BSeT: A Heavy-Duty Transit Bus Size Decision Support Tool

December 1, 2008

Word count: 4,252

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ABSTRACT

Transit managers continue to strive for greater operating efficiency while maintaining an appropriate balance between cost effectiveness and customer service. Over the past decade, the use of heavy-duty buses smaller than the traditional forty-foot variety has expanded for several reasons. In some cases, smaller buses are perceived to cost less to acquire, maintain, and operate. Smaller buses may also be required to accommodate route maneuverability constraints, residential and commercial growth patterns, and off-peak empty bus syndrome. However, the availability of prior studies that considered the effectiveness of small buses has been limited.

The objective of this research project was to develop a decision support tool to assist transit agencies with evaluating heavy-duty bus fleets and making vehicle acquisition and deployment choices. The product of this effort, the Bus Size Evaluation Tool (BSeT), is a user-friendly and easily-modifiable computer application designed within Microsoft Excel. Building off prior studies and earlier investigations that laid the groundwork for this research, BSeT was designed around a life-cycle cost calculator and a template of weighted factors to help transit agencies select buses that are best suited to satisfy their service obligations. The following research paper describes the research effort, details the process of developing the decision support tool, and offers guidelines for utilizing BSeT. It is important to note that the outcome of this project is not intended as a fleet optimization tool.

BACKGROUND

Transit agencies face a host of challenges in the ongoing effort to improve efficiency and to balance cost effectiveness and customer service. Labor and fuel costs continue to rise, while funding streams become increasingly austere. In addition, recent population growth patterns and employer location decisions often favor lower-density areas, which commonly result in less-than-ideal conditions for convenient transit service. In some cases, residential and commercial developments lack adequate space to accommodate traditional 40-foot buses. Such issues tend to form barriers to transit use. With policymakers generally reluctant to authorize fare hikes or tax increases, transit decision-makers must devise alternative solutions to these and other challenges.

As transit operators continue to seek out creative, economical service improvements, one option that has increasingly gained favor is expanding the use of smaller heavy-duty buses. Generally, small buses include any revenue vehicle shorter in length than the standard 40-foot public transit bus. Public policymakers perceive that wider use of small buses will affect dramatic cost savings among the areas of acquisition, maintenance, and operation. By integrating small buses into the fleet mix, many officials also believe that the prevalence of off-peak empty bus syndrome will be reduced. However, the true impact of small bus implementations is largely undocumented, and few resources are currently available to help transit agencies determine their most effective level of small bus utilization. As such, the objective of this project was to develop a support tool to assist transit groups with the evaluation of potential vehicle acquisition and deployment choices.

PROJECT OBJECTIVE AND PROCESS

The objective of this research was to develop a decision support tool for use by transit agencies to assist with evaluating heavy-duty bus fleets and making vehicle acquisition and deployment choices. The intended outcome was a user-friendly, easily-modifiable computer application designed using the Microsoft Excel platform. Building off prior studies and current investigative activities, the tool comprises a life-cycle cost calculator and a template of weighted factors to help transit groups select heavy-duty buses best suited to meet their service needs and priorities. It is important to note that the outcome of this project was not intended as a fleet optimization tool.

The investigative process involved the completion of several tasks. First, prior studies were examined to determine the areas of interest most likely to impact bus acquisition and deployment decisions. The most relevant factors included: fleet replacement and expansion, passenger load factors, vehicle size-related constraints, capital costs, route scheduling and design, and customer feedback. With these variables in mind, researchers proceeded to compile a group of five transit agencies to participate in the study. A key purpose of forming this "project advisory group" was to provide current and accurate data to be used for the development of the decision support tool. Specifically, data were compiled to form a composite bus fleet, which was analyzed and used to calibrate the model. Overall, the composite fleet consisted of 865 heavy-duty, diesel-fueled buses, including 562 large (40-foot) buses and 303 small (less-than-40-foot) buses across 14 model years. Based on composite fleet data, critical assessment factors were calculated and inserted as default values for the tool. Specifically, critical life-cycle variables related to usage intensity levels, variable costs, and fixed costs for small and large buses.

EXISTING PRACTICES AND CONDITIONS

Critical assessment factors and definitions for this research effort were established in large part based on prior studies. For example, an important source was the Transit Cooperative Research Program (TCRP) Synthesis 41: The Use of Small Buses in Transit Service (Hemily and King 2002). Here, the authors surveyed transit agencies and manufacturers, interviewed transit managers and staff, and presented four case studies to document specific uses of small buses, reasons for small bus purchases, user experiences, and relevant issues and technologies. Results indicated that close to 60 percent of North American transit agencies operated small buses, and overall, small buses comprised about 20 percent of urban-area transit bus fleets. Results also showed that larger transit agencies generally operated a lower percentage of small buses, while smaller agencies operated a larger share. Hemily and King also reported that interest in small buses had steadily grown due to a number of reasons, including: growth of suburban areas, limited accessibility, noise and vibrations caused by larger buses, public opinion (including empty bus syndrome) and the desire for greater cost-effectiveness with service in low-demand areas or during low-demand hours (Hemily and King 2002). "Matching capacity to demand" and "maneuverability on small streets" were the most common reasons given for small bus purchases. Eighty-five percent of respondents reported positive experiences with small buses, and the number of transit agencies that had increased the use of small buses in recent years surpassed the number that had reduced small bus use.

Hemily and King indicated common concerns related to small buses, such as reliability and maintenance costs, as well as customer acceptance and acquisition costs. Although larger transit agencies maintained a lower proportion of small buses, they tended to be somewhat less satisfied with them than smaller agencies. Specifically, some agencies experienced excessive passenger loading on small buses during peak periods, while others found the vehicles to be less reliable than large buses. Unfortunately, the research did not specify which types of small buses were most likely to generate such concerns. In general, the availability of information directly related to operator, mechanic, and public opinions of small buses was also limited. However, selected case studies did report positive customer response to services specifically designed for operation by smaller buses.

The synthesis report tended to combine issues, concerns, performance measures, et cetera across all small buses rather than outlining information by bus type. Further, issues specific to smaller heavy-duty buses were generally not presented because the authors included 57 types of smaller transit vehicles in their definition of "small buses." For example, while overall motivations for the acquisition of smaller buses were outlined, details related to procurement and deployment of the heavy-duty varieties were limited. In addition, the synthesis effort did not include a decision-making tool for use by agencies when considering the purchase of small buses. However, the authors pointed out that the development of such a tool was warranted, and they called for greater insight into specific vehicle performance measures. Further study of the cost-effectiveness of small bus services was also suggested.

A second, highly relevant prior study was TCRP Report 61: Analyzing the Costs of Operating Small Transit Vehicles – User's Guide STVe (Small Transit Vehicle economics) (KFH group et al. 2000). Here, researchers developed a Microsoft Excel tool to assist transit decision-makers with the selection of small transit vehicles. The STVe tool incorporated actual cost data with capital, operating, and maintenance costs and allowed users to process such variables to determine cost-effective vehicle procurement solutions. The project also identified several non-financial factors that may impact bus purchasing decisions.

Sensitive to the difficult nature of drawing comparisons among a wide variety of small transit vehicles, STVe model-builders designed the tool to consider a full range of cost details. Because the operating characteristics of small transit vehicles varied considerably, TCRP Report 61 also discussed non-financial and non-quantifiable factors, but these factors were not incorporated into the final analysis tool. The authors pointed out that smaller transit vehicles were more likely to be considered for use in lower density areas and smaller cities. Further, recent commercial and residential growth tended to be low density, and smaller transit vehicles were the most appropriate choice to provide service in such areas.

TCRP Report 61 was also an important influence for vehicle classification definitions and for other critical variables, including vehicle purchase price and service life expectancy; costs for fuel, labor, parts, and other maintenance needs; and non-financial points, such as vehicle-related size constraints, vehicle maneuverability, ride quality, fuel type, vehicle aesthetics, and noise levels. Again, while the importance of these variables was discussed, the tool constructed under this research effort did not include related calculations.

Based on the findings of prior studies and the outcomes of past research conducted by the submitting authors, the areas of interest most likely to impact decisions regarding bus acquisition and deployment were determined to be fleet replacement and/or expansion, passenger load factors, vehicle size-related constraints, capital costs, route scheduling and design, and customer feedback.

ANALYSIS METHODS AND RESEARCH FINDINGS

To establish the project advisory group, the National Transit Database (NTD) was reviewed to identify state transit agencies that directly operated a heavy-duty transit bus fleet from 2001 through 2005. Based on these criteria, organizations limited to demand response and/or purchased services during the time period were eliminated from consideration. Next, the American Public Transportation Association (APTA) Fleet Database was examined for additional information. Overall, agencies were eliminated from consideration based on incomplete data reporting, singular use of small or large buses, and unwillingness to participate in the study.

With participants established, bus fleet data were gathered from each and compiled into a composite bus fleet. Researchers identified and calculated the following life-cycle cost factors: average annual miles, variable costs (including per-mile labor, parts, outside, and fuel costs), and fixed costs (vehicle acquisition costs) (see Table 1.) Study-specific definitions and assumptions were also established. A *small bus* was assumed to be any heavy-duty, diesel-powered bus less than forty feet in length. A *large bus* was assumed to be any heavy-duty, diesel-powered bus that is forty or more feet in length. The midpoint of life (or *mid-life*) of buses in the analysis was 6 years, and the complete service life of buses was 12 years. Further, any route could be served by a small bus at any given time, and operating costs (driver pay, training expenses, etc.) were constant across small and large buses.

TABLE 1.

Life-Cycle Variables	**Small Buses**	**Large Buses**
Usage intensity:		
Average annual miles	49,434	49,966
Average annual miles per gallon	4.3	3.8
Variable costs:		
Average annual per mile labor cost	$0.42	$0.52
Average annual per mile parts cost	+ $0.84	+ $0.73
Average annual per mile maintenance cost (*labor* + *parts*)	$1.26	$1.25
Average annual per mile fuel cost	$0.80	$0.91
Fixed costs:		
Average vehicle acquisition cost	$297,506	$317,586

The evaluation structure followed a basic design that would assure consistent measurement and comparison of relevant factors and inputs. The approach was largely based on a framework proven to be an effective method of predictive analysis (Concas and Winters 2007). Specifically, the tool was calibrated using a dataset large enough to provide significant default values for each variable. The model was designed to be fully customizable, allowing the user to override some or all of the default values. However, a fail-safe system was included to protect users from inadvertent or otherwise unwanted changes to the default values. Afterwards, users complete a series of inputs, and the model performs a series of calculations to yield a potential fleet configuration.

Familiarity with the concepts of constraints, constrained share, and unconstrained share is vital to understanding the function and output of BSeT. *Constraints* refers to required minimum values or quantities. They are discussed in terms of the minimum number of specific bus types required by the BSeT user agency for various reasons, such as vehicle maneuverability, limited access, policy mandates, and other specific needs. *Constrained share* refers to the group of buses that must be maintained at a minimum by the implementing agency. The analysis result may exceed the minimum required quantity but, the result can never fall below the constrained share value. *Unconstrained share* refers to the group of buses that may consist of any combination of vehicle sizes so long as the total passenger capacity of the fleet is maintained. The unconstrained share is the source of vehicles that are allocated by the analysis tool.

With the critical input variables established and fundamental modeling assumptions and concepts described, design of the decision support tool followed. To present the analytical framework underlying BSeT, the following acronyms are used:

TF	=	Total Fleet
TFC	=	Total Fleet Capacity
TOL	=	Passenger tolerance
SB	=	Small Bus
LB	=	Large Bus
BASE	=	Base Case
CONST	=	Constrained
UNCONST	=	Unconstrained

The model developed under this research effort functions according to the following progression:

1. The model requires information regarding the current and programmed bus requisition schedule. The total number of current and projected small and large buses is determined using the following calculation:

$$TF_{BASE} = SB_{BASE} + LB_{BASE}$$

2. Through the qualitative analysis, the minimum required numbers of small and large buses are specified. The fixed quantity of buses

represents a constraint. At this stage, the model splits the projected bus schedule into a constrained share of small and large buses and an unconstrained share of small and large buses that are to be allocated by the tool.

The result provides an initial new fleet requisition schedule that is equal to:

$$TF_{NEW} = SB_{CONST} + SB_{UNCONST} + LB_{CONST} + LB_{UNCONST}$$

3. Through a series of qualifying questions, the unconstrained share is allocated either to small or large buses.

4. Next, the model computes the required number of either small or large buses that maintains the original total bus fleet capacity. This is done by using the passenger tolerance method, as described in Step 5.

5. The final requisition schedule is estimated, which provides the simulated number of small and large buses:

$$TF_{SIM} = SB_{CONST} + SB_{SIM} + LB_{CONST} + LB_{SIM}$$

As described above, once Step 3 is defined, the following formulae are applied to compute the unallocated share of small or large buses:

To compute the current total bus fleet capacity, adjusted by the passenger tolerance factor:

$$TFC_{BASE} = \underbrace{\left(\frac{SB_{APC}}{SB_{SC}}\right)}_{SB_{PLF}} SB_{TOL}^{BASE} + \underbrace{\left(\frac{LB_{APC}}{LB_{SC}}\right)}_{LB_{PLF}} LB_{TOL}^{BASE} \qquad (1)$$

To compute the simulated total bus fleet capacity:

$$TFC_{SIM} = \underbrace{\left(\frac{SB_{APC}}{SB_{SC}}\right)}_{SB_{PLF}} SB_{TOL}^{SIM} + \underbrace{\left(\frac{LB_{APC}}{LB_{SC}}\right)}_{LB_{PLF}} LB_{TOL}^{SIM} \qquad (2)$$

where:

SB_{APC} = Small bus average passenger count across all routes
LB_{APC} = Large bus average passenger count across all routes
SB_{SC} = Small bus seating capacity
LB_{SC} = Large bus seating capacity

SB_{TOL} = Small bus passenger tolerance
LB_{TOL} = Large bus passenger tolerance
SB_{PLF} = Small bus passenger load factor
LB_{PLF} = Large bus passenger load factor

Note that the passenger tolerance is equal to a multiplier of the PLF. For example, if the passenger load factor is equal to 100 percent and the TOL=1.25, then the adjusted passenger load factor is equal to 125 percent.

Once the qualitative factor analysis of Step 3 assigns the unallocated share to either small or large buses, then the model automatically computes equations (1) and (2) and measures the difference between (2) and (1). This difference, divided by the average bus seating, gives the simulated number of marginal small or large buses required to maintain current total fleet capacity levels

$$\Delta BUS_i = \frac{(TFC_{SIM} - TFC_{BASE})}{SC}$$

where:

ΔBUS_i = incremental number of either small or large buses required to maintain current total fleet capacity.

Designed to be as straight-forward as possible to the end-user, the on-screen interface of BSeT guides the user through four analytical steps. First, the user enters organization and analyst identification data. Next, the user inputs the current bus fleet composition, including the numbers of small and large buses by model year. After that, the user inputs vehicle constraints, including minimum numbers of each bus size required by the needs of the service area and the average passenger counts among each bus size. Lastly, the user responds to a series of qualitative statements.

BSeT was designed under the assumption that users would likely run the model several times, in order to create different scenarios. As such, the tool also provides the opportunity for the user to give each analysis trial a unique name. For example after an initial attempt, users might choose to label subsequent trials according to specific data inputs. After the completion of several analytical tests, the user can easily compare the results by referring to the unique titles.

For an existing transit bus fleet, BSeT users may enter up to 12 model years of small and large heavy-duty buses. The model assumes a one-to-one bus replacement schedule by model year; however, the user has the option to enter a customized bus replacement schedule for future years. Unless otherwise modified by the user, BSeT is also designed to preserve the total passenger load capacity of the existing fleet, which is based on the number of buses by size and the number of available seats.

BSeT is designed to account for the unique service needs and/or policy mandates of the implementing agency. In the event that a transit agency must observe specific vehicle size and quantity requirements, the model prioritizes these numbers and incorporates them into the analysis as constraints. As such, the end-user is required to enter minimum numbers of large and small buses necessary to meet agency needs. For example, agency policy might dictate that only large buses may be used on express routes, so the minimum number of large buses would include the total buses necessary to meet express route service. In the event that no such constraints exist, the user must enter a zero in each box in order for the tool to provide an outcome.

To further strengthen the analysis, the user has the option to enter average passenger count data for small and large buses. While agencies may not have such metrics immediately available, these figures are easily determined from passenger count data, especially data provided by automated passenger counting devices. If data are unavailable, the tool refers the programmed default values.

Critical to the analysis, responses to the qualitative statements indicate user priorities regarding small or large buses. Few or no responses indicate no measurable differences, and the model assumes that the current fleet is representative of the user's most critical needs. A series of four tabs is incorporated into the tool for this step. Each tab is dedicated to a critical, qualitative topic related to bus selection and deployment. The first qualifying subject area is designed to determine the user's priorities regarding bus size, if any, related to vehicle acquisition. The next qualitative subject area is concerned with ridership, while the third addresses special concerns. The final qualitative factor reveals general public opinion and bus operator feedback regarding bus size. For each of the nine specific qualifying statements, a seven-point Likert scale was installed as the response. Each response reflects a measurable degree of need satisfied by small buses or by large buses (or indifference), and the summary total dictates the overall priorities of the user.

Because the relevance of each qualitative category varies in terms of overall bus acquisition and deployment choices, the four areas were weighted according to input received from the project advisory group. The following measures were installed as the default weight for each category: vehicle acquisition (30%), ridership (35%), special concerns (25%), and feedback (10%). Like other parameters, the model allows for the modification of qualitative factor weighting assignments, as necessary.

After all required input steps are completed, the analysis is performed and the results are presented. The BSeT model output screen displays the original input followed by the result of the analysis. Users are able to easily compare initial conditions with the impact of the variables that were entered. Specifically, fixed and variable cost calculation outputs, including fuel, maintenance, operating, and acquisition costs, are displayed. Final results and comparisons are highlighted to allow analysts to compare average annual costs per mile for small and large buses. Total vehicle replacement costs are also indicated.

CONCLUSIONS AND RECOMMENDATIONS

This research project did not intend to perform a comparative analysis across participating transit agency bus fleets. Rather, the intent was to gather a sufficient amount of data to calibrate the model, thus ensuring a robust analysis tool. The formation of a project advisory group was vital to the success of the project, and the practical expertise and guidance provided by the group resulted in a more robust and useful analysis tool than would have been produced under isolated laboratory conditions.

A fundamental strength of the model developed during this research effort is the ability of the end-user to modify any or all of the internal parameters according to agency-specific data. The robustness and flexibility of the tool allows for widespread application among transit operators. While prior studies excluded other, non-quantifiable factors, the BSeT includes a series of qualitative subject areas that serve to define and weight the user's priorities related to bus size. However, the tool also provides an analysis output in the event that no advantage of one type of bus over another is indicated.

While cost analysis results generated by BSeT can vary according to the user's data inputs and modifications (if any), the vehicle mix results are generally limited to three possible outcomes, based on the user's overall priorities. Once the qualitative factor analysis has determined the general trend toward one bus type or another, the unconstrained share is assigned entirely to the bus size group that is most likely to satisfy the user's priorities. This outcome is consistent with the goal of devising a tool to aid in the bus acquisition decision-making process but not intended to generate an optimal fleet mix or to predict deployment patterns on a route-by-route basis.

In the event that the analysis reveals indifference regarding bus size, the model output effectively becomes a cost analysis of the existing fleet. Specifically, the indifferent condition is a signal to the tool that the implementing agency has already achieved a satisfactory fleet configuration. As a result, no alternative fleet configuration is suggested by the output.

BSeT does not address operating spare ratios directly; however, the model assumes that the numbers entered into the current fleet composition portion of the analysis include spare vehicles. As such, the tool output can be considered to be inclusive of spare vehicles. In addition, operator costs were not included because the model assumes that there is salary parity between operators of small and large buses.

As indicated earlier, BSeT was not intended to be a fleet optimization tool or to provide specific route analyses. However, this research has laid the groundwork for subsequent research efforts to develop one or both of these tools as either supplemental modules or as stand-alone products. Further, in the event that transit agencies adopt formal service planning guidelines, the tool could be revised to incorporate specific terms into the model.

Formal documentation of customer feedback about bus size and rider comfort was found to be limited, at best. As the use of smaller buses increases, transit agencies would likely benefit by incorporating additional questions related to these areas into their customer survey instruments.

Lastly, as energy prices continue to rise and interest in alternatively-fueled buses grows stronger, a supplemental component to BSeT could be developed to address these types of vehicles and possibly to compare them to conventional transit vehicles.

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