A Study of the Key Variables Affecting Bus Replacement Age Decisions and Total Costs

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ABSTRACT

Due to recent budget and fiscal constraints, it is ever more imperative for transit agencies to manage their fleets in an optimal way. Fleet data have consistently shown that bus operational and maintenance (O&M) per-mile costs increase as buses age. From a purely economic perspective, there is a cost tradeoff between the lower O&M costs of newer fleets and their higher initial capital costs. This tradeoff has a significant impact on the optimal timing of purchase and replacement decisions.

Utilizing realistic cost data and an optimization modeling framework, we analyze the impact of purchase timing decisions on fleet per mile-costs. The results indicate that 1) increases in diesel prices do not affect total bus fleet costs as much as increases in maintenance costs, 2) increases in maintenance costs and utilization per year reduce the optimal replacement age, 3) increases in utilization and fuel economy have a similar impact in terms of total fleet costs, and 4) bus purchase price changes have a significant impact on the optimal replacement age. Given uncertain and hard to forecast market variables, we present a thorough sensitivity analysis to ascertain the key variables that affect bus transit replacement timing.

Keywords: Bus Transit Fleet, Replacement Age Decision Models, Optimization, Sensitivity Analysis

INTRODUCTION

Large transit agencies typically own hundreds of buses. Large fleets' capital and operational costs are a significant expense for resource-strapped transit agencies. In particular, high capital or purchase costs have forced some agencies to postpone bus replacement decisions. The focus of this paper is to present a model and analysis of the key factors affecting the bus replacement age and total fleet costs.

Bus fleet costs can be broken down into a handful of key cost factors: capital purchases, vehicle operation, fuel, general administration, and vehicle and facility maintenance. However, these cost contributions vary widely from operating forty or sixty foot bus types depending on operational policies of the transit agency. In this study, we will focus on sixty foot articulated buses from King County Transit in Seattle, Washington (*1*). Particularly, we restrict our attention to factors that affect the bus replacement age and total costs such as maintenance costs that vary with a bus's age.

LITERATURE REVIEW

The Management Science and Operations Research literature have pioneered the usage of vehicle replacement models to optimize decisions regarding vehicle purchases, utilization, maintenance, and scrapping. A formal optimization model dealing with machine replacement problems was first introduced in the 1950's (*2*). Since then, many researchers have analyzed replacement problems in wide range of fleet types, including transit and police fleets (*3, 4*). Some researchers have added budget constraints (*5*) and even integrated vehicle manufacturing waste factors in an automobile life cycle analysis (*6*). Despite the great uncertainty associated to financial variables and forecasts, all the mentioned models have been deterministic. Furthermore, there has been little or no attention given to sensitivity analysis *(36).*

Researchers have looked at cost trends in transit agencies by tracking fleet costs over time. Long term cost data of bus fleets have consistently shown that operating and maintenance costs rise with age (*7-9*). Other research has shown the value of modeling preventative and unexpected repair costs over time (*10*) and their impact on the optimal bus replacement age (*11*). The cost of replacing, refabricating, and rehabilitating buses has been a focus of research by Khasnabis et al. (*12, 13*) as well as the optimal allocation of Federal Transit Administration (FTA) funds among transit agencies (*14*). Unlike this research work, previous studies have evaluated fleet costs and their impact on replacement age, but they have not modeled all the relevant factors that vary as a function of bus age, e.g. utilization and fuel consumption. A comprehensive literature review on the factors affecting bus replacement modeling can be found in here (*15*).

MODEL FORMULATION

The optimization model utilized in this research to determine replacement costs is presented in this section. The objective of the model is to minimize bus costs over the planning horizon; including purchasing, utilization, maintenance, salvage, emissions, and road call costs. The decision variable is *when* to replace buses over the planning horizon.

Indexes

Age of bus in years: $i \in \mathbf{A} = \{0, 1, 2, \ldots, A\}$,

Time periods, a decision is made at the end of each year: $j \in \mathbf{T} = \{0, 1, 2, \ldots, T\}$,

Binary Decision Variables

X_{ij} = the i-year old bus in use from the end of year j to the end of year $j+1$,

PY_j = whether a bus is procured/salvaged at the end of year j.

Parameters

(a) *Constraints*

A = maximum or forced salvage age (the bus must be salvaged if this age is reached),

u_i = utilization (miles traveled by an i-year old bus),

mpg_i = fuel economy of i-year old bus,

(b) *Costs*

v = cost of purchasing a new bus,

om_i = maintenance costs per mile for an i-year old bus,

rc_i = cost of road calls of an i-year old bus,

s = salvage revenue (negative cost) from selling an old bus when replaced by a new bus,

sf_{iT} = final salvage revenue (negative cost) from selling an i-year old bus at time T,

ec = emissions cost per ton of CO_2 emissions,

d = price of diesel fuel per gallon, and

dr = discount rate.

(c) *Emissions*

eps = production and salvage emissions, in CO_2 tons,

em_i = utilization emissions in CO_2 tons per mile for an i-year bus.

Objective Function, minimize:

$$\sum_{i=0}^{A-1}\sum_{j=0}^{T-1} PY_j(v + ec \cdot eps - s - sf_{iT})(1+dr)^{-j} + \sum_{i=0}^{A-1}\sum_{j=0}^{T-1} X_{ij}(u_i om_i + u_i mpg_i d + u_i em_i ec + rc_i)(1+dr)^{-j} \quad (1)$$

Subject to:

$$PY_0 = 1, where\ s = 0 \tag{2}$$

$$PY_T = 1, where\ v = 0 \tag{3}$$

$$X_{(i-1)(j-1)} = X_{ij} + PY_j \quad \forall i \in \{1, 2, \dots, A\}, \forall j \in \{1, 2, \dots, T\} \tag{4}$$

$$PY_j = X_{0j} \quad \forall j \in \{1, 2, \dots, T-1\} \tag{5}$$

$$X_{Aj} = 0 \quad \forall j \in \{0, 1, 2, \dots, T\} \tag{6}$$

$$X_{iT} = 0 \quad \forall j \in \{0, 1, 2, \dots, T\} \tag{7}$$

$$PY_j, X_{ij} \in \mathbf{I} = \{0, 1\} \tag{8}$$

The objective function expression (1) minimizes the sum of purchasing, maintenance, salvage, emissions, and road call costs over the period of analysis from time zero (present) to the end of the planning horizon (year *T*). At the first time period, the model starts with the purchases of a new bus (2). At the end of the last time period (or horizon time *T*), the existing bus is sold (3) at a value equal to the salvage value for whatever age the bus has at the time *T*, sf_{iT}. The age of any vehicle in use increases by one year after each time period (4). A constraint makes sure that a bus procured equals a new bus in use (5). When a bus reaches the maximum service age it is forced to be salvaged (6). At the last time period, *T*, the bus is not utilized and operational costs are not added (7). Finally, the decision variables associated to purchasing and salvaging decisions must be binary (8).

SUPPORTING DATA AND ASSUMPTIONS

Our modeling assumptions are supported by historical bus cost and utilization data from on a report prepared for King County's trolley and bus evaluation (*1*) and other King County fleet data. We are modeling a bus that has an average operating cost per mile of $2.05 over a 20 year period. Furthermore, we are assuming that the model begins with a new bus and each bus purchased thereafter is also new.

Maintenance costs per mile

The total maintenance costs account for labor, parts, and tire costs as well as the overhead costs required to maintain the building and employee services. Historically, all maintenance costs have been found to rise with age by approximately 1.5% per year while a new bus has the total operating and maintenance costs of $1.70 per mile per unit. These trends have been published in the latest King County Report (*1*).

Fuel efficiency (mpg_i)

The average fuel economy of King County diesel buses has been found to be 3.32 miles per gallon (*1*). This value will be held constant for the entire time horizon of the model.

Passengers' road call (RC) costs (rc_i)

A bus has a 'road call' when it has a mechanical problem and a mechanic must be sent out to fix it. RCs are detrimental to the transit agency because of the additional staff and resources required to repair a bus with mechanical problems. The transit cost of RCs is already integrated in the maintenance cost data. However, previous models have not included passengers' time or inconvenience costs when a bus breaks down. On average, a bus is driven with 8.8 passengers (*17*) and the waiting time associated with road calls is approximately thirty minutes in the Seattle Metropolitan area (*18*). Utilizing a passenger's value of waiting time equal to $23.67 per hour, based on US DOT (*19*) figures and adjusted for inflation (*20*), the average user cost per road call is $103.97 (8.8 passengers). If the bus is loaded with 50 passengers, the cost increases proportionally to $591.75 per RC.

Utilization (u_i)

The average utilization of national sixty foot articulated buses is 31,900 miles per year (*21*), per unit and is held constant for the time horizon of the model.

Salvage Value (s & sf_{iT})

Decommissioning a bus is costly because equipment as well as external markings must be removed (*22*). Additionally, the literature highlights that if revenue from selling a bus exceeds $5,000 the difference must be reimbursed to the FTA if FTA's capital assistance funds were employed (*23*). A salvage value s = $1,000 is assumed. However, on year T when the bus is forced to be sold, a salvage value of $1,000 may not be realistic especially if a relatively new bus is sold. For the final time period, a linear depreciation function is used to determine the final salvage value based on the initial purchase cost, salvage value, and maximum life of a bus. The final salvage value is determined by the following equation.

$$sf_{iT} = v - A_j * (v - s)/30$$

Emissions output and cost (eps, em_i, ec)

Life cycle analysis studies have estimated a passenger vehicle's production and salvage emissions ranging between 8 to 9 CO_2 tons and 13 CO_2 tons for sedans and sport utility vehicles (SUV) respectively (*6, 24-26)*. To the best of the authors' knowledge there is no equivalent bus production and salvage emissions study; a bus CO_2 tons estimation is produced based on a ratio of vehicle weight and the CO_2 released to manufacture and scrap a vehicle (*6, 24-26).* An articulated sixty-foot bus weighs 44,000 lbs whereas a standard sedan and SUV weigh 3,500 and 5,400 lbs respectively (*27*). The emissions associated to the production and salvage of a bus are estimated at 105 tons of CO_2. In addition, there are CO_2 emissions associated with bus usage; this value equals the CO_2 released when a gallon of diesel is burned, which is well known and equals 0.011 CO_2-tons (*28*).

Additional Data Inputs and Assumptions

On average, transit buses are replaced at year 15.1 and bus ages rarely exceed 30 years (*28*). Hence, the bus maximum age is set to 30 years. To ensure at least two cycles, time horizon T is set to 60 years. The discount rate varies across the 60 time horizon and is dependent on King County's bus study (*1*). For reference, after year 11 of the model, the nominal discount rate is fixed at 9.55%. A New Flyer 60' Articulated Bus is assumed to cost v = \$756,000 based on what King County pays for their buses including aftermarket equipment, manuals, and contingency (*1*).

The FTA provides transit agencies grants for up to 80% of bus capital purchases (*23*). When agencies are granted funds, they must adhere to certain FTA guidelines; agencies must keep heavy-duty buses a minimum of 12 years or 500,000 miles, whichever occurs first (*21*). According to a survey of American transit agencies, the average bus retirement age is 15.1 years (*21*). This model will assume that every bus purchase is granted the 80% subsidy.

Regarding CO_2 emissions and climate change effects, there is wide variation in terms of cost per ton. Valuations range from zero (no link between CO_2 and climate change) to \$200/CO_2 -ton or more (*29*, *30*); a recent meta-study found that the average social cost of CO_2 is \$100/CO_2-ton (*31, 32*).

SCENARIO ANALYSIS

Given that some market parameters are highly uncertain or volatile, we provide a set of values for each. Parameters varied in the scenario analysis are presented in table 1.

TABLE 1 Scenario Analysis Parameters and Values

BASELINE	
Gasoline Prices (d)	BASELINE or low projected diesel price = \$2.64/gallon, 2011 (*33*)
Emissions Prices (ec)	BASELINE actual emissions price = \$0/CO2-ton
O&M Costs (om_i)	BASELINE actual O&M costs (*1*)
Utilization (u_i)	BASELINE flat utilization u = 31,900 miles (*21*)
FTA's Capital Assistance	BASELINE capital assistance = 80%
User cost per road call	BASELINE equal to zero
EXTREME	
Gasoline Prices (d)	High projected diesel price = \$4.46/gallon, 2011 (*33*)
Emissions Prices (ec)	High emissions price = \$100/CO2-ton from (*31*)
O&M Costs (om_i)	High O&M costs = 25% increase over the values obtained King County's study
OTHER PARAMETERS ANALYZED INDIVIDUALLY	
User cost per road call	An average of \$103.97 (8.8 passengers) or high of \$591.75 (full bus)
Purchase costs	Decrease total purchase costs by 10%

RESULTS AND ANALYSIS

When the model is run under a 'baseline' or average scenario, results show that O&M, purchase, and fuel costs contribute to 63%, 15%, and 22% percent of the bus costs respectively. In the baseline scenario the optimal replacement age is on average 21.5 years. To observe changes in total costs due to budget constraints, the bus purchase/salvage replacement decisions are forced to be two, four, and six years before and after the optimal replacement age. The lines in figure 1 illustrate the percent cost increases over the optimal replacement age.

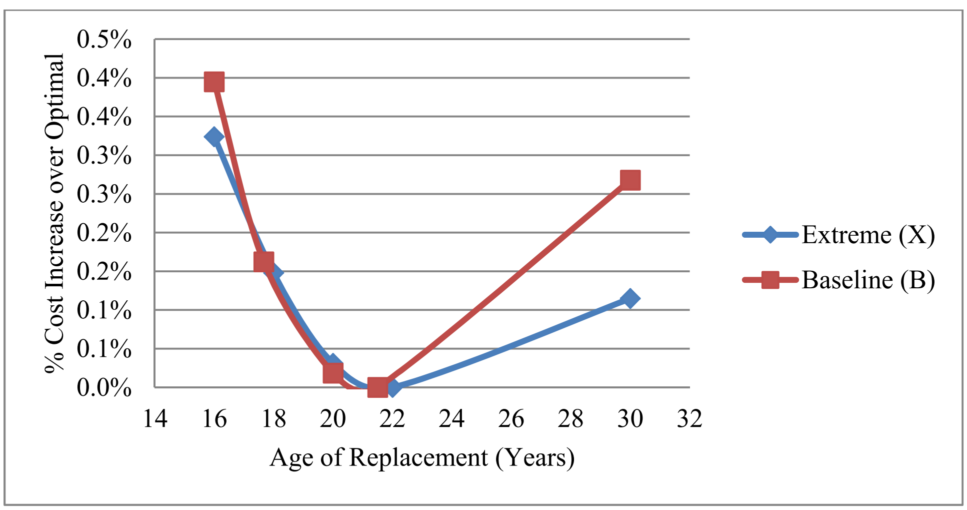

FIGURE 1 Impact of Early and Delayed Replacement Age (% change over 60 year planning horizon discounted costs)

The cost impacts of delaying or hurrying the replacement decisions are not symmetrical. For example, if a replacement decision is delayed to 30 years, the total costs of fleet operation are forecast to increase by 0.1% whereas if the replacement is advanced to year 16 the total cost increases approximately 0.3%. Budget constraints may force a delayed replacement and this is costly but not as costly as an early retirement due to maintenance problems or lack of reliability.

If we assume an extreme scenario (high diesel price forecasts, high CO_2 emissions costs \$100/CO_2-ton, and 25% increase in O&M costs), the optimal replacement age increases from 21.5 to 22 years. Additionally, it is less costly to deviate from the optimal bus replacement age; if a bus is replaced six years before, the cost is forecast to increase by 0.32 and 0.4 percent respectively in baseline and extreme scenarios.

Early and delayed replacement impacts total fleet emissions in a different manner. By replacing the bus six years earlier than optimal, a total of 1.54% emissions are increased because the manufacturing emissions cost is incurred more frequently. If a bus is replaced six years later than optimal, the CO_2 decreases by 1.59%.

TABLE 2 Impact of Cost Increases Relative to Baseline Conditions

Cost Category	High diesel cost	Emissions \$100/CO_2-ton	O&M 25% cost increase	Purchase cost 10% decrease
Total Cost ($)	34.1%	10.5%	13.5%	-1.6%
Purchase Cost ($)	0.0%	-1.2%	4.5%	-8.0%
Salvage Revenue ($)	0.0%	-9.5%	25.8%	17.7%
Fuel Cost ($)	70.1%	0.0%	0.0%	casts
O&M Cost ($)	0.0%	0.3%	19.2%	-0.7%

The difference between low to high diesel price scenarios increased fuel costs by 70.1% and total costs by 34.1%. A 25% increase in O&M costs per mile increased total O&M costs 19.2%, total costs by 13.5% and also affected purchase costs by 4.5%. With higher O&M costs per mile, it is optimal to replace buses earlier. Imposing an emissions cost from zero to \$100/CO_2 ton, increases the total costs by 10.5%, which is less than the high diesel price forecast issued by Linwood Capital (*33*). Lastly, decreasing the bus's purchase price decreases total costs by 10%, total purchase costs by 8% and operating and maintenance costs by 0.7%.

When low and high passenger costs of road calls are integrated into the model, total costs minimally increase by 0.59% and 3.21% while the O&M cost category rises by 0.6 and 4 percent. As a separate scenario we also included the transit agency cost of having additional staff on call from increased road calls, however, we found that the extra cost was insignificant was therefore ignored.

SENSITIVITY ANALYSIS

Finally we perform a sensitivity analysis to understand what factor has the highest impact on the replacement age. We compute the elasticity of costs to each factor using the following arc elasticity formula (1) where η_x^c is the elasticity of per mile cost *c* to parameter *x*:

$$\eta_x^c = \frac{(x_1+x_2)/2}{(c_1+c_2)/2} \cdot \frac{\Delta_c}{\Delta_x} = \frac{(x_1+x_2)}{(c_1+c_2)} \cdot \frac{(c_2-c_1)}{(x_2-x_1)} \qquad (1)$$

We also calculate the elasticity of replacement to each parameter assuming a range shown in table 3 for both types of elasticity (cost per mile and replacement age).

TABLE 3 Cost and Age Elasticity

	Diesel price low to high scenario	O&M 0 to 25% increase	Utilization (miles per year) 0 to 10% increase	Miles per Gallon 0 to 10% increase	Purchase cost 0 to 10% decrease	Total passenger change per cost to board passengers
Cost Elasticity	0.17	0.62	-0.14	-0.20	-0.15	-1.25
Age Elasticity	0	-0.75	-0.82	0	-4.52	-

For example, if diesel prices increase by 1%, the cost elasticity is 0.17 meaning that costs per mile increase 0.17%; the replacement age elasticity is 0.00 meaning that the optimal replacement age was not affected by a gas price increase or increases in fuel economy. As expected, maintenance costs have significant impacts on both costs per mile and replacement age. However, the impact of maintenance costs on replacement age has an opposite sign as expected. Among the remaining variables, fuel efficiency turned out have a lower elasticity than utilization; this indicates that improvements in fuel efficiency go a long way in terms of reducing costs per mile and justifying investments in more fuel efficient buses. Decreasing the purchase price had the most significant impact to decrease the optimal replacement age, which says much about the importance of the 80% capital cost subsidy.

CONCLUSIONS

Budget constrained transit agencies have challenges to minimize total fleet costs. Changing diesel prices, internalizing emissions costs, deteriorating buses and improving fuel economy have been shown to not only change total costs of fleet operation but also change the optimal age of bus replacement decisions. Specifically, it was found that early bus replacement, relative to the optimal replacement decision is more expensive in economic terms than tardy replacement. However, as agencies delay bus replacement, they decrease CO_2 emissions emitted, because of less frequent emissions costs associated with manufacturing.

Elasticities have been calculated to forecast how changes in market and fleet conditions impact replacement age and costs. An increase in bus maintenance costs has a greater impact on total costs relative to higher gas prices while increasing the utilization and fuel economy of buses decreases total costs. Road calls were shown to have an insignificant impact on total costs and decreases in purchase costs had the greatest impact on the optimal replacement age, which speaks to the necessity of transit agencies to receive FTA's bus purchase subsidy.

Despite the complexities of bus fleet costs and characteristics, federal bus policies and market factors, bus replacement modeling is shown to be an effective tool to ascertain market and fleet changes on costs and bus replacement timing.

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REFERENCES

1. King County Metro. King County Trolley Bus Evaluation. May 2011. http://metro.kingcounty.gov/up/projects/trolleyevaluation.html, http://metro.kingcounty.gov/up/projects/pdf/Metro_TB_20110527_Final_LowRes.pdf
2. Bellman, R. Equipment replacement policy. *Journal of the Society for Industrial and Applied Mathematics,* Vol. 3, 1955, pp. 133-136.
3. Rees, L. P., Clayton, E. R., and Taylor, B. W. Network Simulation Model for Police Patrol Vehicle Maintenance and Replacement Analysis. *Computers, Environment and Urban Systems*, Vol. 7, No. 3, 1982, pp. 191-196.
4. Khasnabis, S. M., Bartus, J., and Ellis, R. Asset Management Framework for State Departments of Transportation to Meet Transit Fleet Requirements. *Transportation Research Record: Journal of the Transportation Research Board, No. 1835,* Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 74-83.
5. Karabakal, N., Lohmann, J. R., and Bean, J. C. Parallel Replacement under Capital Rationing Constraints. *Management Science,* 1994, pp. 305-319.
6. Kim, H. C., Keoleian, G. A., Grande, D. E., and Bean, J. C. Life Cycle Optimization of Automobile Replacement: Model and Application. *Environmental Science & Technology,* Vol. 37, No. 23, 2003, pp. 5407-5413.
7. Wabe, J. S. and Coles, O. B. The Short and Long-Run Cost of Bus Transport in Urban Areas. *Journal of Transport Economics and Policy,* Vol. 9, No. 2, 1975, pp. 127-140.
8. Williams, M. Firm Size and Operating Costs in Urban Bus Transportation. *The Journal of Industrial Economics,* Vol. 28, No. 2, 1979, pp. 209-218.
9. Berechman, J. and Giuliano, G. Analysis of the Cost Structure of an Urban Bus Transit Property. *Transportation Research Part B,* Vol. 18, No. 4/5, 1984, pp. 273-287.
10. Simms, B.W., Lamarre, B. G., and Jardine, A. K. K. Optimal Buy, Operate and Sell Policies for Fleets of Vehicles. *European Journal of Operational Research,* Vol. 15, No. 2, 1984, pp. 183-195.
11. Rust J. Optimal Replacement of GMC Bus Engines. An Empirical Model of Harold Zurcher. *Econometrica,* Vol. 55, No. 5, 1987, pp. 999-1033.
12. Khasnabis S. M., and Naseer M. Procedure to Evaluate Alternatives to Transit Bus Replacement. *Transportation Research Record: Journal of the Transportation Research Board,* No. 1731, Transportation Research Board of the National Academies, Washington, D.C., 2000, pp. 51-60.

13. Khasnabis, S. M., Alsaidi E., and Ellis R. D. Optimal Allocation of Resources to Meet Transit Fleet Requirements. *Journal of Transportation Engineering,* Vol. 128, No. 6, 2002, pp. 509-518.
14. Mishra, S., Mathew T. V., and Khasnabis, S. Single-Stage Integer Programming Model for Long-Term Transit Fleet Resource Allocation. *Journal of Transportation Engineering,* Vol. 136, No. 4, 2010, pp. 281-290.
15. Boudart, J. Bus Replacement Modeling and the Impacts of Budget Constraints, Fleet Cost Variability, and Market Changes on Fleet Costs and Optimal Bus Replacement Age, A Case Study. (Master's thesis) Portland State University, 2011.
16. Clark N. N., Zhen. F., et al. Assessment of Hybrid-Electric Transit Bus Technology. *Transit Cooperative Research Program,* Report 132. FTA, U.S. Department of Transportation, 2009.
17. Davis, S. C., Diegal, S. W., and Boundy, R, G. *Transportation Energy Data Book: Edition 28,* U.S. Department of Energy. pp. Table 2.12. ORNL-6984 (Edition 28 of ORNL-5198), 2009.
18. Regional Transit Committee. Service Facility Guidelines. King County Metro Service Development. King County Metro Transit, 2008.
19. Departmental Guidance on the Evaluation of Travel Time in Economic Analysis. memo, U.S. Department of Transportation. Used in STEAM software (www.ota.fhwa.dot.gov/steam), 1997.
20. CPI Inflation Calculator. BLS, U.S. Department of Labor. http://www.bls.gov/data/inflation_calculator.htm. Accessed April 25th, 2011.
21. Laver, R., Schneck, D., Skorupski, D., Brady, S., Cham, L., and Hamilton, B. A. Useful Life of Transit Buses and Vans. Report No. FTA VA-26-7229-07.1. FTA, U.S. Department of Transportation, 2007.
22. King County. Conference Call with King County Fleet Manager Ralph McQuillan, Gary Prince, Kurtis McCoy, Eric Hesse, 2011.
23. Public Transportation in the US: Performance and Condition. A Report To Congress Presented To 49 USC 308. FTA, U.S. Department of Transportation, 1992.
24. DeCicco, J. M. and Thomas, M. A Method for Green Rating of Automobiles. *Journal of Industrial Ecology.* Vol. 3, No. 1, 1999, pp. 55-75.
25. Maclean, H. L. and Lave, L. B. Life Cycle Assessment of Automobile/Fuel Options. *Environmental Science Technology*. Vol. 37, 2003, pp 5445-5452.
26. Samaras, C. and Meisterling, K. Life Cycle Assessment of Greenhouse Gas Emissions from Plug-In Hybrid Vehicles: Implications for Policy. *Environment Science Technology,* Vol. 42, 2008, pp. 3170-3176.
27. Vehicles Keep Inching Up and Putting on Pounds. USA Today and Edmunds. Written on 7/16/2007. Accessed February, 2011.
28. Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel. Environmental Protection Agency. Updated April 12th, 2011, http://www.epa.gov/oms/climate/420f05001.htm. Accessed April 21st, 2011.
29. Tol, R. The Marginal Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties. *Energy Policy,* Vol. 33, 2005, pp. 2064-2074.
30. Stern, N. The Economics of Climate Change. *The Stern Review*. Her Majesty's Treasury, United Kingdom, 2006.

31. Peet, K., Partridge, E., Hale, M., and Le, P, D. Future Fleets: An Applied Model for Bus Fleet Planning Based on Energy Costs and Impacts. CD-ROM. Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 1-16.
32. Wayne, S. W., Sandoval, J. A., and Clark, N. N. Emissions Benefits from Alternative Fuels and Advanced Technology in the U.S. Transit Bus Fleet. *Energy and Environment,* Vol. 20, No. 4, 2009, pp. 497-515.
33. Linwood Capital LLC. Diesel Fuel Price Forecast. March 3rd, 2011.
34. American Automotive Association's Daily Fuel Gauge Report. www.fuelgaugereport.com. Accessed March 28. 2011
35. King County Transit. Annual Performance Measures. http://metro.kingcounty.gov/am/reports/annual-measures. Accessed July 28th. 2011.
36. Keles, Pinar and Hartman Joseph. Case Study: Bus Fleet Replacement. The Engineering Economist, 49: 253-278, 2004.