cities such as San Francisco, and several AC Transit bus lines collectively provide local access to the entire campus periphery. The Bear Transit system has three lines, covered by four total shuttles, that provide access to and within the main campus: the Perimeter (P) line (consisting of two shuttles) travels around the perimeter of campus in a clockwise direction every 12 minutes; the Reverse Perimeter (R) line (consisting of one shuttle) travels counter-clockwise around the perimeter of campus every 27 minutes; and the Central (C) line (consisting of one shuttle) runs back and forth through the center of campus every 20 minutes (Figure 1). The Bear Transit system provides a good case study for our proposed methodologies.

**FIGURE 1** Map of UC Berkeley Main Campus with Bear Transit routes (source: Google Maps).

**Passenger Survey and Performance Audit Results**
Throughout April of 2011, volunteers collected 898 passenger surveys, and over 40 hours of performance audit data. The possible results that can be derived from the data are limited only by one’s imagination. However, in this section we have provided illustrative example analyses that can be done for any small shuttle system.

**Passenger Demographics and Usage Characteristics**
Young passengers used Bear Transit most frequently with 56% of respondents being 16 – 22 years of age. Undergraduate students, graduate students, faculty, and staff represented 61%, 17%, 2%, and 16% of survey respondents respectively (the remaining 2% had no affiliation). Gender was approximately equal with females comprising 55% of respondents.

Bear Transit’s three lines—P, R, and C—account for 81%, 11%, and 8% of system use respectively. Creating charts of the data (not shown) allows for a visual depiction of general passenger information that could be shared decision makers.
To understand the functionality of the system, the survey also inquired on the respondents’ purposes for using Bear Transit. The most common reasons were increased speed (as compared to walking) and avoidance of the steep hill when traveling from West to East. Interestingly, approximately 19% of the respondents rode the shuttle simply because it happened to be at the stop when they were nearby. These “convenience passengers” represent a subpopulation that may grow significantly if the shuttle frequency increased.

**Origin-Destination Data – In-vehicle**

Passenger trip characterization was done on an aggregate level by utilizing the origin-destination data collected from the survey. A visual, Figure 2, was then created to demonstrate the relative flow of passengers between the most popular origin and destination stops. As you can see, this is a concise visual tool that clearly indicates the relative flows and differentiates their popularity with varying sizes of arrows (the larger, the more popular). This figure is beneficial when searching for significant patterns in passengers’ trips and assisting decision makers. For example, here, a significant amount of arrows show passenger travel from west to east (uphill). By utilizing such a powerful tool, we are able to highlight patterns and confirm other significant passenger travel information that may otherwise be considered less significant.

**FIGURE 2** Passenger flow between the most utilized stops or O-D pairs.
The survey inquired about passengers’ trip origin and destination locations (not just the shuttle stop locations and destinations). This information was utilized in creating another map to provide insight into any changes in access or egress distances that might occur from significant route changes.

After dividing the campus into 42 zones (200x200m, 656x656ft) and summing the number of trips originating in each, the percentage of trip origins within each zone was calculated. These results are pictured in Figure 3. The same process was done for trip destinations (not shown due to space restrictions). The numbers with bold face font or that appear in larger font intuitively and at a glance provide decision makers with the overall picture.

This analysis provides a detailed description of where passengers are ultimately traveling when they use Bear Transit. From this, we were able to find one of the major trip generation and destination locations, the Berkeley BART station. These results can be applied to the analysis of different route structures in the future, by providing insight on popular trip origins and destinations outside of the current stops. Another benefit of using this process is minimizing access and egress times—a significant component of average travel time. In this study, this information was utilized to develop an average access and egress distance for each existing shuttle stop when considering alternate routes in the last part of this Section.

Ridership

The results of the audit conducted for the different routes (P, R, and C) provide insights into the ridership (pax/hr) and operational trends. Ridership estimates for each route, on and off peak by day of the week were produced (not shown). There is not a clear difference in number of riders between the peak and off-peak time periods; peak is defined as 8AM – 11AM, noon – 1PM and 4PM – 6PM. Thus, for this system, an average ridership rate that is independent of the time of day is representative of the system at large.

The aggregated ridership values highlight the lopsided ridership shares among the different routes. On average, the P-line (86 pax/hr) services over three times the passengers of the R-line (27 pax/hr), and more than ten times the passengers of the C-line (8 pax/hr).

On-time Performance Evaluation

Since the arrival times at each stop are known from the performance audit data, an easy comparison with the shuttle schedule will reveal on-time performance results. We were not given permission to publish these results.
FIGURE 3 Trip origins by zone (source: UC Berkeley Printable Campus Map).
Stop Utilization

Investigating stop boarding and alighting statistics for each stop can provide for further optimization of
the transit system for travel time and operational cost. By eliminating unnecessary stops and spacing stops
appropriately, travel time may decrease, ridership may increase, and cost of operation may decrease. The
data from the audit is more accurate for this analysis because data collected from the survey does not
account for 100 percent of the passengers as the audit does. The performance audit tracked the actual
number of passengers boarding and alighting at each stop on each route.

On the P-line, it was found that 60% of passengers alighted the system at stops while traveling
up-hill. Whereas the stops passed on the downhill had significantly less activity. It is important to note
that an unpopular destination might be an important origin, and vice versa. In this study, for example, the
shuttle stop at Tolman Hall generated only 4.5% of the alighting passengers but accounted for 17.1% of
the boarding passengers (see Figure 1). These figures suggest that both alighting and boarding passengers
must be considered when evaluating the worth of an individual stop. Another disparate relationship
between those boarding and alighting is the shuttle stop at Cory Hall, near the top of the hill. Relatively
few passengers boarded at Cory Hall (5.3%) while a relatively large proportion (almost 20%) alighted
there. We can thus assume that passengers are not boarding and alighting at the same shuttle stops; rather,
they are only using Bear Transit to access the UC Berkeley campus or reach the top of the hill. Thus, it is
very important to assess both boarding and alighting when evaluating the value of a particular stop, and
not just one or the other.

The stops located on the R-line reported similar behavior to those of the P-line with dissimilar
proportions between boarding and alighting passengers. The shuttle stops on Oxford and Durant Avenue
appeared virtually unused when observing alighting passengers, but contributed to at least 10 percent of
boarding passengers. The BART station and Hearst Mining Circle are still the most popular stops,
representing 26 percent of boarding passengers and 42 percent of alighting passengers. The bulk of
activity on the C-line is primarily restricted to the BART station (94 percent of boarding passengers) and
Hearst Mining Circle (84 percent of alighting passengers). The other routes serve both of these stops as
well.

Tracking passengers boarding and alighting at every stop provided a comprehensive description
of each stop’s utilization. This ensured that no necessary stops were overlooked and provided insight into
possible elimination of unnecessary stops.

In-vehicle Travel Time Analysis: For Each O-D Pair, Passenger Type, and Full System

The performance audit was also used to determine the average in-vehicle running time between shuttle
stops and the average dwell times at each of the shuttle stops. In this way, decision makers have full
knowledge of actual in-vehicle travel times between each O-D pair of stops in the system. When
combined with the survey responses, we were able to assess the statistical significance of average in-
vehicle travel times for each passenger demographic. This knowledge enabled us to both further
understand the travel behavior of different passengers in the shuttle system and evaluate their singular
average travel time to be used as inputs for the analytic model described in the next subsection, which
will compare alternative service scenarios.

To obtain in-vehicle travel times for each survey respondent, we summed the average dwell time
and cruising time between the top 85% of origin and destination shuttle stop pairs for each of the three
lines. We assumed that the passenger was the first person to board at the origin stop and the last person to
alight at the destination stop.

The average in-vehicle travel time for passengers in the system is 8.9 minutes. There is no
statistical difference in travel time for gender, trip reason, or respondent’s satisfaction level with the
shuttle service \( p=0.39, p=0.11, \) and \( p=0.089 \) respectively). However, the travel time for age group and
campus affiliation are both statistically significant (both \( p<0.0001 \)). The youngest riders travel the
shortest distances (8.1 minutes) and the oldest travel the furthest (10.4 minutes). Exhibiting the same
trend, graduate students travel the shortest distances (8.7 minutes) while faculty travel the longest (10.8
minutes). Undergraduates are similar to the graduates and the staff is similar to faculty. Those who are not
affiliated with campus traveled the shortest distances (8.2 minutes)—as most are visitors or tourists. This
type of information and analysis indicates that no special accommodation in a system design is required
for gender or trip purpose. However, decision makers in combination with the shuttle system goals,
objectives, and target demographics may consider the age groups and campus affiliations of the ridership
population carefully.

Analytic Model Inputs: Alternate Scenarios
The analytic model used to compare current and alternative service scenarios used data from both the
passenger survey and the performance audit. Recall Equation 1 is the basis of the model. From the
survey data, the average access/egress time \( E_j \) was found by determining the average distance
passengers walked between the shuttle stop and their origin and destination and dividing by a reasonable
walking speed (4 km/hr, see Table 1). For the status quo (the current system), the average walking
distance is estimated to be about 0.15 km for each of the access and egress movements.

The average time spent waiting for the shuttle \( W_j \) was assumed to be half of the average
headway of a particular line (from Audit data, see Table 1). This assumes that passengers arrive randomly
to the shuttle stop without checking the schedule (which is a reasonable assumption based on observations
made during the survey and audit process) and that headways are fairly regular (which seems to be the
case based on observation and the existence of control points and was confirmed by the audit data).

The first summation in Equation 1 represents the average time (audit data) spent to travel between
the origin shuttle stop and the destination stop for passenger \( i \). This is found by summing the average
cruise times between all links between the origin and destination stops. The average travel time \( t_{m} \) on each
link \( m \) was found using the Audit data, which was collected during several different days that presented
regular traffic conditions. The cruising time between consecutive stops was simply obtained by
subtracting the time when the shuttle’s doors close at a stop \( n – 1 \) from the time corresponding to the
opening of the doors at the next stop \( n \).

The second summation term in Equation 1 represents the average time a passenger spends in the
shuttle while it is not moving (i.e., dwell time: the time required to pick up or drop off other passengers at
intermediate stops, audit data). This is equal to the sum of the average time spent stopped at each stop \( n \).
Linear regression was used to determine the most appropriate form to express time stopped at stop \( n \),
measured as the time between the opening and closing of shuttle doors at the stop. Several functional
forms were tested, but the form with the best fit of the Audit data appears to be \( t_{b}B_{n}^{j} + t_{a}A_{n}^{j} + t_{s} \),
where \( t_{b} \) is the time for a passenger to board, \( t_{a} \) the time for a passenger to alight, \( B_{n}^{j} \) the average number of
boarding passengers at stop \( n \) on route \( j \), \( A_{n}^{j} \) the average number of alighting passengers at stop \( n \) on route
\( j \) and \( t_{s} \) a fixed time per stop. The parameters estimates from the linear regression were \( t_{s} = 10.2 \) seconds,
\( t_{b} = 2.7 \) seconds/pax, and \( t_{a} = 0.9 \) seconds/pax; this model had a goodness-of-fit \( R^2 \) value of 0.193.

This model was found to be appropriate for all stops except the Downtown Berkeley Bart Station
and Hearst Mining Circle. For these two special cases, the shuttle currently tends to wait a fixed amount
of time (60.2 seconds on average) independent of the number of a passengers boarding or alighting. These
two stops act as control points; if the shuttle is ahead of schedule, which it frequently is, the driver will
dwell at these stops until the scheduled departure time. This is used to keep shuttles from getting off
schedule and “bunching". The bus-bunching phenomenon is a fairly common problem observed when
multiple buses operate on the same route with low headways. It results in buses pairing up while in
service and increases variability in observed headways; more information about the bus-bunching
phenomenon can be found in the work by Daganzo and Pilachowski (13, 14).
Analytic Model Results: Alternate Scenarios

Two main scenarios were tested with the analytical model: 1) the status quo (current operation of P, R and C-lines); and, 2) the elimination of the underutilized C and R-lines. In scenario 2a, one shuttle from the eliminated R and C-lines was moved onto the P-line while the other was removed completely (resulting in three shuttles to serve this line to save on operating costs). In scenario 2b, both shuttles were moved onto the P-line (for a total of four shuttles on this line and no operating cost improvement).

For the second scenario, it was assumed stationary demand; that passengers would shift from the C and R-lines and instead make all their trips on the P-line. For some origin-destination pairs, this would increase the in-vehicle travel time because passengers would be forced to take a more circuitous route. However, average-waiting times would be decreased because more shuttles would be used on the P-line. Average access/egress distances were assumed to increase by 0.05 km in each direction due to the elimination of the R and C-lines. Additionally, passengers boarding and alighting at all stops on the P-line were assumed to increase proportionally to represent the fact that the P-line would carry the entire system ridership (which would mean an increase of about 40% at each stop), but also that headways would decrease (reducing passengers boarding and alighting by about 33% when three shuttles are used and 50% when four shuttles are used).

Average trip time calculations are presented in Table 1. The first four rows (in italics) represent the analysis of the current system. Current average trip times on each of the P, C and R-lines were calculated and a weighted average status quo trip time was computed using the current ridership shares \( w_j \) (71.32% on P, 21.88% on R and 6.80% on C):

\[
T = \sum_{j=0}^{3} w_j T^j
\]

The average trip time in the current scenario is found to be 21.3 minutes. Also shown in Table 1 are the current average cycle times for the shuttles that are predicted by the analytical model. Note that these are consistent with the actual cycle times for all lines, except for the C-line which differs due to the excessive slack time inserted in its schedule. This shows that the analytical model successfully predicts current conditions and will give an accurate estimate for future conditions.

If the R and C-lines are eliminated and shuttles moved onto the P-line, we predict that average trip times will decrease to 19.3 minutes (9.4% decrease) if three shuttles are used, 18.1 minutes (15.4% decrease) when four shuttles are used. As shown in Table 1, this reduction is mainly due to a decrease in the average waiting time (due to lower headways). Average access/egress time increases due to (slightly) longer walking distances and in-vehicle travel time increases due to the fact that passengers who currently make short trips on the R-line must now travel in the opposite direction, which takes more time. However, as shown in the table, the increase in waiting time more than makes up for this increase in travel time. Estimated cycle times are also shown in Table 1. We assumed that these cycle times would be inflated (to approximately 24 minutes) to allow some slack in the schedule to keep shuttle headways fairly even using a more sophisticated control algorithm than is currently used to reduce dwell times (15).

Scenario 2b envisions what would happen to average trip time if the operator costs were to remain constant (i.e., the same number of shuttles would be in operation). However, we see from Scenario 2a that average trip times can be decreased even when removing one of the four shuttles from circulation. Assuming that all lines are in operation for the same amount of time per day, this should lead to a decrease in operating costs of 25%, while improving the average level of service.
TABLE 1  Average Trip Time Calculations for Current and Future Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>In-Veh Travel Time (min)</th>
<th>Waiting (min)</th>
<th>Access/Egress (min)</th>
<th>Total (min)</th>
<th>Cycle Times (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Status Quo - Perimeter</td>
<td>8.8</td>
<td>6.0</td>
<td>4.5</td>
<td>19.3</td>
<td>23.5</td>
</tr>
<tr>
<td>1) Status Quo - Central</td>
<td>6.8</td>
<td>10.0</td>
<td>4.5</td>
<td>21.3</td>
<td>14.5</td>
</tr>
<tr>
<td>1) Status Quo - Reverse</td>
<td>9.9</td>
<td>13.5</td>
<td>4.5</td>
<td>27.9</td>
<td>26.5</td>
</tr>
<tr>
<td>1) Status Quo - Weighted Average</td>
<td>8.9</td>
<td>7.9</td>
<td>4.5</td>
<td>21.3</td>
<td>N/A</td>
</tr>
<tr>
<td>2a) New Perimeter - 3 Shuttles</td>
<td>9.2</td>
<td>4.1</td>
<td>6.0</td>
<td>19.3</td>
<td>22.9</td>
</tr>
<tr>
<td>2b) New Perimeter - 4 Shuttles</td>
<td>9.0</td>
<td>3.1</td>
<td>6.0</td>
<td>18.1</td>
<td>22.5</td>
</tr>
</tbody>
</table>

This analysis was performed assuming that average ridership demand remains the same. However, we expect that in future scenarios average ridership would increase due to lower headways—more passengers would use the shuttle for convenience trips. This should increase the number of passengers boarding and alighting at each stop and (slightly) increase average trip time; however, Bear Transit will then serve more passengers.

CONCLUSION
The data methodologies developed for this study proved a very effective way to comprehensively evaluate a small to medium sized shuttle system. The characteristics of the data collection methodologies were demanding in that it was required that they be quick, inexpensive, practical, anonymous, and incredibly powerful. Classically, the research team had a tight timeline, and little budget with which they hoped to gain top quality data on both passenger demand distributions in the form on origin-destination data, passenger demographics, and system usage characteristics as well as complete system performance data. The data was used to ultimately provide decision makers with several illustrative views of both passenger and system characteristics and to facilitate use of an analytic model capable of comparing various service scenarios for minimization of both average passenger travel time and operating costs. The possible analyses and outcomes that could be derived from the data are only limited by the imagination of the researcher.

For a case study, an on-board passenger survey (n=898) and an on-board performance audit (over 40 hours of data), described in detail, combined to provide passenger demographics, passenger origin-destination information, passenger system usage characteristics, system ridership, average travel times, and stop utilization statistics. In the end, an analytical model provided a complete and accurate performance predictions of alternate routes and schedules for the system. In the future we plan to use this data for a more comprehensive access and egress analysis study (missing from the current body of literature), to evaluate for passenger characteristic interactions (it appears that the most of those who took the shuttle to “avoid the hill” were 18-year old males), and to evaluate additional system scenarios of both routes and schedules that were suggested by the administration.
The analytical model delivered accurate estimates of travel time for the current and alternate systems. The times were consistent with existing scheduled times, indicating that the methodology is a useful tool for similar shuttle system analyses. Using this model, it was concluded that eliminating two of the three shuttle lines and instead utilizing those resources on a single line would improve the level of service. By completely eliminating one of the four shuttles when merging lines, costs could be reduced as well. These results indicate that for this small shuttle system located on a college campus, where travel is frequent and ever-changing, it is better to put intensive resources on a single-loop shuttle system instead of providing low levels of service on multiple routes that serve similar locations.

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