Bus acquisition and retirement decisions

by
Ezra Hauer
Department of Civil Engineering, University of Toronto

INTRODUCTION

Bus fleet planning is part and parcel of orderly management of a bus transit property. Budgetary provisions need to be made for the future acquisitions of new buses; maintenance programs tailored to the upcoming retirement of old ones; subsidies requested, orders placed etc. It is not uncommon to prepare Strategic Acquisition and Retirement Programs several years into the future for internal planning or as a part of request for subsidies towards the purchase of new equipment, or for both.

The managerial and technical content of the process leading to the formulation of such acquisition and retirement programs seems to be less than well documented. A recent servey of four transit properties in Ontario revealed a predictable variability in practice. One property follows the general guideline that "...a vehicle is retired when it starts to cost more in depreciation, operation and maintenance than the costs associated with the acquisition and operation of a new bus"; another property attempts to replace buses after 15 years of service; elsewhere, buses are candidates for resale already at the early age of ten years provided the selling price is right; others aim to obtain an average fleet age of 6-7.5 years through an appropriate acquisition and retirement program.

Documented studies of bus fleet planning seem to be few. Those which came to our attention are faulty in concept and therefore in their conclusions. One study [1] postulates that "...the optimum economic age of a bus occurs just prior to the occurrence of the first major maintenance repair...". This leads to the baseless conclusion "...the optimum economic life of a bus can be identified as eight years...". Another study [2] disregards the fact that annual mileage varies with vehicle age (from 60,000 miles/annum for new buses to 10,000 miles/annum for old ones). Thus, the author concludes that a bus making 30,000 miles per annum in Cleveland should be replaced at the age of 20 years, whereas in Chicago it should be retired after 11 years.

In summary, the preparation of bus acquisition and retirement programs by transit properties is guided by a variety of rationales and is largely qualitative in method. The aforementioned quantitative studies are not applicable to real situations. The need exists to forge a tool which can deal effectively with the more quantitative aspects of bus acquisition and retirement to aid management in bus fleet planning.

PROBLEM DEFINITION AND DESCRIPTION

It appears that the process leading to the acquisition of new buses and to the resale of some old vehicles is complex and involves many people at different levels of management. However, a certain hierarchical structure is apparent in the larger properties. A strategic program for several years into the future is prepared. This program merely specifies the number of vehicles to be acquired and retired during each of the budgetary periods throughout the program. The Five-Year Program for the London (Ontario) Transportation Commission illustrates the concept (Table I). The guidelines incorporated in this strategic program are later made specific, determining which vehicles will be retired, what type of vehicle purchased etc. All this in accordance with the conditions prevailing at the time decisions are made. Application procedures for subsidies make the preparation of similar strategic programs mandatory also for the smaller bus transit properties.

Discussion in this paper will focus on the generation of Strategic Acquisition and Retirement Programs to be denoted (for brevity) SARP.

Selection of the phrase "acquisition and retirement" instead of the more customary term "replacement" is deliberate. Firstly, when an old bus is retired from service, its task is not assigned to the new vehicle joining the fleet. Rather, the next oldest vehicle remaining in the

Research supported by National Research Council Canada Grant A8158.

Table I – Five Year Program of Replacements and Additions (Adapted from Schedule "B" June 11, 1974, The London Transportation Commission)

Year	Proposed Purchases	Proposed Retirements	Net Addition	Buses in Fleet at year end
1974				126
1975	25	7	18	144
1976	15	7	8	152
1977	14	11	3	155
1978	12	8	4	159
1979	11	5	6	165

fleet assumes the task of the retiring bus and is called into service only during periods of peak vehicle utilization. The incoming new bus, on the other hand, will be used as much as possible. Consequently acquisition and retirements cause a shift in the tasks performed by all vehicles in the fleet. Therefore, the concept of "replacement" is misleading. Secondly, buses are acquired and retired in face of changing demand conditions often without any reference to "replacement". It is impossible, therefore, to discuss the bus acquisition and retirement problem in terms of a "one for one" substitute or comparison. That is, the prototype model of substituting a new (low maintenance cost) item for an old (high maintenance cost) piece of equipment does not apply. Indeed, the following factors should influence SARPs (Strategic Acquisition and Retirement Programs):

1. Number of buses needed in the fleet in future years and their utilization.
2. Budget and subsidy considerations.
3. Operating and maintenance cost characteristics of *all* vehicles in the fleet as well as their reliability performance.
4. Purchase and resale prices of buses.

Missing in the group of factors is the less tangible but not less important consideration of desirability of riding new vehicles both as passengers and as drivers. As will become evident later the evaluation procedure allows for management judgement in this respect.

The objective of modelling then, is to formulate a limited number of SARPs to be presented for consideration to management. All alternatives must comply with constraints specified by 1 and 2 and be presented parsimoniously in terms of the implications in 3 and 4.

FACTS AND FIGURES

In concept it is not difficult to see that the number of buses acquired and retired during a particular budgetary period should be such that neither the operating cost budget, nor the budget for purchase of capital equipment are exceeded while at the same time the fleet is large enough to satisfy demand for service, and the resulting fleet age profile is a good base for the next period. The difficulty resides in the quantification of the exact relationships which determine how many miles per year, which bus is being used, and what is the associated variable cost of operation and maintenance and how this would change if more (or less) buses are bought and retired etc. Clarification of some of these basic ingredients is the subject matter of the present section.

Preparation of forecasts of a wide variety is part of routine planning activity by transit properties. Forecasting methods may differ in sophistication from naive trend projections to elaborate econometric models. Whichever method is used, formulation of a SARP requires estimates of:

a. Number of buses needed in future periods. (See, e.g., column 5 in Table I);

b. Total annual vehicle miles of travel for future periods, (See, e.g., Figure 1).

Estimates of the costs associated with operation, maintenance and reliability as a function of fleet composition are more difficult to come by. It is commonly assumed that vehicle age has little to do with costs of operation which do not fall into the "maintenance" category. (Fuel comsumption, driver wages, etc.). The dependence of maintenance cost on vehicle age and mileage will be discussed in the next section. The influence of age and accumulated mileage on vehicle reliability is to our knowledge not documented. Thus costs associated with reliability (towing, vehicle reserve, service disruption etc.) can not at present be accounted for. Research in this area is continuing.

Bus Maintenance Costs

Some costs associated with the maintenance of a bus fleet are largely independent of the fleet age profile and the details of fleet utilization. (e.g. allocated costs, cleaning, tyre grooving etc.). This component of maintenance cost should exert no influence on the formulation of bus acquisition and retirement programs. Thus, in what follows, only those items of maintenance are considered which vary with vehicle age.

Detailed accounting information on such maintenance costs was obtained from the Toronto Transit Commission, the Ottawa-Carleton Regional Transit Commission and the Guelph Transportation Commission. On its basis estimation equations for components of maintenance costs were derived. These are illustrated (Equations 1-4) for a specific vehicle type (GMC bus, Model 5303, seating 41 passengers).

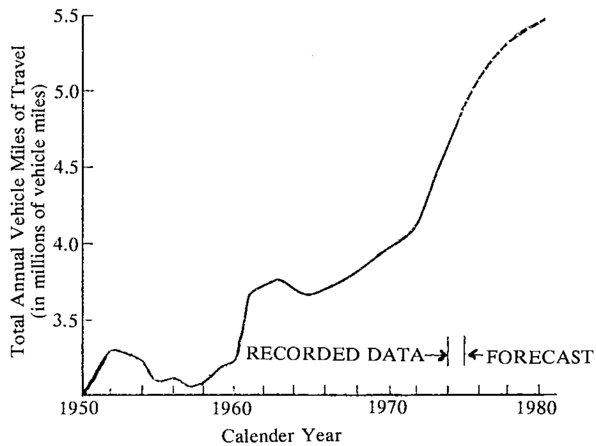

Figure 1 - Annual Vehicle Miles of Travel. Recorded Data Based on: Annual Report 1974, London Transportation Commission.

Let

TC_{ijk}	be the annual cost of bus maintenance during calendar year i when the age of the vehicle is j and its annual mileage is k.
ELH	Number of Labour Hours spent annually on Engine maintenance of an (average) bus.
BLH	Number of Labour Hours spent annually on Body maintenance of an (average) bus.
EM	The cost of parts and Materials spent annually on the maintenance of the Engine of an (average) bus estimated in 1972 dollars.
BM	The cost of parts and Materials spent annually on the maintenance of the Body of an average bus estimated in 1972 dollars.
AGE	Age of vehicle (years after purchase) at end of year for which information on annual basis is given.
ANN. MILEAGE	Annual number of vehicle miles averaged over vehicles of a group.

Then,

TC_{ijk} = [(ELH(AGE=j, ANNUAL MILEAGE=k) + BLH(AGE = j)] x (Wage Rate for Year i) + [EM(AGE =j, ANNUAL MILEAGE =k) + BM (AGE = j)] x (Material Cost Index for Year i)

[(ELJ(AGE=j, ANNUAL MILEAGE=k) + BLH(AGE=j)] x (Wage Rate for Year i) +
[EM(AGE=j, ANNUAL MILEAGE=k) + BM(AGE=j)] x (Material Cost Index for Year i)

86 + 38.05 (AGE) for AGE < 6 years
24 + 0.009224 (ANN. MILEAGE) Otherwise ... 1

22 - 9.4 (AGE-0.5) + 6.75$(AGE-0.5)^2$-0.3528 $(AGE-0.5)^3$ for AGE < 13 years
156 Otherwise ... 2

136 + 201.87 (AGE) for AGE < 6 years
771+0.004955 (ANN. MILEAGE) Otherwise ... 3

26+27.3 (AGE-0.5) + 4.02 $(AGE-0.5)^2$ - 0.3700 $(AGE-0.5)^3$ for AGE < 13 years
365 Otherwise ... 4

Information on different vehicle types as well as other details are given in reference 3. Figure 2 serves to illustrate the association of the average annual vehicle mileage with vehicle age and also the variation of the total maintenance cost per vehicle with age for the given average annual mileage.

Determination of Annual Vehicle Mileage

It appears that the cost of maintenance of a bus depends on its utilization which is in turn measured by "annual vehicle mileage". The annual mileage of a specific vehicle is dictated by two factors. Firstly, by the diurnal pattern by which vehicles are inserted into and removed from service. (See e.g., Figure 3). Secondly, on

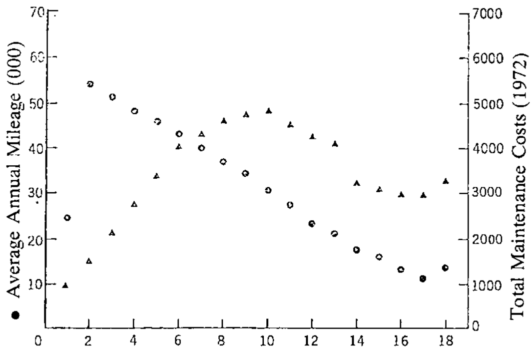

Figure 2 - Maintenance costs and Average Annual Mileage for a "Fleet Average" vehicle (Toronto Transit Commission)

the prevailing fleet composition which determines largely when the specific vehicle will be called on and how long it will remain in the shift.

The concept is best illustrated by example. Consider the vehicle utilization pattern for the Toronto Transit Commission depicted in Figure 3. Normally, the shiny new vehicles will serve the bottom part of the bus requirement graph whereas the veteran buses will be called on to cover the peaks. The shaded portions of the graph represent the share of the service burden carried by the youngest and the oldest 10% of the fleet. Thus, derived from the daily utilization pattern (Figure 3) is the relationship between the proportion of fleet miles performed and different segments of the fleet, as shown in Figure 4. As may be seen, the 10% of the fleet composed of the newest vehicles performs some 18% of the total annual mileage whereas the 10% of the fleet containing the oldest vehicles perform only some 3% of the total annual mileage.

Fleet Maintenance Cost Estimation

Thus, to obtain a sensible estimate of the fleet maintenance cost for a certain period,

1. Convert the applicable daily utilization pattern into an equivalent graph, showing duration of service vs. proportion of fleet in service for that duration of time.
2. Allocate annual fleet miles to vehicles using the equivalent graph from (1) and assuming that normally younger vehicles are assigned longer hours of service.
3. Calculate the cost of maintenance for each age group of vehicles.
4. Aggregate the maintenance costs over all age groups.

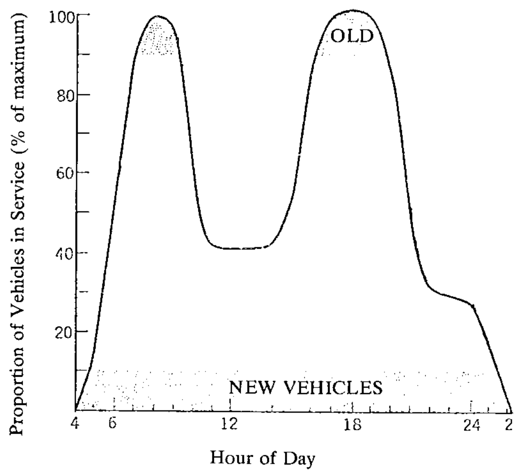

Figure 3 - T.T.C. Daily Bus Utilization (April - May, 1972).

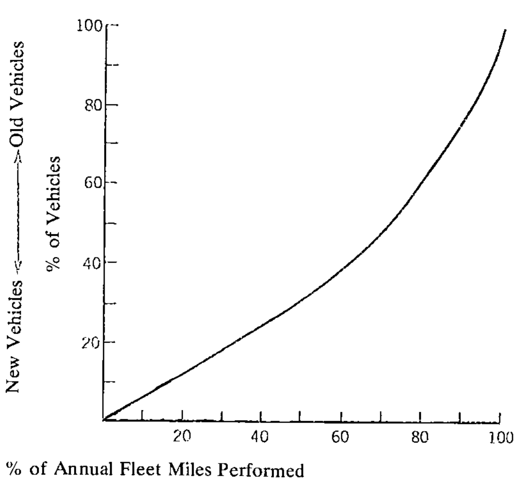

Figure 4 - Proportion of Annual Fleet Miles Performed by Proportions of the Fleet.

Consider, e.g., the fleet age profile in column 2 of Table II. (This will be shown to be the fleet age profile prevailing during 1975 in an example used in the later part of this paper). The annual fleet vehicle miles for 1975 are 4,850,000 (Figure 1). Using the proportions of vehicles by age group given in column 3 and Figure 4, the proportion of annual fleet miles assigned to each age group is determined. Using now the annual mileage of an average vehicle by age group as determined in column 5, the average annual cost of maintenance can be calculated from Equations 1-4. Multiplied by the number of vehicles in each age group (column 7) the sum represents the total fleet maintenance cost for 1975.

It appears then that a tool for the estimation of fleet maintenance costs has been forged. It remains to specify the machinery by which all sensible acquisition and retirement options can be examined and evaluated.

THE BUS ACQUISITION AND RETIREMENT MODEL

Consider the bus requirements specified in Table I. During, say, 1975, a total of 18 buses need to be added to the fleet. This could be accomplished by acquiring just 18 new buses and no retirements. Alternatively, one could purchase 19 new buses and retire one old vehicle; or buy 20 and sell 2 etc. The entire range of options is conveniently represented in tabular form. In Table III, line 1 represents the SARP in which no buses are retired throughout the duration of the program. The shaded entries correspond to the SARP embodied in Table I.

The total number of SARPs which can be formulated is given by the number of lines in Table III raised to the power of the number of periods for which the SARP is being prepared. When represented in this manner, the computational problems associated with the search for a set of good SARPs do not appear formidable. Even explicit enumeration by brute force appears feasible. As

Table II - Fleet Maintenance Cost Estimation

1	2	3	4	5	6	7
Age Group (Years)	Number of Vehicles In Group	Proportion of Vehicles in Group	Proportion of Fleet Miles Assigned to Group	Annual Mileage of on Vehicle (Miles)	Average Annual Cost of Maintenance per Vehicle $	Average Cost of Maintenance for Group $
0- 1	20.000	0.148	0.255	61770.	937.512	18750.240
1- 2	11.000	0.081	0.135	59305.	1442.640	15869.030
2- 3	7.500	0.056	0.083	53424.	2012.036	15090.260
3- 4	7.000	0.052	0.070	48402.	2631.080	18417.550
4- 5	7.000	0.052	0.063	43668.	3285.156	22996.080
5- 6	9.000	0.067	0.072	38629.	3959.641	35636.760
6- 7	10.000	0.074	0.069	33270.	4124.426	41244.250
7- 8	10.000	0.074	0.059	28388.	4062.414	40624.130
8- 9	8.500	0.063	0.043	24515.	4035.786	34304.170
9-10	7.000	0.052	0.031	21702.	4032.838	28229.860
10-11	3.500	0.026	0.014	19992.	4041.444	14145.050
11-12	2.500	0.019	0.010	19084.	4029.510	10073.770
12-13	2.500	0.019	0.009	18364.	3946.541	9866.348
13-14	5.000	0.037	0.018	17342.	3342.646	16713.220
14-15	7.500	0.056	0.024	15777.	3251.454	24385.890
15-16	5.500	0.041	0.016	14305.	3165.719	17411.450
16-17	5.500	0.041	0.015	13182.	3100.288	17051.580
17-18	2.500	0.019	0.006	12423.	3056.122	7640.305
18-19	0.000	0.000	0.000		2332.399	0.000
19-20	0.000	0.000	0.000		2332.399	0.000
20-21	2.500	0.019	0.006	11976.	3030.081	7575.199
21-22	1.000	0.007	0.002	11674.	3012.436	3012.436
22-23	0.000	0.000	0.000		2332.399	0.000
23-24	0.000	0.000	0.000		2332.399	0.000

Fleet Maintenance Cost $ 399,037.

Table III - Representation of Acquisition and Retirement Options

	(1)		(2)		(3)		(4)		(5)	
Year	1975		1976		1977		1978		1979	
Net Additions	18		8		3		4		6	
	A	R	A	R	A	R	A	R	A	R
1	18	0	8	0	3	0	4	0	6	0
2	19	1	9	1	4	1	5	1	7	1
3	20	2	10	2	5	2	6	2	8	2
4	21	3	11	3	6	3	7	3	9	3
5	22	4	12	4	7	4	8	4	10	4
6	23	5	13	5	8	5	9	5	11	5
7	24	6	14	6	9	6	10	6	12	6
8	25	7	15	7	10	7	11	7	13	7
9	26	8	16	8	11	8	12	8	14	8
10	27	9	17	9	12	9	13	9	15	9
11	28	10	18	10	13	10	14	10	16	10
12	29	11	19	11	14	11	15	11	17	11

A – Acquisitions R – Retirements

will become evident, significant computational shortcuts are available.

Each of the many SARPs represented by Table III is associated with a unique fleet composition (assuming that the oldest vehicles are retired first). Column I of Table IV represents the fleet age profile for the London Transportation Commission prevailing at the end of 1974. The proposed acquisitions and retirements embodied in Table I yields for the period 1975-79 the fleet composition given in columns 2-6 of Table IV. The first line always contains the newly acquired buses; the remaining groups are shifted one line down for each year; the oldest buses are retired.

Selection of a specific SARP from Table III has the following consequences:

1. It determines the fleet age profile for all periods of the program.
2. It implies a stream of expenditures for acquisition of new buses as well as a stream of receipts from the resale of old ones.
3. It determines the cost of fleet maintenance as influenced by the fleet age profile prevailing during the periods of the program.

Table IV - Fleet Age Profiles

Age Group (Years)	Number of Vehicles in Age Group at the end of					
	(1) 1974	(2) 1975	(3) 1976	(4) 1977	(5) 1978	(6) 1979
0- 1	15	25	15	14	12	11
1- 2	7	15	25	15	14	12
2- 3	8	7	15	25	15	14
3- 4	6	8	7	15	25	15
4- 5	8	6	8	7	15	25
5- 6	10	8	6	8	7	15
6- 7	10	10	8	6	8	7
7- 8	10	10	10	8	6	8
8- 9	7	10	10	10	8	6
9-10	7	7	10	10	10	8
10-11	0	7	7	10	10	10
11-12	5	0	7	7	10	10
12-13	0	5	0	7	7	10
13-14	10	0	5	0	7	7
14-15	5	10	0	5	0	7
15-16	6	5	10	0	5	0
16-17	5	6	5	8	0	0
17-18	0	5	4	0	0	0
18-19	0	0	0	0	0	0
19-20	0	0	0	0	0	0
20-21	5	0	0	0	0	0
21-22	2	0	0	0	0	0

All the aforementioned consequences can be quantified by methods described in this paper. However, as each of the very many SARPs is now characterized by a long string of measures of performance, the need exists to separate the wheat from the chaff.

Constraints

Constraints arising out of practical consideration serve the useful purpose of eliminating from further analysis alternatives which can not be implemented. Two constraints will be considered.

1. The cost of acquisition of new vehicles during any period contained in the program can not exceed the budget allotment for purchase of capital equipment. (The same constraint can be used to introduce limitations on availability of equipment etc.).
2. The cost of fleet maintenance can not exceed the budgetary allotment for that purpose during any of the periods contained in the program.

In some situations additional constraints may be applicable. The aforementioned two, however, seem to capture the most common concerns.

The first constraint is easy to comply with. If, e.g., the maximum number of buses that could be considered for acquisition during 1975 is 26, no SARPs containing more than 26 buses are feasible. Thus, column 1 of Table III can be terminated at the heavy line. The heavy line in Table III indicates that the largest number of acquisitions to be considered throughout the program are 26, 17, 14, 15 and 14.

The second constraint sets limits to the cost of fleet maintenance. Consider, e.g., the SARP indicated by the shading in Table III. Assume that the fleet maintenance cost associated with it does nog exceed the limits in any period. The next SARP to be considered in the search is one which retains the same entries in all columns, save column 5. Here the number of acquisitions is changed from 11 to 10. Assume that now the fleet maintenance cost limit for 1979 is exceeded. Surely, all SARPs which have in 1979 even less acquisitions that 10 (while retaining unchanged entries in all other columns) need not be considered. Two conclusions follow. First, that the enumeration search should commence at the lower boundary of Table III. Second, that the systematic search proceed in the upward direction till the maintenance cost limit is violated.

Narrowing the Choice

Ordinarily, in spite of the constraints, admissible options are many. Consequently, additional criteria must be invoked to narrow the choice.

The period by period information on fleet maintenance costs, cost of acquisitions and receipts from bus resale are easily converted to present values and aggregated. The only other relevant aspect of the choice of a SARP is the fleet age profile at the end of the program.

The younger the fleet at that point in time, the better the heritage for future programs.

It is easy to envision what form the relationship between the present value of the aggregate cost and the fleet age profile at the end of the program will take. As more new buses are acquired, the present cost of new acquisitions (less resale) increases, the present cost of fleet maintenance drops and the fleet delivered at the end of the program is generally younger. (Figure 5). Obviously, options to the right of point 1 are inferior on two counts. Firstly, they have a higher aggregate cost than the alternative represented by point 1.

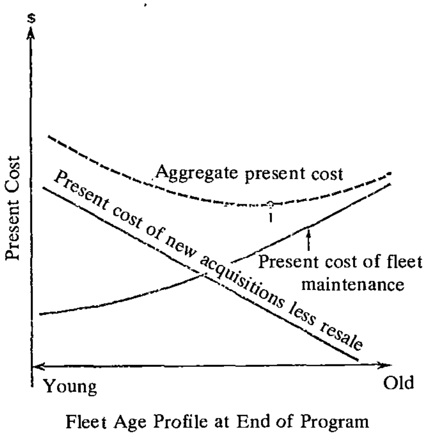

Figure 5 - Relationship between Aggregate Cost and Fleet Age Profile at End of Program.

Second, they deliver a generally older fleet at the end of the program. This observation translates into the algorithmic search procedure as follows: The search begins with the youngest feasible fleet. This corresponds to the extreme left in Figure 5 and to the lower boundary of Table III (as before). The search will be discontinued when the aggregate present cost commences to increase while the fleet age profile continues to deteriorate.

The range of choice is now narrowed to options which are to the left of point 1 in figure 5. Some of the options contained in this range may again be shown to be inferior to others. Towards this end, a compact characterization of the fleet age profile is needed. Management would most likely prefer "average fleet age" as a measure of fleet age profile quality. Alternatively, "annual cost of fleet maintenance" or "fleet resale value" could be used. In the following, "average fleet age" will serve as a proxy for the quality of the fleet age profile at the end of the program.

Each of the remaining SARPs can then be described by two numbers:

1. Average Fleet Age at end of program,
2. Aggregate present cost.

The complete set of options can be represented as in Figure 6. Evidently, SARPs labelled 1-6 dominate the other options. Thus, only the labelled options need to be considered by management.

ILLUSTRATION

It remains to bring the illustrations used throughout this paper to their conclusion. The objective is to generate a set of SARPs for the period 1975-1979 for the initial fleet age profile shown in column 1 of Table IV and using the cost and limit information of Table V.

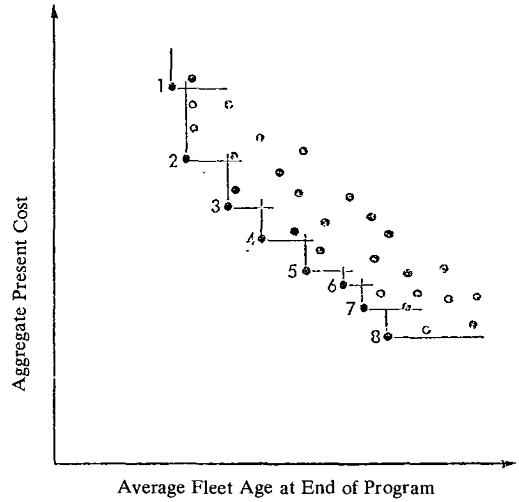

Figure 6 - Cost-Effectiveness

Alternative 1, being the least restricted by allowable acquisititions and maintenance costs represents a broad range of options. Point A, e.g., will yield an average fleet age of 7.5 years at the end of 1979. The present cost of maintenance, acquisition and resale of this alternative is \$5.492 million. The SARP is implemented by acquisition of 18, 9, 12, 13, 13 new buses during the corresponding years of the program. The associated number of retirments is 0, 1, 9, 9, 7. As during the third and fourth period of the program the maximum number of acquisitions is reached, relaxation of this constraint could be considered in order to reduce cost. Point B in Figure 7 implies an average fleet age of 8.0 years at the end of 1979. The present aggregate cost of this alternative is \$5.257 million. It can be implemented by acquiring 18, 8, 11, 7 and 15 new buses during the corresponding years of the program.

Alternative 2 has a lower maintenance cost limit and thus SARPs with terminal average age higher than 7.3 years can not be attained. Alternative 3 is also restricted by the same low maintenance budget. Simultaneously, budget limitations for the acquisition of new buses are also in effect. This limits the left hand branch of the cost effectiveness curve for alternative 3.

DISCUSSION

A quantitative tool for the formulation of Strategic Acquisition and Retirement Programs has been developed. It is sufficiently versatile to allow exploration of a fairly wide range of options and assess the sensitivity of the solutions to various budgetary constraints.

The major shortcoming of the method at present resides in the lack of quantitative information on the costs associated with fleet reliability and the functional relationship between reliability and fleet age profile.

REFERENCES

1. The Cleveland Transit System: **Optimum Bus Age Study.** W.C. Gilman Inc., Cleveland, Ohio, September 1970.

2. W.B. Tye: **The Economic Costs of the Urban Mass Transportation Capital Grant Program,** Ph.D. Thesis, Department of Economics, Harvard University, October 1969.

3. E. Hauer: **Maintenance Cost of Buses for Economic Life Studies,** Ontario Ministry of Transportation and Communications, O.J.T. & C. Research Project T-31, October 1974.

Table V - Input Data for the Generation of SARPs

Period number (1)	Net additions (2)	Max. no. of acquisitions (3)	Annual fleet miles (4)	wage rate (5)	Material cost index (6)	Maintenance cost limit (7)	Cost of new bus (8)
1	18		4850000.	5.70	1.15		57000.
2	8		5020000.	6.05	1.20		62000.
3	3		5160000.	6.40	1.25		68000.
4	4		5280000.	6.75	1.30		75000.
5	6		5360000.	7.10	1.35		82000.

Columns 3 and 7 of Table V are left blank intentionally as the following alternatives will be tried out.

Alternative number	Max. no. of acquisitions (3)	Maintenance cost limit (7)
	27	500000.
	17	550000.
1	12	600000.
	13	650000.
	15	700000.
	27	500000.
	17	550000.
2	12	600000.
	13	600000.
	15	600000.
	26	500000.
	16	550000.
3	11	600000.
	12	600000.
	14	600000.
	26	500000.
	16	550000.
4	11	600000.
	12	650000.
	14	700000.

The corresponding cost-effectiveness curves are shown in Figure 7.

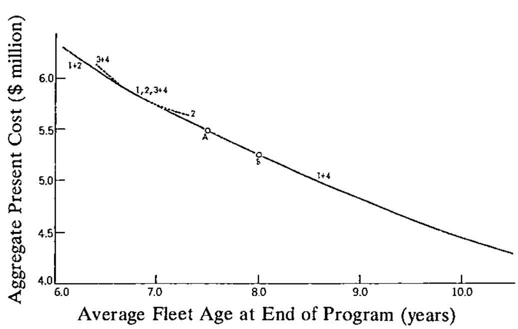

Figure 7 - Cost effectiveness curves for alternatives 1 - 4.