Use of Life-Cycle Cost Analysis in Transit Capital Overhaul/Replace Decisions—An Application to the PATH Railcar Fleet

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As fleets of rail cars age and become increasingly costly to maintain, two options are available to transit properties: conduct a major overhaul or replace with new cars. In a 1984 study for the Port Authority (of New York and New Jersey) Trans-Hudson Corporation (PATH), an in-depth engineering evaluation and life-cycle cost analysis was conducted for a portion of the PATH fleet. Ten- and twenty-year overhaul programs for existing cars were compared with a new car purchase in a life-cycle cost framework. The results of the analysis showed the new car purchase option to be most cost-effective under most combinations of assumptions on future conditions. PATH subsequently made a decision to buy new cars, and these are now in operation. Described in more detail in this paper is the analysis conducted for PATH, including cost estimate procedures, inflation and discount rate assumptions, and methods for estimating residual value. The results of extensive sensitivity testing are discussed, including the issue of what can and cannot be generalized to other studies. Use of life-cycle cost analysis was found to be effective and useful in this application and was seriously considered by PATH and Port Authority management in their decision making. Applications to other systems should be encouraged. These will be enhanced through further research and development of methodologies for estimating operating and maintenance costs.

The development of policies, procedures, and analytical tools for managing capital reinvestment in the transit industry must consider—among a myriad of other issues—the specific needs of those who seek answers to the question of whether an item should be either replaced or overhauled. This basic issue raises related questions of cost, timing of investment (prioritization), and quality of the resulting product. One analytical tool that provides a good deal of help in addressing many of these questions is what is commonly known as "life-cycle cost analysis" (LCC).

A form of economic analysis, life-cycle cost analysis has seen increasing use in recent years as a decision tool for new construction and capital equipment procurement. First documented and promoted by the U.S. government in the 1930s, LCC is an analytical framework that considers the full range of costs of construction or procurement over the entire anticipated life of the item in question, including:

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- Acquisition or construction,
- Installation,
- Operation and maintenance, and
- Disposal.

Until 1978, the U.S. Department of Defense and the General Services Administration were the principal U.S. government proponents of LCC techniques. At least one study has addressed LCC in transit technology selection (*1*); however, it was not until 1978 that the Surface Transportation Assistance Act included language stating for the first time that the acquisition of transit rolling stock "may be awarded based on considerations of performance, standardization, life-cycle costs and other factors. . ." (Sec. 12(b)(2), "Rolling Stock Acquisition Contracts"). Studies were commissioned by UMTA, forums for transit operators and equipment suppliers were convened by the American Public Transit Association (APTA), and several procurement contracts for advanced-design buses were awarded based, in part, on the results of a life-cycle cost analysis (*2*). LCC was held to be useful in reducing total lifetime costs in situations where (a) downstream costs are large relative to first costs and (b) real procurement alternatives exist. Used effectively, LCC was held not only to reduce costs, but also to lead to improved design and operation (*3*).

In the early 1980s, it was reported that over 80 percent of the transit industry respondents at UMTA hearings testified in opposition to required LCC analysis for rolling stock procurement actions (*4, 5*). The consensus at the hearings was that while LCC was not inherently flawed, it was difficult to use in an effective way. Principal drawbacks listed include:

- Lack of adequate cost and performance data,
- Uncertainty about future cost conditions, and
- Fundamental problems with certain analytical definitions which can lead to ambiguous results and conclusions.

It was felt that conflicts with manufacturers and other problems would abound as a result of the application of the LCC approach in situations where the lack of consistent guidelines or adequate data prevented defensible conclusions.

In evaluating the controversy surrounding LCC, it should be noted that, heretofore, practical applications and discussions of

LCC have dwelled mainly on building and other physical plant designs and on procurement of new equipment. Also, some attention has been given to the LCC benefits of improved rail car maintenance (*6*). A related, but strikingly different, issue for transit operators, among others, is the disposition of aging capital equipment where major overhaul or reconstruction is a viable option. The question is this case in not which of two new rail cars would incur the lowest life-cycle costs, but whether rebuilding a structurally sound rail car would be a more cost-effective solution to providing equivalent service. Although an increasing number of transit properties are confronting the choice of retaining or disposing of aging portions of their fleets, very limited use of LCC to test this question has produced mixed results, and there is no conclusive body of evidence to support or deny the efficacy of using LCC in this context.

Presented in this paper is a discussion of the procedures used and findings obtained in a 1984 study conducted for the Port Authority (of New York and New Jersey) Trans-Hudson Corporation (PATH) to determine if PATH's fleet of 47 K-cars then in revenue service should be rehabilitated to unrestricted service or if they should be replaced with new cars. The study combined a detailed engineering assessment of the existing K-car fleet with a full LCC analysis of the rehabilitation and replacement options. It is the intent of this paper to report and comment on the performance of LCC in this application, focusing specifically on the utility of the technique in questions of rehabilitation versus replacement.

STUDY PURPOSE AND APPROACH

In 1984, the PATH transit system operated a fleet of transit vehicles that had been procured in stages since the mid-1950s. The oldest vehicles in the PATH fleet were its 47 K-cars, first placed in service in 1957. More recently, six of those cars had been taken out of revenue service and used as "work cars" (cars used to ferry workers, equipment, and supplies for maintenance of system components, such as track, power, and signals). With one collision-damaged car out of service, 40 cars remained in revenue service at that time.

To address the problems of a spiraling rate of maintenance incidents and in-service failures of its K-car fleet, PATH commissioned a study to consider the following alternatives:

- *Alternative 1*: Rehabilitate the existing K-car fleet of 47 cars to add 10 years of useful operating life, and purchase seven new dedicated work cars to replace six K-cars and one other car now used for work service.
- *Alternative 2*: Rehabilitate the 47 K-cars to add 20 years of useful operating life; purchase seven new dedicated work cars as in Alternative 1.
- *Alternative 3*: Procure 47 new PA4 cars to replace the K-car fleet for revenue service. Retain all or a portion of the K-car fleet for use as work cars. (There is no need to procure new work cars with the K-fleet available for conversion to this purpose.)

In these alternative actions, two different levels of rehabilitation were considered against one procurement action. An additional facet of the study was to determine the effect of larger buys of new cars (80 and 100) on the unit cost of a new car. In light of growing passenger demand, the continued use of K-cars for work service was considered unacceptable in the event the K-car fleet was to be rehabilitated for revenue service. Thus, the rehabilitation alternatives included the purchase of seven dedicated work cars so that the revenue fleet could be brought up to 47. The procurement alternative did not include purchasing work cars because the entire K-car fleet would then be available for work service. The inclusion of work cars in the rehabilitation alternatives increased the total life-cycle costs for those alternatives but did not change the outcome under most assumptions.

Using the LCC framework, all costs—rehabilitation or procurement, maintenance, operations (electric power), and interim overhauls—were compared for the three alternatives in question for a common period of time (the "analysis period" or "life cycle") to determine the alternative requiring the lowest total expenditure over the time period. The analytical framework used in assessing total life-cycle costs was discounted cash flow, where discounted present values of costs incurred during the analysis period were calculated and then summed. The identification of the most efficient alternative was based, therefore, on the sum of the discounted present values of all life-cycle costs.

[Note that it is also possible to calculate what is often termed the "equivalent annual cost" of a life-cycle cost, as well as determine the internal rate of return of a stream of benefits and costs. Both methods are used when service levels, as well as other benefits, are not the same for all alternatives. Equivalent annual cost is useful in determining the cost of a unit of output (often calculated in annual periods), while the internal rate of return measures the "return" (profit) on a series of capital and operating expenditures of a projected stream of benefits, monetary or otherwise. The three alternatives were defined so as to produce essentially equivalent levels of service; benefits, therefore, were not quantified. Given the analytical purpose of assessing only the cost implications of the alternatives, the use of the sum of present values of total life-cycle costs was judged equivalent or superior to the other two methods, and it was used exclusively.]

COST ESTIMATES

The following cost elements were estimated in determining total life-cycle cost:

- Capital—rehabilitation or procurement contract, ancillary, and financing;
- Annual maintenance—labor;
- Overhaul—major and minor; and
- Annual operating—electric power.

Costs were first estimated in terms of constant 1983 dollars (based on 1983 prices) and scheduled over the analysis period (project life) by year of anticipated occurrence. Thus, for example, the total capital cost of procuring a new fleet of cars was distributed over the number of years appropriate to a purchase contract of that size. Interim overhauls of car fleets were scheduled in appropriate years based on standard practice for rail car maintenance.

Capital Costs

The total costs associated with rehabilitation of the K-cars and procurement of new work cars and PA4 cars are given in Table 1, expressed in terms of 1983 prices. The contract cost represents the payment to a car builder or rehabilitation contractor, including labor, materials, performance bond, insurance transportation, and spare parts. Ancillary costs include all "soft" costs, including specification writing, contract monitoring, and testing. Contract monitoring includes engineering staff as well as general administration.

TABLE 1 TOTAL ESTIMATED CAPITAL COSTS BY CAR TYPE AND ALTERNATIVE

Car	Contract Cost: Unit[a] ($)	Contract Cost: Fleet[b] ($ millions)	Ancillary Costs[c] ($ millions)	Total[c] ($ millions)
K (10-year rehabilitation)	471,000	24.9	2.2	27.1
K (20-year rehabilitation)	521,000	27.5	2.3	29.8
Work car	1,452,000	12.0	4.1	16.1
PA4	995,000	52.6	5.3	57.6

NOTE: Data presented in 1983 dollars.

[a]Does not include contingency and spare parts. See text.

[b]Includes the cost of contingency and spare parts.

[c]Does not include financing.

When including costs of contingency and spare parts, the costs became $529,000 per K-car 10-year rehabilitation, $585,000 per K-car 20-year rehabilitation, $1,709,000 per work car, and $1,118,000 per new PA4 car. A contingency rate of 5 percent was used for the K-car rehabilitation costs. A higher contingency rate of 7 percent was used for the new car programs—work and revenue—since they would have longer lives and would have the possibility of a foreign exchange component.

PA4 car basic contract costs were estimated for purchase quantities of 80 and 100 cars. For 80 cars they are $959,000 and for 100 cars, $941,500. These costs represented a 3.62 percent and 5.43 percent reduction, respectively, on the estimated contract cost for 47 cars.

The K-car rehabilitation costs and scheduling were developed by the project team based on an in-depth examination of the condition of the K-car fleet. These costs were supported by preliminary estimates submitted by car repair shops. PA4 car and work car procurement costs were derived from a comparative price analysis of recent car purchases for cars similar to the PA4.

Maintenance Costs

Maintenance costs for the rehabilitated K-car and the new PA4 car were developed from historical PATH data. The findings (in 1983 dollars) are as follows:

Car	*Fixed*	*Variable*	*Total*
Rehabilitated K-car	18,100	13,800	31,900
PA4 car	18,100	8,000	26,100

In addition, the variable portion of the maintenance costs for each car type was forecast to increase in real terms at about 6 percent per year, based on historical PATH maintenance data. Note that maintenance, overhaul, and power costs for work cars are common to all alternatives and therefore were excluded from the analysis.

Interim Overhaul Costs

Interim overhauls are performed on a periodic basis to restore car reliability and reduce regular maintenance costs. Two levels of overhaul (minor, major) were assumed for each of the car fleets according to a schedule (year of car life) by alternative (Table 2). A fourth overhaul (minor) was added to Alternative 3 in Year 28 of car life when a 35-year analysis period was assumed during a sensitivity test.

TABLE 2 PROPOSED OVERHAUL SCHEDULE

	Minor (years)	Major (years)
Alternative 1		
K	None	None
PA4	7, 14	21
Alternative 2		
K	None	None
PA4	7, 14	None
Alternative 3	7, 14	21

Overhauls in the seventh, fourteenth, and twenty-eighth years were estimated to cost approximately $125,000 (1983 prices) and include the following items:

- Propulsion—complete overhaul;
- HVAC—complete overhaul;
- Brakes—complete overhaul;
- Batteries—replace if needed;
- Communications—replace if needed;
- Trucks—overhaul, recondition, or replace; and
- Car body—overhaul, recondition, or replace.

The twenty-first year of overhaul was estimated to cost $325,000 (1983 prices) and include all items in the seventh year overhaul plus the following:

- Replacement of batteries,
- Replacement of floor covering,
- Propulsion control replacement,
- Seat replacement,
- Sidewall replacement (as needed),
- Side and end door replacement,
- Draft gear rehabilitation,
- Air-conditioning system replacement,
- Brake system replacement,
- Wiring replacement (large scale),
- Operator's cab refurbishment,
- Communication and PA system replacement.

The effect of the scheduled interim overhauls would not be to lower the rate of increase in operations and maintenance costs, but rather to "rejuvenate" the car. In other words, after each overhaul the car would "become younger" and its maintenance costs would move downward and to the left on the cost curve roughly as follows:

Overhaul Year	*Variable Maintenance Cost in Following Year Same As*
7	Cost in Year 3
14	Cost in Year 11
21	Cost in Year 16
28	Cost in Year 25

Power Costs

Both the rehabilitated K-cars and the PA4 cars would be expected to incur the same labor costs. However, since the K-cars are approximately 10,000 lb heavier than the PA cars, the K-car would require more power to operate. Using (a) historical PATH power costs, (b) published electrical power rates by PSEG (the PATH power supplier), (c) PATH test data on power consumption per mile, (d) internal PATH analysis on costs per 1,000 lb-mi, and (e) average annual car usage yielded an average K-car power usage differential of about $900 (in 1983 dollars) per car per year:

Car	*Total*
Rehabilitated K-car	8,011
PA4 car	7,105

Financing Cost

Capitalized Interest

Most capital expenditures for K-car rehabilitation, PA4 car procurement, and new work car procurement were assumed, for this analysis, to be financed through regular Port Authority revenue bonds. At the time of the study, the Port Authority's average cost of capital was approximately 10 percent. Accordingly, a 10 percent "finance cost" or allowance for capitalized interest during construction was added to the direct contract and associated non-Port Authority ancillary costs. In effect, this 10 percent finance cost represented this project's pro rata share of the total finance cost of larger, multipurpose bond issues. Finance costs were calculated as 10 percent of the outstanding debt (or drawdown) in any given year during rehabilitation or procurement. Additionally, it was assumed that all monies required during the year would be obtained as of January 1 of that year.

Safe Harbor Leasing

One of the financing tools available to the Port Authority in 1984 was Safe Harbor Leasing (SHL), which allowed a private, taxable concern to purchase cars, take various tax benefits from such a purchase, then lease the car back to the Port Authority. Both entities would share in the tax benefits. This leasing mechanism would allow the operating authority such as PATH to reduce its purchase costs by anywhere from 10 to 25 percent, with the actual percentage dependent upon the length of the lease, prevailing interest rates, and the financial position of the purchasing entity.

The mechanism was applicable to the rehabilitated K-car as well as the PA4 and work cars. It should be noted that in order for the Port Authority to take advantage of this mechanism, cars were required to be in service by December 31, 1987. According to the proposed procurement and rehabilitation schedule, this deadline could be met (and was met) for all alternatives. As such, a range of "percent savings" realized with Safe Harbor Leasing was postulated.

ESTIMATES, ASSUMPTIONS, AND CONVENTIONS

In order to use the LCC method in a responsible manner, a variety of concerns were investigated and reviewed with PATH before incorporation into the analysis. During the course of the study, the following issues were addressed:

- Economic (useful) life,
- Analysis period,
- Residual value,
- Discount and inflation rates, and
- Sensitivity testing.

The approach taken and the reasoning behind each is now briefly outlined in the following sections.

Economic Life

The determinants of the useful life of a new rail car were studied in some detail, and it was found that a well-maintained car frame could be used for 50 years and more. Ambiguity set in, however, in the search for break-even points for various car components, and no firm determination was made of the overall scrap point of a car. A nominal 30-year life was selected to represent industry maintenance experience and to reflect the need for periodic fleet modernization.

Analysis Period and Residual Value

Life-cycle costs for all alternatives under consideration must be compared over identical time periods to make such comparisons valid. If the useful, or economic, lives of the alternatives are all the same, this poses no problem. If they are different, however, an analysis period is selected corresponding to the useful life of one of the alternatives, and a residual—or "salvage" — value must be calculated for alternatives where there is useful life in the capital stock remaining at the end of the analysis period.

An analysis period of 30 years plus procurement time (33 years) was selected for the cost accounting framework. This period is based on an analysis of industry experience and corresponds with the useful life for Alternative 3 (procure new PA4 cars).

Alternatives 1 and 2 both called for replacing the K-car fleet with new cars at the end of the projected life spans of the rehabilitated K-cars. In the case of Alternative 1, new cars (also assumed to be PA4 cars) would be purchased after 10 years, resulting in the new cars being only 20 years old at the end of the analysis period. In Alternative 2, the new cars would be bought after 20 years, making them only 10 years old at the close of the analysis period. Under Alternative 1, therefore, there would be 10 years of useful life remaining; under Alternative 2, 20 years of life would remain.

As a consequence of this structure, it was necessary to calculate residual values for the new cars purchased under

Alternatives 1 and 2. Several approaches were reviewed and it was determined that two alternative methods be considered:

- *Method A:* Straight-line depreciation, where the residual value is directly proportional to the years of life remaining, and
- *Method B:* Deferred car purchase, which calculates the "savings" (through discounting) achieved by deferring the purchase of a new car until the end of an existing car's useful life instead of purchasing a new car immediately.

Given that the fleet cost of 47 new PA4 cars was estimated to be $67.3 million (1983 dollars) inclusive of contract, management, and financing costs, the residual values of these cars at the end of the analysis period was determined (in millions of dollars with a 2 percent discount rate) as follows:

Method	*Alternative 1*	*Alternative 2*
Straight-line depreciation	10.3	21.8
Deferred car purchase	5.7	11.0

Inflation Rates

The major cost components considered in this analysis were labor, materials and services, energy (electricity), new car procurement, and overhaul costs. At issue were the rates at which the various cost components would escalate and whether the rates would be uniform or would vary among the components. Extensive research on historical and projected trends in inflation rates for each of the above cost categories was undertaken. Based on this research, it was concluded that the inflation rates given in Table 3 should be adopted for the analyses.

TABLE 3 INFLATION RATES USED IN ECONOMIC ANALYSIS, 1983–2016

Cost Category	Adopted (%)	Sensitivity Test (%)
General rate	6	4, 8
Differential rate[a]		
Labor	0	None
Materials and services	0	None
Energy	0	1
New car procurement	0	2
Overhaul	0	None

[a]Defined as the variance from the general inflation rate.

Discount Rate

Discounting is the reciprocal function of compounding. It calculates how much less a cash flow is worth today as its timing moves further into the future. When used in investment studies, the discount rate reduces the value today of future costs (and revenues) by

- The amount that can, in theory, be received from investing funds today that are not needed for cost coverage until that future date or
- The amount that is not made today because a revenue is not received until that future date.

While it is widely recognized that the practice of discounting carries some ambiguity for the public sector, its use remains appropriate where the types of costs and benefits are essentially equivalent for all alternative actions under study. The discount rate should reflect at least the following considerations:

- The overall cost of capital to the organization,
- Underlying price inflation,
- The expected return on the project above simple cost coverage, and
- An assessment of risk in the project.

There is little, if any, difference in the risk associated with the alternatives, and, therefore, this element was not considered in determining a discount rate. The discount rate for this analysis, then, was determined using financial considerations, and was based on using forecasts of inflation and the cost of capital for the Port Authority.

A discount rate of 2 percent was selected for the analysis, net of inflation. This was based on an analysis of data on the difference between inflation rates and the net cost of capital for the Port Authority over the past 15 years. Defining the discount rate in this manner meant that no general inflation was assumed in the analysis. To include forecasts of global inflation would simply require increasing the desired discount rate to equal the inflation rate plus approximately 2 percentage points—the apparent historical "spread" between inflation and the Port Authority's cost of borrowing.

FINDINGS

Life-Cycle Costs Using Primary Assumptions

The results of accumulating the net present values of life-cycle costs as described earlier are presented in Table 4. There, total costs for the 33-year analysis period are summed for major cost categories. The figures in this table are based on what were termed "primary" assumptions, namely, those assumptions considered the best predictors of future conditions. Specifically, these assumptions were

- No differential inflation;
- Six percent annual increase in real maintenance costs;
- Cost reductions due to safe harbor leasing as follows: K-car (10 year)—10 percent, K-car (20 year)—16 percent, work car and PA4 car—20 percent;
- Midpoint estimates for capital costs, as indicated in Table 3;
- 30-year life for the PA4 car; and
- A 2 percent discount rate (used to derive the figures given in Table 3).

The cost reductions due to safe harbor leasing were estimated partly as a function of the expected useful life of the car. Thus, the longer the life, the greater the value of the car, and the greater potential tax savings from leasing. (As will be shown later, the greater SHL cost savings for the new car purchase partly contributed to its selection as the preferred action for PATH.)

TABLE 4 SUMMARY OF LIFE-CYCLE COSTS FOR ALTERNATIVES 1, 2, AND 3 USING 2 PERCENT DISCOUNT RATE

	Cost ($ thousands)		
	Alternative 1	Alternative 2	Alternative 3
K-car rehabilitation	25,824	26,663	–
K-car maintenance[a]	17,901	32,793	–
K-car interim overhauls	–	9,195	–
Work car procurement	13,938	13,938	–
PA4 car procurement	53,147	43,599	51,824
PA4 car maintenance[a]	22,673	10,365	38,700
PA4 car interim overhauls	15,490	3,308	18,512
Subtotal	148,973	139,861	109,036
New car residual value (A)[b]	–10,340	–21,828	–
Total life-cycle cost (A)	138,633	118,033	109,036
New car residual value (B)[c]	–5,724	–10,995	–
Total life-cycle cost (B)	143,249	128,866	199,036

NOTES: For assumptions, see text.
[a]Includes electric power.
[b]A is straight-line depreciation.
[c]B is deferred car purchase.

Using primary assumptions, total life-cycle costs were lowest for Alternative 3 (PA4 car purchase) and highest for Alternative 1 (K-car 10-year rehabilitation). There was a progressive reduction, therefore, moving from Alternative 1 to Alternative 3. Excluding residual value, the new car purchase alternative had a life-cycle cost of some $30 million less than the next more costly alternative (K-car 20-year rehabilitation), or 22 percent. Alternative 2, in turn, had life-cycle costs $9.1 million less than Alternative 1, a difference of 6 percent.

The order of the results did not change with either method of calculating residual value. At a 2 percent discount rate, straight-line depreciation (Method A) resulted in a residual value approximately twice that obtained when using the deferred car purchase method (Method B). (This difference all but disappeared with higher discount rates.) When residual value was deducted from the total life-cycle cost of Alternative 2 using the straight-line depreciation method, Alternative 3 was still 7.6 percent (9 million) less costly over the 33-year analysis period. This spread was considerably larger (15.4 percent) when the deferred car purchase method was used.

Total life-cycle costs on a per car basis were

- K-Car 10-year rehabilitation: Method A—2.9 million, Method B—$3.0 million;
- K-Car 20-year rehabilitation: Method A—$2.5 million, Method B—$2.7 million; and
- PA4 car purchase—$2.3 million.

For purchases of 80 and 100 PA4 cars, unit (per car) life-cycle costs were approximately $44,000 and $63,000 less, respectively.

Sensitivity Analysis

The sensitivity of the principal finding—that Alternative 3 produces the lowest total life-cycle cost—to changes in key assumptions was tested extensively. In particular, the following items were tested:

- Discount rate,
- Differential inflation rates,
- Maintenance cost rate of increase,
- Return from safe harbor leasing,
- Residual value calculation method,
- Capital costs, and
- Analysis period.

Fourteen sets of assumptions were tested using a computer algorithm; each was run for five different alternatives (Alternatives 1 and 2 each required two treatments of residual value). Thus, 70 computer runs were required. (See Tables 5 and 6 for assumptions used.)

TABLE 5 ASSUMPTIONS USED IN SENSITIVITY ANALYSIS

Test	Differential Inflation	Maintenance Cost Increase	Safe Harbor Leasing	Capital Costs	New Car Life (years)
1[a]	No	Mid	Mid	Mid	30
2	No	Mid	Low	Mid	30
3	No	Mid	High	Mid	30
4	No	Mid	None	Mid	30
5	No	Mid	No K	Mid	30
6	No	High	Mid	Mid	30
7	No	Low	Mid	Mid	30
8	Yes	Mid	Mid	Mid	30
9	No	Mid	Mid	Low K[b]	30
10	No	Mid	Mid	High K	30
11	No	Mid	Mid	Low PA4	30
12	No	Mid	Mid	High PA4	30
13	No	Mid	Mid	Mid	35
14[c]	No	Low	None	Low K and High PA4	30

NOTES: See text and Table 6 for more detail.
[a]Primary assumptions.
[b]"Low K" assumptions also include low work car.
[c]"Worst case" assumptions.

In all tests, figures were calculated with discount rates of 1 percent, 2 percent, 6 percent, and 10 percent. Also, both methods for calculating residual value were used: straight-line depreciation (Method A) and deferred car purchase (Method B). A final "worst case" scenario was created for Test 14. This test included only assumptions that would favor the K-car rehabilitation alternatives over the new car purchase alternative:

- No differential inflation, minimizing the future cost of procuring a new car after the rehabilitated K-cars have been expended;
- Low maintenance cost increase factor, minimizing the gap between K-car and PA4 car maintenance;
- No safe harbor leasing for any alternative, eliminating the greater leverage afforded Alternative 3 by this device;
- Low capital cost estimates for rehabilitation of the K-car fleet and high estimates for procurement of the new PA4 cars; and
- Use of the 30-year life for the PA4 car.

TABLE 6 KEY TO ASSUMPTIONS USED IN SENSITIVITY ANALYSIS

	Low	Mid	High
Differential inflation (%)			
New car procurement		2	
Electric power		1	
Maintenance cost increase (annual) (%)	2	6	10
Safe harbor leasing (cost reduction) (%)			
K-car (10 years)	10	10	12
K-car (20 years)	14	16	18
PA4 and work car	18	20	22
Capital costs (base contract only, per car) ($ thousands)			
K-car (10 years)	400	471	510
K-car (20 years)	500	521	560
Work car	1,200	1,452	1,600
PA4 car	896	995	1,095

The results of the sensitivity tests are presented in Tables 7 and 8 using 2 percent and 6 percent discount rates, respectively. In none of the first 13 tests (including Test No. 1, primary assumptions) did the life-cycle cost for Alternative 3 exceed that for Alternative 2. Using the 2 percent discount rate, the cost for the new car purchase ranged from 35.7 percent less than the 20-year rehabilitation (Test No. 4A) to over 30 percent less (Test No. 8B). Using the 6 percent discount rate, Alternative 3 was approximately equal to Alternative 2 in Test No. 4B (no safe harbor leasing with the deferred car purchase method for calculating residual value) and was still over 10 percent less in Test No. 5A.

Only in the case of Test No. 14, where all assumptions were set to favor Alternatives 1 and 2, did the life-cycle cost of Alternative 3 exceed that for Alternative 2. Using the preferred discount rate of 2 percent, this only occurred with the straight-line depreciation method for calculating residual value; the deferred car purchase method still resulted in a lower life-cycle cost for Alternative 3. With the 6 percent rate, Alternative 3 had a higher life-cycle cost using both methods. The use of the 6 percent rate is itself a test of sensitivity and produced significant results only when combined with other assumptions established to favor the K-car rehabilitation.

Test 4A (no safe harbor leasing), using both the 2 percent and 6 percent discount rates, produced results which were very close for both the overhaul and new car purchase options. Given that SHL is no longer available to transit operators, this suggests that special care should be taken in evaluating the overall results of this study.

CONCLUSIONS

The use of LCC to assist in making an overhaul-or-replace decision for PATH rail cars proved effective in identifying the most cost-effective alternative on technical grounds. The analysis considered all relevant and significant capital and operating and maintenance costs associated with three alternative actions over a common analysis period of 33 years. Future costs were discounted to reflect the time value of money, and residual values were calculated for equipment having useful life remaining at the end of the analysis period.

TABLE 7 SUMMARY OF SENSITIVITY ANALYSES USING 2 PERCENT DISCOUNT RATE

	Cost ($ thousands)			
Test Number	Alternative 1	Alternative 2	Alternative 3	Difference Alternatives 2 and 3 (%)
1A	138,633	118,033	109,036	7.62
1B	143,248	128,866	109,036	15.39
2A	139,409	118,865	110,205	7.29
2B	144,025	129,698	110,205	15.03
3A	137,856	117,200	107,867	7.96
3B	142,472	128,033	107,867	15.75
4A	143,770	125,194	120,727	3.57
4B	148,385	136,027	120,727	11.25
5A	141,262	122,687	109,036	11.13
5B	145,878	133,519	109,036	18.34
6A	141,719	121,396	112,871	7.02
6B	146,335	132,229	112,871	14.64
7A	136,207	115,362	106,366	7.80
7B	140,823	126,195	106,366	15.71
8A	145,169	121,931	114,520	6.09
8B	165,846	165,583	114,520	30.84
9A	133,325	115,307	109,036	5.44
9B	137,940	126,140	109,036	13.56
10A	141,615	120,884	109,036	9.80
10B	146,230	131,717	109,036	17.22
11A	134,546	116,032	104,360	10.06
11B	138,883	125,864	104,360	17.09
12A	142,869	120,034	113,713	5.27
12B	147,613	131,866	113,713	13.77
13A	140,905	125,745	117,678	6.42
13B	148,207	137,014	117,678	14.11
14A	139,441	121,176	123,903	–2.25
14B	144,185	133,009	123,903	6.85

NOTE: For assumptions, see Tables 5 and 6. A is straight-line depreciation. B is deferred car purchase.

The results of the analysis indicated that PATH should act to purchase 47 new (PA4) rail cars and consider the purchase of a larger numbers of cars to secure lower unit prices and allow for growth in ridership. The new car purchase alternative was superior in 13 out of 14 sensitivity tests of assumptions, each using two methods of calculating residual value.

The recommendation that PATH purchase a minimum of 47 new cars to replace the existing K-car fleet was based solely on the analysis of life-cycle costs. It did not reflect any advantages or disadvantages that might be present relative to rail car design, fleet operations, rider amenities, and maintenance of the PATH system.

The application of LCC analysis to the PATH system provided considerable insight into the strengths and weaknesses of the procedure, including the following:

- The overhaul/replace issue is much more complex than that of straight procurement and requires considerably more data collection and analysis.
- The additional complexity notwithstanding, the approach can prove effective in presenting the long-term cost implications of the alternative actions.
- Future costs were found to be less influential in the final result than expected. Energy proved insignificant, while

TABLE 8 SUMMARY OF SENSITIVITY ANALYSES USING 6 PERCENT DISCOUNT RATE

	Cost ($ thousands)			Difference
Test Number	Alternative 1	Alternative 2	Alternative 3	Alternatives 2 and 3 (%)
1A	95,825	81,546	76,755	5.88
1B	94,618	80,881	76,755	5.10
2A	96,537	82,309	77,789	5.49
2B	95,329	81,644	77,789	4.72
3A	95,114	80,783	75,720	6.27
3B	93,907	80,118	75,720	5.49
4A	100,503	88,099	87,096	1.14
4B	99,296	87,434	87,096	0.39
5A	98,260	85,855	76,755	10.60
5B	97,053	85,190	76,755	9.90
6A	97,448	83,353	78,372	5.98
6B	96,241	82,688	78,372	5.22
7A	94,523	80,092	75,579	5.63
7B	93,315	79,427	75,579	4.84
8A	103,567	87,039	80,993	6.95
8B	103,517	88,848	80,993	8.84
9A	90,965	79,077	76,755	2.94
9B	89,757	78,412	76,755	2.11
10A	98,555	84,154	76,755	8.79
10B	97,347	83,489	76,755	8.07
11A	92,982	80,381	72,618	9.66
11B	91,924	79,774	72,618	8.97
12A	98,709	82,711	80,891	2.20
12B	97,311	81,987	80,891	1.34
13A	96,944	84,497	79,088	6.40
13B	96,738	84,325	79,088	6.21
14A	96,467	84,778	91,091	−7.45
14B	95,070	84,054	91,091	−8.37

NOTE: For assumptions, see Tables 5 and 6. A is straight-line depreciation. B is deferred car purchase.

maintenance cost differentials were only modest when compared with initial costs.

- Differential inflation rates proved to be totally insignificant following extensive research on the subject. All sensitivity tests for inflation produced nonsignificant results.
- Major concerns during the study included selecting an appropriate discount rate and developing a method for calculating residual value. While the final outcome was found to be relatively insensitive to the method used for determining residual value, the choice of discount rate was significant for ranges of six points and more.
- Obtaining useful maintenance cost data was perhaps the most difficult aspect of the analysis; however, the sensitivity of the final result to variations in maintenance costs was limited.
- The use of safe harbor leasing in the analysis may have had a significant effect on the final outcome. Future analyses that cannot consider SHL may yield different conclusions.
- In general, the use of sensitivity testing to lend support to principal findings was very successful, and it should be applied in all cases where reasonable doubts exist regarding estimates and assumptions.

While there are no explicit federal or state policies on LCC for this type of application, transit operators should consider its use, as rail car fleets continue to age and require overhaul or replacement, as part of comprehensive efforts to prioritize and program capital investment and renewal. To assist any such analyses in the future, operators should give greater attention to ways of collecting and presenting maintenance cost data. Greater standardization of accounting procedures should help this effort. Also, future studies should address the question of replacement versus overhaul before a car has reached the end of its useful life. Such analyses may yield strikingly different results from those presented here.

ACKNOWLEDGMENTS

The author wishes to acknowledge the contributions made by John Chow, Mike Henderson, and Joni Markovitz of Parsons Brinckerhoff Quade & Douglas, Inc. (PB) in conducting this study, as well as the extensive support given by others at PATH and PB. The material in this paper was presented in a somewhat different form at the 1984 APTA Rapid Transit Conference.

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Publication of this paper sponsored by Committee on Transit Management and Performance and Committee on Transportation Programming, Planning, and Systems Evaluation.