Life-Cycle Cost Analysis of Electronic Registering Fareboxes: A Case Study

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The financial analysis presented in this paper is the outcome of a revenue-service-testing demonstration project on electronic registering fareboxes conducted by the Detroit Department of Transportation (DDOT) and Booz, Allen and Hamilton, Inc. The life-cycle cost analysis uses farebox reliability, operating cost, and capital cost data generated during the demonstration. The data are further supplemented with transit industry experience in electronic fareboxes. The results of the life-cycle cost analysis can be combined with anticipated revenue changes and revenue handling expense savings attributable to the technology. Significant reduction in revenue handling expense and improvement in farebox revenue per rider were found in Detroit. Revenue handling expense was estimated to be reduced by $600,000 annually. Farebox revenue per rider was found to increase by 18 percent. The farebox reliability data presented in the paper provide useful component performance information. The failure rates found at DDOT were not extraordinarily higher than those found at other agencies with similar first generation electronic fareboxes. Electronic fareboxes currently available represent a second generation in design and can be expected to be more reliable than those tested. Regardless of the reliability, the results of the analysis show that electronic registering fareboxes are a cost-effective investment. While Detroit elected to invest in mobile crews to reduce farebox-related road calls, other approaches with considerably less expense may be appropriate. The investment is still found to be cost effective, even with the investment in mobile farebox repair crews.

The Detroit Department of Transportation (DDOT) raised the adult base fare on July 1, 1982 from 75 cents to $1.00. This fare change caused a dramatic increase in the number of dollar bills collected daily and compounded several previously recognized and growing problems:

- *Revenue losses through short fares.* Passengers increasingly inserted folded or crumpled halves of dollar bills into the circa 1940 Cleveland fareboxes. Estimated losses due to these short fares have approached $1,200/day.
- *Farebox jams and equipment damage.* The Cleveland fareboxes were not designed to handle the large volumes of dollar bills that followed the fare increase. Jams increased substantially and delays in transit service occurred as supervisors responded to road calls to unjam the fareboxes.
- *Reduced revenue security.* The inability of the current revenue handling equipment to contain the volume of bills being received led to an increase in revenue security breaches at the transit system.

To address these problems, DDOT tested in revenue service 32 bill-accepting electronic registering fareboxes. The fareboxes were procured and field tested on one route, Woodward Avenue, during the period December 1984 to May 1985. A description of the equipment tested and a summary of the field test are presented in a separate study (*1*). Field testing of the electronic registering farebox was funded by UMTA. Equipment reliability data collected during the field test form one source of data for the life-cycle cost analysis. Subsequent to the field-test analysis, life-cycle-costs revenue handling and revenue security changes were determined. This paper presents the life-cycle cost analysis and compares the results with revenue-handling expense reductions and improvement in farebox revenue.

LIFE-CYCLE COST ANALYSIS

Life-cycle cost analysis is a method for estimating the total cost of purchasing, operating, and maintaining equipment over its useful service life. The analysis combines one-time and periodic capital expenditures with the recurring expense of operating and maintaining the equipment. The analysis used for this study is based on a present-value methodology which translates future costs to the base year of 1986. In this context, the life-cycle cost analysis produces a lump-sum cost figure which can be compared with alternative capital investments to identify the most beneficial investment for DDOT capital funds.

The data used in this analysis were obtained from the DDOT farebox evaluation project conducted between December 1984 to May 1985 and from experience with electronic registering fareboxes at other transit systems. All expense data were adjusted to reflect 1986 prices using either the producers' price index or the Consumer Price Index compiled by the U.S. Department of Labor.

The life-cycle cost analysis assumes fleet-wide installation of electronic fareboxes, which would require the purchase of a total of 630 fareboxes plus spares. The analysis addresses the cost to purchase and maintain the fareboxes. Revenue handling is not a part of the equipment life-cycle cost. However, revenue handling and net financial impact were analyzed and reported to DDOT (*2*).

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INITIAL INVESTMENT REQUIREMENTS

Initial investment requirements were developed from DDOT's purchase of 32 fareboxes and auxiliary equipment for the demonstration program. The prices projected to 1986 using the transportation equipment producers' price index for 1985 and estimated for 1986 and were then reviewed with the manufacturer of the electronic registering fareboxes. Total estimated initial cost is $3,334,000 for 630 fareboxes, support equipment, and parts. The average cost per farebox is $5,292. A summary is provided in Table 1.

TABLE 1 INITIAL INVESTMENT COST SUMMARY FOR 630 FAREBOXES

Cost Component	Total Cost ($)
Fare collection equipment	2,937,000
Data processing system	113,000
Training, warranty, and documentation	30,000
Initial spare parts inventory	207,000
Maintenance equipment	11,000
Mobile crew vehicles and equipment	36,000
Total initial investment cost	3,334,000

The initial cost component of the life-cycle cost analysis includes the cost of 630 fareboxes and all initial materials and equipment to support the fareboxes as follows:

- Fare collection equipment consisting of fareboxes and installation, electronic farebox access keys, key encoder, vaults, and mobile bins.
- Data processing system to collect, aggregate, and report fare and ridership data and revenue performance indicators, encompassing central facility and remote division microcomputers, and communications.
- Training, warranty, and documentation based at $50.00 per farebox and incorporating maintenance training, operator training, warranty labor and shipping, administration, and documentation.
- Farebox spare parts and inventory to provide an initial supply of parts and materials to meet the anticipated component failure rates and maintenance requirements.
- Maintenance equipment to troubleshoot, diagnose, and repair failed farebox electrical and mechanical components consisting of three test benches incorporating variable power supplies, photoelectric cells, oscilloscopes and other meters, and simulators.
- Mobile crew vehicles and radio equipment to provide logistical support to minimize farebox road-call response time and service interruption.

A listing of required parts, quantities, and cost of the initial inventory is provided in Table 2. The quantities were derived from the failure rate data collected during April and May 1985 of the test period and by cross checking with initial spare parts inventories used by other transit systems operating electronic registering fareboxes. Total estimated cost of the initial inventory is $207,000.

A 5 percent spare rate for complete fareboxes was assumed for the estimates. Though each major component of the farebox is replaceable, complete fareboxes are needed to cover the unlikely occurrence of multiple component failures in one farebox housing or possible structural failure, or damage of the farebox frame and stand.

TABLE 2 ESTIMATE OF INITIAL SPARE PARTS AND INVENTORY COST

Item	Quantity	Unit Price ($)	Total Cost[a] ($)
Spare fareboxes—complete	32	3,890	124,000
Coin mechanism	32	500	16,000
Bill stuffer	32	225	7,000
Bill transport	32	500	16,000
Circuit board set[b]	25	1,050	26,000
Cashboxes	18	510	9,000
Coin escrow assemblies	15	180	3,000
Driver keypad	15	90	1,000
Driver display board	15	210	3,000
Miscellaneous parts	Lot	2,000	2,000
Total			207,000

[a]Rounded to nearest $1,000.
[b]Contains logic board and power module.

In cases where the failure experience of components during the farebox evaluation was much lower than anticipated, the inventory level was increased to reflect experience at other transit systems, provide a minimum number of spares for each terminal, and expedite repair time without impeding vehicle availability because of insufficient parts. It is assumed that no parts will be taken from a spare coach's farebox to repair a failed in-service farebox.

The quantity of spare cashboxes considers the auditing of individual fareboxes and component failure rates. The DDOT specified auditing rate is 10 percent of all fareboxes each month, or three fareboxes per day. This auditing rate will result in each farebox's being audited at least once a year and will require a minimum of six spare cashboxes. Twelve additional spare cashboxes will be available in the event of cracks in weldings, worn locks, or other cashbox failures.

To minimize service disruption when jams or equipment failures occur, mobile farebox repair crews will be dispatched daily by DDOT to provide quick response to farebox-related road calls. This approach to minimizing service disruption was developed during the farebox evaluation program. Other transit agencies may be able to provide the same degree of support through existing road-call crews. Concern for revenue security and terms within the labor agreement precluded DDOT's use of regular road-call crews for in-service farebox maintenance.

Three crews were assigned to cover the service area. A tentative plan for assignment of the three mobile vehicles was as follows:

- *Downtown.* A farebox crew downtown will service all routes that originate in the downtown area and most Gilbert terminal routes.
- *West Side.* The West Side crew will service Coolidge terminal, particularly the north-south routes that do not go downtown.
- *East Side.* The East Side crew will service Shoemaker terminal, particularly the north-south routes that do not go downtown.

Each of the three crews will require a radio-equipped vehicle envisioned as similar to a mini-van. In addition to being radio-equipped, each mini-van will be equipped with shelves to carry a sufficient supply of spare parts, components, and tools to perform basic fingertip repairs and change out failed components. The estimated cost of three vehicles and equipment is $12,000 each, or $36,000. The estimated service life of the vehicle is 6 years, which is half that of the farebox; a new fleet of vehicles is assumed to be required every 6 years for the purpose of the life-cycle cost analysis.

RECURRING COST ESTIMATE

Recurring costs are those expenses that occur on an annual basis. Labor is typically the largest component of recurring costs. Parts and materials consumed as part of the maintenance activities are also included. The estimate of operating expenses, presented in the following discussion, assumes that the reliability performance of the fareboxes remains similar to that experienced during the farebox evaluation in April and May 1985. The April and May 1985 period was selected since initial reliability problems with the fareboxes had been resolved and the breaking period completed.

Corrective Maintenance Labor Requirements

Central shop corrective maintenance labor requirements were estimated based on the failure rates identified during the farebox evaluation program and on repair times experienced by DDOT and other transit systems operating electronic registering fareboxes.

First, transactions between failures were determined using data compiled on mechanical and electronic component failures and passenger-caused jams during the evaluation, as presented in Table 3. The DDOT failure experience with the fareboxes may be slightly higher than with currently available electronic registering fareboxes. The relatively high failure rate can be attributed to the first generation design of the fareboxes, rigid reporting requirements for farebox failures required during the demonstration program, the one-route demonstration program design, and the high ridership levels on the test route. However, in examining experience of other transit agencies with the same generation of fareboxes, equipment-caused failure rates found at DDOT were not extraordinarily higher.

The passenger-caused failure rates experienced during the evaluation were adjusted to reflect assumed operating conditions for fleet-wide installation. Since the evaluation was conducted on only one route, passenger-caused failures were higher than if the electronic fareboxes were installed system-wide because of passenger unfamiliarity with the fareboxes. During the evaluation, passengers who infrequently use Woodward Avenue (the test route) may not have been familiar with how to insert bills, coins, and tickets into the farebox. This unfamiliarity with the farebox resulted in a higher failure rate.

Fleet-wide installation of the fareboxes, on the other hand, combined with a promotional campaign on the use of the fareboxes before installation is expected to reduce passenger-caused failures. As the ridership becomes more familiar with the electronic fareboxes, the failure rate should decline from the rates found during the evaluation program. Therefore, a 35 percent reduction in passenger-caused failures was assumed. The failure rates of the coin mechanism, bill transport, and bill stuffer components are improved by this assumption, while other components are unaffected.

Dividing this adjusted number of equipment failures into the total number of fare transactions for the same time period produces the mean transactions between failures (MTBF). The overall failure rate for the electronic registering fareboxes is 2,750 MTBF. Coin mechanisms have the worst performance, with 7,800 MTBF. The most reliable components are the display boards and coin escrows, with a failure rate of 553,400 MTBF.

Second, an estimated number of repair actions per year was determined. To do this, the estimated number of failures per year is determined by dividing the farebox failure rates (MTBF) into the estimated total fare transactions per year. The total fare transactions per year are estimated at 62,375,000 based on ridership data for January through October 1985. The estimated failures per year for each component are shown in the second column of Table 4.

Total failures per year are then separated into those repairs performed at the central maintenance shop and those performed on the road by the mobile crews. The separation of failure data used component replacement data collected during the farebox evaluation, adjusted to reflect a reduction in passenger-caused

TABLE 3 CALCULATION OF MEAN TRANSACTIONS BETWEEN FAILURES

Farebox Component	Equipment-Caused Failures	Passenger-Caused Failures	Adjusted Passenger Failures	Adjusted Total Failures	Mean Transactions Between Failures
Coin mechanism	9	96	62	71	7,800
Bill transport	47	4	3	50	11,100
Control panel	6	0	0	6	92,200
Logic board	3	0	0	3	184,500
Bill stuffer	62	–[a]	–[a]	62	8,900
Display board	1	0	0	1	553,400
Power board	5	0	0	5	110,700
Coin escrow	1	0	0	1	553,400
Cashbox	2	0	0	2	276,700
Total farebox	136	100	65	201	2,750

[a]Passenger-caused failures of the bill transport also affect the bill stuffer but are not double counted here.

TABLE 4 ESTIMATED NUMBER OF FAREBOX REPAIR ACTIONS PER YEAR

Farebox Component	Mean Transactions Between Failures	Estimated Annual Failures	Estimated Annual Failures Requiring Component Replacements (%)	Estimated Number of Repairs per Year: Performed in Central Shop	Performed on the Road
Coin mechanism	7,800	8,000	35.0	2,800	5,200
Bill transport	11,100	5,620	13.7	770	4,850
Control panel	92,200	680	66.7	450	230
Logic board	184,000	340	66.7	230	110
Bill stuffer	8,900	7,010	13.7	960	6,050
Display board	553,400	110	0	20	90
Power board	110,700	560	60.0	340	220
Coin escrow	553,400	110	0	20	90
Cashbox	276,700	220	0	40	180
Total farebox	2,750	22,650	22.5	5,630	17,020

failures. The results are an estimated 5,630 shop repairs and 17,020 road repairs, as shown in Table 4.

Next, maintenance labor is estimated by combining the number of farebox failures with the estimated mean time to repair (MTTR) each failure. The DDOT farebox evaluation program provided on-board remove and replace (R&R) repair times. Central shop MTTR data were obtained from other transit authorities. The estimated annual labor hours for repair by farebox component are provided in Table 5. An estimated 4,500 total annual labor hours are required to maintain the fareboxes. This includes 3,570 annual labor hours for central shop repairs and 910 annual labor hours for repairs on board buses by the mobile crews.

To complete the maintenance staff labor hour estimate, the total annual labor hours must be summed. An additional factor that is included in the calculation is unaccounted time. Two recent maintenance studies by Booz, Allen for the National Cooperative Transit Research and Development Program (NCTRP) and the California Department of Transportation have shown that a significant portion (25 percent) of repair staff time cannot be accounted for through the performance of specific maintenance activities and the occurrence of unaccounted time increases as fleet size increases (*3, 4*). Thus, for the estimate of DDOT maintenance staff levels, the annual labor hours have been increased by 25 percent for unaccounted time.

Total annual technician labor time is 4,460 hours, equivalent to 2.4 person-years for repair activities at the central shop associated with 630 fareboxes. A figure of 1,860 hr/person-year is used for calculation of staff size, which reflects existing DDOT vacation, holidays, sick leave, and other paid leave. This labor hour per year rate is conservative for the class of employee responsible for maintaining fareboxes since it was derived from data which included bus operator absences.

Preventive Maintenance Labor Requirements

Preventive maintenance activities include routine cleaning, adjustment, and lubrication. Manufacturer-suggested preventive maintenance intervals and labor estimates are as follows:

- Clean and inspect every 3 months, with each inspection taking 10 to 15 min/farebox.
- Adjust and lubricate every 6 months, with a duration of 35 min/farebox.

The preventive maintenance requirements produce a total of 1,550 annual technician labor hours, including unaccounted time, to support 630 fareboxes.

TABLE 5 ESTIMATED TOTAL REPAIR LABOR HOURS PER YEAR (*5*) (*1*)

	Estimated Annual Number of Repairs		Estimated Mean Time to Repair (min)		Estimated Total Labor Hours	
Farebox Component	Central Shop	On the Road	Central Shop	On the Road	Central Shop	On the Road
Coin mechanism	2,800	5,200	45	3.0	2,100	260
Bill transport	770	4,850	30	2.4	390	190
Control panel	450	230	15	3.5	160	10
Logic board	230	110	45	5.0	170	10
Bill stuffer	960	6,050	30	4.1	480	410
Display board	20	90	30	2.0	10	–
Power board	340	220	45	2.6	260	10
Coin escrow	20	90	30	5.0	10	10
Cashbox	40	180	60	2.5	40	10
Total farebox	5,630	17,020			3,570	910

Mobile Crew Labor Requirements

The analysis of failure rates and farebox reliability during the evaluation period revealed that most maintenance actions were performed by roving maintenance crews. The labor requirements and associated expense are influenced by the policy of the transit operator. DDOT's experience during the test period resulted in the decision to invest in mobile crews to keep farebox-related road calls to a minimum.

Based on this experience, mobile crew labor requirement estimates to support systemwide installation of electronic registering fareboxes are based on the following assumptions:

- One crew member assigned per shift per base area.
- Two shifts per day:
  - Morning shift, 6:00 a.m. to 2:00 p.m.
  - Evening shift, 2:00 p.m. to 10:00 p.m.
- Crews assigned six days per week year-round.

This level of coverage requires 15,000 hr of mobile crew labor or eight technicians working 1,860 hr per year. All requirements for reporting, maintenance labor, employee breaks, and unaccounted time are included in this estimate.

The analysis of repair labor per year (see Table 5) indicated an annual on-the-road labor hour total of 910 hr. Therefore, most of a mobile crew's time will be used in waiting for failures, traveling to the bus that reports farebox failure, and returning to the base location. To defray some of this cost, it may be desirable to have the mobile crew available and equipped to perform other types of repairs. However, constraining factors such as revenue security and labor agreement terms preclude using the mobile crews for additional repairs at DDOT.

Total Maintenance Labor Cost

Total annual maintenance labor cost for 630 fareboxes includes technicians, mobile crews and supervision. The previous discussions have revealed a need for

- 4,460 hr of corrective maintenance, equivalent to 2.4 person-years.
- 1,550 hr of preventive maintenance, equivalent to 0.3 person-years.
- 15,000 hr of mobile crew labor, equivalent to 8 person-years.

Since preventive maintenance and corrective maintenance can be performed by the same technicians, total labor requirements for the position are 6,010 hr, equivalent to 3.1 person-years. The cost for three technicians working full-time plus approximately 400 hr of overtime was estimated to be $127,000 based on wage rates for electronic technicians, current contributions to fringe benefits and pension funds, and 2,080 pay hr/year, including excused absences.

In addition to technicians and mobile crew, a full-time farebox repair supervisor is needed to supervise the work of the day shift, manage the parts inventory, schedule the mobile crew drivers, and provide quality assurance and support management on all issues related to the farebox. A night shift foreman is needed to supervise the night mobile crew, make sure there are sufficient buses with working fareboxes for the morning pull-out, and assist with farebox repairs as needed.

The total annual labor cost for farebox repair is as follows:

Personnel	*Cost ($)*
One supervisor	42,000
One night-shift foreman	41,000
Three technicians	127,000
Eight mobile crew	313,000
Total	523,000

Parts and Materials Expense

During the DDOT farebox evaluation, farebox parts were provided under the manufacturer's warranty. For this analysis, material and supply costs were estimated based on a Booz, Allen study of electronic registering fareboxes conducted in 1983 (*5*). In that study, the Southeastern Pennsylvania Transportation Authority (SEPTA) in Philadelphia identified a material and supply cost of $1.80 per farebox per week. An inflation factor of 1.07 was used to adjust this cost to reflect 1986 costs. The resulting adjusted material and supply cost is $1.93 per farebox per week.

Extrapolating the weekly unit cost to an annual total cost results in an estimated annual expense for farebox material and supplies of $63,000. The average parts and materials cost per farebox per year is approximately $100.

TOTAL LIFE-CYCLE COST

The farebox life-cycle cost estimate is influenced by the costs discussed previously and by the farebox service life and interest rate. For this analysis, a 10 percent annual interest rate was assumed. Lowering the interest rate would result in higher total life-cycle cost since future annual expense would have a higher present value.

A 12-year farebox service life is assumed. This corresponds to UMTA bus service-life requirements. Increasing the service-life increases the life-cycle cost at a rate equivalent to the discounted annual recurring expenses. If the farebox service life is extended beyond the assumed 12-year life to 15 or 20 years, then the mobile crew vehicles and possibly some of the other maintenance equipment will require replacement in the thirteenth and nineteenth years.

The results of the life-cycle cost analysis are presented in Table 6. Costs previously presented, as well as the present value of recurring costs, are summarized in the table. For the 12-year analysis, mobile vehicles are assumed to be replaced at the beginning of the seventh year.

During the first year, recurring expenses are realized at a rate that is less than the second year and subsequent years. The reduced expense is attributed to warranty terms and draw-down of the initial parts and material inventory. Corrective and preventive maintenance labor expense (expense for central shop technicians) is not included in the first year.

Salvage value estimates are based on a 10 percent salvage value at the end of the mobile vehicle service life. The salvage value of the fareboxes is assumed to be zero. This assumption reflects the modular construction of the farebox, which allows for the replacement of major components on failure. The only

TABLE 6 LIFE-CYCLE COST SUMMARY

	Initial or Annual Cost ($)		
	First Year	Second and Subsequent Years	Present Value 12th Year[a]
Initial capital cost	3,334,000	0	3,030,900
Recurring annual expense[b]			
Labor	396,000	523,000	
Parts and materials	0	63,200	
Total	396,000	586,200	3,820,400
Salvage value			
Mobile crew vehicles			–3,200
Life-cycle cost			
Total			6,848,100
Total per farebox			10,870
Annualized equivalent cost per farebox			1,595

[a]The total life-cycle cost is equal to capital cost plus net present value of recurring costs minus salvage value of equipment.
[b]Recurring annual expense is reduced during the first year to reflect the warranty terms and the reduced need for corrective maintenance technicians and draw-down of initial parts and materials inventory.

components of the farebox that may have a salvage value are the stand, frame, and bins. The salvage value of these items is assumed to be negligible at the end of the service life.

The data processing system may have a minimal salvage value. However, given the existing rate of innovation in computer technology, it is likely that the data processing system will be obsolete by the end of the farebox service life.

Three life-cycle cost measures are provided in Table 6. These include the total life-cycle cost of 630 fareboxes, total life-cycle cost per farebox, and annualized equivalent cost per farebox. Total life-cycle cost for 630 fareboxes is estimated to be $6.85 million, which is equivalent to a unit life-cycle cost of $10,900/farebox or $1,595/year per farebox.

INDUSTRY IMPLICATIONS

While this paper does not present detailed results of the revenue handling cost analysis and reduction in short fares attributed to improved revenue security, the savings are considerable (2). The study team found that during the test period, DDOT experienced an 18 percent increase in farebox revenues without a gain in ridership on the test route. If similar revenue increases were found systemwide, annual farebox revenue would increase by almost $5 million/year based on a ridership of 62.4 million per year. Elimination of mutilated bills and short-fares systemwide is anticipated to increase revenue by $300,000/year. Actual farebox revenue improvement would be somewhere between $0.3 and $5.0 million/year.

Revenue handling costs were estimated to be reduced by $600,000/year as a result of streamlining bill stacking and facing procedures, elimination of outside contract for bill counting, and elimination of two field revenue collection functions. Most transit agencies with electronic registering fareboxes view the revenue handling cost savings to be the principal benefits.

Combining the minimum revenue increase of $300,000/year with the $600,000 per year reduction in handling costs produces a $900,000 annual improvement. This equates to $1,428/year per farebox, only $166/year less than the annualized equivalent cost of $1,595/year per farebox. Further reductions in fare evasion and improved revenue security can be identified, through additional investigation, which total more than the difference between cost and revenue.

Finally, the installation of electronic fareboxes is clearly a cost-effective use of capital funds, particularly where dollar fares are used. While DDOT's decision to invest in mobile farebox maintenance crews may not be appropriate for all transit systems, the cost is generally offset by revenue handling savings and improvements in farebox revenues.

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