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ANALYSIS OF LIFE-CYCLE COSTS AND MARKET APPLICATIONS OF FLYWHEEL ENERGY-STORAGE TRANSIT VEHICLES

D.L. Goeddel
G. Ploetz

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Transportation Systems Center
Cambridge MA 02142

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16. Abstract
The Urban Mass Transportation Administration (UMTA) has recently completed the Phase I activities of its Flywheel Energy Storage Program involving an analysis of the operational requirements and the conceptual design of flywheel energy storage vehicles for transit service. Flywheel energy storage systems are being proposed as means of reducing the energy requirements of fixed-route, multi-stop, urban trans vehicles. The Phase I studies have paved the groundwork for the succeeding progra phase which include the design, fabrication, test, and evaluation of prototype flywheel vehicle systems for demonstrations in transit service. As part of the overal program, UMTA has requested the Transportation Systems Center (TSC) to conduct an independent assessment of the life cycle costs and the potential market applications of flywheel storage vehicles within the urban transit industry. This report documents the results of these analyses. It examines the economic viability and the potential market applications of these proposed concepts within urban transit operations. The report presents a description of the structure, the approach, and the assumptions of the analysis; defines the design characteristics, the system capital costs, and the annual recurring operations/maintenance costs associated with the conventional diesel bus, the trolley bus, and the three flywheel-powered vehicle systems considered in the study; describes the results of the life-cycle analysis and the sensitivity of these results due to variations of key assumed input variables; and discusses the potential demand and the market applications of flywheel energy storage vehicles within transit service operations.

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PREFACE

This study was conducted at the U.S. Department of Transportation - Transportation Systems Center in support to the Urban Mass Transportation Administration program on Flywheel Energy Storage Systems.

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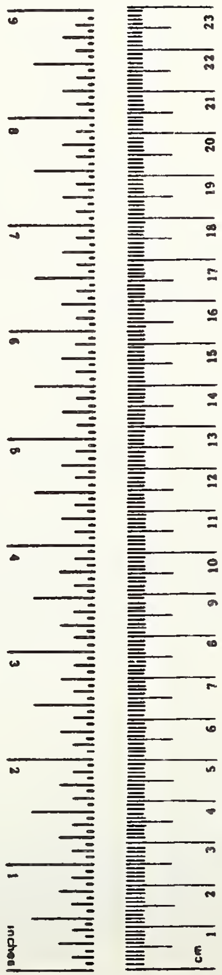
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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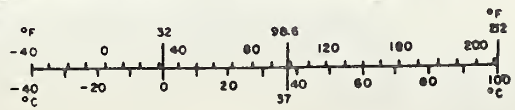
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

The Urban Mass Transportation Administration (UMTA), under its Flywheel Energy Storage System (FESS) program, has completed a series of studies on the conceptual design and the operational requirements associated with the application of flywheel propulsion systems within urban transit vehicles. The planned succeeding phases of the FESS program (Reference 1) include the design, fabrication, test, and evaluation of prototype vehicle systems for transit service demonstration and deployment.

To support UMTA in the evaluation of flywheel energy storage propulsion systems, the Transportation Systems Center (TSC) has conducted a study of the life-cycle costs and the potential applications of flywheel powered vehicle systems within urban transit operations.

The study was structured such that a comparative evaluation could be made of the life-cycle costs of conventional and flywheel-powered vehicle systems in order to identify those areas where flywheel bus operations are viable and cost-effective. Two conventional and three proposed flywheel vehicle concepts, identified below, were considered:

Conventional Vehicle Systems	Flywheel Vehicle Systems
• Diesel bus	• All-Flywheel bus
• Trolley bus	• Flywheel/Diesel bus
	• Flywheel/Battery bus

A series of sensitivity analyses were conducted to determine and express the life-cycle costs of each of these vehicle systems under alternative transit operating conditions and costing assumptions. A present worth costing procedure was used to express the life-cycle costs of each of these vehicle systems to current, equivalent 1977 dollars. Under this technique, the present value life-cycle cost of each vehicle system was determined by discounting, on a consistent basis, all expected fixed capital and annual recurring operations/maintenance costs over the period of the investment. The OMB recommended annual discount rate of 10% and an investment period of 23 years were used.

Life-Cycle Cost Analysis:

Figure ES-1 depicts, for high- and low-density transit route operations, the per vehicle-mile present value costs (in 1977 dollars, discounted at 10% over 23 years) for the diesel, trolley bus, and the three proposed flywheel vehicle concepts.

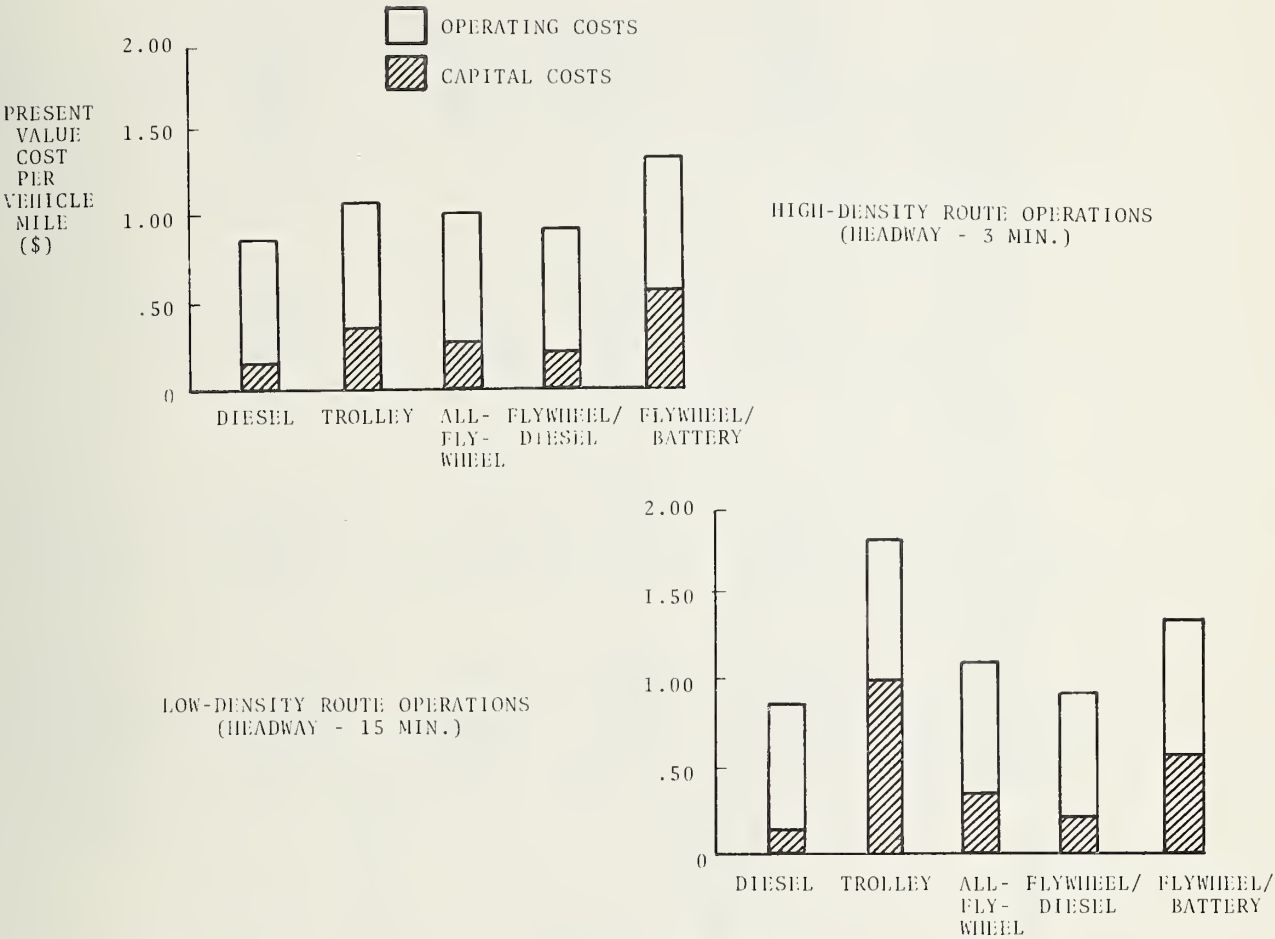


FIGURE ES-1. PRESENT VALUE LIFE-CYCLE COSTS PER VEHICLE MILE (1977 Dollars, 10% Discount, 23 Years)

A summary of the per vehicle-mile life-cycle costs, by major capital and operating cost categories, is presented in Tables ES-1 and ES-2 for each of the vehicle systems considered in this analysis.

One of the critical variables affecting the per vehicle-mile life-cycle costs of both the trolley bus and

TABLE ES-1. PRESENT VALUE COSTS/VEHICLE MILE (Dollars) -- HIGH-DENSITY ROUTE OPERATIONS -- HEADWAY 3 MIN. (1977 Dollars, 10% Discount Rate, 23 Years)

	Diesel Bus	Trolley Bus	All-Flywheel Bus	Flywheel/ Battery Bus	Flywheel/ Diesel Bus
SYSTEM CAPITAL COSTS:					
•Vehicles	0.10	0.14	0.19	0.18	0.16
•Garage/Maintenance	0.05	0.05	0.05	0.05	0.05
•Wayside Stations			0.02	0.06	
•Overhead Power Line		0.16			
•Battery Packs				0.29	
Total	0.15	0.35	0.26	0.58	0.21
OPERATIONS/MAINTENANCE COSTS:					
•Driver Payroll	0.33	0.33	0.35	0.34	0.33
•Vehicle Maintenance	0.10	0.08	0.11	0.11	0.10
•Fuel/Power	0.04	0.05	0.04	0.06	0.04
•Overhead Power Line		0.02			
•Wayside Stations			0.00	0.01	
•Other Fixed O/M	0.26	0.26	0.26	0.26	0.26
Total	0.73	0.74	0.76	0.78	0.73
TOTAL	0.88	1.09	1.02	1.36	0.94

TABLE ES-2. PRESENT VALUE COSTS/VEHICLE MILE (Dollars) -- LOW-DENSITY ROUTE OPERATIONS -- HEADWAY 15 MIN. (1977 Dollars, 10% Discount Rate, 23 Years)

	Diesel Bus	Trolley Bus	All-Flywheel Bus	Flywheel/ Battery Bus	Flywheel/ Diesel Bus
SYSTEM CAPITAL COSTS:					
•Vehicles	0.10	0.14	0.19	0.18	0.16
•Garage/Maintenance	0.05	0.05	0.05	0.05	0.05
•Wayside Stations			0.10	0.06	
•Overhead Power Line		0.83			
•Battery Packs	—	—	—	0.29	—
Total	0.15	1.02	0.34	0.58	0.21
OPERATIONS/MAINTENANCE COSTS:					
•Driver Payroll	0.33	0.33	0.35	0.34	0.33
•Vehicle Maintenance	0.10	0.08	0.11	0.11	0.10
•Fuel/Power	0.04	0.05	0.04	0.06	0.04
•Overhead Power Line		0.09			
•Wayside Stations			0.01	0.01	
•Other Fixed O/M	0.26	0.26	0.26	0.26	0.26
Total	0.73	0.81	0.77	0.78	0.73
TOTAL	0.88	1.83	1.11	1.36	0.94

the proposed all-flywheel vehicle system is the assumed vehicle density on the route. Figure ES-2 illustrates, for each of the vehicle systems, the sensitivity of their per vehicle-mile present value costs as a function of the assumed vehicle density on the route.

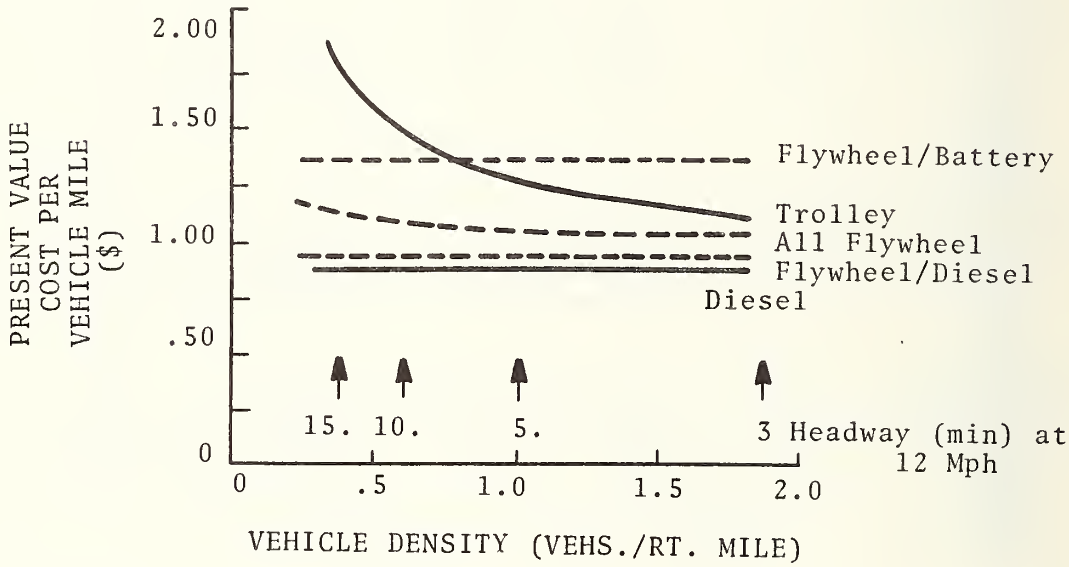


FIGURE ES-2. PRESENT VALUE COST/VEHICLE MILE AS A FUNCTION OF VEHICLE DENSITY

As shown, the present value costs per vehicle-mile for both the trolley and all-flywheel vehicle systems are inversely related to the assumed vehicle density on the route, while the per vehicle-mile present value costs of the diesel, the flywheel/diesel, and flywheel/battery vehicle systems are unaffected by any changes in the vehicle headway. For the diesel, the flywheel/diesel, and the flywheel/battery vehicle systems, their total present value costs increase in direct proportion to the increase in the vehicle density on the route since the fixed capital and annual operating costs of these systems are directly related to the size of the total vehicle fleet deployed. This is not the case, however, for the trolley and all-flywheel vehicle systems where substantial capital costs are incurred for overhead power lines and wayside power stations. By operating these vehicle systems on high density, low headway routes, the capital costs of the system can be apportioned over a larger vehicle fleet size thus reducing the overall present value cost/vehicle mile of the system.

Energy Consumption:

Presented in Table ES-3 is a comparison of the energy consumption requirements (in equivalent BTU's per vehicle-mile operated) and the cost of the energy consumed for the diesel, trolley bus, and the flywheel-powered vehicle systems.

TABLE ES-3. ENERGY CONSUMPTION COMPARISON

Vehicle	Energy Consumption At Source[1]	Energy Consumption (BTU/Veh-mi)	Energy Cost[2] (¢/Veh-mi)
Diesel	.31 gal/mi.	40,300	10.8
Trolley	4.5 kw-hr/mi.	45,000	13.5
All-Flywheel	3.5 kw-hr/mi.	35,000	10.5
Flywheel/Diesel	.285 gal/mi.	37,050	9.9
Flywheel/Battery	5.9 kw-hr/mi.	59,000	17.7

[1]Adjusted for inefficiency in the production, refining, and transmission of fuel and electric power.
[2]Based on unit cost of 35¢/gallon and 3¢/kw-hr.

As shown, the proposed flywheel/diesel vehicle system offers an 8% savings over the baseline diesel bus, while the all-flywheel vehicle offers a 22% savings over the trolley bus on the amount of energy consumed per vehicle-mile operated. The flywheel/battery bus, on the other hand, is a highly energy intensive system, consuming nearly 31% more energy per vehicle-mile operated than the trolley bus.

Potential Demand and Market Applications:

An estimate of the potential market for flywheel-powered vehicle systems in the United States was made based on the expected trends in the national transit coach demand and assumptions on the feasible applications of these vehicle systems within the transit industry. For the eleven-year forecast period (1980-1990), a total urban bus demand of nearly 72,100 vehicles was projected at an average annual demand of 6,555 vehicles per year. Assuming that these new vehicle systems are introduced as replacements or additions to the existing vehicle fleets that operate on high-density transit routes, a market share of 10% to 30% of the total new bus demand was projected for the flywheel powered vehicle systems. At this market share level, the average annual demand for flywheel vehicles could range from as low as 650 vehicles/year to as high as 2,000 vehicles/year for the 1980-1990 period.

1. INTRODUCTION

The Urban Mass Transportation Administration (UMTA) has recently completed the Phase I activities of its Flywheel Energy Storage Program involving an analysis of the operational requirements and the conceptual design of flywheel energy storage vehicles for transit service. The Phase I studies have paved the groundwork for the succeeding program phases which include the design, fabrication, test, and evaluation of prototype flywheel vehicle systems for demonstrations in transit service.

As part of the overall program, UMTA has requested the Transportation Systems Center (TSC) to conduct an independent assessment of the life-cycle costs and the potential market applications of flywheel energy storage vehicles within the transit industry. This report documents the results of these analyses.

Section 2 provides a description of the structure, the approach, and the assumptions of the analysis. Section 3 defines the design characteristics, the system capital costs, and the annual recurring operations/maintenance costs associated with the diesel bus, the trolley bus, and the three flywheel-powered vehicle systems considered in the study. Section 4 describes the results of the life-cycle analysis and the sensitivity of these results due to variations of key assumed input variables, while the concluding Section 5 discusses the potential demand and the market applications of flywheel-energy storage vehicles within transit service operations.

2. ANALYSIS APPROACH AND ASSUMPTIONS

This section presents a discussion of the overall approach and the underlying assumptions used in this analysis. Key points covered include a description of the structure of the analysis, a definition of the life-cycle costing procedures, and a summary of the more important assumptions made in the analysis.

2.1 ANALYSIS APPROACH

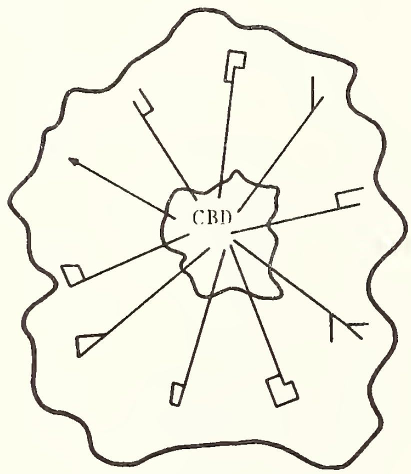
The analysis was directed towards the examination of the life-cycle costs associated with conventional- and flywheel-powered transit vehicles. Five urban transit vehicle systems were considered; they included:

<u>Conventional Vehicles</u>
- Diesel Bus
- Trolley Bus

<u>Flywheel Vehicles</u>
- All Flywheel Bus
- Flywheel/Battery Bus
- Flywheel/Diesel Bus

The analysis was structured such that each of the vehicle systems was analyzed under common and equivalent terms. That is, the fixed capital and the annual recurring operating costs associated with these vehicle systems were determined based upon each vehicle providing an equivalent level of service under a pre-defined operating condition (i.e., system extent, route structure, vehicle density, etc.).

In this analysis, an operating scenario, representative of the transit operations in medium size U.S. cities, was selected as a reference point -- termed the 'base case' -- for the cost comparisons. Figure 2-1 illustrates the base operating service area used in the analysis and some of the parameters which define this area.



- System Extent - 200 route miles
- Ave. Route Length - 10 miles
- Ave. Veh. Headway - 15 minutes
- Route Stop Density - 5 stops/mile
- Vehicle Fleet Size - 150-200 vehicles

FIGURE 2-1. SERVICE AND OPERATING AREA: BASE CASE

The relationship of the selected base service/operating area to current transit operations is depicted in Figure 2-2. As shown, a service area of 200 route-miles and a peak vehicle fleet size of 150 to 200 vehicles is representative of the current transit operations within U.S. cities such as: Syracuse NY, Omaha NB, Providence RI, Louisville KY, and Indianapolis IN.

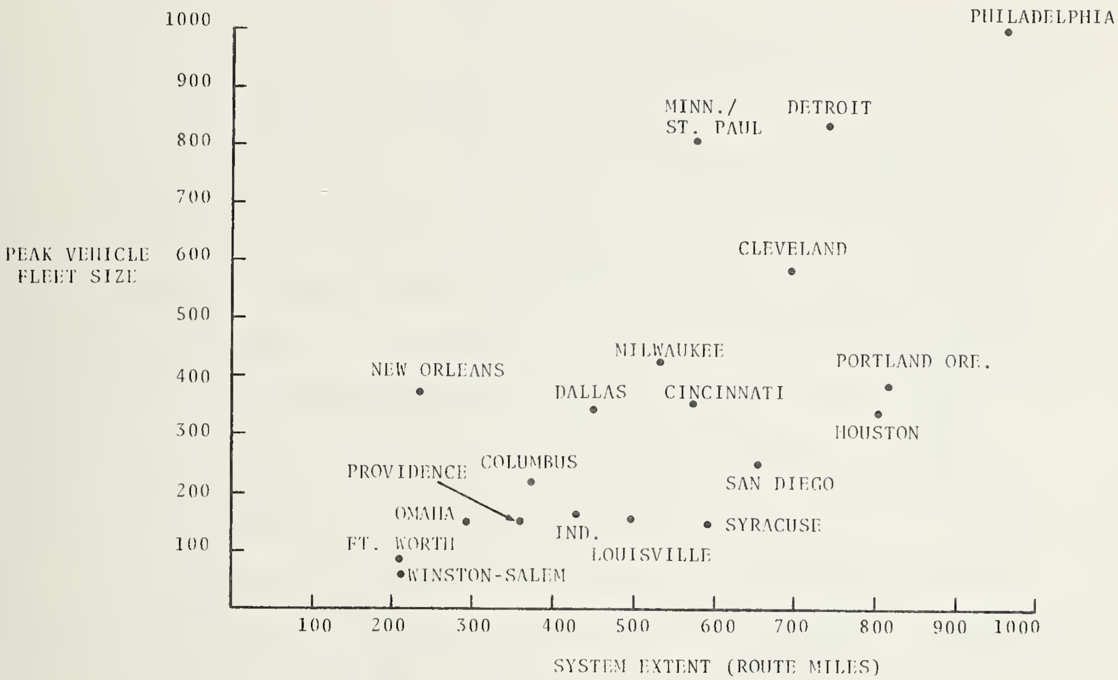


FIGURE 2-2. VEHICLE FLEET DENSITY OF SELECTED U.S. TRANSIT OPERATIONS

In this analysis, initial comparisons of the life-cycle costs associated with the conventional- and flywheel-powered vehicle systems are presented with reference to the identified base case. However, to provide some insight into the application and costs of these vehicle technologies in larger urban areas and under alternative transit operating conditions, a series of analyses were conducted to examine the sensitivity of the study results in these cases. All cost comparisons of the baseline and the flywheel vehicle systems are presented in Section 4.

2.2 STRUCTURE OF THE ANALYSIS

Figure 2-3 illustrates the structure of the cost analysis that was conducted. As shown, the analysis addressed not only the capital and operating costs of the conventional and flywheel vehicle technologies, but also, the operating performance of these vehicle systems in an urban environment.

A computerized model of the overall life-cycle cost methodology was developed to facilitate the calculation of the vehicle operations and cost data used in this analysis. Presented in Appendix A is the output of the life-cycle cost model for each of the conventional and flywheel vehicle systems under analysis. A description of the overall structure of the cost analysis is presented below.

2.2.1 Vehicle Operations

One of the basic assumptions of this analysis was that the life-cycle costs of the conventional and flywheel vehicle systems would be analyzed based on each of these vehicle systems providing an equivalent level of transit service. However, since each of these vehicle systems is unique in terms of its propulsion system charging

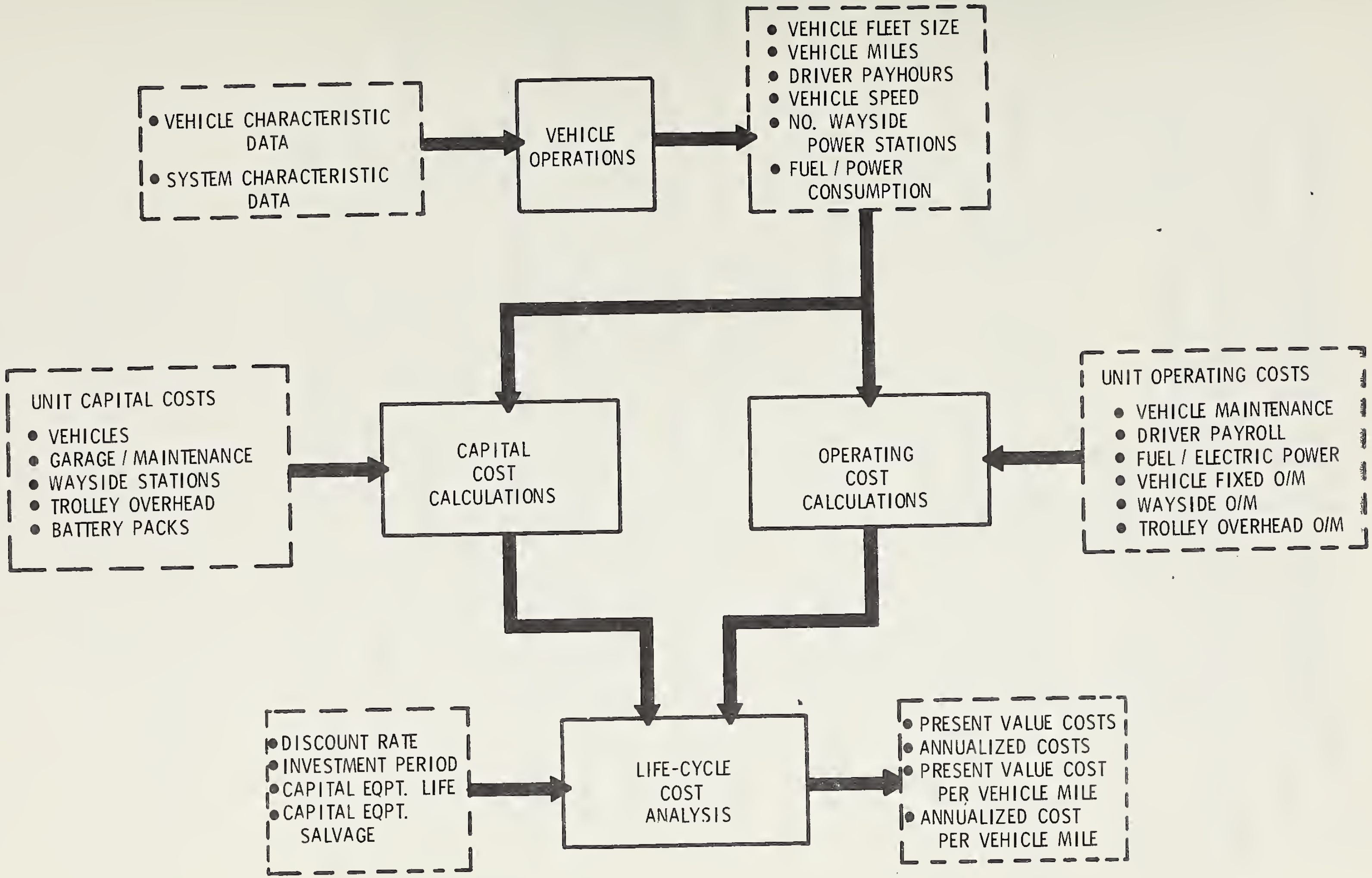


FIGURE 2-3. STRUCTURE OF LIFE-CYCLE COST ANALYSIS APPROACH

requirements, their route running-times, and their fuel/power consumption, it was necessary to consider all of these characteristics in determining the fleet sizes, mean speeds, annual vehicle-miles traveled, etc., of the respective vehicle operations.

2.2.1.1 Vehicle Driving Cycle - Three vehicle driving cycles were initially considered in the analysis to determine the energy requirements of the vehicle's propulsion system and the vehicle running times under various route operating conditions. The first driving cycle, designated Cycle A, is the FAKRA driving cycle established in Europe for the evaluation of electric and battery powered buses. The second driving cycle, identified as Cycle B, is representative of the vehicle operations on high stop-density routes requiring high vehicle acceleration and energy consumption levels. The third driving cycle, referred to as Cycle C, reflects the typical all-day operations of a transit system under average vehicle headway and route stop-density conditions. The characteristics of each of these three driving cycles are shown in Table 2-1.

TABLE 2-1. BUS DRIVING CYCLE CHARACTERISTICS

	Cycle A	Cycle B	Cycle C
Max. Acceleration Rate (mph/sec)	1.4	3.5	2.5
Acceleration Time to Cruise (sec)	21.6	10.3	10.0
Cruise Speed (mph)	31	31	25
Cruise Time (sec)	11.2	4.9	18.8
Max. Deceleration Rate (mph/sec)	2.2	3.5	2.5
Deceleration Time to Stop (sec)	14.4	8.9	10.0
Dwell (sec)	30	16	20.4
Turnaround Time (sec)	0	0	330 every 6 mi.
Stops/Mile	4	8	5
Mean Speed (mph)	11.7	11.2	10.26

In the evaluation of the life cycle costs of the candidate vehicle systems, it was necessary to select a common driving cycle capable of being met by each of the vehicle propulsion systems, and yet, representative of current transit operations over an entire service period. As such, duty cycle C, as represented in Figure 2-4, was selected as the base vehicle driving cycle to be considered in the analysis.

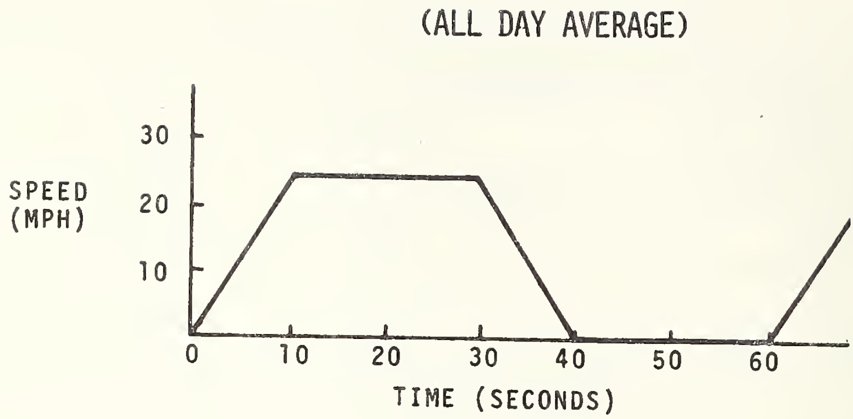


FIGURE 2-4. URBAN BUS DRIVING CYCLE - DUTY CYCLE C

2.2.1.2 Fuel/Power Consumption - The fuel and power consumption data of the baseline and the flywheel-powered vehicle systems were determined based upon detailed simulations* of the vehicle propulsion systems. The general methodology of the energy calculations within the simulation model considers the power requirements of the various propulsion system components along with the effects of

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*The fuel/power consumption data for the diesel bus were obtained based upon runs of TSC simulation model. Data for the trolley bus and the three flywheel vehicle systems were obtained from computer simulations conducted by Garrett Airesearch and independently verified by TSC.

external forces (i.e., air resistance, rolling inertia, and grade resistance) acting upon the body of the vehicle. To express the energy requirements of these vehicle systems on a common basis, the transit driving cycle C, described above, was used for all the vehicles. Figure 2-5 illustrates the fuel and power consumption data of the conventional- and flywheel-powered vehicle systems under duty cycle C for a range of route stop-densities.

2.2.1.3 Transit Route Operations - The performance of the conventional- and the flywheel-powered vehicle systems in transit route operations was determined based upon the defined operating characteristics and changing requirements of each system. In the analysis, all five vehicle systems were assumed to meet and perform according to the acceleration, deceleration, and cruise time specifications of the transit driving cycle C. However, for the all-flywheel and the flywheel/battery systems, the effects of the vehicle's propulsion system charging requirements on its en route operations was considered.

Two en route charging concepts were considered for the all-flywheel vehicle system. One concept would require the all-flywheel vehicle to charge while stationary from a series of wayside power stations along the route every 3-5 miles. The spacing of the wayside stations, or conversely,

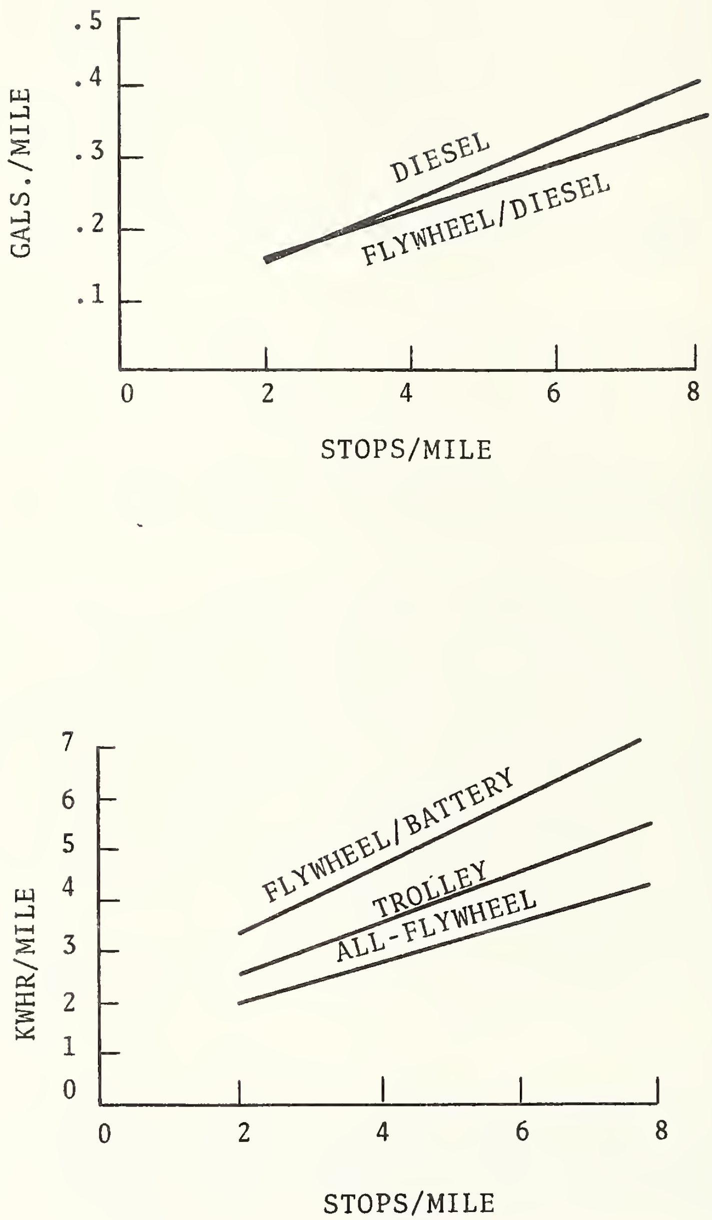

FIGURE 2-5. FUEL/POWER CONSUMPTION AS A FUNCTION OF ROUTE STOP DENSITY

the discharge range of the vehicle's propulsion system, is determined based upon energy dissipated in the route operations. On high stop-density routes (i.e., eight stops/mile), wayside power stations were assumed to exist at three-mile intervals; whereas on lower stop-density routes (four stops/mile), the station spacings were five miles. Under the stationary charge concept, the time required to charge the flywheel from half to full speed at each wayside station was two minutes. The second charging technique considered for the all-flywheel vehicle system was an en route charging concept from overhead trolley wires. As was the case with stationary charge concept, power to the vehicle's propulsion system is supplied by a series of wayside power stations spaced along the route every three to five miles depending on the stop-density of the route. The power is fed to the vehicle through a 1/4 mile overhead trolley wire associated with each wayside station. Unlike the stationary charge concept, there are no delays in vehicle operations with this technique since the vehicle charges its flywheel while moving en route under the overhead trolley system. In this case, the time required to charge the flywheel from half to full speed is approximately 1.5 minutes.

The en route charging requirements for the proposed flywheel/battery vehicle propulsion system was determined based on the experience in West Germany with all-battery vehicle systems. For the proposed flywheel/battery vehicle system, onboard battery packs are used to meet the peak power requirements of the flywheel and to provide accessory power to the vehicle's hotel loads. The entire propulsion system is maintained in a charged state through the replacement of the battery packs at designated battery charging/changing stations along the route. Under normal transit operating conditions, the flywheel/battery propulsion system would have a range of approximately 50 miles between battery replacements. A replacement time of 5 to 10 minutes is required to change the onboard batteries. The number of wayside battery charging/changing stations required was determined based on the total size of the vehicle fleet deployed. From the West German experience, an en route battery charging/changing station is required for every eight or nine operating vehicles.

Using the operating characteristics and the propulsion system charging requirements of the vehicle systems under analysis, relationships were developed to determine the average route running times, the mean vehicle speeds, and the total size of the vehicle fleet to be deployed. These relationships were developed as a function of the total system extent, the average route length, the mean vehicle headway, and the route stop-density. A definition of these relationships is presented in Appendix B.

Figures 2-6 and 2-7 illustrate, respectively, the average one-way route running-times and mean vehicle speed of each of these vehicle systems as a function of various route stop densities. The differences shown in the route running-times and the mean speeds for the all-flywheel and the flywheel/battery vehicles as compared with the baseline diesel, trolley bus, and the flywheel/diesel vehicle systems is attributed solely to the delays incurred en route for the charging of the vehicle's propulsion system.

Because of the lower mean speed of the all-flywheel and the flywheel/battery vehicle systems, a larger vehicle fleet size is required to be deployed for these systems to provide an equivalent level of transit service. Figure 2-8, below, depicts the relationship of the total vehicle fleet size to the variation in the route stop-density for a system extent of 200 route-miles, an average route length of 10 miles, and an average vehicle headway of 15 minutes.

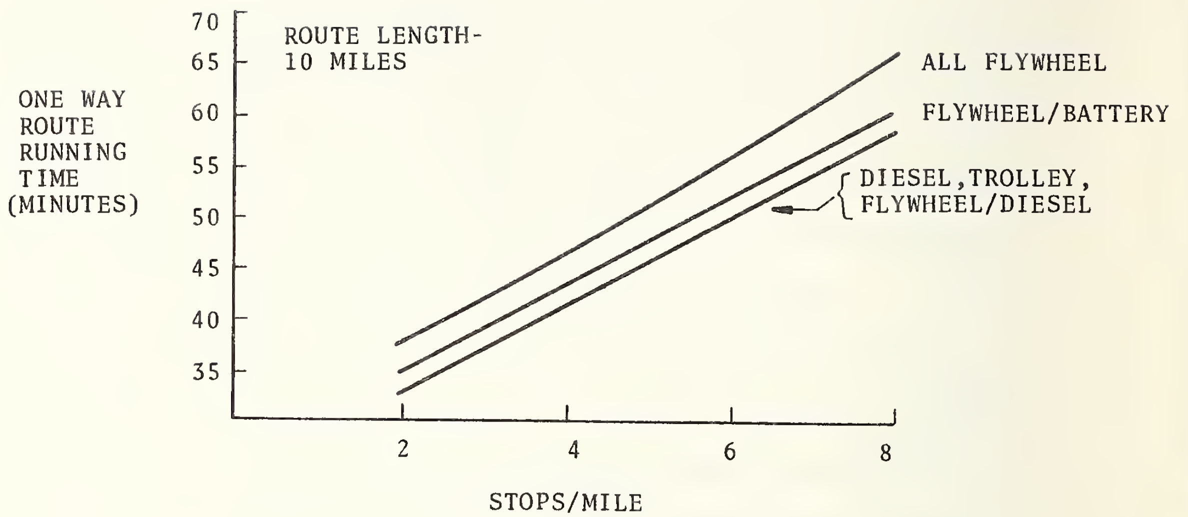

FIGURE 2-6. ONE-WAY ROUTE RUNNING TIME AS A FUNCTION OF ROUTE STOP DENSITY

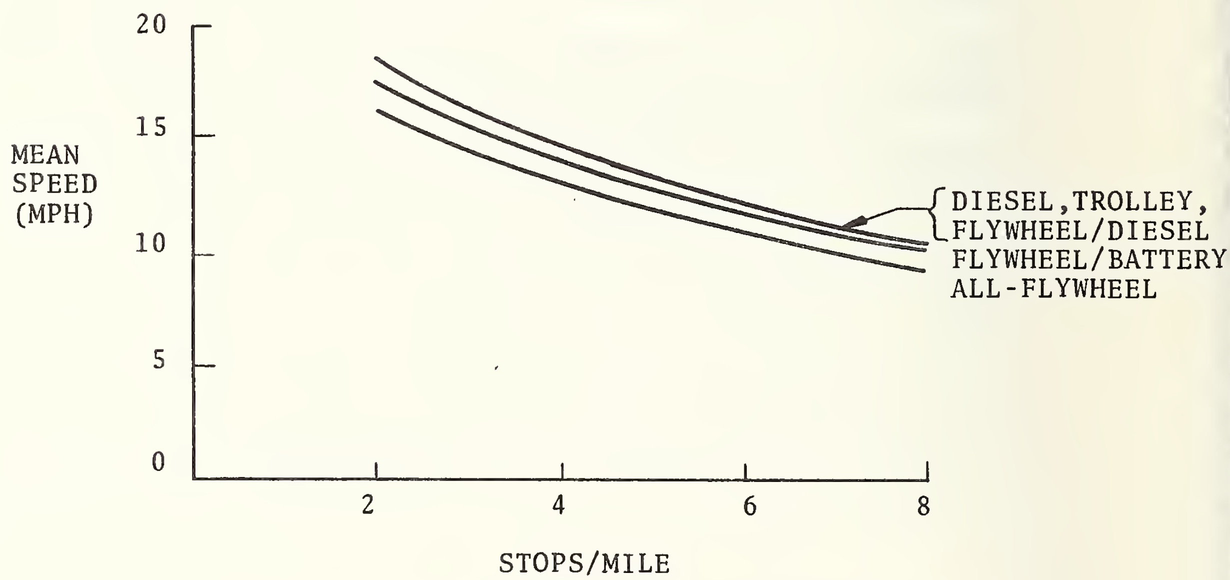

FIGURE 2-7. MEAN VEHICLE SPEED AS A FUNCTION OF ROUTE STOP DENSITY

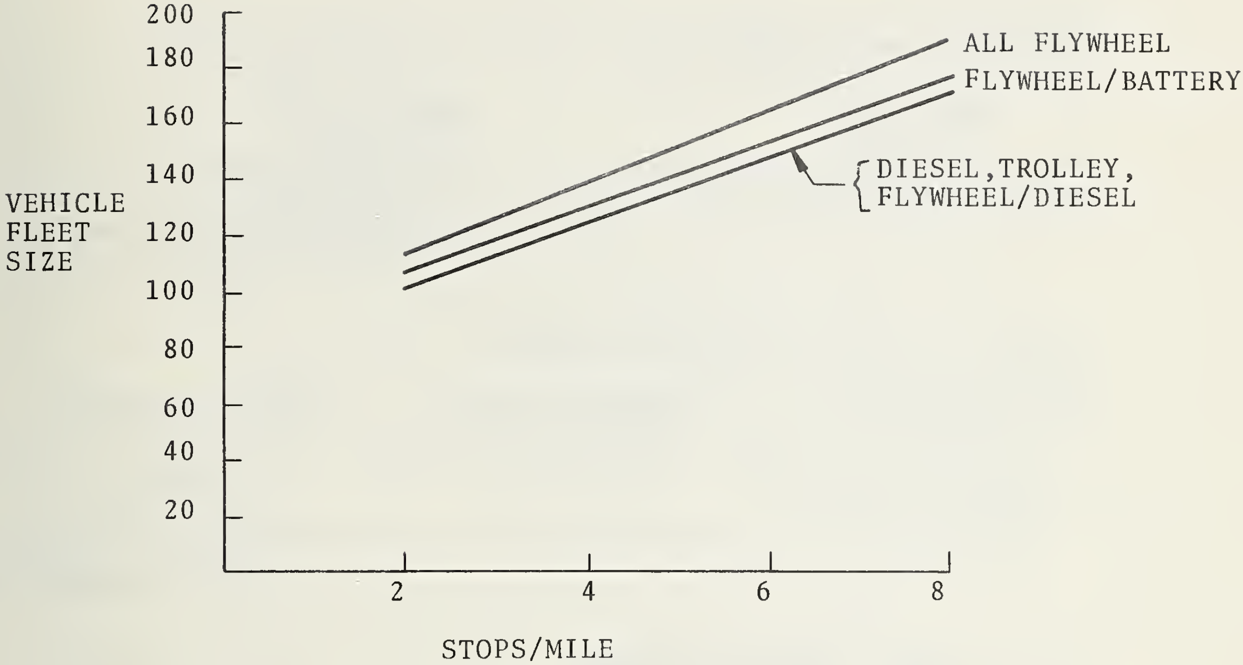

FIGURE 2-8. VEHICLE FLEET SIZE AS A FUNCTION OF ROUTE STOP DENSITY

2.2.2 System Capital Costs

The only costs of capital investment considered in this analysis were those that can be directly attributed to the design and operation of the baseline diesel, trolley bus and the proposed flywheel vehicle technologies. A summary of the capital cost elements considered in the life-cycle cost analysis is presented below for each of the vehicle systems. A complete definition of the unit costs, the economic service life, etc., made pertaining to these capital elements are described in the appropriate sub-sections of Section 3:

Conventional Bus Systems:

<u>Diesel Bus</u>
- Vehicles
- Garage/Maintenance Facilities

<u>Trolley Bus</u>
- Vehicles
- Garage/Maintenance Facilities
- Overhead Trolley Line and Substations

Proposed Flywheel Vehicle Systems:

<u>All-Flywheel Bus</u>
- Vehicles
- Garage/Maintenance Facilities
- Wayside Charging Stations

<u>Flywheel/Diesel</u>
- Vehicles
- Garage/Maintenance Facilities

<u>Flywheel/Battery</u>
- Vehicles
- Garage/Maintenance Facilities
- Battery Charging/Changing Stations
- Vehicle Battery Packs

2.2.3 System Operating Costs

Annual recurring costs associated with the operations and maintenance of the baseline diesel, trolley bus and the flywheel vehicle systems were also considered in the overall life-cycle cost accounting. For the most part, these costs were computed based upon the level and the extent of the vehicle operations deployed. The principal operations/maintenance cost elements considered in the analysis were:

- driver payroll costs -- computed based upon the annual hours of vehicle service deployed,
- vehicle maintenance costs -- computed based upon the annual vehicle-miles of service deployed,

- fuel/power costs -- computed based on the annual vehicle miles deployed,
- maintenance of overhead power lines and substations -- (applicable only to the trolley bus) computed based upon the extent (route miles) of the system operations,
- maintenance of wayside power stations -- (applicable only for the all-flywheel and the flywheel/battery vehicle systems) computed based upon the number of stations deployed, and,
- other fixed operations/maintenance costs -- i.e., costs such as administrative, insurance, taxes, advertising that are not directly affected by the vehicle design but affected by the level and size (vehicles deployed) of the system operations.

A complete definition of the unit costs, the data sources, and assumptions made pertaining to the vehicle operations/maintenance costs are presented within the appropriate sub-sections of Section 3.

2.2.4 Life-Cycle Cost Analysis

In order to determine and express the life-cycle costs of the baseline and the flywheel vehicle systems on a uniform, equivalent basis, an analysis methodology and related cost measures were defined. The cost technique utilized was a 'present worth' analysis, which expresses all costs to a current value (1977 dollars) by discounting, on a consistent basis, expected future costs and benefits over the period of investment. All costs considered in the analysis would fall into one of the following three categories:

1. capital investments costs -- the costs incurred initially to deploy or replace capital equipment (vehicles, wayside stations, etc.),

2. annual recurring costs -- the costs incurred each year associated with the operation and maintenance of the vehicle systems (i.e., costs for fuel/power, vehicle maintenance, etc.), or

3. salvage credits -- negative costs or benefits on the value of the capital equipment (less depreciation) that is attained at the end of the economic life of the capital equipment or at the end of the investment period under analysis.

The result of this process is a single dollar value, referred to as the 'net present value', that is used to measure and compare directly the overall life-cycle costs of the baseline diesel, trolley bus and the flywheel vehicle systems.

The structure of the 'present worth' life-cycle cost analysis, depicted in Figure 2-9, below, is defined by the following series of equations:

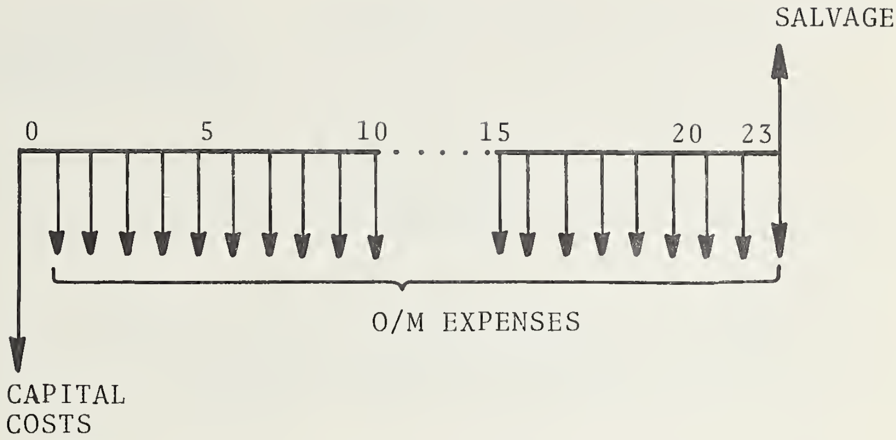

FIGURE 2-9. PRESENT WORTH COST ANALYSIS

Present Value of Capital Investments

$$PV_c = \sum_{n=1}^{p} C_c \left[\frac{1}{(1+i)^n} \right]$$

where:

PV_c = present value of all capital costs incurred over the investment period p

C_c = cost of the capital equipment

i = discount rate

n = index of investment years

p = number of investment years.

Present Value of Operations/Maintenance Costs

$$PV_{O/M} = \sum_{n=1}^{p} (O/M) \left[\frac{1}{(1+i)^n}\right]$$, for single or a non-uniform series of O/M costs during the investment period p;

or;

$$PV_{O/M} = O/M \left[\frac{(1+i)^n-1}{(1+i)^n i}\right]$$

where:
$PV_{O/M}$ = present value of all O/M costs incurred over the investment period p.
O/M = annual O/M costs incurred in year n.

Present Value of Salvage Credits

$$PV_S = \sum_{n=1}^{p} (S) \left[\frac{1}{(1+i)^n}\right]$$

where:
PV_S = present value of all salvage credits on capital equipment over the investment period p.
S = salvage credit attained in year n on capital equipment.

Net Present Value

The net present value (NPV) of all costs incurred over the investment period of analysis is equal to the sum present value costs for capital equipment and operations/maintenance expenses less the present value costs of any salvage credits on capital equipment.

$$NPV = PV -PV +PV$$

In this analysis, an annual discount rate of 10% -- as recommended by the Office of Management and Budget (OMB) -- and an investment period of 23 years, representing the economic service life of the proposed flywheel vehicle systems, were used in the present value calculations.

All analysis results comparing the life-cycle costs of the baseline diesel, trolley bus and the flywheel vehicle systems are expressed, for the most part, as total present value costs (in current 1977 dollars) or as present value costs per vehicle or vehicle-mile operated.

Also presented in Section 4 are the amortized life-cycle costs of these vehicle systems expressed in terms of equivalent annualized costs. These costs represent the uniform annual series of payments that are required to repay the debt of capital investment with interest along with the annualized expenses for vehicle operations and maintenance. In the case of this analysis where the annual operations/ maintenance are uniform throughout the investment period, the equivalent annualized cost is given by the following relationship:

$$A_c = (PC_c - PV_s)\left[\frac{i(1+i)^p}{(1+i)^p - 1}\right] + O/M$$

where:

A_c = the equivalent annualized cost

PV_c = present value of capital investment

PV_s = present value of salvage credits

O/M = annual operations/maintenance cost incurred each year of the investment period

$\left[\frac{i(1+i)^p}{(1+i)^p - 1}\right]$ = capital recovery factor for the investment period p at an interest rate i.

Normalized measures of the annual expenditures made per vehicle deployed or vehicle mile operated are also reported.

2.3 ANALYSIS ASSUMPTIONS

In structuring this analysis, a number of assumptions were made concerning the costs to be considered and the procedures for performing the life-cycle cost calculations. Included in these assumptions were the following:

- All costs were expressed in constant 1977 dollars, thus ignoring the effect of inflation on costs incurred during the investment period. Historical cost data (prior to 1977) were adjusted to 1977 dollars by appropriate price indexes.
- The debt on capital investment was amortized equally each year of the economic life of such equipment.
- The OMB recommended discount rate of 10%/year was used and applied to all cost elements. The discount

rate remained constant each year of the investment period.

- All vehicle systems were assumed to provide an equivalent level of transit service and their system operations were sized accordingly. As such, revenues from passenger fares were assumed to be equivalent for each of the vehicle systems, and thus, were not considered as a system benefit.
- Land for power stations, wayside stations, garage/maintenance facilities was assumed to exist and the costs for such land were ignored.
- Capital equipment, when it reaches the end of its economic life, would be replaced by similar equipment having the same capital cost and salvage value. Salvage credits, computed by means of a straight-line depreciation, were applied on all capital equipment having an economic life beyond the investment period under analysis.
- Initial vehicle development costs were assumed to be borne by the Government, and thus, were not considered.
- System and component costs for the proposed flywheel vehicle systems relate to the production/fabrication costs of the ten thousandth vehicle over a production period of ten years.

and finally,

- The analysis did not consider any societal benefits or indirect costs due to reduced noise, air emissions, etc., for any of the vehicle systems. Lack of adequate data and the inability to assign true dollar costs to the data precluded the use of this information in the analysis.

3. DESCRIPTION OF THE BASELINE DIESEL, TROLLEY BUS, AND PROPOSED FLYWHEEL ENERGY STORAGE VEHICLE CONCEPTS

This section presents a discussion of the baseline diesel, trolley bus, and the proposed flywheel energy storage vehicle concepts considered in this analysis. Primary topics covered include a description of the vehicle's propulsion system design -- its power requirements and operating characteristics -- along with a definition of the fixed capital and the annual recurring costs of each vehicle system.

This analysis was focused only on the life-cycle costs associated with the baseline diesel, trolley bus, and the proposed flywheel vehicle systems. As such, the engineering design and performance characteristics of the proposed flywheel energy storage vehicle concepts were assumed based upon the current studies being performed for UMTA under its Flywheel Energy Storage Vehicle Program.

3.1 BASELINE DIESEL BUS

The baseline diesel bus considered in this analysis is representative of the current 40-foot transit buses in service today. As was noted in a 1972 study (Ref. 3-1), the 40-foot transit coach represents nearly two-thirds of the total 44,000 vehicles in the United States 1972 transit bus fleet. Most of these vehicles were equipped with standard

6V-71 engines, a two-speed transmission, drum brakes, and generally without air conditioning.

Recent production models of the 40-foot transit coaches (AMG-10240, Flxible-870, GMC T8H-5307A) have changed to more streamlined bodies with wider access doors and are now equipped with 8V-71 240HP-265HP rated engines with turbomatic or hydraulic transmission units. Based on the later production models of the 40-foot U.S. transit coach, the following characteristics, as shown in Table 3-1, were assumed for the baseline diesel bus.

TABLE 3-1. BASELINE DIESEL BUS CHARACTERISTICS

Curb Weight	23,000 lb.
Gross Weight	30,200 lb.
Seating Capacity	40-50 passengers
Length	40 ft.
Width	102 inches
Height	124 inches
Peak Engine HP (8V-72 Engine)	265 HP
Initial Acceleration	4 MPHPS
Acceleration Time to Cruise Speed (30 MPH)	13-16 seconds
Maximum Speed	55 MPH
Hotel Loads (Average)	36 HP
- Air Conditioning Compressor	
- Air Compressor	
- Engine Fan	
- Alternator	
Propulsion System Weight	4,500 lb.
Fuel Consumption	3.5 mi./gal.

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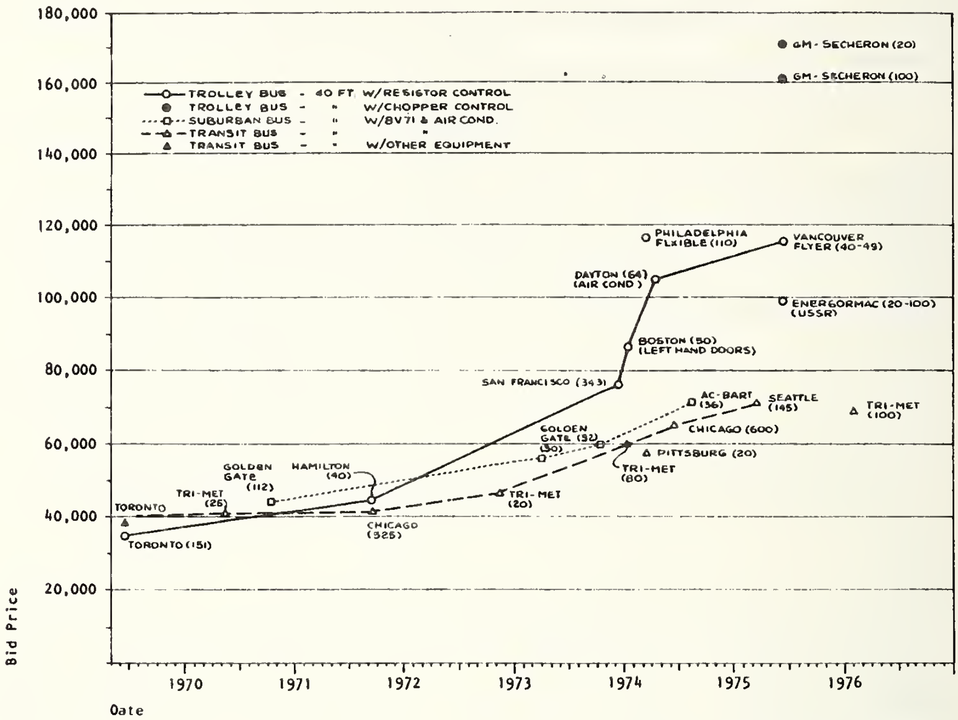
- Air Conditioning Compressor	
- Air Compressor	
- Engine Fan	
- Alternator	
Propulsion System Weight	4,500 lb.
Fuel Consumption	3.5 mi./gal.

3.1.1 Diesel Bus System Capital Costs

In this analysis, fixed capital investment costs for vehicles and garage/maintenance facilities were considered for the baseline diesel bus.

In the U.S. transit industry, the market for the sale of transit coaches is very competitive as is reflected in the current 'bid prices' being received on 40-foot diesel buses. Presented in Appendix C are the results of two independent studies that collected and analyzed data on the variation and trend in 'bid prices' from the three major U.S. manufacturers of diesel buses. The first study (Ref. 3-2), cited in Appendix C, examined a sample of ten bids that were submitted and awarded in 1974 on 40-foot diesel coaches. This study showed a price variation between the highest and the lowest average manufacturer's bids of less than 5%, with an overall average bid price of $62,000 in 1974 dollars. The second referenced study (Ref. 3-3), examined the trend in trolley and diesel bus bid prices between 1969 and 1976 as part of a trolley bus evaluation study conducted for the TRI-MET transit authority in Portland, Oregon. This data, depicted in Figure 3-1 below, shows a slowly increasing trend in the price of comparably equipped diesel buses since 1969, with the most current bid prices (1975-1976) ranging between $65,000 and $70,000. These bid prices are for 40-foot diesel buses equipped with an eight-cylinder Detroit Diesel 8V-71 engine and with air conditioning.



TROLLEY AND DIESEL BUS BID PRICE TRENDS

Source: De Leuw, Cather & Company

FIGURE 3-1. TROLLEY AND DIESEL BUS BID PRICE TRENDS

Based on the information presented above, a unit capital cost of $70,000 (in 1977 dollars) per vehicle was established for the baseline diesel bus. A cost breakdown by major bus components was also developed using information cited in a similar study (Ref. 3-4) that examined 1975 diesel production costs as part of an analysis of expected TRANSBUS costs.

TABLE 3-2. BASELINE DIESEL BUS CAPITAL COST

System Categories	1975 Production Bus[1] (1975 Dollars)	TSC Baseline Diesel Bus (1977 Dollars)
Body Structure, Doors, Glazing	10,500	12,100
V8 Diesel Engine and Power Steering	9,500	10,950
Driveline and Support Systems	14,050	16,200
- Transmission		
- Exhaust System		
- Cooling System		
- Fuel System		
- Drive Shafts		
- Wheels		
- Brakes		
Suspension	6,600	7,600
Interior Fittings, Trim & Seats	8,250	9,510
Air Conditioning, Heating and Electrical	6,300	7,260
G&A and Profit (10%)	5,520	6,380
Estimated Total	60,720	70,000

[1]Source: TRANSBUS Operational Passenger and Cost Impacts, Booz-Allen Applied Research, July 1976.

As shown, the unit capital cost assumed in this analysis for the baseline diesel bus is approximately 15% higher than the 1975 production cost of a comparably equipped 40-foot diesel bus considered in the Booz-Allen TRANSBUS cost impact study. The major cost elements (64%) of the diesel bus are for the body structure, the driveline, suspension and support systems; while the diesel engine, power steering, heating, air conditioning and electrical systems represent 26% of the total bus cost.

A period of 14 years was assumed in this analysis as the economic service life of the diesel bus. This assumption was based upon data presented in a 1972 study (Ref. 3-1) that examined the age distribution of the national diesel bus fleet as a basis for forecasting the future demand for 40-foot transit coaches. The 1972 fleet age distribution, which is presented in Appendix D, is depicted in Figure 3-2 as a cumulative percentage of the total national fleet of 28,600 40-foot diesel buses in the transit industry.

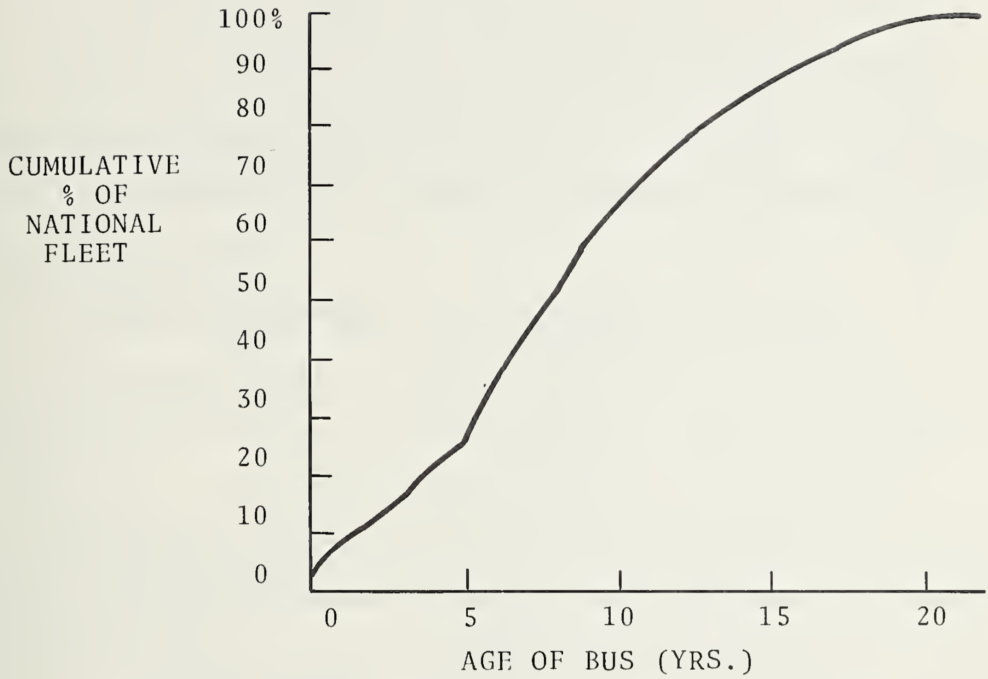


FIGURE 3-2. FLEET AGE DISTRIBUTION OF 40-FOOT DIESEL BUSES (1972)

As shown, the median age of the 1972 transit diesel bus fleet was eight years, with 16% of the total fleet having an age greater than 14 years.

The only other fixed capital investment cost considered in this analysis for the baseline diesel bus was for garage and vehicle maintenance facilities. The capital costs of such facilities are usually determined as a function of the number of vehicles to be garaged and serviced.

In this analysis, a capital cost of $38,000 per vehicle was assumed based upon a recent cost quotation of a diesel bus garage/maintenance facility in San Francisco. The capital cost of the San Francisco MUNI Woods Bus Center, which services a fleet of 240 buses, was nine million dollars. Further, a period of thirty years was also assumed as the economic service life of such a facility.

3.1.2 Diesel Bus Operations and Maintenance Costs

Table 3-3 presents the vehicle operations and maintenance costs (in cents/vehicle mile, 1977 dollars) used in this analysis for the baseline diesel bus. The unit operations/maintenance costs were derived from actual transit authority cost records as compiled and reported in two independent cost studies.

The first study (Ref. 3-4) examined the current operating costs of diesel buses in relation to the expected operating costs of the Interim and the TRANSBUS vehicle designs. This data, presented below, represents the average 1973 operating costs of the ten largest all-bus transit systems reporting to the American Public Transit Association. The second study (Ref. 3-2), conducted by Advanced Management Systems Inc., surveyed the 1974 operations/maintenance costs of seven transit authorities in order to develop a life-cycle costing procedure for the purchase of new urban transit buses.

TABLE 3-3. DIESEL BUS OPERATIONS/MAINTENANCE COSTS

Operations/Maintenance Cost Categories	Booz-Allen Study (Ref. 3-4) (¢/mi-1973$)		AMS Study (Ref. 3-2) (¢/mi-1974$)		TSC Diesel Bus (¢/mi-1977$)	
Vehicle Maintenance and Garage-Total	22.58		24.2		25.0	
- Repairs to Vehicles		-10.93		-12.5		
- Tires		- 1.28		- 1.4		
- Other		-10.37		-10.3		
Transportation-Total	78.65		85.7		95.0	
- Drivers Wages		-62.07		-61.3		-85.0
- Fuel[2]		- 7.75		- 6.1		-10.0
- Oil[3]		- 0.16		- 0.1		-
- Other[4]		- 8.67		-18.2		-
Station-Total	1.15		.2		1.36	
Traffic, Advertising	1.89		1.5		2.04	
Taxes & Licenses	3.64		5.5		8.16	
Insurance/Safety	6.48		6.2		8.84	
Operating Rents	0.18		-		-	
General & Administrative	19.97		33.2		47.6	
TOTAL[1]	134.5		156.5		188.0	

NOTES:
[1]Does not include depreciation on capital equipment.
[2]Based on .28 gals/mile and 35¢/gal.
[3]Included in vehicle maintenance cost.
[4]Included in driver payroll costs.

As shown above, approximately 82% of the diesel bus unit operations/maintenance costs (i.e., costs for driver payroll, advertising, insurance, taxes/licenses, and general/administrative) are unaffected and unrelated to the vehicle design. Only those costs for vehicle maintenance

(25¢/vehicle-mile) and fuel/power (10¢/vehicle-mile) can be attributed to the vehicle design.

In order to develop cost estimates for the operations/maintenance of the flywheel-powered vehicle systems, the unit maintenance costs for the diesel bus were examined at major vehicle component levels based on a similar breakdown of vehicle maintenance data presented in the Advanced Management Systems Life-Cycle Cost Study (Ref. 3-2).

The referenced cost data, in Table 3-4, reflects the average vehicle maintenance costs for six transit properties expressed in cents/vehicle-mile (1975 dollars). The assumed diesel bus vehicle maintenance costs (adjusted to 1977 dollars), shown below, were utilized in the determination of the unit vehicle maintenance costs for the trolley bus and the three proposed flywheel-powered vehicle systems.

TABLE 3-4. DIESEL BUS COMPONENT MAINTENANCE COSTS

Vehicle Maintenance Component Costs	AMS LCC Study (Ref. 3-2) (¢/veh mi-1974$)	TSC Diesel Bus (¢/veh mi-1977$)
Body & Chassis	4.11	4.43
Propulsion System	3.80	4.10
Power Transmission	3.58	3.86
Electrical Equipment	1.90	2.05
Brakes	2.80	3.02
Heating, Vent., Air-Condition	2.23	2.40
Air Operation Equipment	0.35	0.38
Lighting	1.10	1.18
Other (farebox, graphics)	.44	.47
SUB-TOTAL	20.31	21.89
Preventive Maintenance	1.20	1.30
Tires	-	1.51
Oil	-	.21
TOTAL	21.51	24.90

3.2 BASELINE TROLLEY BUS

The baseline trolley bus considered in this analysis is an electrically propelled rubber-tired vehicle that draws power from a central source through an overhead trolley wire system.

The production and use of trolley buses reached its peak in North America during the post-war years (1946-1950), when over 6,500 vehicles were in transit service in 22 U.S. and Canadian cities. Since then, trolley bus operations, like the street car, were soon virtually abandoned in favor of the diesel bus because of aging electrical equipment and changing route structures. Today, there are less than 1,200 trolley buses in transit service in five U.S. and four

Canadian cities (see Table 3-5). In each of these systems, the trolley buses are generally operated on the high-patronage, low-headway routes within the inner city.

TABLE 3-5. TROLLEY BUS OPERATIONS IN THE UNITED STATES AND CANADA

City	No. Vehicles (Active)	No. Vehicles (Peak)	2-Way Route-Miles of Overhead
Dayton	75	60	133.0
Seattle	57	53	62.0
Boston	50	32	25.5
San Francisco	282	234	157.0
Philadelphia	115	74	41.6
Vancouver	300	-	85.0
Toronto	151	101	56.5
Edmonton	103	-	-
Hamilton	50	-	-
Calgary[1]	39	-	31.5

[1]Calgary Trolley Bus Operations suspended effective June 1975.
Data Sources: References: 3-3, 3-6, 3-7, 3-8.

The structure of the trolley bus is virtually identical to the diesel bus except for having the diesel engine replaced by an electric traction motor. In North America, the basic trolley bus is the Flyer 10240 manufactured by Flyer Industries of Winnipeg, Canada. This bus has the same body structure as the AMG 10240 diesel bus except that it is powered by a 600V DC traction motor with resistor control.

In this analysis, the following vehicle characteristics, shown in Table 3-6, were assumed for the baseline trolley bus (Ref. 3-9).

TABLE 3-6. BASELINE TROLLEY BUS CHARACTERISTICS

Curb Weight (empty)	22,000 lb.
Gross Weight (full seated load)	29,200 lb.
Seating Capacity	45-50 passengers
Length	40 ft.
Width	102 in.
Height	128 in.
Peak Traction Motor Power	260 hp
Hotel Loads (Average)	20 kw
- Air Conditioning Compressor	
- Air Compressor	
- Low Voltage Supply	
- Heater	
Initial Acceleration	3.5 mph/sec
Acceleration Time to Cruise Speed (30 mph)	10 sec.
Maximum Speed	40 mph
Propulsion System Weight	3,500 lb.
Power Consumption	4.06 kw-hr/mi.

3.2.1 Trolley Bus System Capital Costs

In this analysis, capital investment costs were considered for the following equipment of a trolley bus system:

- Vehicles,
- Overhead trolley power lines and substations, and
- Garage/vehicle maintenance facilities.

As shown in Figure 3-1 of Section 3.1.1, the capital cost of trolley buses was relatively competitive to the cost of the diesel bus up until 1972. Since then, the cost of the trolley has increased at an approximate rate of 32% a year to the point that its capital cost is now 64% higher than the diesel bus. As cited in one study (Ref. 3-3), no clear reasons are available for the recent escalation in the price of the trolley bus although a low demand for vehicles, and a lack of competition among trolley bus manufacturers have certainly contributed to such increases.

Based on the recent 'bid prices' presented in Figure 3-1 and in Appendix C, a unit capital cost of $115,000 per vehicle (in 1977 dollars) was assumed for the baseline trolley bus. A breakdown of the total trolley bus capital cost by major vehicle components is shown below:

TABLE 3-7. BASELINE TROLLEY BUS CAPITAL COST

Body Structure (body, doors, suspension interior, trolley pole, etc.)	$ 42,500
Driveline and Support System (wheels, brakes, electrical, heating, drive shafts)	23,800
Traction Motor and Controls	31,400
Air-Conditioning and Other	6,900
G&A and Profit (10%)	10,400
	$115,000

The trolley bus body structure and support systems represent nearly 64% of the total cost, with traction motor and controls accounting for 27% of the cost.

Historical data on the service life for the retirement and replacement of trolley buses is somewhat limited. APTA data on pre-1975 trolley coach deliveries (Ref. 3-10) indicates that only five new trolley buses were delivered (to an APTA reporting transit property) between 1955 and 1975. This information conflicts, however, with the data in Appendix C in that it does not include the most recent trolley bus purchases by Vancouver, Dayton, Boston, and San Francisco. Presented in Appendix D is pre-1975 APTA data on the age distribution of trolley bus fleets from five reporting transit systems. As shown, the mean age of these vehicle fleets ranged from 23 to as high as 34 years. In this analysis, a period of 23 years was selected as a reasonable economic service life for these vehicles even though there is evidence to the fact that trolley buses are retained in the fleet beyond 25 years.

The single largest capital cost item for the trolley bus, however, is the overhead trolley lines and suspension system. Data from several sources (Refs. 3-3, 3-11) indicate that the capital cost for the overhead power network for the trolley bus depends not only on the extent (route-miles) of deployment, but also on the type of substations, power distribution, and suspension systems utilized. In this analysis, we assumed an underground feeder distribution system, with hardwire suspension powered by rectifier stations rated at 150 kw/route-mile. Presented in Table 3-8 is a summary of representative unit cost data cited in two independent studies (Refs. 3-3, 3-11) for overhead trolley power distribution systems. A more detailed definition of the referenced capital costs is presented in Appendix E.

TABLE 3-8. REPRESENTATIVE CAPITAL COSTS FOR A TROLLEY OVERHEAD AND POWER DISTRIBUTION SYSTEM [Dollars/Route-Mile (2-way operation)]

Cost Component	Study (Ref. 3-11) (1975-$)	Study (Ref. 3-3) (1976-$)[1]
Overhead (power lines, poles, spans, etc.)	335,000	239,000
Feeder Distribution and Substations	160,000	123,000
Total Cost	495,000	362,000

[1]NOTE: Data reflects the average unit cost/route mile on following TRI-MET Routes 53, 14 and 12.

In view of the disparity in the unit capital costs of the two studies (i.e., the 1975 dollar costs higher than the 1976 unit costs), the unit cost data cited in the San Francisco MUNI study was used -- unadjusted to 1977 dollars. Therefore, a total capital cost of $495,000 per route-mile (2-way operation), with a service life of 30 years was assumed for the trolley bus.

The capital cost for a trolley bus garage and maintenance facility was developed based on the same cost assumptions made for the baseline diesel bus. To a base garage/maintenance facility cost of $38,000 per vehicle, an additional cost of $4,400 per vehicle was considered for the electrification of the yard/maintenance facilities, and for additional capital equipment to maintain the overhead power lines. This cost estimate is quite conservative in that the TRI-MET study (Ref. 3-3) estimated an additional cost of

$8,000 per vehicle over the diesel bus for added garage/maintenance equipment and facilities for the trolley bus. Thus, a total capital cost of $42,400 per vehicle was used for the trolley bus garage/maintenance facility and equipment with a service life of 30 years.

3.2.2 Trolley Bus Operations and Maintenance Costs

Past study results (Refs. 3-3, 3-6) vary on the relative differences in the vehicle operations and maintenance expenses for diesel and trolley bus systems. Primary areas for a variance in such costs are:

- Fuel/power,
- Vehicle maintenance (i.e., vehicle servicing, inspections, labor and component costs), and
- Maintenance of the trolley bus overhead power lines.

For vehicle maintenance, the SEPTA trolley bus evaluation study (Ref. 3-6) cited a 27% lower annual vehicle maintenance cost for the trolley bus system as compared to that of the diesel bus; however, with the costs of maintenance of the overhead trolley facilities considered, the total annual expenditures for trolley bus vehicle and facility maintenance was nearly four times greater than the diesel bus. In the TRI-MET trolley bus evaluation study (Ref. 3-3) vehicle maintenance costs were assumed to be

2¢/vehicle-mile lower than the diesel bus. Data on the maintenance costs of the overhead trolley power lines from several trolley-bus transit operations were also cited. These annual costs ranged from as low as $4,000/route-mile (2-way), to as high as $15,000/route-mile (2-way); a unit cost of $6,000/route-mile (2-way) was eventually used in the TRI-MET study.

Presented in Table 3-9 are the unit operations and maintenance costs used in this analysis for the baseline trolley bus system.

TABLE 3-9. TROLLEY BUS OPERATIONS AND MAINTENANCE COSTS

Cost Category	Trolley Bus (¢/veh-mile, 1977 $)	
Vehicle Maintenance and Garage Expenses	20.00	
Transportation	97.00	
- Driver Wages		- 85
- Power[2]		- 12
- Other[3]		- –
Station-Total	1.36	
Traffic/Advertising	2.04	
Taxes, Licenses	8.16	
Insurance, Safety	8.84	
General & Administrative	47.60	
TOTAL[1]	185.00	
Maintenance of Overhead Power Facility [$/route-mile (2-way)]	$6,000	

[1]Does not include depreciation on capital equipment.
[2]Based on 4.06 kw-hr/mile and 3¢/kw-hr.
[3]Included in driver payroll costs.

As was the case with the diesel bus, 82% of the trolley bus vehicle operations and maintenance costs are fixed costs unrelated to the vehicle design. The assumed vehicle maintenance cost, as defined in Table 3-10 below, for the trolley bus is 20% less than that of the diesel bus.

TABLE 3-10. TROLLEY BUS COMPONENT MAINTENANCE COSTS

Maintenance Component	¢/Veh.-Mi.	Comment
Body & Chassis	4.4	
Propulsion System	5.0	3¢/mile less than Diesel Bus (Ref. 3-3)
Brakes	1.0	1/3 less than Diesel Bus (Ref. 3-6)
Electrical Equipment	1.7	16% less than Diesel Bus
Heating, Air Condition	2.4	
Air Operation Equipment	.4	
Lighting	1.2	
Preventive Maintenance	1.3	
Tires	1.5	
Trolley Pole	1.0	Based on data in Ref. 3-6
Other	.5	
TOTAL	20.4	

3.3 PROPOSED ALL-FLYWHEEL VEHICLE CONCEPT

3.3.1 Vehicle Design and Charging Requirements

One of the proposed all-flywheel vehicle concepts (Ref. 3-9) under consideration by UMTA is a 40-foot transit bus with the following propulsion system components: a flywheel assembly, a flywheel motor, a dual converter, and a separately excited DC traction motor.

Figure 3-3 (Ref. 3-9) illustrates the major components of the proposed all-flywheel propulsion system.

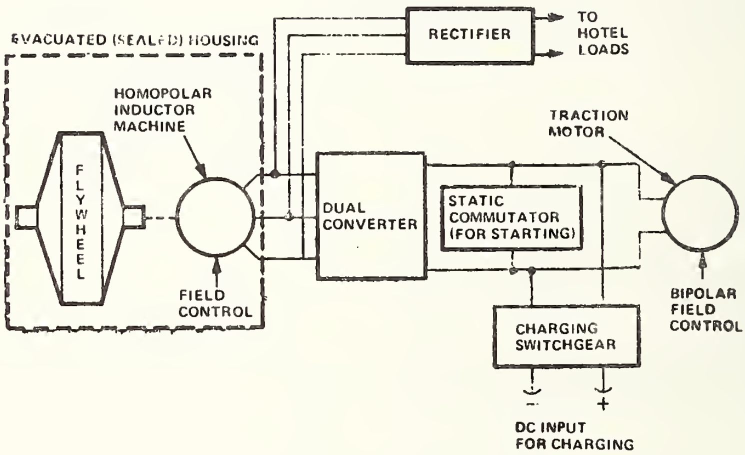


FIGURE 3-3. PROPOSED ALL-FLYWHEEL VEHICLE PROPULSION SYSTEM

The size and power rating of the all-flywheel propulsion system was designed to provide full traction power for a full passenger load consistent with the axle loads and housing requirements of an urban 40-foot transit bus. As defined in the system concept design study (Ref. 3-9), the energy storage capacity of the flywheel assembly is

20 kw-hr at the 11,600-rpm maximum operating speed. With an assembly weight of 4,200 lb., this represents an energy density of 4.8 watt-hours per pound for the fully contained flywheel system. The usable capacity of this flywheel when operated over the recommended 2 to 1 speed range is 15 kw-hr. The total weight of the all-flywheel propulsion system of 6,450 lbs is at the load limit of a 38,000 lb. (gross vehicle weight) vehicle with a crush passenger load of 13,000 lbs. The optimum all-flywheel system configuration is with the flywheel and flywheel motor enclosed within a sealed vacuum housing.

The operation of the pure flywheel system is relatively straightforward. Initial charging to base speed is accomplished by the dual converter which provides controlled voltage and frequency power to the synchronous flywheel machine that is then brought up to base flywheel speed. When the flywheel is fully charged, propulsion is accomplished by controlled rectification of the flywheel machine output voltage to provide proper control of voltage applied to the separately excited field-type DC traction motor. This configuration is fully bilateral so that energy from vehicle braking operations can be coupled back to the flywheel by the load commutated inverter operation of the dual converter and flywheel electrical machine. The vehicle hotel loads are provided by rectifying the fixed voltage output of the flywheel machine.

Table 3-11 presents a summary of the design characteristics of the proposed all-flywheel vehicle system.

TABLE 3-11. PROPOSED ALL-FLYWHEEL VEHICLE DESIGN CHARACTERISTICS

Size			Same as 40-ft Diesel
Curb Weight			24,950 lb.
Propulsion System Weight			6,450 lb.
Crush Load Weight (86 passengers)			38,000 lb.
Permissible Axle Loading			38,000 lb.
Hotel Loads:	Peak	Average	
-A/C Compressor	6 kw	6 kw	
-Air Compressor	3 kw	1 kw	
-Alternator	17 kw	8 kw	
	26 kw	15 kw	
Peak hp to Road			300 HP
Initial Acceleration			3.5 mph/sec
Maximum Speed			55 mph
Acceleration to Speed			30 mph in 10 sec.
Urban Route Range			3-5 miles
Peserve Energy			0.6 mi. or 5 min.
Time to Charge at Stop			2 min.
Time to Charge Enroute			1.5 min.
Length of Charging Overhead Wire			0.25 mi.
Energy Consumption Per Mile (from overhead)			3.16 kw-hr

Source: Ref. 3-9

Two techniques were proposed (Ref. 3-9) for the en route charging of the all-flywheel vehicle propulsion system while in transit service. In each of these cases, the number of wayside power stations required en route and the power rating of each station were determined based upon the urban route range of the vehicle, its charging time, and its respective energy consumption.

One proposed technique, shown in Figure 3-4, is the stationary charging technique that requires the vehicle to draw power while at rest from wayside power stations. The discharge range of the all-flywheel propulsion system, which is a function of the type of route the vehicle is operated on, determines the required spacing (in route-miles) between the wayside power stations. On high stop-density routes (i.e., eight stops/mile) where the vehicle's energy consumption is the greatest, the range of the vehicle and the required spacing between wayside stations is only three miles as compared to operations on low stop-density routes (i.e., four stops/mile) where the vehicle's charge/discharge range and required station spacing is five miles. In this analysis, the all-flywheel vehicle was assumed to operate under a duty cycle C (all-day average) driving cycle with a route stop density of five stops/mile. Under these conditions, the range of the vehicle's propulsion system and the required spacing between en route power stations was 4.5 miles.

The time required to charge the 20 kw-hr all-flywheel propulsion system, which has a useful energy capacity of 15 kw-hr and a maximum charging power input of 360 kw, is around two minutes. Under the stationary charging technique, each wayside station is required to have a power rating of 670 kw in order to charge two vehicles simultaneously in two-way route operations. The power rating of the station was determined as follows:

$$PR = (Vehs)\left[\frac{E_f}{t}\right]\left[\frac{60\ min/hr}{e}\right] \quad (f)$$

where: PR = power rating of the wayside station (kw)
Vehs = maximum number of vehicles drawing power from substation
E_f = useable energy capacity of the flywheel (15 kw-hr)
t = vehicle charging time (2 minutes)
e = efficiency of station (85%)
f = adjustment factor based on worst case of having 2 vehicles drawing power from the substation for a period of 2 minutes at a headway of 5 minutes $(2\ min/5\ min/veh)^{1/2}$.

The second proposed technique (Ref. 3-9), shown in Figure 3-5, is the en route charging of the vehicle through an onboard automatic collector system from a .25 mile overhead trolley wire at each wayside station. Unlike the stationary charging technique, there are no delays incurred en route since the vehicle is being charged while in motion. Under duty cycle C conditions, the discharge range of the vehicle (or the route mile spacing between stations) is 4.5 miles; the charging time en route is 1.5-2.0 minutes at a mean vehicle speed of 11 to 12 mph. Using a charging time of 1.5 minutes, the power rating (kw) of each wayside station for charging two vehicle simultaneously in two-way operations (according to the equation defined above) would be approximately 770 kw.

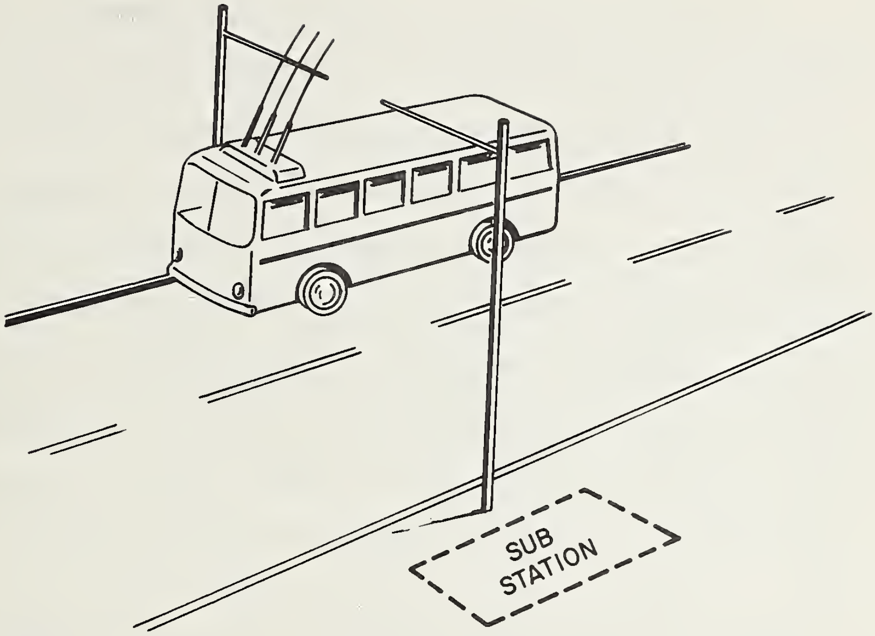


FIGURE 3-4: ALL-FLYWHEEL STATIONARY WAYSIDE CHARGING TECHNIQUE

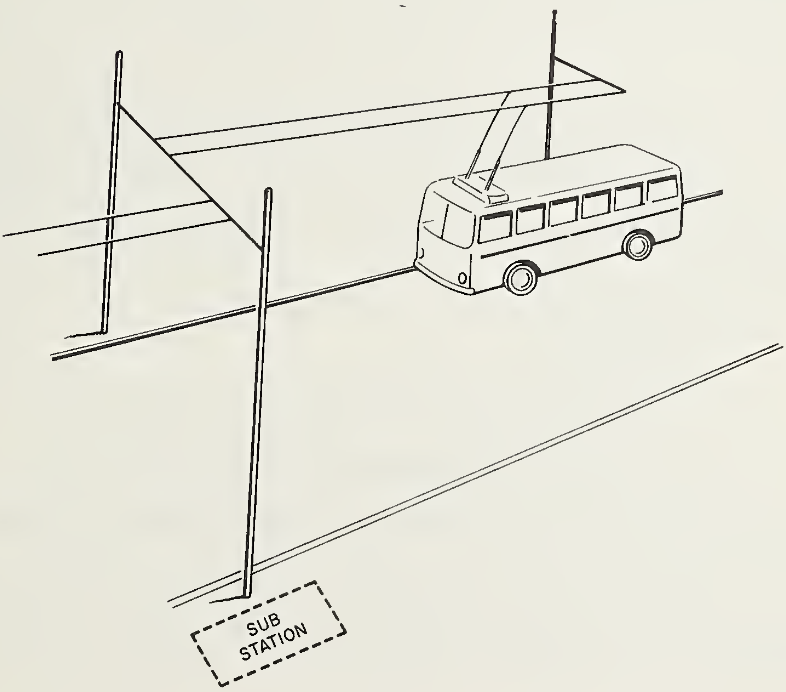


FIGURE 3-5: ALL-FLYWHEEL EN ROUTE CHARGING TECHNIQUE

In this analysis, the stationary charging technique was adopted in determining the life-cycle cost of the all-flywheel vehicle system. It should be noted that under the stationary charging technique, a 6% larger vehicle fleet is required to provide an equivalent level of service because of the delays incurred en route for the charging of the vehicle's propulsion system. The additional costs of the larger fleet size, however, are offset, in comparison to the costs associated with the en route wayside charging technique, by the lower cost of each wayside power station. Thus, in terms of total system costs, there were no significant differences found in the life-cycle costs of the all-flywheel vehicle system under either one of the two proposed vehicle charging techniques.

3.3.2 Proposed All-Flywheel System Capital Costs

For the proposed all-flywheel vehicle system, fixed capital investment costs were considered for the following capital equipment:

- Vehicles,
- Wayside power charging stations, and
- Vehicle garage/maintenance facilities.

The capital cost of the all-flywheel vehicle was developed, for the most part, based on the cost data presented for the trolley bus with cost adjustments for the different components in the vehicle's propulsion and power control system. Common cost items of the two vehicle systems are in the body structure, the driveline, and support systems.

Presented in Table 3-12 is a breakdown of the estimated unit capital costs for each of the major components of the proposed all-flywheel vehicle system. A total capital cost of $149,000 per vehicle (in 1977 dollars) excluding initial development costs and based on a production level of 10,000 vehicles over 10 years, was used in this analysis.

TABLE 3-12. ALL-FLYWHEEL VEHICLE CAPITAL COST

Component	Unit Capital Cost (1977 Dollars)
Body Structure, Driveline and Support Systems	66,000
Propulsion System	
-Flywheel and Housing	16,400
-Flywheel Motor	14,200
-Power Control Unit	33,100
-DC Traction Motor	13,300
Installation and Assembly (4%)	6,000
TOTAL COST	$149,000

As shown, the propulsion system accounts for nearly 52% of the total estimated cost of the proposed all-flywheel vehicle design. A definition of the component cost estimates of the vehicle's propulsion system is presented in

Appendix F. The body structure of the all-flywheel vehicle was assumed to be equivalent to the trolley bus, in terms of cost and design, and as such, a comparable service life of 23 years was used in the analysis.

The unit capital cost of the all-flywheel wayside power stations was determined based on costs of similar equipment that converts high voltage AC utility power to 600 volts DC. The major components of the wayside power stations include a high voltage AC breaker and fuse block, a transformer to convert to low voltage AC power, a low voltage AC breaker and fuse block, a rectifier, and a DC circuit breaker (Ref. 3-12).

Figure 3-6 (Ref. 3-12) illustrates the unit capital cost (adjusted to 1977 dollars) for equipment and installation of 600-VDC wayside charging substations as a function of the steady state power rating of the station.

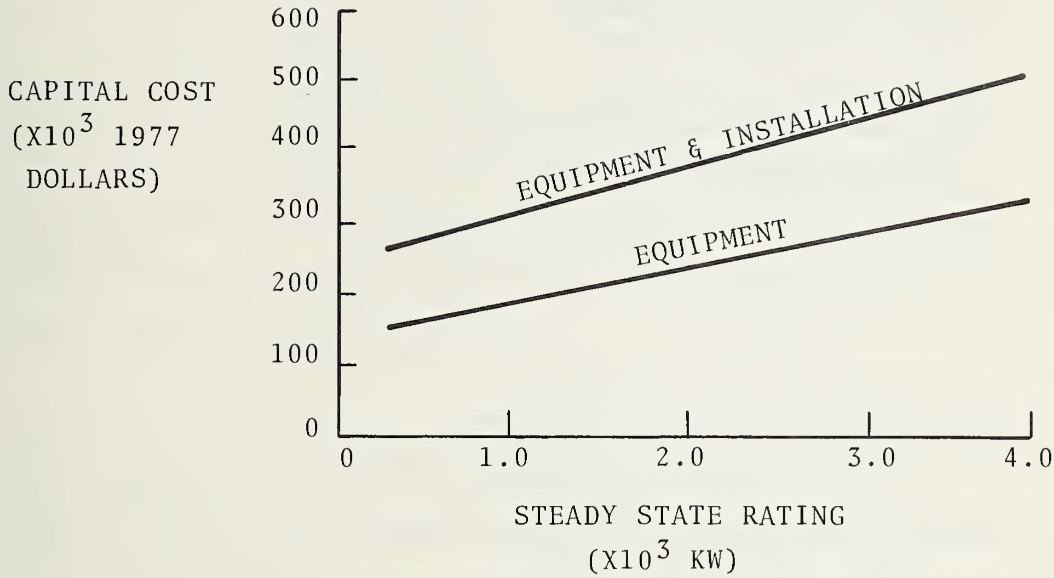


FIGURE 3-6. WAYSIDE CHARGING STATION CAPITAL COSTS

For the proposed en route and stationary vehicle charging techniques, the total capital cost (equipment and installation) of an all-flywheel wayside power station supporting 2-way route operations is as follows:

TABLE 3-13. ALL-FLYWHEEL WAYSIDE STATION CAPITAL COSTS

	Stationary Charging Technique	En Route Charging Technique
Power Rating of Substation (2-way operation) in kw	670 k	770 k
Capital Cost (1977 $) -Equipment and Installation	286,000	295,000
-Trolley Lead Wire (.25 miles/direction)	--	55,000
TOTAL COST	$286,000	$350,000

A thirty-year service life was assumed for the all-flywheel wayside power stations.

The garage and maintenance facility requirements of the proposed all-flywheel vehicle systems were assumed to be equivalent to that of the trolley bus. A unit cost of $38,000 per vehicle was assumed for the garage/maintenance facility, plus an additional $4,400 per vehicle to cover the costs of having flywheel charging equipment at the facility and the capital equipment to maintain the wayside power stations. Therefore, a total cost of $42,400 per vehicle (in 1977 dollars) was used as the capital cost of the garage/maintenance facility and related capital equipment. A service life of 30 years was also assumed on this capital expenditure.

3.3.3 All-Flywheel System Operations and Maintenance Costs

Recurring annual operations and maintenance expenses for the all-flywheel vehicle system include costs for:

- Fuel/power,
- Vehicle maintenance,
- Fixed operating expenses, and
- The maintenance of the wayside power stations.

Presented in Table 3-14 are the unit operations and maintenance costs used in this analysis for the proposed all-flywheel vehicle design.

TABLE 3-14. ALL-FLYWHEEL OPERATIONS AND MAINTENANCE COSTS

Cost Category	All-Flywheel (¢/veh-mile, 1977 $)	
Vehicle Maintenance and Garage Expenses	29.00	
Transportation	100.00	
-Driver Wages[1]		-91
-Power[2]		- 9
-Other[3]		- 0
Station - Total	1.36	
Traffic/Advertising	2.04	
Taxes, Licenses	8.16	
Insurance and Safety	8.84	
General and Administrative	47.60	
TOTAL[4]	197.00	
Maintenance of Wayside Power Stations ($/station/year)	$1,500	

[1]Per vehicle-mile cost based on lower mean speed of all-flywheel vehicle.
[2]Based on energy consumption of 3.16 kw-hr/mile and 3¢/kw-hr.
[3]Included in driver payroll costs.
[4]Does not include depreciation on capital equipment.

As shown, the total per vehicle-mile operations and maintenance costs of the all-flywheel vehicle system is, respectively, 5% and 6% higher than that of the baseline diesel and trolley bus systems. The increase in the per vehicle mile cost is attributed to higher driver payroll and vehicle maintenance expenses. For the all-flywheel vehicle system, the unit cost for driver wages and other transportation expenses is 7% higher than that of the diesel and trolley bus because of a lower mean operating speed of the vehicle (due to en route charging of the flywheel) which, in turn, increases the total driver payhours in transit service. The fuel/power cost of the all-flywheel vehicle is 1¢/vehicle-mile and 4¢/vehicle-mile, respectively, less than that of the diesel and trolley bus; while the assumed per vehicle-mile maintenance cost of the all-flywheel vehicle is 16% and 45% higher, respectively, than that of the diesel and trolley bus systems. Cost differences for vehicle maintenance between the all-flywheel and baseline vehicle systems are reflected in areas such as maintenance of the propulsion system, brakes, electrical equipment, and the pantograph. Table 3-15 presents a component cost breakdown of the all-flywheel vehicle unit maintenance costs.

TABLE 3-15. ALL-FLYWHEEL COMPONENT MAINTENANCE COSTS (1977 Dollars)

Maintenance Component	Unit Cost ¢/veh-mile	Notes
Body & Chassis	4.4	
Propulsion System	9.5	Assumed to be 20% higher than diesel bus
Brakes	3.1	Equivalent to diesel bus
Electrical Equipment	3.0	45% higher than diesel bus
Heating, A/C	2.4	
Air Operation Equipment	0.4	
Lighting	1.2	
Preventive Maintenance	2.0	
Tires	1.5	
Pantograph	1.0	Assumed to be the same as trolley bus
Other	0.5	
TOTAL	29.0	

In addition to the vehicle related operations and maintenance costs defined above, an annual cost of $1,500 per station was assumed for the maintenance of the all-flywheel wayside power stations.

3.4 PROPOSED FLYWHEEL/DIESEL VEHICLE DESIGN CONCEPT

3.4.1 Vehicle Design Characteristics

The proposed flywheel/diesel vehicle design shown in Figure 3-7 utilizes a 6 kw-hr flywheel, and a 75 hp diesel engine to provide the motive power for the vehicle.

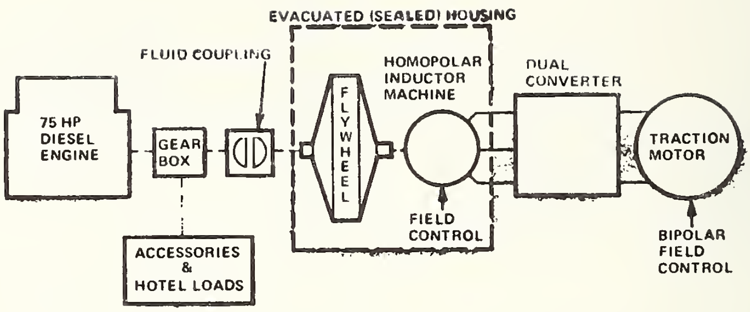


FIGURE 3-7. PROPOSED FLYWHEEL/DIESEL PROPULSION SYSTEM DESIGN

As defined in the vehicle design study (Ref. 3-9), the diesel engine is coupled to the flywheel through speed increasing gears and a fluid coupling mechanism. Initially, the flywheel is brought up to the engine speed by operating the diesel engine at minimum speed and placing fluid into the clutch. The clutch will then transmit torque to the flywheel which will bring the flywheel up to speed. As the flywheel speed is increased, the diesel engine can be accelerated to maximum speed to fully charge the flywheel.

A dual converter couples the flywheel machine to a DC traction motor, and controls the flow of power to and from the vehicle. Besides providing power for the initial charging of the flywheel, the diesel engine is also capable of providing make-up power for any propulsion system losses, vehicle hotel loads, and engine accessories.

The design characteristics of the flywheel/diesel vehicle system are defined in Table 3-16.

TABLE 3-16. FLYWHEEL/DIESEL VEHICLE DESIGN CHARACTERISTICS

Size			Same as 40-ft diesel
Curb Weight			24,235 lb.
Propulsion System Weight			5,260 lb.
Fuel Tank Weight (50 gal.)			475 lb.
Crush Load Weight (86 passengers)			37,285 lb.
Permissible Axle Loading			38,000 lb.
Flywheel			6 kw-hr
Diesel Engine			75 hp
Hotel Loads:	PEAK	AVERAGE	
A/C Compressor	9 kw	6 kw	
Air Compressor	3 kw	1 kw	
Engine Fan	8 kw	4 kw	
Alternator	17 kw	8 kw	
	37 kw	19 kw	
Peak hp to Road			300 HP
Initial Acceleration			3.5 mph/sec.
Acceleration to Speed			30 mph in 10 sec.
Maximum Speed			55 mph
Urban Route Range			250 miles
Fuel Consumption			3.84 mi./gal.

Source: Reference 3-9

The proposed flywheel/diesel vehicle system does not require any external power source for the charging of its 6 kw-hr flywheel. The flywheel is charged solely from the 75 hp diesel engine with the vehicle capable of operating at a range of nearly 250 miles between refuelings.

3.4.2 Flywheel/Diesel System Capital Costs

The fixed capital investment costs considered in this analysis for the flywheel/diesel bus were for vehicles and garage/maintenance facilities.

The capital cost of the flywheel/diesel bus was developed based on having comparable design to that of a trolley bus especially in the vehicle component areas such as the body structure, the driveline, and vehicle support systems. In this analysis, a total capital cost of $130,000 per vehicle (in 1977 dollars) was assumed for the proposed flywheel/diesel vehicle design. Table 3-17 presents a breakdown of the total capital cost by major vehicle components. This cost excludes any initial development costs on the vehicle's propulsion system and, further, is based on an assumed production level of 10,000 vehicles over 10 years. The cost estimates for the flywheel/diesel propulsion system components are defined in Appendix F of this report.

TABLE 3-17. FLYWHEEL/DIESEL VEHICLE CAPITAL COST

Component	Unit Capital Cost (1977 Dollars)
Body Structure, Driveline and Support Systems	66,000
Propulsion System	
- Flywheel and Housing	8,300
- Flywheel Motor	6,400
- Traction Motor	13,300
- Power Control Unit	26,500
- Diesel Engine/Transmission[1]	4,500
Installation and Assembly (4%)	5,000
TOTAL COST	$130,000

[1]The 75 hp diesel engine/transmission is assumed to have a useful life of 12 years. This cost includes a replacement cost of the diesel engine and transmission unit after that period.

As shown, the propulsion system represents 45% of the vehicle's total capital cost with the primary cost elements being the DC traction motor, and the power conditioning and control unit. Since this vehicle design was assumed to be equivalent to that of the trolley bus, an economic service life of 23 years was used in the analysis for the flywheel/diesel vehicle.

The garage and maintenance facility requirements for the flywheel/diesel vehicle were assumed to be comparable to that of the baseline diesel bus even though additional maintenance equipment may be needed to service and maintain the electrical and flywheel components of the vehicle's propulsion system. In this analysis we assumed a capital cost of $38,000 per vehicle (in 1977 dollars) over a service life of 30 years for the flywheel/diesel garage/ maintenance facility and equipment.

3.4.3 Flywheel/Diesel System Operations and Maintenance Costs

Presented in Table 3-18 are the annual expenses (expressed in cents/vehicle mile, 1977 dollars) that are incurred in the operation and maintenance of a flywheel/ diesel vehicle system. They include expenditures for fuel, vehicle maintenance, and other fixed costs such as driver payroll, administration, etc., that are generally unrelated to vehicle design.

TABLE 3-18. FLYWHEEL/DIESEL OPERATIONS AND MAINTENANCE COSTS

Cost Category	Flywheel/Diesel (¢/vehicle-mile, 1977 $)	
Vehicle Maintenance and Garage Expenses	26.00	
Transportation	94.00	
-Driver Wages		-85
-Fuel[1]		- 9
-Other[2]		- 0
Station	1.36	
Traffic/Advertising	2.04	
Taxes/Licenses	8.16	
Insurance and Safety	8.84	
General and Administrative	47.60	
TOTAL[3]	188.00	

[1]Based on .26 gals/mile and 35¢/gal.
[2]Included in Driver Payroll Costs.
[3]Does not include depreciation on capital equipment.

The total unit operations and maintenance costs of the flywheel/diesel bus is equivalent to that of the baseline diesel bus. The only cost differentials between the two systems in terms of component unit costs/vehicle-mile are in fuel and vehicle maintenance expenses. The flywheel/diesel bus is reported (Ref. 3-9) to have a 7% lower fuel consumption than the diesel bus, and as such its per vehicle mile fuel cost is one cent less than the diesel bus. The unit vehicle maintenance costs for the flywheel/diesel bus were assumed to be equivalent to that of the diesel bus except in the area of maintaining the vehicle's propulsion and transmission system. As shown in Table 3-19, a higher unit maintenance cost was assumed for the propulsion/transmission unit because of the mix of electrical and mechanical components.

TABLE 3-19. FLYWHEEL/DIESEL COMPONENT MAINTENANCE COSTS (1977 Dollars)

Maintenance Component	Unit Cost (¢/veh-mi)	Notes
Body and Chassis	4.4	
Propulsion System	8.8	Assumed to be 10% higher than diesel bus
Brakes	3.0	
Electrical Equipment	2.0	
Heating, A/C	2.4	
Air Operation Equipment	.4	
Lighting	1.2	
Preventive Maintenance	1.3	
Tires	1.5	
Oil	0.2	
Other	0.5	
TOTAL	25.7	

3.5 PROPOSED FLYWHEEL/BATTERY VEHICLE CONCEPT

3.5.1 Vehicle Design and Charging Requirements

A second flywheel hybrid vehicle system considered in this analysis is a 40-foot flywheel/battery transit bus. As shown in Figure 3-8, the flywheel/battery vehicle utilizes a 7 kw-hr flywheel and a 100 kw-hr, 6 metric-ton battery pack as the source of its tractive motive power.

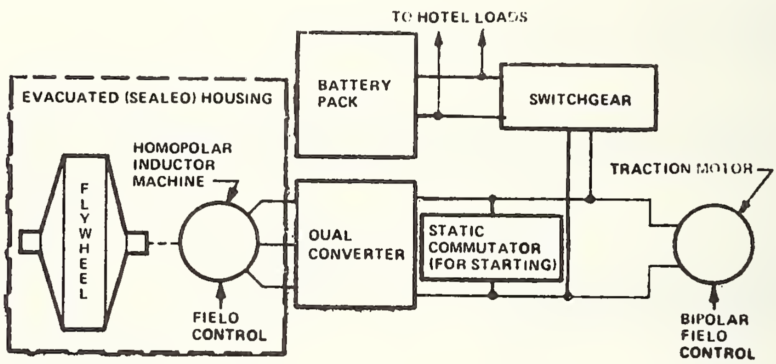


FIGURE 3-8. PROPOSED FLYWHEEL/BATTERY PROPULSION SYSTEM

As defined in the vehicle systems design study (Ref. 3-9), the operation of the flywheel/battery propulsion system is very similar to that of the all-flywheel vehicle design. In the flywheel/battery hybrid drive system, power from the flywheel is used for the propulsion of the vehicle and for meeting the auxiliary load requirements during acceleration and braking. Regeneration power in excess of that required by the auxiliary load is returned to the flywheel during braking. Power from the battery pack is used for cruise propulsion and the supply of the auxiliary load during cruise and dwell. The power control unit does not accept power from the battery unit during vehicle acceleration or braking.

As was cited above, the proposed battery pack considered for the flywheel/battery propulsion system is a six metric-ton, 100 kw-hr unit that is relatively equivalent to the battery pack used in the West German Electrobus. Since the peak power requirements of the vehicle during acceleration is provided by the flywheel and the power from the battery is used only for cruise propulsion and to supply auxiliary load during cruise and dwell, the useful service life of the battery pack for the proposed flywheel/battery vehicle is expected to be higher than that of the West German Electrobus. In this analysis, a service life of 2000 charge/discharge cycles was assumed for the battery pack on the flywheel/battery vehicle as compared to a service life of 1000-1200 charge/discharge cycles being experienced by the West German all-battery Electrobus. To support the weight (approximately 13,200 lbs.) of the battery pack, the conventional two-axle bus design is required to be changed with an addition of a third steerable support axle. Presented in Table 3-20 are the proposed (Ref. 3-9) design characteristics of the flywheel/battery vehicle system.

TABLE 3-20. FLYWHEEL/BATTERY VEHICLE DESIGN CHARACTERISTICS

Size			Same as 40-ft. diesel
Curb Weight			37,110 lb.
Propulsion System Weight			17,880 lb.
Battery Weight			13,200 lb.
Crush Load Weight (73 passengers)			48,000 lb.
Permissible Axle Loading			48,000 lb.
Battery Pack			100 kw-hr
Flywheel			7 kw-hr
Hotel Loads:	PEAK	AVERAGE	
- A/C Compressor	6 kw	6 kw	
- Air Compressor	3 kw	1 kw	
- Alternator	17 kw	8 kw	
	26 kw	15 kw	
Peak hp to Road			350 HP
Initial Acceleration			3.5 mph/sec.
Acceleration to Speed			30 mph in 10 sec.
Maximum Speed			55 mph
Urban Route Range			50 miles
Reserve Energy			5 miles
Time to Change Battery Packs			10 minutes
Energy Consumption Per Mile			5.31 kw-hr/mile
Battery Useful Cycle Life			2000 cycles

The charging of the flywheel/battery propulsion system is accomplished by the replacement and the recharging of the vehicle's battery packs at wayside battery charging and changing stations. Based on the experience of the West

German Electrobus demonstration (Ref. 3-13), each fully charged battery has an urban route range of 25 miles and a reserve range of 3 miles. Three battery charging/changing stations were required to support a total of 19 battery packs in use by a fleet of 13 vehicles. The replacement time for the battery packs at the wayside charging/changing stations is 5 to 10 minutes with each battery pack having a useful service life of 2,000 charge/discharge cycles.

In this analysis, it was assumed, with the addition of a 7 kw-hr flywheel to the vehicle's propulsion system, the urban route range of the flywheel/battery vehicle would effectively be doubled to a range of 50 miles. With a longer driving range between battery recharges, the number of wayside charging/changing stations required to support a fleet of vehicles in service is reduced. For this analysis, the number of wayside battery charging/changing stations required was determined as a function of the vehicle fleet at a rate of 1-1/2 wayside stations per fleet of 13 vehicles. The battery pack requirements of the vehicle fleet were assumed to be the same as the West German Electrobus at 1-1/2 battery packs per vehicle.

3.5.2 Flywheel/Battery System Capital Costs

For the flywheel/battery vehicle system, fixed capital investments are required for the following capital equipment:

- Vehicles,
- Battery packs,
- Wayside battery charging/changing stations, and
- Garage/maintenance facilities.

The capital cost of the flywheel/battery vehicle system was based on the design of a 40-foot trolley bus adjusted to account for the additional cost of a third steerable axle to support the weight of the vehicle's propulsion system. Table 3-21 identifies the breakdown of the total capital cost of $147,800 per vehicle (in 1977 dollars) by major vehicle components. This cost does not include the cost of the initial battery pack, nor any development costs of the vehicle's propulsion system and is based on a production level of 10,000 vehicles over a period of 10 years. Appendix F defines the cost estimates and assumptions of the flywheel/battery propulsion system components. A 23-year period was assumed in the analysis as the economic service life of the vehicle.

TABLE 3-21. FLYWHEEL/BATTERY VEHICLE CAPITAL COST (1977 Dollars)

Component	Unit Capital Cost (1977 Dollars)
Body Structure, Driveline and Support System	66,000
- Added Third Axle	8,400
Propulsion:	
- Flywheel and Housing	9,300
- Flywheel Motor	7,000
- Traction Motor	15,000
- Power Control Unit	35,000
Installation and Assembly (5%)	7,100
TOTAL COST	$147,800

The cost of the battery pack for the flywheel/battery vehicle was determined based on unit cost data (100,000 D.M.) cited (Ref. 3-13) for the West German Electrobus. In this analysis, the cost of an equivalent 6 metric-ton, 100 kw-hr battery pack was assumed to be $41,300 (in 1977 dollars). With a service life of 2,000 charge/discharge cycles per pack, a vehicle range of 50 miles between recharges, and an average annual vehicle mileage of 35,000 miles, the effective service life of 1-1/2 battery packs that are purchased per vehicle is 4.3 years. The replacement costs of the vehicle battery packs, including the salvage credits on the used batteries, were treated as recurring capital investment expenditures occurring every 4.3 years over the investment period under analysis.

The capital cost of the wayside battery charging/changing stations was also determined based on the cost information reported (Ref. 3-13) for the West German Electrobus system. At a reported cost of 1,000,000 D.M. per station, the assumed capital cost for the battery charging/changing station used in this analysis was $413,000 (in 1977 dollars). A service life of 30 years was also assumed for the battery charging/changing stations.

The garage and maintenance facility requirements for the flywheel/battery bus was assumed to be equivalent to the diesel bus even though additional equipment would probably be required for the overnight charging and maintenance of the battery packs. A total capital cost of $38,000 per vehicle, and a service life of 30 years was used in the analysis for the flywheel/battery garage, and maintenance facilities and equipment.

3.5.3 Flywheel/Battery Operations and Maintenance Costs

For the flywheel/battery bus, annual recurring expenses are incurred for the operation and maintenance of the vehicle, and for the maintenance of the wayside battery charging/changing stations.

Table 3-22 summarizes the unit operations and maintenance costs used in this analysis for the flywheel/battery bus. The vehicle related expenses (i.e., vehicle maintenance, power, and fixed operating expenses) are expressed in terms of cents per vehicle-mile operated (in 1977 dollars). An annual operating expense of $1,000 per station was assumed for the maintenance of the wayside battery charging/changing stations.

TABLE 3-22. FLYWHEEL/BATTERY UNIT OPERATIONS AND MAINTENANCE COSTS (1977 Dollars)

Cost Category	Flywheel/Battery (¢/veh-mi, 1977 $)	
Vehicle Maintenance and Garage Expenses	28.00	
Transportation	104.00	
-Driver Wages[1]		-88
-Power[2]		-16
-Other[3]		- 0
Station	1.36	
Traffic and Advertising	2.04	
Taxes and Licenses	8.16	
Insurance and Safety	8.84	
General and Administrative	47.60	
TOTAL[4] (¢/vehicle-mile)	200.00	
Maintenance of Wayside Battery Charging Stations ($/year/station)	$1,000	

[1]Per vehicle mile cost based on a lower mean speed of flywheel/battery bus.
[2]Based on 5.31 kw-hr/mile and 3¢/kw-hr.
[3]Included in driver payroll costs.
[4]Does not include depreciation on capital equipment.

As shown, the total per vehicle-mile operations and maintenance costs of the flywheel/battery bus is 6% to 8% higher than that of the baseline diesel and trolley bus systems. The increase in the unit operations/maintenance costs is explained by higher unit costs for vehicle maintenance, power, and driver wages.

Table 3-23, below, presents a breakdown of the component vehicle maintenance costs for the flywheel/battery bus. In comparison to the baseline diesel and trolley systems, higher vehicle maintenance costs were assumed for the maintenance of the flywheel/battery propulsion system (flywheel and battery packs), brakes, and electrical system.

TABLE 3-23. FLYWHEEL/BATTERY VEHICLE MAINTENANCE UNIT COSTS (1977 Dollars)

Maintenance Component	Unit Cost (¢/veh-mi)	Notes
Body and Chassis	4.4	
Propulsion System	9.5	20% higher than diesel
Brakes	3.1	Equivalent to diesel bus
Electrical Equipment	3.0	45% higher than diesel
Heating, A/C	2.4	
Air Operation Equipment	0.4	
Lighting	1.2	
Preventive Maintenance	2.0	
Tires	1.5	
Other	0.5	
TOTAL	28.0	

In comparison to the diesel and trolley bus systems, slightly higher (3¢/vehicle-mile) per vehicle-mile costs for driver wages are experienced by the flywheel/battery bus because of delays incurred en route in the replacement of the vehicle's battery packs. These delays reduce the overall mean operating speed of the vehicle which, in turn, increases the total driver payhours required in transit service. The power costs, expressed on a per vehicle-mile basis, for the charging of the vehicle's battery packs are

3¢/vehicle-mile and 5¢/vehicle-mile higher, respectively, than the trolley and diesel bus.

3.6 SUMMARY OF THE FIXED CAPITAL AND OPERATIONS/ MAINTENANCE COSTS

Presented in Table 3-24 is a summary of the fixed capital and the annual recurring operations/maintenance costs for each of the diesel, trolley, and the flywheel-powered vehicle systems. All costs are expressed in 1977 dollars.

TABLE 3-24. SUMMARY OF FIXED CAPITAL AND OPERATIONS/MAINTENANCE COSTS

	Diesel Bus	Trolley Bus	All-Flywheel	Flywheel/ Diesel	Flywheel/ Battery
FIXED CAPITAL COSTS:					
Vehicles ($/vehicle)	70.0K	115.0K	149.0K	130.0K	147.8K
Garage/Maintenance Facility ($/vehicle)	38.0K	42.4K	42.4K	38.0K	38.0K
Overhead Trolley and Sub-stations ($/2-way route-mile)	-	495.0K	-	-	-
Wayside Station ($/station)	-	-	286.0K	-	413.0K
Battery Pack ($/pack)	-	-	-	-	41.3K
ANNUAL OPERATIONS/MAINTENANCE COSTS:					
Driver Payroll ($/veh-mi)	.85	.85	.91	.85	.88
Vehicle Maintenance ($/veh-mi)	.25	.20	.29	.26	.28
Fuel/Power ($/veh-mi)	.10	.12	.09	.09	.16
Fixed O/M ($/veh-mi)	.68	.68	.68	.68	.68
TOTAL ($/veh-mi)	1.88	1.85	1.97	1.88	2.00
Wayside System ($/station/year)	-	-	1.5K	-	1.0K
Overhead Trolley ($/route mile/year)	-	6.0K	-	-	-

4. LIFE CYCLE COST ANALYSIS RESULTS

This section presents the results of the analysis conducted on the life-cycle costs of the baseline diesel, trolley bus and the flywheel powered vehicle systems. Described in subsection 4.1 are the life-cycle costs for each of the vehicle systems with respect to the defined 'base case'* of this study. Since these results are only applicable to the fixed and limited case under study, a series of additional analyses were conducted to test the sensitivity of these results under various operating conditions and assumptions. These analyses were directed towards examining the sensitivity of the vehicle life-cycle costs due to:

- Uncertainties in the unit capital and the operations/maintenance costs,

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*In the definition of the 'base case' for analysis, the selection of 15 minutes as being representative of a typical all-day average vehicle headway that is operated on urban transit routes was a critical assumption that directly affected the per vehicle-mile life-cycle costs of both the baseline trolley and the proposed all-flywheel vehicle systems. As such, a series of sensitivity analyses were conducted in which the assumed vehicle operating headway was varied. The results of these analyses, presented in Section 4.5, indicate that the per vehicle-mile life-cycle costs of both vehicle systems are significantly reduced for operations on high-frequency, low-headway routes.

- Variations to the extent and density of vehicle operations in transit service, and
- Alternative discount rates and periods of investment.

The results of the sensitivity case analyses are discussed in subsections 4.2 through 4.7 of this report, while the final section, 4.8, presents a comparative evaluation of the energy consumption requirements of the conventional and flywheel powered vehicle systems in urban transit operations.

4.1 BASE CASE ANALYSIS RESULTS

Table 4-1 presents the total present value costs of the conventional and the flywheel powered vehicle systems considered in this analysis. These costs, discounted over a period of 23 years at an annual rate of 10%, are expressed in current 1977 dollars.

As shown, the baseline diesel bus has the lowest life-cycle costs of the five vehicle systems considered in this analysis. Second in the ranking is the flywheel/diesel bus with a total present value cost of $109.3 million dollars, or approximately 6% higher than the total present value costs of the diesel bus. The all-flywheel and the flywheel/battery bus systems follow, respectively, with total life-cycle costs that are significantly higher (33% and 60%) than the comparable present value costs of the diesel bus. Of the five vehicle systems, the baseline trolley bus exhibited the highest life-cycle costs with a total present value of $213.4 million dollars for a system extent of 200 route-miles, and a total fleet size of 145 vehicles. The high life-cycle cost of the trolley bus system is attributed primarily to the large capital investments that are required for overhead trolley lines and en route power substations.

A somewhat equivalent picture of the vehicle life-cycle costs is presented in Table 4-2 which reflects a normalization of the total present value costs of each of these vehicle systems on a per vehicle-mile operated basis. The total vehicle-miles operated by each of the vehicle systems was computed based on the size of the vehicle fleet deployed and the assumption that each vehicle would be in service an average of 35,000 miles/year. As shown, the present value costs per vehicle-mile ranged from as low as 88 cents for the diesel bus, to as high as $1.83 for the trolley bus. As one would expect, the ranking and the percentage distribution of the per vehicle-mile present value costs for each of the vehicle systems remains the same as that presented in Table 4-1.

Except for the trolley and the flywheel/battery bus, the life-cycle costs of the vehicle systems are dominated by the annual costs for operations and maintenance rather than

TABLE 4-1. TOTAL PRESENT VALUE COSTS (In Millions, 1977 Dollars, 10% Discount, 23-Year Investment Period)

	Diesel Bus	Trolley Bus	Pure Flywheel Bus	Flywheel/ Battery Bus	Flywheel/ Diesel Bus
SYSTEM CAPITAL COSTS:					
Vehicles	12.4	16.7	22.9	22.2	18.8
Garage/Maintenance	5.4	5.9	6.3	5.6	5.4
Wayside Stations			12.4	6.9	
Overhead Power Line		96.4			
Battery Packs				35.4	
Total	17.8	119.0	41.6	70.1	24.2
(%)	(17%)	(56%)	(30%)	(43%)	(22%)
OPERATIONS/MAINTENANCE COSTS:					
Driver Payroll	38.5	38.5	43.6	41.6	38.5
Vehicle Maintenance	11.3	9.0	13.9	13.1	11.7
Fuel/Power	4.4	5.5	4.5	7.4	4.1
Overhead Power Line		10.6			
Wayside Stations			0.6	0.2	
Other Fixed O/M	30.8	30.8	32.7	31.9	30.8
Total	85.0	94.4	95.3	94.2	85.1
(%)	(83%)	(44%)	(70%)	(57%)	(78%)
TOTAL	102.8	213.4	136.9	164.3	109.3

TABLE 4-2. PRESENT VALUE COSTS PER VEHICLE-MILE (In 1977 Dollars, 10% Discount Rate, 23-Year Investment Period)

	Diesel Bus	Trolley Bus	Pure Flywheel Bus	Flywheel/ Battery Bus	Flywheel/ Diesel Bus
SYSTEM CAPITAL COSTS:					
Vehicles	.11	.14	.19	.19	.16
Garage/Maintenance	.04	.05	.05	.04	.04
Wayside Stations			.10	.06	
Overhead Power Line		.83			
Battery Packs				.29	
Total	.15	1.02	.34	.58	.20
(%)	(17%)	(56%)	(30%)	(43%)	(22%)
OPERATIONS/MAINTENANCE COSTS:					
Driver Payroll	.33	.33	.35	.34	.33
Vehicle Maintenance	.10	.08	.11	.11	.10
Fuel/Power	.04	.05	.04	.06	.04
Overhead Power Line		.09			
Wayside Stations			.01	.01	
Other Fixed O/M	.26	.26	.26	.26	.26
Total	.73	.81	.77	.78	.73
(%)	(83%)	(44%)	(70%)	(57%)	(78%)
TOTAL	.88	1.83	1.11	1.36	.93

the investment costs for capital equipment. As shown in Tables 4-1 and 4-2, the present value costs for the operations and maintenance of the diesel, the all-flywheel, and the flywheel/diesel buses account for 70% to 80% of the total present value costs of these vehicle systems. The differences in the life-cycle costs between the baseline diesel, trolley bus and the flywheel powered vehicles, however, are almost totally in the capital investment costs rather than in the costs for operations and maintenance. For any of the five vehicle systems considered in this analysis, there exists less than a 10% variation in the present value costs for operations/maintenance while the variation in the present value capital costs of these vehicle systems is significantly higher.

The baseline trolley bus, the flywheel/battery, and the all-flywheel vehicles are highly capital intensive systems as compared to the diesel bus or the proposed flywheel/diesel vehicle. For the trolley bus, the primary capital cost items are for vehicles, overhead trolley lines, and power substations. The present value cost for the overhead trolley power lines and substations was $96.4 million, or 45% of the total present value cost of the system. For the flywheel/battery system, the principal capital equipment expenditures are for vehicles, wayside battery charging/changing stations, and battery packs for the vehicle's propulsion system. The present value capital cost of $35.4 million for the initial purchase and replacement of the vehicle's battery packs over a period of 23 years exceeded the present value capital cost for the purchase of the entire fleet of 150 flywheel/battery vehicles. Further, the capital expenditure for the vehicle battery packs accounted for 21% of the total present value cost of the flywheel/battery system while the capital expenditures for vehicles and wayside battery charging/changing stations represented, respectively, only 13% and 4% of that total cost.

The all-flywheel vehicle system is characterized by having the largest present value capital cost expenditure for vehicles of any of the other baseline or flywheel-powered vehicle systems considered in this analysis. The present value capital cost for the all-flywheel vehicles ($22.9 million) was 85% higher than the comparable present value cost of the diesel bus ($12.4 million), and 22% greater than the present value capital cost of the flywheel/diesel bus ($18.8 million). The high present value capital cost for the all-flywheel system can be explained by the fact that this system has the highest unit cost per vehicle, and requires a slightly larger vehicle fleet size (154 vehicles) to be deployed to provide an equivalent level of transit service. The system that requires the largest number of vehicles to be purchased over the 23-year period is the baseline diesel bus which has the lowest total present value capital cost for vehicles of any of the other systems considered. Over 290 vehicles are purchased during the 23-year period for the baseline diesel bus system, as compared to a total fleet of only 145 to 154 vehicles for the baseline trolley or for any of the flywheel powered vehicle systems.

If only costs affected by the design or the technology of the vehicle systems were considered in the analysis, the life-cycle cost picture of the baseline diesel, trolley bus and the flywheel powered vehicle systems would remain unchanged. Table 4-3 summarizes the present value costs for those areas that are affected by the design or the operation of the vehicle technologies. Costs excluded from this table include the costs for the garage/maintenance facilities, driver payroll, and other fixed operations/ maintenance expenses. These costs are proportionate to the total size of the vehicle fleet deployed rather than the design of the vehicle system. As shown, for certain vehicle systems (i.e., trolley, flywheel/battery, all-flywheel), a high percentage of their total life-cycle costs are affected by the design and operation of the vehicle system; whereas for other vehicle systems like the diesel and flywheel/diesel

TABLE 4-3. LIFE-CYCLE COSTS AFFECTED BY VEHICLE DESIGN (In Millions, 1977 Dollars, Present Value Costs, 10% Discount, 23-Year Investment Period)

	Diesel Bus	Trolley Bus	Pure Flywheel Bus	Flywheel/ Battery Bus	Flywheel/ Diesel Bus
SYSTEM CAPITAL COSTS:					
Vehicles	12.4	16.7	22.9	22.2	18.8
Wayside Stations			12.4	6.9	
Overhead Power Line		96.4			
Battery Packs				35.4	
	12.4	113.1	35.3	64.5	18.8
OPERATIONS/MAINTENANCE COSTS:					
Vehicle Maintenance	11.3	9.0	13.9	13.1	11.7
Fuel/Power	4.4	5.5	4.5	7.4	4.1
Overhead Power Line		10.6			
Wayside Stations			0.6	0.2	
	15.7	25.1	19.0	20.7	15.8
TOTAL:	28.1	138.2	54.3	85.2	34.6
% OF TOTAL LIFE-CYCLE COST	27%	65%	40%	52%	32%

bus these costs represent only 25 to 30% of their total life-cycle costs.

For a system extent of 200 route-miles and a vehicle fleet size of approximately 150 vehicles, the total annual costs for the deployment and operation of the baseline diesel, trolley bus, and the flywheel-powered vehicle systems ranged from as low as $11.6 million for the diesel bus, to as high as $24.0 million for the trolley bus. These costs, shown in Table 4-4, represent the uniform annual payments required to be made in order to repay the debt (with interest) on the capital equipment plus the annual expenses incurred each year to maintain and operate the vehicle systems.

Expressed differently, the annual costs per route-mile, per vehicle deployed, and per vehicle-mile operated for each of the baseline and the flywheel vehicle systems are as follows:

Annual Cost:	Diesel	Trolley	All-Flywheel	Flywheel/Battery	Flywheel/Diesel
-per route-mile	$57,855	$120,201	$ 77,083	$ 92,494	$61,518
-per vehicle	$79,800	$165,795	$100,108	$123,325	$84,852
-per vehicle-mile	$2.28	$4.74	$2.86	$3.51	$2.42

4.2 SENSITIVITY TO VARIATION IN THE SYSTEM UNIT CAPITAL COSTS

The total present value life-cycle costs of the three flywheel vehicle systems considered in this analysis are

TABLE 4-4. TOTAL ANNUAL SYSTEM COSTS (In Millions, 1977 Dollars)

	Diesel Bus	Trolley Bus	Pure Flywheel Bus	Flywheel/ Battery Bus	Flywheel/ Diesel Bus
SYSTEM CAPITAL COSTS:					
Vehicles	1.4	1.9	2.6	2.5	2.1
Garage/Maintenance	0.6	0.6	0.7	0.6	0.6
Wayside Stations			1.3	0.8	
Overhead Power Line		10.9			
Battery Packs	—	—	—	4.0	—
Total	2.0	13.4	4.6	7.9	2.7
(%)	(17%)	(56%)	(30%)	(43%)	(22%)
OPERATIONS/MAINTENANCE COSTS:					
Driver Payroll	4.3	4.3	4.9	4.7	4.3
Vehicle Maintenance	1.3	1.0	1.6	1.5	1.3
Fuel/Power	0.5	0.6	0.5	0.8	0.5
Overhead Power Line		1.2			
Wayside Stations			0.06	0.02	
Other Fixed O/M	3.5	3.5	3.7	3.6	3.5
Total	9.6	10.6	10.8	10.6	9.6
(%)	(83%)	(44%)	(80%)	(57%)	(78%)
TOTAL	11.6	24.0	15.4	18.5	12.3

relatively insensitive to any variation in the unit costs of capital equipment for these systems.

In this analysis, a variation in the unit costs of the following capital equipment was considered:

All-Flywheel

- Vehicles
- Wayside Charging Stations

Flywheel/Diesel

- Vehicles

Flywheel/Battery

- Vehicles
- Battery Charging/ Changing Stations

As is shown in Table 4-5 and as depicted in Figure 4-1, there are no significant changes in either the total present value cost or the present value cost per vehicle-mile as a result of a ±30% variation in the unit costs of capital equipment for these systems.

TABLE 4-5. TOTAL PRESENT VALUE COSTS AS A FUNCTION OF VARIATION IN SYSTEM CAPITAL COSTS (In Millions, 1977 Dollars, 10% Discount, 23 Years)

	-30%	-20%	-10%	Base	+10%	+20%	+30%
All-Flywheel	126.7	130.1	133.5	136.9	140.3	143.7	147.4
Flywheel/ Diesel	103.7	105.6	107.4	109.3	111.1	113.0	114.8
Flywheel/ Battery	155.2	158.2	161.3	164.3	167.7	170.4	173.5

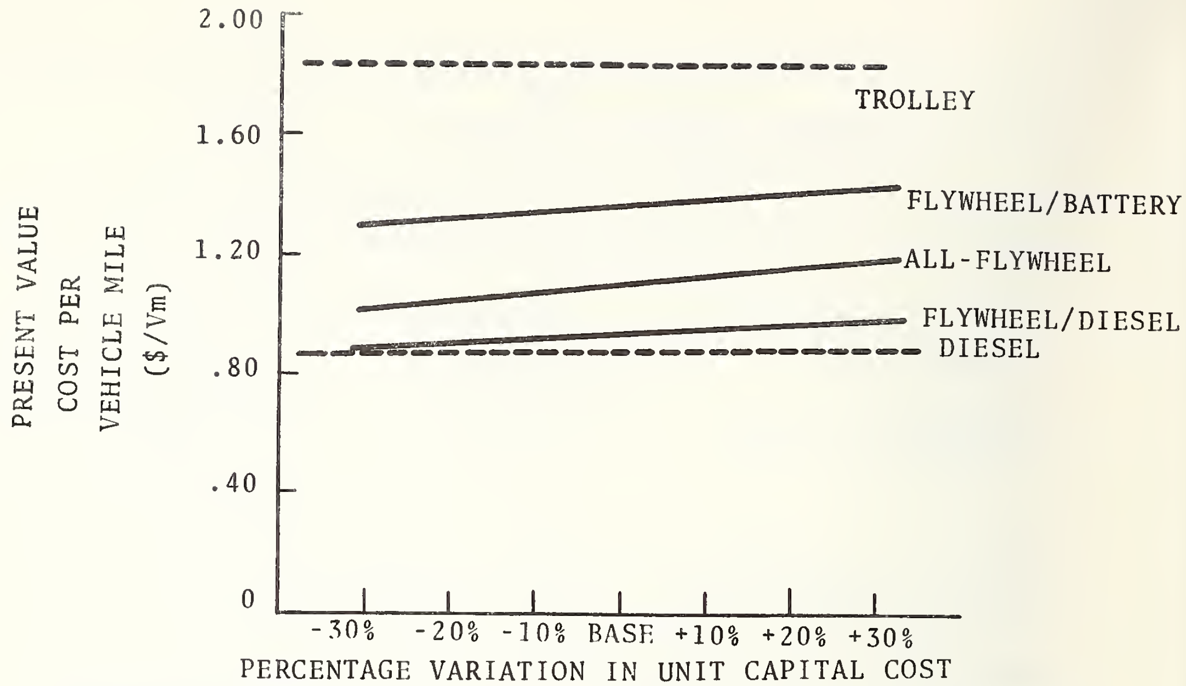

FIGURE 4-1. PRESENT VALUE COST PER VEHICLE-MILE AS A FUNCTION OF VARIATION IN UNIT CAPITAL COST

For the all-flywheel, the flywheel/diesel, and the flywheel/battery vehicle systems, a ±30% variation in the unit costs of capital equipment yields only a ±5% to ±8% change in total present value cost or the per vehicle-mile present value cost of these systems. This insensitivity is due to the fact that the cost of capital equipment for the proposed flywheel vehicle systems represent only 20% to 40% of their total present value life-cycle costs.

In comparison to the baseline vehicle systems, Figure 4-1 indicates that at the -30% unit cost level the per vehicle-mile present value cost of the flywheel/diesel system approaches the present value cost of the diesel bus. At this unit cost level, however, is the implied assumption that the flywheel/diesel bus can be purchased at a unit cost of $91,000/vehicle while still retaining its 23-year service life.

4.3 SENSITIVITY TO VARIATION IN VEHICLE OPERATIONS/ MAINTENANCE COSTS

As in the case described above, the total present value costs of the proposed flywheel vehicle systems are also relatively insensitive to any variation in the assumed unit costs for vehicle maintenance, diesel fuel, or electric power. These cost areas were examined since they represent the only variable operations and maintenance costs that are affected by vehicle design.

For the three proposed flywheel vehicle systems, the cost of vehicle maintenance represents only 8 to 10% of their total present value life-cycle cost. Figure 4-2 depicts the effect on the present value cost per vehicle-mile for each of the flywheel vehicle systems as a result of a ±50% and a ±100% variation in their base vehicle maintenance unit cost. As shown, the present value cost per vehicle-mile increases at a rate of only 4 to 5% for every 50% increase in the assumed base vehicle maintenance cost.

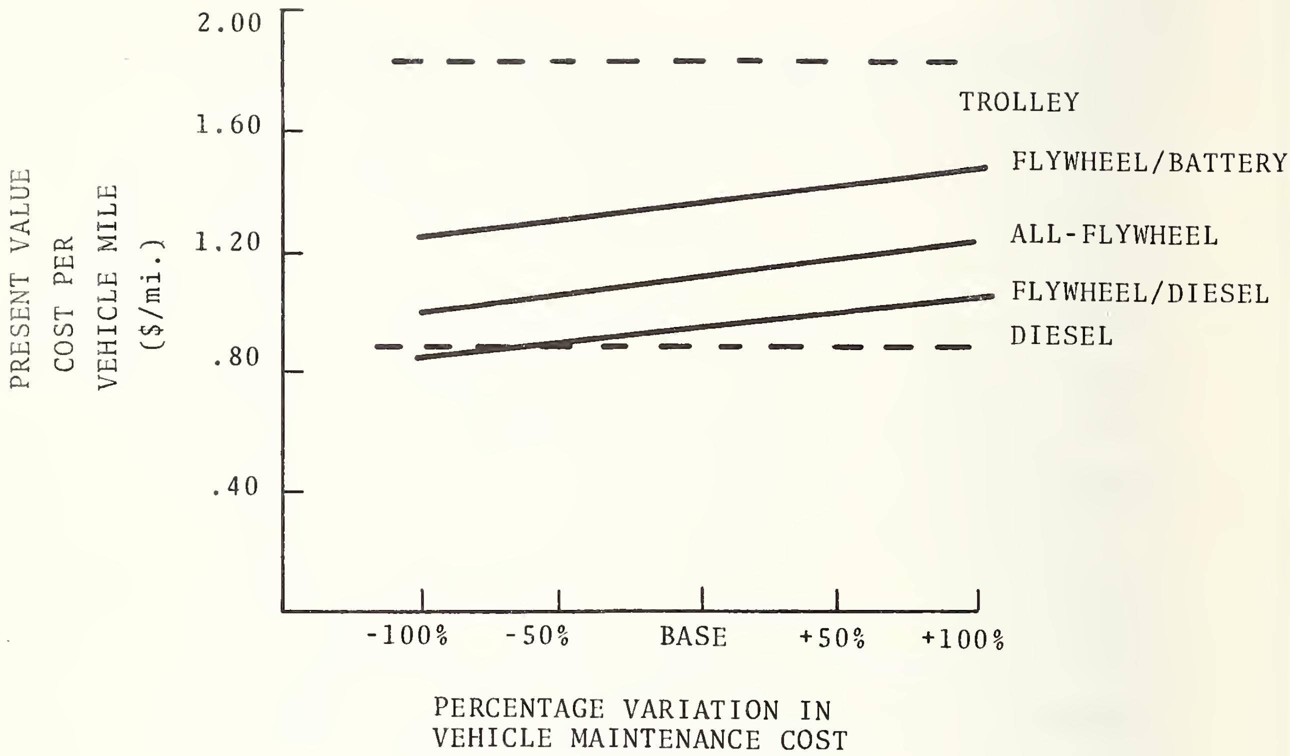

FIGURE 4-2. PRESENT VALUE COST PER VEHICLE-MILE AS A FUNCTION OF VARIATION IN VEHICLE MAINTENANCE UNIT COSTS

Although savings in energy consumption and in the costs of such energy can be achieved over the baseline diesel and trolley bus with the application of the all-flywheel and the flywheel/diesel vehicle systems, the total present value costs of the baseline and the flywheel vehicle systems are quite insensitive to any changes in the price of diesel fuel or electric power. Table 4-6, below, identifies the effect on the present value cost per vehicle-mile for each of the baseline and flywheel vehicle systems as a result of a 100% and a 200% increase in the price of diesel fuel and electric power.

TABLE 4-6. PRESENT VALUE COST PER VEHICLE-MILE AS A FUNCTION OF PRICE OF DIESEL FUEL AND ELECTRIC POWER

	Base	+100%	+200%
Price of Diesel Fuel:	$.35/gal	$.70/gal	$1.05/gal
Electric Power:	$.03/kw-hr	$.06/kw-hr	$.09/kw-hr
Diesel	0.88	0.92	0.96
Trolley	1.83	1.88	1.93
All-Flywheel	1.11	1.14	1.18
Flywheel/Diesel	0.94	0.97	1.01
Flywheel/Battery	1.36	1.42	1.48

As shown, the variation in the per vehicle-mile present value cost ranged from as low as 5 to 6% (for the trolley and all-flywheel vehicles), to 9% (for the diesel and the flywheel/battery systems) as a result of a 200% increase in the price of diesel fuel and electric power.

If the price of electric power was held constant at a rate of $.03/kw-hr (as illustrated in Figure 4-3), the price of diesel fuel would have to increase to over two dollars per gallon before the present value cost per vehicle-mile of the flywheel/diesel and diesel bus systems would exceed the present value cost per vehicle-mile of the all-flywheel vehicle.

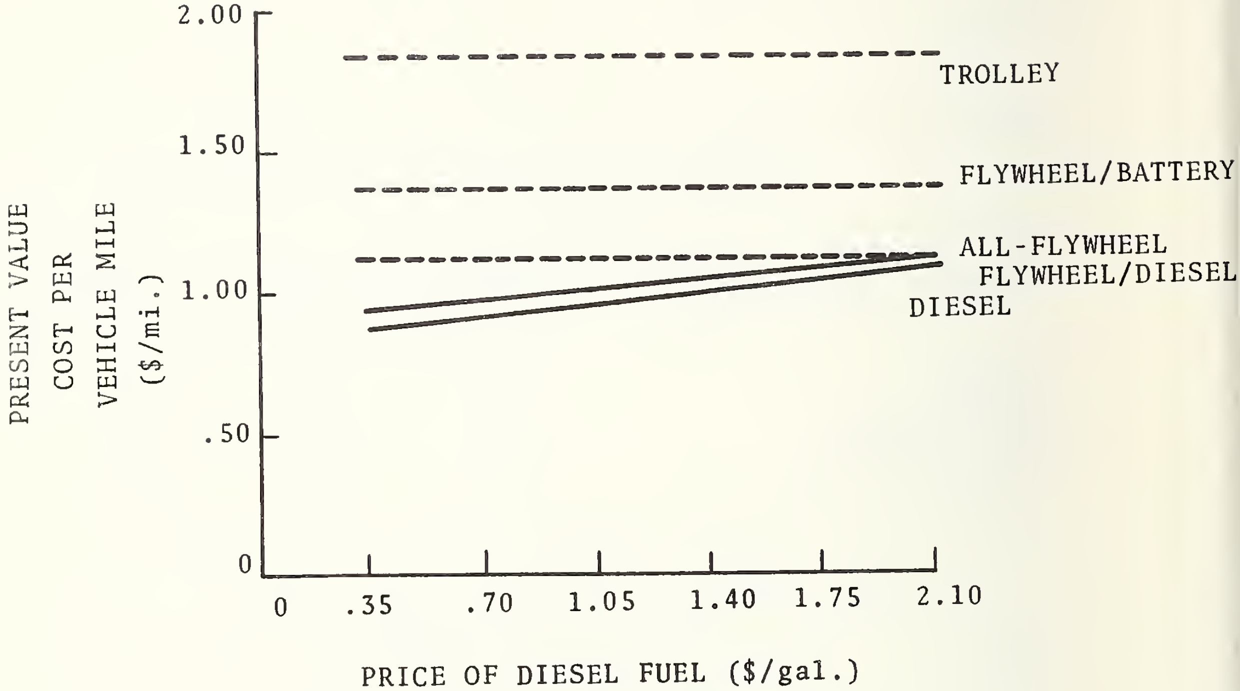

FIGURE 4-3. PRESENT VALUE COST PER VEHICLE-MILE AS A FUNCTION OF PRICE OF DIESEL FUEL

4.4 SENSITIVITY TO VARIATION IN SYSTEM EXTENT

Figure 4-4 depicts the sensitivity of the total present value life-cycle costs for the baseline diesel, trolley bus and the flywheel vehicle systems as a function of the system extent (route-miles) of deployment. In this case, the average vehicle headway (15 minutes) and the vehicle density on the routes were held constant, so the total vehicle fleet to be deployed increased in proportion to the growth in the system route-miles.

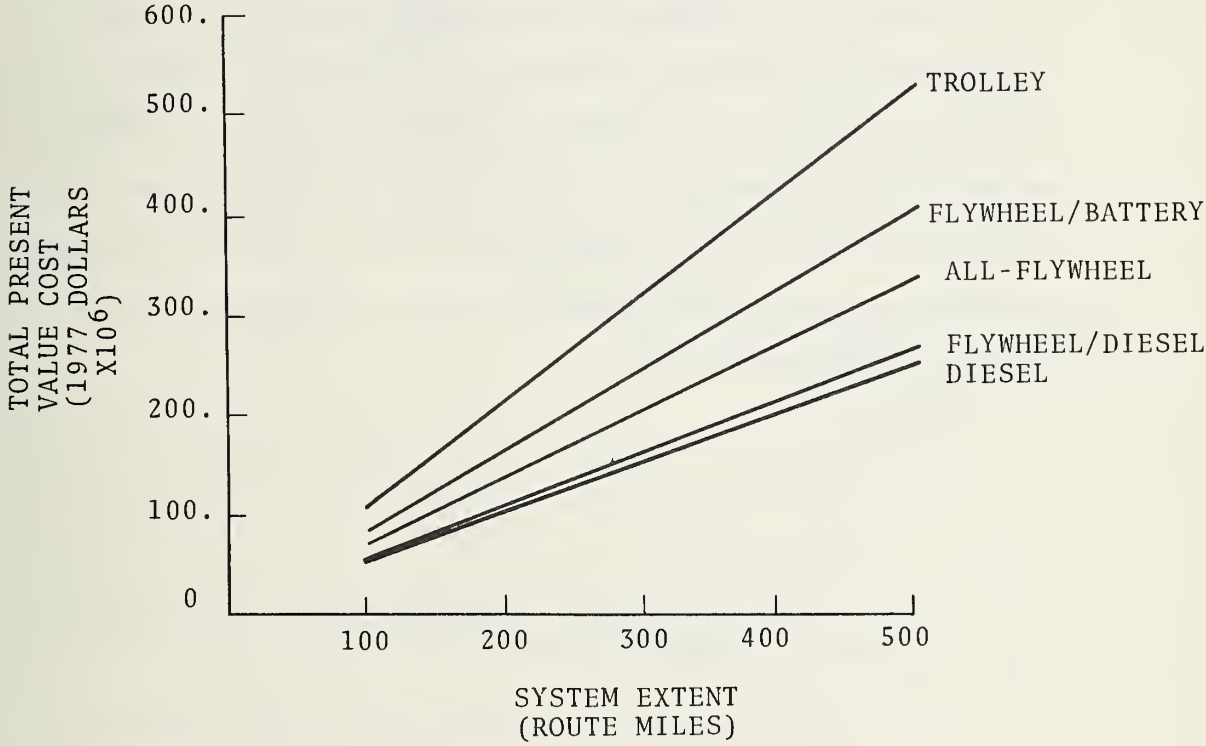

FIGURE 4-4. TOTAL PRESENT VALUE COSTS AS A FUNCTION OF A VARIATION IN SYSTEM EXTENT

Under this assumption, the total present value costs for each of the vehicle systems increased in direct proportion to the increase in the system route-miles. This would be expected since the present value costs for capital equipment and for vehicle operations and maintenance expenses are a function of either the system route-miles or the number of vehicles deployed.

4.5 SENSITIVITY TO VEHICLE DENSITY EN ROUTE

Figure 4-5 illustrates the sensitivity of the total present value life-cycle costs of the baseline diesel, trolley bus, and the flywheel vehicle systems as a function of the vehicle headway (or vehicle density) on the route. In this case, the vehicle density on the route was increased by reducing the vehicle headway under a constant system extent of 200 route-miles.

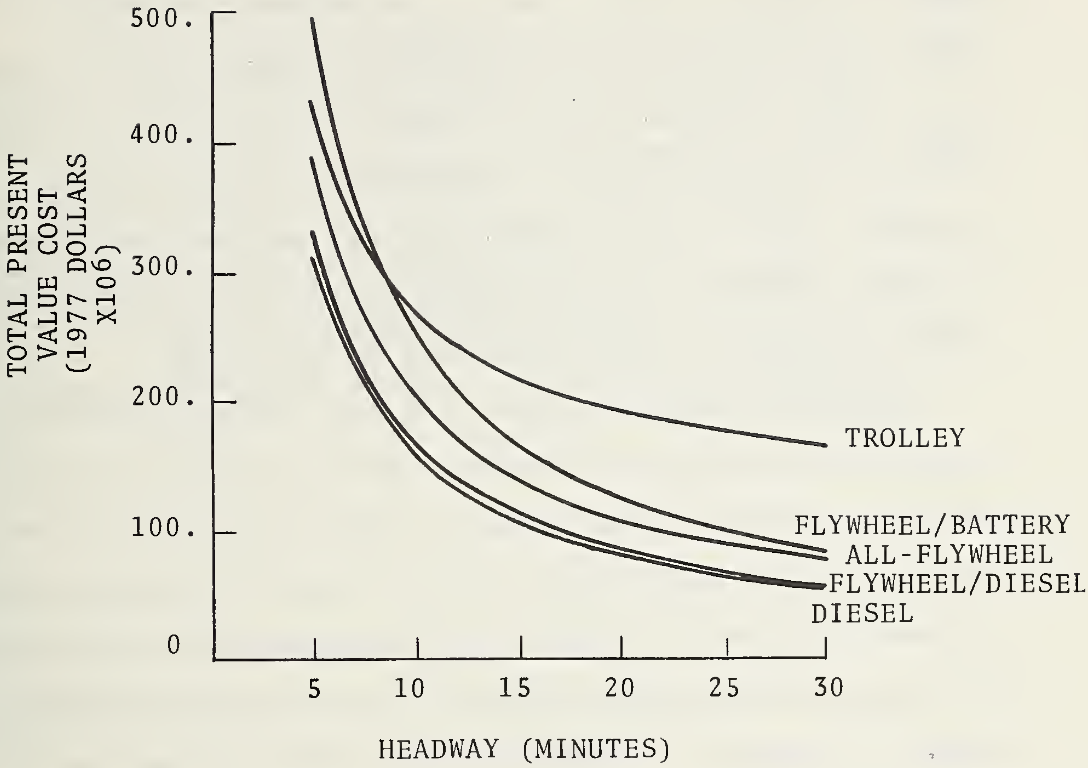

FIGURE 4-5. TOTAL PRESENT VALUE COSTS AS A FUNCTION OF VEHICLE HEADWAY EN ROUTE

For the diesel, the flywheel diesel, and the flywheel/battery vehicle systems, the total present value costs increase in direct proportion to the density of the vehicles on the routes. Thus, at low vehicle headways (5 to 10 minutes), the percentage increase in the total present value life-cycle costs could be as high as 100%, whereas at higher vehicle headways (i.e., 20 to 25 minutes), the percentage increase in the present value costs is only 25%.

The direct relationship between the present value costs and vehicle density on the route is due to the fact that the fixed capital and the operations/maintenance costs of these three vehicle systems are determined, in part, by the total vehicle fleet size and the corresponding vehicle-miles traveled. As such, the present value costs per vehicle-mile for each of these vehicle systems would remain constant even under increasing vehicle densities on the route.

These conditions, however, do not hold true for the trolley bus and the all-flywheel vehicle systems. For both of these systems, major capital expenditures are incurred for overhead trolley power lines and wayside stations, the present value costs of which are determined as a function of the system extent (route-miles). As the vehicle headway en route is reduced, the present value costs of these two vehicle systems increase, but at a much lower rate than the corresponding increase in the vehicle fleet size.

At the higher route vehicle densities, the percentage differences in the total present value costs of the trolley and all-flywheel vehicle systems are also reduced in comparison to the corresponding present value costs of the flywheel/diesel and the baseline diesel bus systems. For example, at a vehicle headway of 5 minutes the total present value costs of the trolley and all-flywheel vehicle systems are, respectively, 38% and 25% higher than that cost of the diesel bus; whereas at a vehicle headway of 15 minutes, they are 108% and 33% higher.

This is further exemplified in an examination of the present value costs per vehicle-mile of these vehicle systems as a function of the vehicle density on the route. As shown in Figure 4-6, and as was noted earlier, the present value cost per vehicle-mile of the diesel bus, the flywheel/diesel, and the flywheel/battery vehicle systems remains unchanged as the vehicle headway is increased.

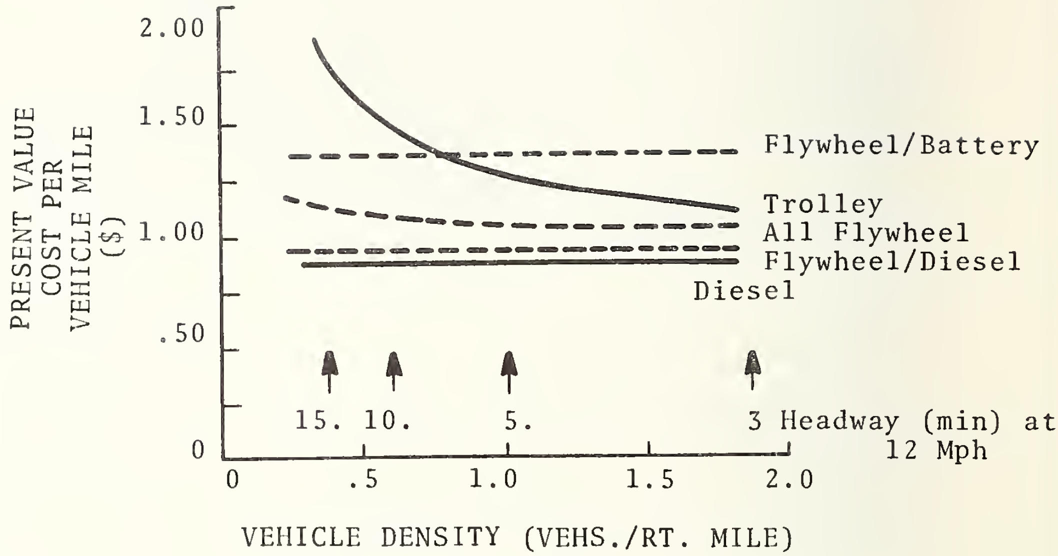

FIGURE 4-6. PRESENT VALUE COSTS PER VEHICLE-MILE AS A FUNCTION OF VEHICLE DENSITY EN ROUTE

However, the present value costs per vehicle-mile of the trolley bus and the all-flywheel vehicle decrease as the vehicle density on the route is increased. This occurs by the fact that certain fixed capital costs of these systems (i.e., costs for overhead trolley power lines, wayside power stations, etc.), can be apportioned over a larger vehicle fleet size thus reducing the present value costs per vehicle-mile of these two systems. As shown in Figure 4-6, at a vehicle headway of 5 minutes (or an average vehicle density of one vehicle per route-mile), the present value costs per vehicle-mile of the trolley and all-flywheel vehicle systems are, respectively, $1.22 and $1.04 in 1977 dollars, or 38% and 18% higher than the corresponding cost per vehicle-mile of the diesel bus.

4.6 SENSITIVITY TO VARIATION IN DISCOUNT RATE

In this analysis, the OMB recommended discount rate of 10% was utilized in the calculation of the present value cost (in 1977 dollars) of the fixed capital investments and the annual recurring costs that are incurred in the investment period. As defined in the OMB circular A-94 (Ref. 4-1), this discount rate represents the average rate of return on private investments before taxes and after inflation.

Figure 4-7 illustrates the effect on the present value cost per vehicle-mile, for each of the baseline and the flywheel vehicle systems, as a result of a variation in the discount rate over an assumed investment period of 23 years.

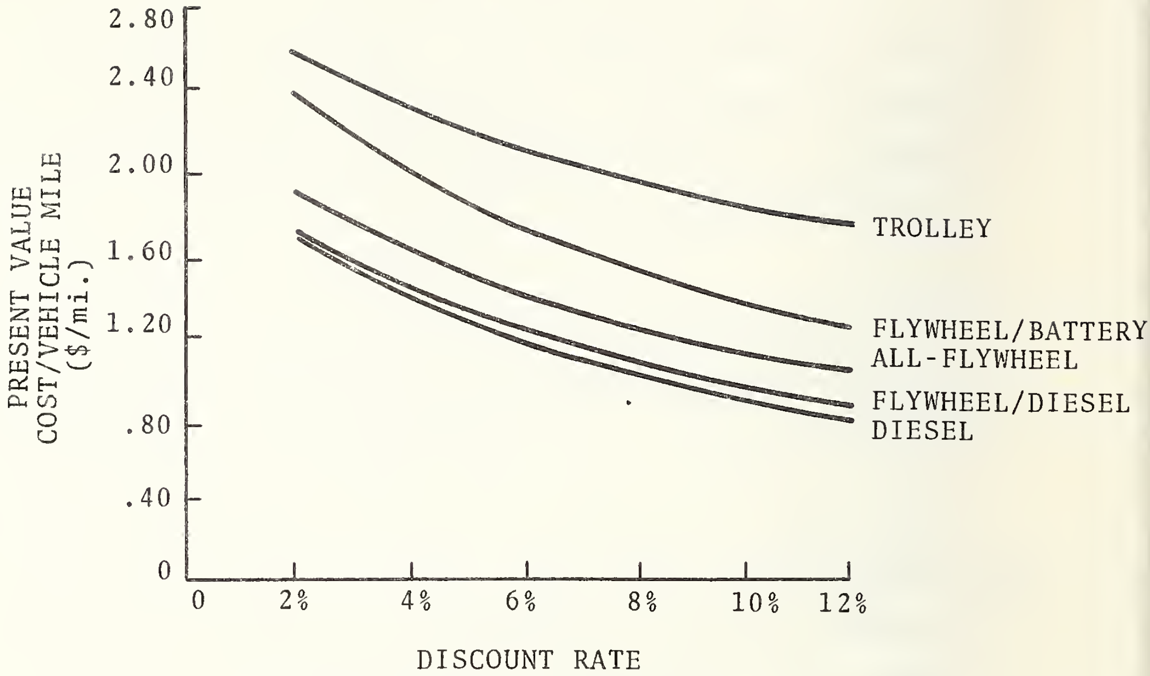

FIGURE 4-7. PRESENT VALUE COSTS PER VEHICLE-MILE AS A FUNCTION OF VARIATION IN DISCOUNT RATE

As shown, the present value costs of these vehicle systems are inversely related to the change in the discount rate. For capital-intensive systems with high initial investment costs, such as the trolley bus, an increase from a relatively low to a higher discount rate produces a smaller percentage decrease in total present value costs for such vehicle systems, as compared to vehicle systems that are less capital intensive. As an example, for a variation in the discount rate from 4% to 10%, the present value costs of the trolley bus decreased by 21%, whereas the percentage decrease in the present value costs for the diesel and the flywheel vehicle systems ranged from 30% to 40%. This is further evident in the fact that the percentage difference in the total present value life-cycle costs of the trolley and the flywheel vehicle systems over the diesel bus is less at lower discount rates. Presented in Table 4-7 are the total present value costs and the present value cost per vehicle-mile of the five vehicle systems discounted at 4% and 6% over 23 years.

4.7 SENSITIVITY TO VARIATION IN PERIOD OF INVESTMENT

As was the case with the variation in the assumed discount rate, the present value life-cycle costs of the baseline diesel, trolley bus, and the flywheel vehicle systems are also inversely related to the period of investment. For this study, an investment period of 23 years was selected since it represented the economic service life of the proposed flywheel vehicle systems under analysis. Capital equipment, having a service life less than 23 years, was replaced by similar equipment through new capital investments at the end of their service life. Likewise, salvage credits (negative costs) were applied on

TABLE 4-7. PRESENT VALUE COSTS DISCOUNTED AT 4 AND 6 PERCENT OVER 23 YEARS

	Discount Rate: 4%			Discount Rate: 6%		
	Present Value Cost ($x10^6$-1977$)	Present Value Cost/Veh-Mi ($)	% PVC/VM over Diesel Bus	Present Value Cost ($x10^6$-1977$)	Present Value Cost/Veh-Mi ($)	% PVC/VM over Diesel Bus
Diesel	161.7	1.39	-	136.6	1.17	-
All-Flywheel	199.7	1.61	16%	172.9	1.40	20%
Flywheel/Diesel	166.1	1.42	2%	141.8	1.22	4%
Flywheel/Battery	243.1	2.01	45%	209.6	1.73	48%
Trolley	269.8	2.31	66%	246.2	2.11	80%

any capital equipment having a useful life beyond the investment period under analysis.

Shown in Table 4-8 are the total present value costs and the present value costs per vehicle-mile, discounted at 10%, for each of the vehicle systems over various investment periods.

The sensitivity of the present value costs per vehicle-mile as a function of a variation in the investment period is depicted in Figure 4-8.

TABLE 4-8. PRESENT VALUE COST AS A FUNCTION OF PERIOD OF INVESTMENT

		Diesel	Trolley	All-Flywheel	Flywheel/Diesel	Flywheel/Battery
Present Value Cost ($\times 10^6$ 1977 Dollars, 10%):						
Investment Period:	10 years	71.9	156.5	93.1	77.6	116.7
	15 years	88.2	188.7	119.5	94.9	142.7
	20 years	98.6	206.8	132.0	105.2	153.1
	25 years	104.9	217.2	139.8	111.7	167.8
	30 years	108.7	223.2	144.9	116.0	174.1
Present Value Cost Per Vehicle-Mile (1977 Dollars, 10%)						
Investment Period:	10 years	1.42	3.09	1.82	1.53	2.22
	15 years	1.16	2.48	1.48	1.25	1.81
	20 years	0.97	2.04	1.23	1.04	1.50
	25 years	0.83	1.71	1.04	0.88	1.28
	30 years	0.71	1.47	0.90	0.76	1.10

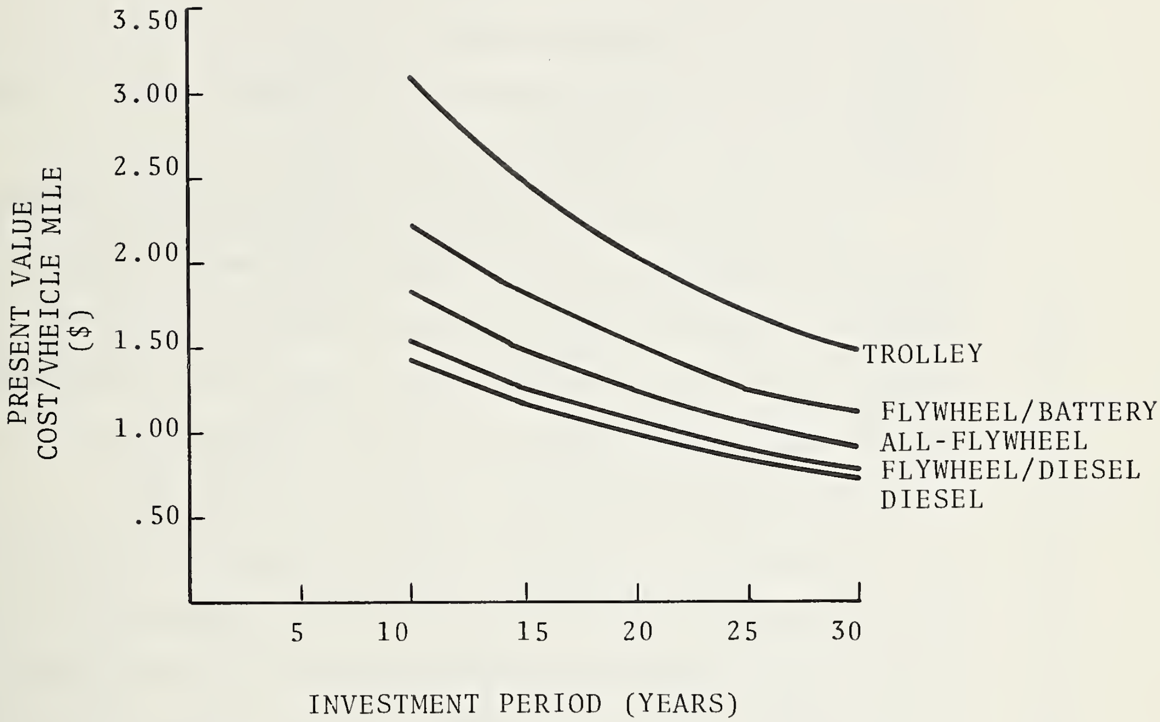

FIGURE 4-8. PRESENT VALUE COSTS PER VEHICLE-MILE AS A FUNCTION OF PERIOD OF INVESTMENT

As shown, the present value costs per vehicle-mile, for each of the vehicle systems, drops off rapidly as the period of the investment increases. This is caused by the discounting process in that costs incurred 20 or 30 years hence have an increasingly negligible contribution to the total present value cost of the system, as compared to those costs that are incurred in the near term.

4.8 ENERGY CONSUMPTION SAVING

One of the primary reasons cited (Ref. 1-1) for the development of flywheel energy storage systems is the energy savings that can be accrued with the application of such systems within urban transit vehicles.

The savings in the energy consumed per vehicle-mile operated would be achieved through the recuperation of the vehicle's kinetic energy that is normally dissipated in the form of heat during braking, and through the load leveling of the power peaks that are normally imposed on the vehicle's propulsion system during acceleration.

Based on the fuel and power consumption data* used in this analysis, the energy consumption requirements of the conventional and flywheel powered vehicle systems were determined. Figure 4-9 illustrates the assumptions used in this analysis to express the energy requirements for the petroleum and the nonpetroleum based vehicles on equivalent terms (in BTU's per vehicle-mile operated). For the petroleum based vehicles (i.e., diesel bus, flywheel/diesel), a heating value of 130,000 BTU (thermal) per gallon of diesel fuel was assumed along with a 90% efficiency for

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*The fuel consumption data for the diesel bus was obtained based upon runs of the TSC diesel bus simulation model. Data for the trolley bus and the three flywheel vehicle systems was obtained from computer simulation conducted by GARRETT AIRESEARCH.

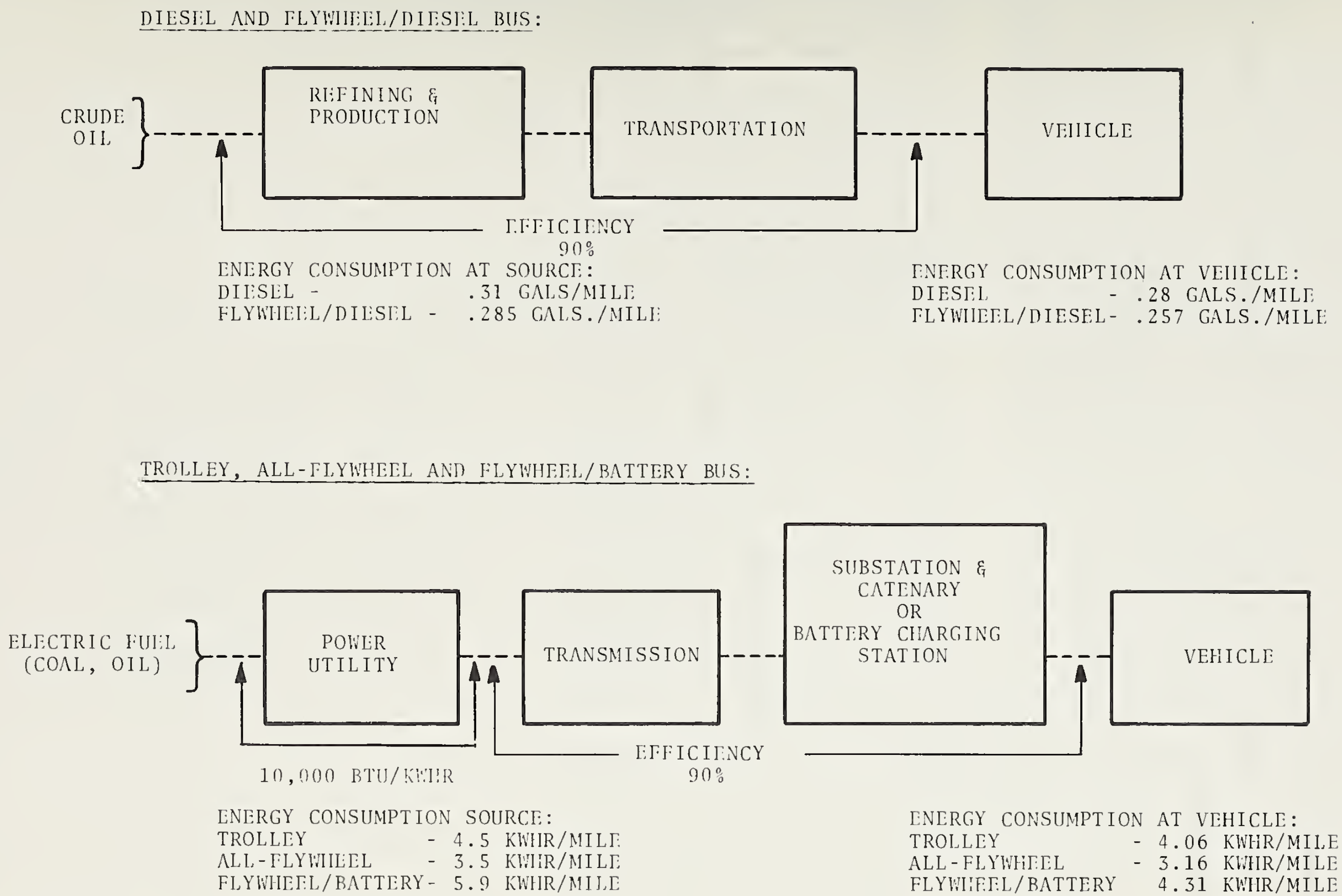

FIGURE 4-9. ENERGY CONSUMPTION COMPARISON

the refining, production, and transportation of the fuel. For the electrified vehicle systems, a heating value of 10,000 BTU per kw-hr was assumed for the generation of electric power with a 90% efficiency for the transmission of the power to the vehicle.

Presented in Table 4-9 is a comparison of the energy consumption requirements in equivalent BTU's per vehicle-mile operated for each of the baseline and flywheel powered vehicle systems.

As shown, the proposed flywheel/diesel vehicle system offers an 8% saving over the baseline diesel bus, while the all-flywheel vehicle offers a 22% saving over the trolley bus on the amount of energy consumed per vehicle-mile operated. The flywheel/battery bus, on the other hand, is a highly energy intensive system, consuming nearly 31% more energy per vehicle-mile operated than the trolley bus.

TABLE 4-9. ENERGY CONSUMPTION COMPARISON

Vehicle	Energy Consumption At Vehicle		Energy Consumption At Source		Energy Consumption	% Over All-Flywheel
	gal/mile	kw-hr/mile	gal/mile	kw-hr/mile	BTU/mile	
Diesel Bus	0.28	-	0.31	-	40,300	15%
Trolley Bus	-	4.06	-	4.5	45,000	28%
All-Flywheel	-	3.16	-	3.5	35,000	-
Flywheel/ Diesel	0.26	-	0.285	-	37,050	6%
Flywheel/ Battery	-	5.31	-	5.9	59,000	68%

5. POTENTIAL MARKET FOR FLYWHEEL BUS SYSTEMS WITHIN THE TRANSIT INDUSTRY

This section characterizes the current and forecasted operations of urban transit vehicles within the transit industry, and provides an assessment of the potential demand and applications for flywheel powered vehicle systems for the 1980 to 1990 period.

5.1 CHARACTERIZATION OF CURRENT URBAN BUS OPERATIONS

The primary form of public transportation in the United States today is the motorbus. Whether expressed in terms of the number of systems operated, the number of vehicles deployed, or by the total revenue-miles operated, urban transit service is dominated by diesel bus operations.

Of the 947 transit systems in existence in 1975, approximately 98% (928) provide transit service exclusively with the diesel bus, while the remaining systems utilize some form of rail service in combination with bus for their operations. The majority of the motor bus properties are small, privately owned systems operating in areas having a population less than 50,000, or in suburban areas. Thirty-five percent (333) of the transit systems are publicly owned authorities with operations in the large metropolitan areas. These systems tend to dominate the urban public transportation statistics in that in 1975 they accounted for 86% of the total vehicle-miles operated, 90% of the revenue passengers, 80% of the total vehicle fleet, and 86% of the total acquired operating revenue within the transit industry (Ref. 5-1).

The distribution and level of transit service that is provided in urbanized areas is further exemplified in Table 5-1 which presents a summary of selected 1971 bus operating statistics by various urban area population classes.

Up until recent years, the trend in urban bus transit has been one of declining patronage, higher fares, and cutbacks in the level of service provided. Since 1972, however, this trend appears to have been reversed. As shown in Figures 5-1 and 5-2, respectively, the number of annual revenue passengers carried, and the annual vehicle-miles operated by urban bus systems have both increased at a rate of 5% per year between 1972 and 1975.

TABLE 5-1. BUS OPERATING STATISTICS BY URBAN AREA POPULATION CLASSES (1971)[1]

OPERATING STATISTIC	Urbanized Area Population, Thousands						Total or
	2,000 & and over	1,000 & under 2,000	500 & under 1,000	250 & under 500	100 & under 250	50 & under 100	Average of All Areas
Number of Areas[2]	10	13	29	40	80	69	241
Total Population[2] (thousands)	59,309	18,041	20,097	13,120	12,417	5,205	128,189
Bus Route Miles	52,746	20,205	17,202	11,814	11,563	4,594	118,124
Number of Vehicles	26,680	6,992	5,768	3,186	2,666	909	46,201
Annual Vehicle Miles (millions)	758	231	179	96	76	24	1,364
Median Age of Vehicles (years)	10.5	9.0	11.0	13.0	10.0	10.0	
Annual Person Trips per Capita	46	35	24	17	12	10	33
Annual Passenger Miles per Capita	179	151	136	58	44	28	137
Annual Bus Seat Miles per Capita	572	615	529	291	230	191	494
Annual Vehicle-Miles per Capita	13	13	9	7	6	5	11
Average Trip Length (min.)	18.3	20.7	19.0	17.7	15.9	14.2	18.6
Average Trip Length (mi.)	3.5	4.4	4.1	3.5	3.6	3.0	3.7
Average Peak Hour Speed (mph)	11.0	12.0	12.0	12.0	13.0	13.0	12.0
Average Peak Hour Headway (min.)	14.2	18.2	21.5	26.3	32.7	32.0	20.7
Average Peak Hour Vehicle Occupancy (persons/vehicle)	17.2	19.3	15.1	13.1	12.7	13.1	16.6
Annual Cost per Vehicle-Mile (¢)	139.0	94.5	83.3	68.6	68.3	69.9	113.9

[1]Source: Reference 5-2
[2]Based on 1972 population

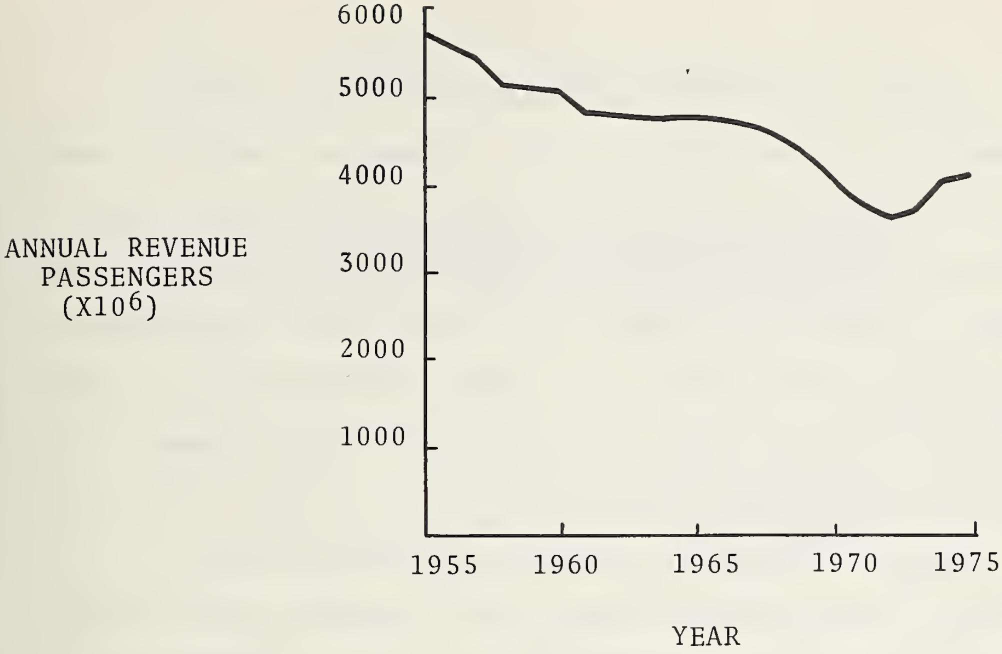

FIGURE 5-1. ANNUAL REVENUE PASSENGERS CARRIED BY URBAN DIESEL BUSES

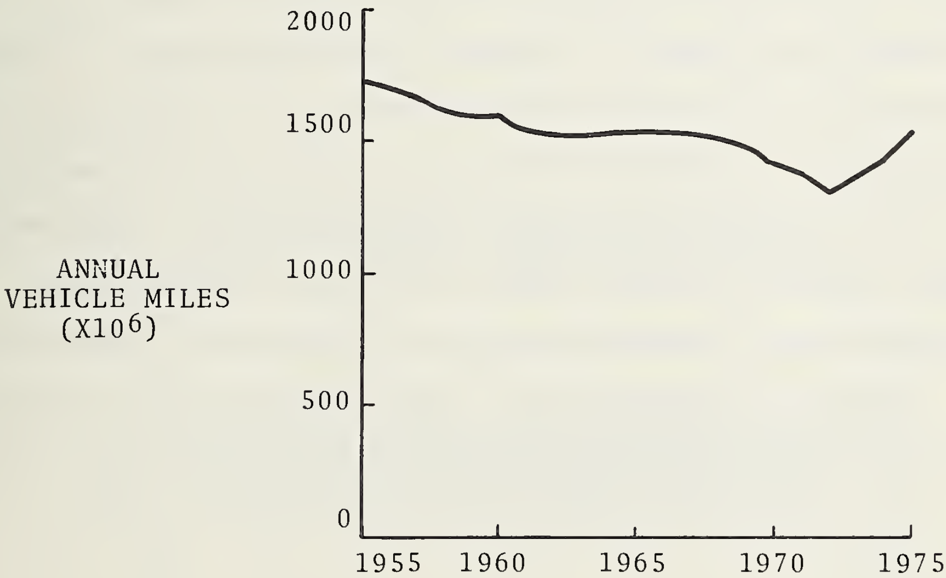

FIGURE 5-2. ANNUAL VEHICLE MILES OPERATED BY URBAN DIESEL BUSES

Despite the recent increases in both the number of passengers carried and the level of service provided, there has not been any significant increase in the size of the national diesel bus fleet over the past two decades. Since 1960, the size of the diesel bus fleet within the industry has increased only 6% to its current (1976) level of 52,380 vehicles with the largest percentage of this increase occurring since 1973.

New bus deliveries to transit authorities have generally been used to replace aging equipment rather than to increase the size of the vehicle fleet for service expansion. This is evident in an examination of the APTA fleet inventory data, which indicates that the mean age of the diesel bus fleet has declined from 10.05 years in 1972 to 8.97 years in 1975. A summary of the 1972 diesel bus fleet age distribution is presented in Appendix D (Table D-1); while the 1975 fleet inventory distribution, a selected sample (49% of the total fleet) from the 23 largest U.S. urbanized areas reporting to APTA, is outlined in Table D-3.

Figure 5-3 and Table 5-2, below, identify the trend of new bus deliveries during the period between 1955 and 1976.

TABLE 5-2. ANNUAL NEW BUS DELIVERIES AND BUS RETIREMENTS (1955-1976)

Year	Fleet Size	Annual Change from Previous Year	No. of New Buses Installed	% of Total Fleet	No. of Buses Retired	% of Total Fleet
1976	52,382	+1517	4,745	9.0	3,174	6.1
1975	50,811	+2111	5,261	10.3	3,150	6.2
1974	48,700	+414	4,818	9.8	4,404	9.0
1973	48,286	-789	3,200	6.6	3,989	8.3
1972	49,075	- 75	2,904	5.9	2,979	6.1
1971	49,150	-550	2,514	5.1	3,064	6.2
1970	49,700	+100	1,442	2.9	1,342	2.7
1969	49,600	-400	2,230	4.5	2,630	5.3
1968	50,000	-180	2,228	4.4	2,408	4.8
1967	50,180	+ 50	2,500	4.9	2,450	4.9
1966	50,130	+530	3,100	6.1	2,570	5.1
1965	49,600	+400	3,000	6.0	2,600	5.2
1964	49,200	-200	2,500	5.0	2,700	5.5
1963	49,400	+600	3,200	6.5	2,600	5.3
1962	48,800	-200	2,000	4.1	2,200	4.5
1961	49,000	-600	2,415	4.9	3,010	6.2
1960	49,600	+100	2,806	5.6	2,706	5.5
1959	49,500	-600	1,537	3.1	2,137	4.3
1958	50,100	-700	1,698	3.4	2,398	4.8
1957	50,800	-600	1,946	3.8	2,546	5.0
1956	51,400	-1000	2,759	5.4	3,759	7.3
1955	52,400	-1600	2,098	4.0	3,698	7.1

Source: Reference 5-1

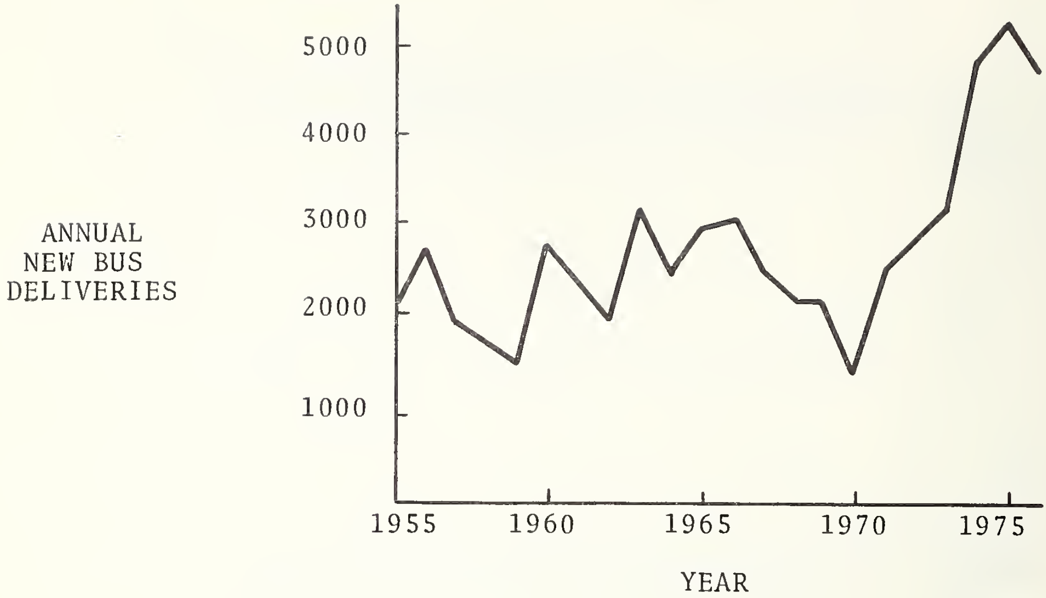

FIGURE 5-3. NEW DIESEL BUS DELIVERIES TO APTA REPORTING TRANSIT SYSTEMS (1955-1976)

Except for the period between 1965-1970, new bus deliveries to transit authorities have generally shown an increasing trend each year with the most significant increases occurring since 1970. Between 1960 and 1970, the rate of new bus installations have averaged 2,598 vehicles per year with an average annual retirement rate of 2,587 vehicles during that same period. Since 1970, however, the average number of annual new bus deliveries have increased nearly 37% to 3,555 vehicles per year with an average annual vehicle retirement rate of 3,157 buses per year.

5.2 FORECAST OF URBAN BUS DEMAND

In this analysis, the estimation of the future demand for urban buses within the transit industry was based on the results of three studies conducted in this area. For the most part, these studies utilized historical data on current levels of transit patronage, vehicle fleet inventories, bus replacement practices, and forecasted data on the expected growth in urban travel to determine the demand for transit coaches and the net increase in the national urban bus fleet.

A summary of the assumptions, procedures, and the results of these studies is presented below.

1) Forecast of Urban 40-Foot Coach Demand (Reference 5-3):

This study, conducted in December 1972 by Booz-Allen Applied Research, estimated the U.S. demand for 40-foot transit coaches from 1972 through 1990 as part of an overall market assessment for the UMTA TRANSBUS program. The data base used in the analysis was the 1972 APTA national bus fleet inventory which represented approximately 95% of the total number of transit coaches in the major U.S. urban areas. The study focused only on the demand for 40-foot transit coaches which represented 65% (28,600) of the total U.S. bus fleet of 43,800 vehicles in 1972. The study's forecast estimated the net additions to the fleet because of a growth in transit patronage, and the replacements to the existing fleet due to retirement of vehicles at the end of their service life.

The forecast of new additions to the 40-foot bus fleet was determined based on a number of factors that included an increase in transit demand due to the construction of exclusive busways, pricing policies on transit fares, the prohibition of autos in CBD areas, and the replacement of other transportation modes such as trolley coaches, 35-foot transit coaches, and school buses. Table 5-3 summarizes the study's forecast of new bus additions to the U.S. 40-foot transit coach fleet for the period 1972 to 1990. As shown, starting with a base fleet of 28,600 vehicles in 1972, the new bus additions were estimated to be approximately 1,250 vehicles per year for the first four years, increase to 1,400 vehicles per year between 1976-1980, and then level off at 1,100 vehicles per year during the decade of the 1980's.

The annual number of replacements to the vehicle fleet was determined by using the age distribution of the 1972 40-foot transit coach fleet and maintaining the current size of that fleet (28,600 vehicles) based on the retirement of vehicles at a service life of 12 years. Under this schedule of retirement, new replacement vehicles would be added to the vehicle fleet at a rate of 2,383 vehicles per year

TABLE 5-3. FORECAST OF NEW 40-FT. TRANSIT COACH ADDITIONS TO NATIONAL BUS FLEET (1972-1990)

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Present Estimated Number of 40-Foot Coaches at Beginning of Year	28,800	29,856	31,112	32,387	33,622	35,028	36,433	37,839	39,245	40,499	41,603	42,708	43,813	44,918	46,024	47,129	48,235	49,340	50,445
FACTORS INFLUENCING 40-FOOT BUS DEMAND																			
Regional Growth Considerations	(26)	(26)	(27)	(26)	(26)	(27)	(26)	(26)	(27)	(26)	(26)	(27)	(26)	(26)	(27)	(26)	(26)	(27)	(26)
Trip Purpose, Trip Location and Peak-to-Base Ratios	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction of Fringe Parking Lots and Exclusive Busways	879	879	879	879	879	879	879	879	879	878	879	879	879	879	879	879	879	879	879
Pricing Policies	16	16	18	15	16	18	16	18	15	16	18	16	15	16	16	16	15	16	16
Prohibition of Automobiles	79	79	79	79	79	79	79	79	79	79	78	79	79	79	79	79	79	79	79
Replacement of 35-Foot Coaches	150	150	150	150	150	150	150	150	0	0	0	0	0	0	0	0	0	0	0
Displacement of Other Fleets (School Buses)	158	158	158	158	158	158	158	158	158	157	158	158	158	158	158	158	158	158	157
Replacement of Trolley Coaches	0	0	0	0	150	150	150	150	150	0	0	0	0	0	0	0	0	0	0
Projected Number of 40-Foot Coaches at End of Year	29,856	31,112	32,387	33,822	35,028	38,433	37,839	39,245	40,499	41,603	42,708	43,813	44,918	46,024	47,129	48,235	49,340	50,445	51,550
Net Additions to the 40-Foot Bus Fleet During Year	1,256	1,256	1,265	1,255	1,406	1,405	1,406	1,406	1,254	1,104	1,105	1,105	1,105	1,106	1,105	1,106	1,105	1,105	1,105

between 1973 and 1983, and then increase to a rate of 3,678 vehicles per year between 1984 and 1990 to account for the replacement of the projected new bus additions.

A summary of the forecasted annual vehicle replacements and new bus additions to the 40-foot transit coach fleet is presented in Table 5-4.

TABLE 5-4. FORECAST OF 40-FOOT TRANSIT COACH REPLACEMENTS AND ADDITIONS (1972-1990)

Year	No. of 40-ft. Coaches At Beginning Of Year	No. of 40-ft. Coaches Required: Replacements	Additions	Total	Projected No. of 40-ft. Coaches At End of Year
1972	28,600	-	1,256	1,256	29,856
1973	29,856	2,383	1,256	3,639	31,112
1974	31,112	2,383	1,255	3,638	32,367
1975	32,367	2,384	1,255	3,639	33,622
1976	33,622	2,383	1,406	3,789	35,028
1977	35,028	2,383	1,405	3,788	36,433
1978	36,433	2,384	1,406	3,790	37,839
1979	37,839	2,383	1,406	3,789	39,245
1980	39,245	2,383	1,254	3,637	40,499
1981	40,499	2,384	1,104	3,488	41,603
1982	41,603	2,383	1,105	3,488	42,708
1983	42,708	2,383	1,105	3,488	43,813
1984	43,813	3,678	1,105	4,783	44,918
1985	44,918	3,679	1,106	4,785	46,024
1986	46,024	3,677	1,105	4,782	47,129
1987	47,129	3,678	1,106	4,784	48,235
1988	48,235	3,678	1,105	4,783	49,340
1989	49,340	3,678	1,105	4,783	50,445
1990	50,455	3,678	1,105	4,783	51,550
TOTAL		51,962	22,950	74,912	

As shown, the forecasted 'net addition' and 'replacement' vehicle requirements generate a total demand of nearly 75,000 40-foot buses over the 18-year period. Of this total, approximately 23,000 vehicles, an 80% fleet expansion, would be needed to accomodate the expected increase in transit demand with the remaining 52,000 vehicles used for replacement of existing coaches when they reach their maximum service life.

2) <u>United States Transit Bus Demand</u> (Ref. 5-4):

This study, conducted in June 1975 by the Highway Users Federation, forecasted the annual demand for urban transit buses based upon a number of assumed policies involving fleet expansion and vehicle retirement. As was the case in the previous study, the 1972 APTA national bus fleet inventory was used as the data base for this analysis.

The 'best estimate' projection of this study was based on the policy of increasing the vehicle fleet 3% each year and reducing the average service life of the vehicle to 12 years by 1990. The result of this projection is presented in Table 5-5. As shown, an 80% expansion in the total urban bus fleet was projected over the 18-year period with the annual demand for new buses increasing to slightly under 7,400 vehicles per year by 1990.

TABLE 5-5. PROJECTION OF UNITED STATES TRANSIT BUS DEMAND (1972-1990)

U. S. TRANSIT BUS FLEET AGE PROFILES - "BEST ESTIMATE"

"Increase the fleet by three percent each year and reduce the average life to 12 years in a 14-year period"

	Simpson-Curtin/ Booz- Allen	Service Retirement Model																			
	1972	1972	1973	1974	1875	1876	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1887	1988	1989	1990	
1944	4																				1944
1945	95																				1945
1946	131																				1946
1947	767	6																			1947
1948	476	40	4																		1948
1949	360	84	19	2																	1949
1950	538	192	67	15																	1950
1851	1009	744	328	114	7																1951
1952	419	521	286	126	19																1952
1953	1038	1023	669	367	87	6															1953
1954	1443	1355	1013	663	230	36	1														1954
1955	1326	1550	1278	956	457	120	14														1955
1958	1541	2307	2038	1681	1023	404	84	4													1956
1957	1514	1756	1627	1438	1043	555	176	24													1957
1958	1642	1604	1532	1420	1161	768	345	77	5												1958
1959	1499	1492	1452	1387	1227	842	556	196	33	1											1959
1960	2717	2767	2724	2851	2466	2100	1505	760	212	22											1960
1961	2455	2401	2381	2345	2248	2047	1668	1077	453	69	4										1961
1962	1884	1996	1988	1972	1925	1827	1617	1235	704	224	28										1962
1963	3047	3198	3194	3181	3141	3053	2844	2430	1716	815	188	9									1963
1964	2452	2500	2499	2495	2480	2442	2348	2152	1746	1101	423	68	1								1964
1965	3055	3000	3000	2999	2991	2969	2908	2771	2458	1868	1021	291	28								1965
1966	3981	3100	3100	3100	3097	3088	3057	2977	2790	2392	1662	733	139	5							1966
1967	1798	2500	2500	2500	2500	2497	2487	2453	2372	2181	1767	1085	372	41							1967
1963	2112	2228	2228	2228	2228	2227	2224	2211	2175	2077	1354	1400	729	178	9						1968
1969	1674	2230	2230	2230	2230	2230	2229	2225	2207	2157	2055	1751	1196	490	77	1					1969
1970	1406	1442	1442	1442	1442	1442	1442	1441	1437	1422	1381	1274	1033	615	180	16					1970
1971	2207	2514	2514	2514	2514	2514	2514	2514	2512	2502	2466	2369	2128	1597	785	152	5				1971
1872	1195	2904	2904	2904	2904	2904	2904	2904	2904	2900	2394	2833	2684	2314	1557	583	67				1972
1973			3200	3200	3200	3200	3200	3200	3200	3199	3194	3168	3088	2868	2329	1338	341	16			1973
1974				4818	4818	4818	4818	4918	4818	4818	4816	4804	4754	4596	4156	3097	1421	212	25		1974
1975					4771	4771	4771	4771	4771	4771	4771	4768	4751	4679	4460	3865	2558	852	209	24	1875
1976						4756	4756	4756	4756	4756	4756	4755	4752	4727	4631	4334	3525	1942	849	209	1976
1977							4799	4799	4799	4799	4799	4799	4798	4792	4755	4617	4206	3127	1960	557	1977
1978								5068	5068	5068	5068	5068	5068	5067	5057	5002	4800	4184	3302	2070	1978
1979									5377	5377	5377	5377	5377	5377	5375	5357	5271	4975	4439	3504	1979
1980										5665	5665	5665	5665	5665	5665	5663	5637	5506	5242	4677	1980
1981											5793	5793	5793	5793	5793	5793	5787	5743	5629	5360	1981
1982												5737	5737	5737	5737	5737	5737	5728	5688	5575	1982
1983													5509	5509	5509	5509	5509	5508	5501	5462	1983
1984														5458	5458	5458	5458	5458	5457	5450	1984
1885															5941	5941	5941	5941	5941	5940	1985
1986																7037	7037	7037	7037	7037	1986
1987																	8287	8287	8287	8287	1987
1988																		9217	9217	9217	1988
1969																			7162	7162	1989
1990																				7394	1990
Total	43,800	45,454	46,218	48,746	50,208	51,715	53,266	54,864	56,510	58,205	59,952	61,750	63,603	65,511	67,476	69,500	71,585	73,733	75,945	78,223	
Avg. Age	11.11	10.[illegible]	9.83	9.42	8.90	8.48	8.16	7.84	7.52	7.19	6.90	6.90	6.86	6.70	6.72	6.60	6.33	5.97	8.02	6.07	
Avg. Life	19.0	19.0	19.0	18.0	18.5	18.0	17.5	17.0	16.5	16.0	15.5	15.0	14.5	14.0	13.5	13.0	12.5	12.0	12.0	12.0	
Ann. Installations	1195	2904	3200	4818	4771	4756	4799	5068	5377	5665	5793	5737	5509	5458	5941	7037	8287	9217	7162	7394	

3) United States Transit Industry Market Survey (1975) (Source: Reference 5-5):

In June 1975, the American Public Transit Association published a survey on the near and medium term demand for transit equipment within the industry. The survey was based on a sample of 100 transit systems operating nearly 32,000 buses - 65% of the total U.S. bus fleet.

Each respondent was asked to report the minimum and maximum anticipated purchases of transit vehicles for the calendar years 1975 through 1979, along with their estimate of expected bus purchases beyond 1980. A summary of the survey results including an expansion of the forecasted demand to the total industry is presented in Table 5-6. The expansion was based on the ratio of the sample fleet size to that of the 1974 national fleet.

TABLE 5-6. ANTICIPATED DEMAND FOR TRANSIT BUSES 1975-1990 (APTA SURVEY)

			Anticipated Demand							
			Reporting Systems				Expanded to Total Industry [a]			
Time Period (calendar years)	*Number of Transit Systems Reporting*	*September '74 Fleet Size of Reporting Systems*	*Minimum Order*	*Minimum Yearly Average*	*Maximum Order*	*Maximum Yearly Average*	*Minimum Order*	*Minimum Yearly Average*	*Maximum Order*	*Maximum Yearly Average*
1975	97	31,647	3,311	—	5,025	—	5,124	—	7,777	—
1976	97	31,647	3,106	—	5,195	—	4,807	—	8,040	—
1977	97	31,647	3,043	—	4,646	—	4,710	—	7,191	—
1978	97	31,647	2,445	—	3,894	—	3,784	—	6,027	—
1979	97	31,647	2,531	—	3,975	—	3,917	—	6,152	—
1980-1984	25	11,669	5,809	1,162	6,080	1,216	24,244 [b]	4,849 [b]	25,375 [b]	5,075 [b]
1985-1989	17	3,845	3,064	613	3,201	640	38,808 [b]	7,762 [b]	40,543 [b]	8,109 [b]

Source: American Public Transit Association, *1975 United States Transit Industry Market Survey* (Washington, D.C.: 1975) pp. 5-7.

[a] Based on U.S. transit industry total fleet size of 48,700 transit buses (motor coaches) as of September 1974.

[b] Fluctuation of anticipated transit bus demand between the five-year time periods results from the limited survey response rather than from identifiable trends in anticipated bus demand.

As a result of the APTA survey, the minimum and maximum average annual demand for new buses within the entire transit industry was projected to be 4,468 to 7,037 vehicles per year between 1975 and 1979, 4,849 to 5,075 vehicles per year from 1980 to 1984, and 7,762 to 8,109 vehicles per year from 1985 through 1990.

5.3 PROJECTED DEMAND FOR FLYWHEEL-POWERED BUS SYSTEMS

A projection of the potential market for flywheel powered vehicle systems in the United States has been made based upon estimates of the expected trends in the national transit coach demand and estimates of the feasible applications of these vehicle systems within the transit industry. Implicit in the projections are assumptions concerning the future growth in transit patronage, the continuation of the current Federal capital assistance policy for the purchase of new transit coaches, and assumptions on the manner in which these vehicle systems are introduced and used in the national urban bus fleet. Since there is no current or historical experience in the United States on the application of flywheel energy storage propulsion systems in urban bus operations, the projection of the potential applications of these vehicle systems is considered to be highly judgmental.

For this analysis, the projected annual demand for vehicles within the entire transit industry was determined by taking the average of the annual vehicle demand as forecasted in the three referenced studies. This projected annual demand for new urban buses for the period 1977 through 1990 is summarized in Table 5-7 and depicted in Figure 5-4. Note that the projected annual vehicle demand shown for the Booz-Allen Study represented only the demand for 40-foot transit coaches (approximately 65% of the total national bus fleet), and was adjusted to reflect the total demand for urban buses within the transit industry.

TABLE 5-7. FORECASTED ANNUAL NEW VEHICLE DEMAND (1977-1990)

Year	Booz-Allen Study 40-Ft Coach Demand	Booz-Allen Study Total (Adjusted)	Highway Users Study	APTA Survey	TSC Assumed Vehicle Demand (Average)
1977	3788	5828	4799	4710	5122
1978	3790	5830	5068	3784	4894
1979	3789	5829	5377	3917	5041
1980	3637	5595	5665	4849	5369
1981	3488	5366	5793	4849	5366
1982	3488	5366	4737	4849	4984
1983	3488	5366	5509	4849	5241
1984	4783	7358	5458	4849	5888
1985	4784	7360	5941	7762	7021
1986	4783	7358	7037	7762	7385
1987	4784	7360	8287	7762	7803
1988	4783	7358	9217	7762	8112
1989	4783	7358	7162	7762	7427
1990	4783	7358	7394	7762	7504

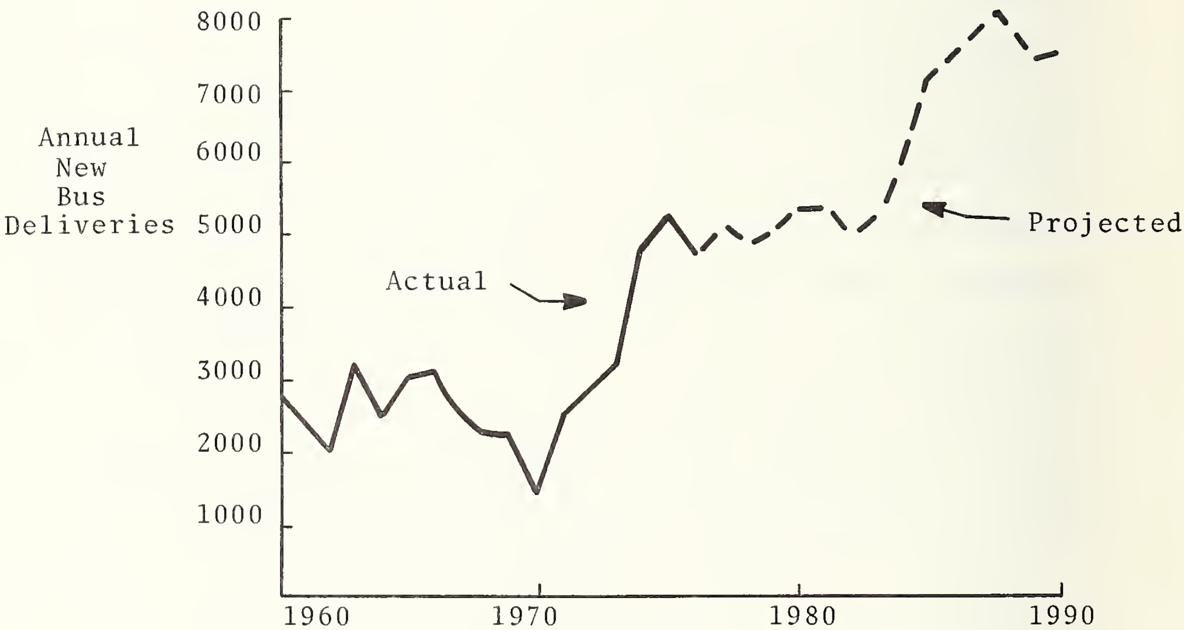

FIGURE 5-4. FORECASTED ANNUAL NEW BUS DEMAND (1977-1990)

As shown, a total urban bus demand of nearly 87,160 vehicles is projected for the 14-year period, with an average annual demand of approximately 6,225 vehicles per year.

The percentage of this total urban bus demand that would be representative of the potential market in the transit industry for flywheel powered vehicle systems is dependent on the manner in which these vehicles are introduced and used in urban bus operations.

Assuming:

- that the technology of the flywheel propulsion systems would be fully developed, tested, and demonstrated such that production versions of these vehicle systems would be available by 1980,

and secondly,

- that these vehicle systems are introduced into the transit industry as new additions or replacements to existing vehicle fleets operating on high stop density, low headway routes,

then the potential market for flywheel powered bus systems is projected to range from 10% to 30% of the total demand for new transit coaches during the period 1980 through 1990. This projected market share was based on the data presented in Table 5-8, which summarizes current (1977) vehicle fleet distributions during the peak period by various route

TABLE 5-8. PEAK-PERIOD FLEET DISTRIBUTIONS BY TRANSIT ROUTE CLASSES

Route Classification Headway:	0-5 min.	6-10 min.	11-15 min.	16-20 min.	21-30 min.	>30 min.	TOTAL
Chicago							
No. Vehicles	1151	964	94	9	-	1	2219
% of Total	52%	43%	4%	1%	-	-	100%
Los Angeles							
No. Vehicles	250	535	196	188	350	334	1853
% of Total	13%	30%	10%	10%	19%	18%	100%
D.C.							
No. Vehicles	1057	249	88	134	63	96	1687
% of Total	63%	15%	5%	8%	4%	5%	100%
Boston							
No. Vehicles	122	222	187	47	16	97	691
% of Total	18%	32%	27%	7%	2%	14%	100%
San Francisco							
No. Vehicles	180	167	33	28	1	4	413
% of Total	44%	40%	8%	7%	-	1%	100%
Minn./St. Paul							
No. Vehicles	143	313	169	90	8	12	735
% of Total	20%	42%	23%	12%	1%	2%	100%
Philadelphia							
No. Vehicles	174	543	288	10	15	12	1042
% of Total	17%	52%	28%	1%	1%	1%	100%
San Diego							
No. Vehicles	18	28	45	62	93	23	269
% of Total	6%	10%	17%	23%	36%	8%	100%

Source: Reference 5-6

classifications for eight U.S. transit authorities. As shown, there is a significant variation in the distribution of the vehicle fleet deployments on low headway routes for the cities in this sample. For cities having a low population density (i.e., Los Angeles, San Diego), the peak-period vehicle distribution on low headway routes ranges from 10% to 20% of the total fleet; whereas, for cities having a high center-city population density (i.e., Chicago, San Francisco), the percent fleet deployment on the low headway routes could be as high as 40% to 50%.

Table 5-9 presents the projected annual demand for flywheel powered vehicles within the United States for the 1980 to 1990 period for various assumed market shares. As shown, at a 10% market share level, a total of over 7,200 flywheel powered vehicle systems is projected for the 11-year forecast period with an average annual demand of approximately 650 vehicles per year. At a 30% market share level, the total production of flywheel powered bus systems would increase to a projected total of over 21,600 vehicles in the 11-year period at an average annual demand of nearly 2,000 vehicles per year.

TABLE 5-9. PROJECTED ANNUAL DEMAND FOR FLYWHEEL-POWERED VEHICLES (1980-1990)

Forecast Year	Forecasted Total Urban Bus Demand	Projected Flywheel-Powered Bus Demand Market Share: 10%	20%	30%	40%	50%
1980	5369	537	1074	1611	2148	2685
1981	5366	537	1074	1611	2148	2685
1982	4984	498	996	1494	1992	2490
1983	5241	524	1048	1572	2096	2620
1984	5888	589	1178	1767	2356	2945
1985	7021	702	1404	2106	2808	3510
1986	7385	739	1478	2217	2956	3695
1987	7803	780	1560	2340	3120	3900
1988	8112	811	1622	2433	3244	4055
1989	7427	743	1486	2229	2972	3715
1990	7504	750	1500	2250	3000	3750
TOTAL	72,100	7,221	14,420	21,630	28,840	36,050
AVERAGE ANNUAL DEMAND	6555	656	1311	1996	2622	3277

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APPENDIX A

LIFE-CYCLE COST ANALYSIS MODEL

In the conduct of this study, a computerized analysis model was developed to determine the present value life-cycle costs of the diesel, trolley, and the flywheel-powered vehicle systems.

Presented below is a definition of the model's input variables and output reports. The data shown reflects the input data and the analysis results for the assumed 'base case' of the study.

1. Vehicle Variable Names:

- DIESL - Diesel bus
- TROLY - Trolley bus
- FLYWL - All flywheel vehicle concept
- FLYDL - Flywheel/diesel vehicle concept
- FLYBT - Flywheel/battery vehicle concept

2. Input Variables:

a. Parameters:

- ROUTES - Number of transit routes under analysis
- RTMILE - Average route length (miles)
- HDWY - Average vehicle headway (minutes)
- ISTOP - Route stop density (no. stops/mile)
- HOURS - Not used

- DWELL - Vehicle dwell time at stop (seconds)
- VEL - Vehicle cruise velocity (mph)
- ACCRT - Not used
- DECRT - Not used
- CHDIS - Range of vehicle between charging of the flywheel or replacement of battery pack (miles)
- CHTIM - Time required for charging of the flywheel or the replacement of the battery pack (minutes)
- CYL T - Cycle time (duty cycle C) excluding dwell time (seconds)
- PWCON - Fuel/power consumption (gallons/miles or kw-hr/mile)
- INV - Number of years of investment under analysis
- DIS - Discount rate (%)

b. Unit Capital Costs:

- VEHS - Vehicle capital cost ($/vehicle)
- MAINT - Garage and maintenance facility capital cost ($/vehicle)
- WAYST - Capital cost of wayside charging station ($/station)
- PWRLN - Capital cost of overhead trolley ($/route mile - 2-way)

- BATRY - Capital cost of 1-1/2 battery packs
  ($ per 1-1/2 pack)

c. Unit Operating Costs:

- PAYRL - Driver payroll and other costs ($/payhour)
- MAINT - Vehicle maintenance costs ($/vehicle-mile)
- POWER - Fuel/power costs ($/gallon, $/kw-hr)
- PWRLI - Maintenance cost of overhead power line
  ($/year per route-mile -- 2-way)
- WAYST - Maintenance cost of wayside power station
  ($/year per station)
- FXOM - Vehicle fixed operations/maintenance costs
  ($/vehicle-mile)

3. <u>Computed Output Variables</u>

a. Operations Data:

- VEHS - Vehicle fleet size (no. of vehicles)
- SPEED - Mean vehicle speed (mph)
- VHMIL - Total annual vehicle-miles (vehicle-miles)
- VEHHR - Total annual vehicle-hours (vehicle-hours)
- PAYHR - Total annual driver payhours (payhours)
- POWER - Annual fuel/power consumed (gallons or kw-hr)
- WAYST - Number of wayside stations required
  (wayside stations)

- MI/VH - Annual miles per vehicle (miles)
- RUNT - Vehicle route running-time - one-way (minutes)
- NCHRG - Number of vehicle charges en route-oneway

b. System Capital Costs:

- $/UNIT - Unit capital cost
- UNITS - Number of units purchased
- NO. - Number of capital equipment purchases over the investment period under analysis
- CAPCOST - Total capital cost ($)
- PVSALV - Present value of salvage credits ($)
- PVCAP - Present value cost of capital equipment ($)

c. System Operating Costs:

- $/UNIT - Unit operating cost
- OPRCOST - Annual operating cost ($)
- PVOPR - Present value of operating costs ($)

d. System Cost Summary:

- PVCST - Total present value cost ($)
- ANCST - Equivalent annualized cost ($/year)
- PVCMI - Present value cost per vehicle-mile ($/vehicle-mile)
- PVCVH - Present value cost per vehicle deployed ($/vehicle)

- ANCMI - Annualized cost per vehicle-mile ($ per year/vehicle-mile)
- ANCVH - Annualized cost per vehicle ($ per year/vehicle)

4. <u>Model Output Reports</u>:

PAR, IRTS, RTMI, HDWY, ISTOP, DIESL, ELPWR, HRS, DWEL, VEL, IYR, DIS

ROUTES	RTMILE	HDWY	STOPS/MI	HOURS	DWELL	VEL.	TOTRTMI
20	10.	15.	5	20.	20.	25.	200.

VEHICLE CHARACTERISTIC DATA

	DIESL	TROLY	FLYWL	FLYDL	FLYBT
ACCRT	3.00	5.00	3.00	3.00	3.00
DECRT	3.00	5.00	3.00	3.00	3.00
CHDIS	0.00	0.00	4.50	0.00	50.00
CHTIM	0.00	0.00	2.00	0.00	10.00
CYL T	38.80	38.80	38.80	38.80	38.80
PWCON	0.28	4.06	3.16	0.26	5.31

SYSTEM UNIT CAPITAL COSTS

	DIESL	TROLY	FLYWL	FLYDL	FLYBT
VEHS	70000.	115000.	149000.	130000.	147800.
MAINT	38000.	42400.	42400.	38000.	38000.
WAYST	0.	0.	286000.	0.	413000.
PWRLN	0.	495000.	0.	0.	0.
BATRY	0.	0.	0.	0.	56000.

SYSTEM OPERATING COSTS

	DIESL	TROLY	FLYWL	FLYDL	FLYBT
PAYRL	8.00	8.00	8.00	8.00	8.00
MAINT	0.25	0.20	0.29	0.26	0.28
POWER	0.35	0.03	0.03	0.35	0.03
PWRLI	0.00	6000.00	0.00	0.00	0.00
WAYST	0.00	0.00	1500.00	0.00	1000.00
FX OM	0.68	0.68	0.68	0.68	0.68

VEHICLE OPERATIONS DATA

	DIESL	TROLY	FLYWL	FLYDL	FLYBT
VEHS	145.	145.	154.	145.	150.
SPEED	12.	12.	11.	12.	12.
VHMIL	5071111.	5071111.	5380978.	5071111.	5257778.
VEHHR	416958.	416958.	472211.	416958.	449832.
PAYHR	542045.	542045.	613874.	542045.	584782.
POWER	1422447.	20588712.	17030795.	1303276.	27931945.
WAYST	0.	0.	44.	0.	17.
MI/VH	35000.	35000.	35000.	35000.	35000.
RUNT	49.	49.	53.	49.	51.
NCHRG	0.	0.	2.	0.	0.

YEAR OF INV. 30 DISCOUNT RATE .10

DIESL SYSTEM COSTS

ITEM	$/UNIT	UNITS	NO.	CAPCOST	PVSALV	PV CAP
VEHS	70000.	145.	3	10142222.	498203.	13516283.
MAINT	38000.	145.	0	5505778.	0.	5505778.
WAYST	0.	0.	0	0.	0.	0.
PWRLN	0.	200.	0	0.	0.	0.
BATRY	0.	1.	0	0.	0.	0.
TOTAL				15648000.	498203.	19022061.

ITEM	$/UNIT	OPR.COST	PV OPR$
PAYRL	8.00	4336364.	40878529.
MAINT	0.25	1267778.	11951233.
POWER	0.35	497856.	4693249.
PWRLI	0.00	0.	0.
WAYST	0.00	0.	0.
FX OM	0.68	3468640.	32698573.
TOTAL		9570638.	90221583.

TROLY SYSTEM COSTS

ITEM	$/UNIT	UNITS	NO.	CAPCOST	PVSALV	PV CAP
VEHS	115000.	145.	2	16662223.	664270.	18523029.
MAINT	42400.	145.	0	6143289.	0.	6143289.
WAYST	0.	0.	0	0.	0.	0.
PWRLN	495000.	200.	0	99000000.	0.	99000000.
BATRY	0.	1.	0	0.	0.	0.
TOTAL				121805512.	664270.	123666318.

ITEM	$/UNIT	OPR.COST	PV OPR$
PAYRL	8.00	4336364.	40878529.
MAINT	0.20	1014222.	9560986.
POWER	0.03	617661.	5822641.
PWRLI	6000.00	1200000.	11312297.
WAYST	0.00	0.	0.
FX OM	0.68	3468640.	32698573.
TOTAL		10636887.	100273025.

FLYWL SYSTEM COSTS

ITEM	$/UNIT	UNITS	NO.	CAPCOST	PVSALV	PV CAP
VEHS	149000.	154.	2	22907591.	913253.	25465870.
MAINT	42400.	154.	0	6518670.	0.	6518670.
WAYST	286000.	44.	0	12711111.	0.	12711111.
PWRLN	0.	200.	0	0.	0.	0.
BATRY	0.	1.	0	0.	0.	0.
TOTAL				42137373.	913253.	44695651.

ITEM	$/UNIT	OPR.COST	PV OPR$
PAYRL	8.20	910901.	46295495.

POWER	0.03	510924.	4816435.
PWRLI	0.00	0.	0.
WAYST	1500.00	66667.	628461.
FX OM	0.60	3680589.	34696596.
TOTAL		10729654.	101147532.

FLYOL SYSTEM COSTS

ITEM	$/UNIT	UNITS	NO.	CAPCOST	PVSALV	PV CAP
VEHS	130000.	145.	2	18835556.	750914.	20939077.
MAINT	38000.	145.	0	5505778.	0.	5505778.
WAYST	0.	0.	0	0.	0.	0.
PWRLN	0.	200.	0	0.	0.	0.
BATRY	0.	1.	0	0.	0.	0.
TOTAL				24341334.	750914.	26444855.

ITEM	$/UNIT	OPR.COST	PV OPRS
PAYRL	8.00	4336364.	40878529.
MAINT	0.26	1318489.	12429282.
POWER	0.35	456146.	4300054.
PWRLI	0.00	0.	0.
WAYST	0.20	0.	0.
FX OM	0.60	3468640.	32698573.
TOTAL		9579639.	90306437.

FLYBT SYSTEM COSTS

ITEM	$/UNIT	UNITS	NO.	CAPCOST	PVSALV	PV CAP
VEHS	147800.	150.	2	22202845.	885157.	24682418.
MAINT	38000.	150.	0	5708445.	0.	5708445.
WAYST	413000.	17.	0	7158667.	0.	7158667.
PWRLN	0.	200.	0	0.	0.	0.
BATRY	56000.	225.	8	12618667.	361579.	37922799.
TOTAL				47688623.	1246736.	75472329.

ITEM	$/UNIT	OPR.COST	PV OPRS
PAYRL	8.00	4678254.	44101499.
MAINT	0.20	1472178.	13878094.
POWER	0.05	837958.	7899362.
PWRLI	0.00	0.	0.
WAYST	1000.00	17333.	163400.
FX OM	0.60	3596320.	33902201.
TOTAL		10602044.	99944556.

	DIESL	TROLY	FLYWL	FLYOL	FLYBT
PVCST	108745441.	223275074.	144929930.	116000378.	174170150.
ANCST	11535635.	23684853.	15374058.	12305233.	18475839.
PVCMI	0.71	1.47	0.90	0.76	1.10
PVCVH	750549.	1541009.	942681.	800616.	1159417.
ANCMI	2.27	4.67	2.86	2.43	3.51
ANCVH	79617.	34[illegible]	99999.	84929.	122990.

APPENDIX B

ANALYSIS MODEL SYSTEM OPERATIONS EQUATIONS

Defined below are the equations and the relationships utilized in determining the average, one-way route running-times, mean speeds, and fleet size for each of the vehicle systems under analysis.

- Total Cycle Time (excluding dwell):

$$t_c = 3600/(\text{Stop})(\text{Vel}) - 1/2t_a - 1/2t_d$$

$$t_t = t_c + t_a + t_d$$

where:

t_t = total cycle time (seconds)

t_c = vehicle cruise time (seconds)

t_a = vehicle acceleration time (10.0 seconds - duty cycle C)

t_d = vehicle deceleration time (10.0 seconds - duty cycle C)

Stop = number stops/mile

Vel = vehicle cruise velocity (25 mph - duty cycle C)

- Number of En Route Charges:

$$Nc = RMI/CDv$$

where:

Nc = number of en route charges per 1-way route direction

RMI = total 1-way route mileage (miles)

CDv = vehicle charging distance (miles)

- One-Way Route Running-Time:

$$RUNv = \left[\frac{(t_t)(Stop)(RMI) + (Nc)(CTv)(60) + ((Stop)(RMI)-Nc))(Dwel)}{60} \right]$$

where:

$RUNv$ = 1-way route running-time (minutes)

t_t = total cycle time (seconds)

$Stop$ = stops/mile

RMI = 1-way route mileage

Nc = number vehicle charges per 1-way route direction

CTv = vehicle charge time (minutes)

$Dwel$ = vehicle dwell time (seconds)

- Mean Vehicle Speed

$$SPDv = (RMI/RUNv)(60)$$

where:

SPDv = mean vehicle speed (mph)

RMI = 1-way route mileage

RUNv = 1-way route running-time (minutes)

- Vehicle Fleet Size:

$$VEHv = [\{(2)(RUNv) + 10\}/HDWY](RTS)$$

where:

VEHv = total vehicle fleet size

RUNv = 1-way route running-time (minutes)

HDWY = average vehicle headway (minutes)

RTS = no. of transit routes under analysis.

APPENDIX C

RECENT BID PRICES ON DIESEL AND TROLLEY BUSES IN THE UNITED STATES

STUDY: Life-Cycle Costing for Current ROHR, AM General, and General Motors RTS-II Bus, Advanced Management Systems, Inc., Report No. UMTA-VA-06-0039-76-1, July 1976.

DATA SOURCE CITED: UMTA files for 40-foot diesel buses.

TABLE C-1

SAMPLE BIDS SUBMITTED AND AWARDED IN CY 1974 FOR DIESEL BUSES

Bid Number (Disguised)	Quantity	Bid Prices		
		Manufacturer A	Manufacturer B	Manufacturer C
1	300	$53,506	$54,722	$53,212
2	145	71,311	------	75,894
3	148	65,457	------	62,340
4	152	------	------	52,941
5	100	56,032	55,402	57,890
6	156	56,875	56,947	62,206
7	179	65,812	65,195	68,235
8	500	65,251	67,073	64,768
9	205	61,425	61,246	61,822
10	111	70,985	------	67,605
Total Buses	1,996			
Av. Price Per Bus Per Mfg.		$62,962	$60,098	$62,691
Overall Average------------------$62,166				

STUDY: TRI-MET Trolley Bus Evaluation Study, DeLeuw, Cather & Company, March 1976.

DATA SOURCE: Compiled by DeLeuw, Cather & Company.

TABLE C-2

RECENT BID PRICES ON DIESEL AND TROLLEY BUSES IN THE UNITED STATES AND CANADA

RECENT DIESEL BUS BID PRICES

CITY	DATE BID OR ORDERED	NO. OF BUSES	BIDDER	BID PRICE	DESCRIPTION				
					Type	Length	Engine	Air Cond.	Other
Seattle	Sept '75	145	AM General	$71,311	Trans.	40 ft.	8V71	No	47 forward facing transit seats on raised deck. Double stream rear doors
Orange County	Sept '75*	55	Flxible	$69,602		40 ft.			44 seats
AC Transit (for BART)	Feb. '75	36	Flxible	$71,108	Subn.	40 ft.	8V71	Yes	45 forward facing reclining seats on raised deck, carpeting, climate control, single door.**
AC Transit (for BART)	Feb '75	36	GM	$75,145	Subn	40 ft.	8V71	Yes	" " "
Fresno	Feb '75	?	AM General	$66,895	Trans.	40 ft.	8V71	Yes	51 seats
Fresno	Feb '75	?	GM	$68,542	Trans.	40 ft.	8V71	Yes	51 seats
Chicago	Dec '74*	600	GM	$64,768	Trans.	40 ft.	8V71	Yes	50 fiberglass seats with pads, climate control, two-way radio, balloon bumpers (front & rear).
Chicago	Dec '74	500	AM General	$65,251	Trans.	40 ft.	8V71	Yes	" " "
Chicago	Dec '74	100	AM General	$66,751	Trans.	40 ft.	8V71	Yes	" " "
Chicago	Dec '74	500	Flxible	$67,073	Trans.	40 ft.	8V71	Yes	" " "
Chicago	Dec '74	100	Flxible	$69,990	Trans.	40 ft.	8V71	Yes	" " "
San Francisco	Nov '74		AM General	$57,500	Trans.	35 ft.		No	
Pittsburgh	Sept '74*	20	Flxible	$57,200	Trans	40 ft.	8V71	Yes	51 seats
Pittsburgh	Sept '74	50	Flxible	$56,500	Trans.	35 ft.	8V71	Yes	43 seats
Denver	Aug '74	83	AM General	$53,870	Trans.	40 ft.	8V71	Yes	47 seats

* Date of report in trade press

** Rear seats do not recline

Source: Compiled by De Leuw, Cather & Company

TABLE C-2 (cont'd)

CITY	DATE BID OR ORDERED	NO. OF BUSES	BIDDER	BID PRICE	DESCRIPTION				
					Type	Length	Engine	Air Cond.	Other
Denver	Aug '74	10	GM	$57,880	Subn.	40 ft.	8V71	Yes	49 seats
Tri-Met	Jul '74	80	Flxible	$60,000	Trans.	40 ft.	8V71	Yes	49 seats
Golden Gate Tr.	Apr '74	32	GM	$59,000	Subn.	40 ft.	8V71	Yes	45 reclining seats (Similar to AC/BART buses)
Golden Gate Tr.	Fall '73	30	GM	$56,000	Subn.	40 ft.	8V71	Yes	" " "
Tri-Met	May '73	20	GM	$46,546	Trans.	40 ft.	8V71	Yes	49 spring cushioned seats. Water bumpers (front & rear)
Tri-Met	May '73	20	Flxible	$45,499	Trans.	35 ft.	8V71	Yes	42 seats
Chicago	Apr '73	545	GM	$41,686	Trans.	40 ft.	8V71	Yes	50 seats (Similar to later order of 600 buses)
Chicago	Mar '72	525	GM	$41,764	Trans.	40 ft.	8V71	Yes	" " "
Chicago	Mar '72	525	Flxible	$42,605	Trans.	40 ft.	8V71	Yes	" " "
Denver	Dec '71	26	Flxible	$42,922	Trans.	40 ft.	8V71	Yes	
Denver	Dec '71	26	GM	$42,958	Trans.	40 ft.	8V71	Yes	
Tri-Met	Nov '70	25	GM	$40,552	Trans	35 ft.	8V71	Yes	43 seats, carpeting
Golden Gate Tr.	Apr '71	112	GM	$43,477	Subn.	40 ft.	8V71	Yes	45 reclining seats (Similar to AC/BART buses)
Tri-Met	Nov '70	25	GM	$40,552	Trans.	40 ft.	8V71	Yes	51 seats
Tri-Met	Nov '70	50	Flxible	$36,058	Trans	35 ft.	6V71	Yes	43 seats
Toronto	1969	?	GM(Canada)	$38,750	Trans	40 ft.	6V71	No	Estimated cost of TTC diesel buses when decision was made to order 151 trolley buses from Western Flyer Coach Limited (later Flyer Industries Limited) in Nov. 1969. Cost was based on current TTC contracts with GM (Canada).

Note
Bid prices shown are subject to variable factors such as taxes, freight and equipment options.

Source: Compiled by De Leuw, Cather & Company

TABLE C-2 (cont'd)

RECENT TROLLEY BUS BID PRICES

CITY	DATE		NO. OF BUSES	BIDDER	BID PRICE	DESCRIPTION
	Bid or Order	First Delivery				
Toronto	May '67	Jul '68	1	Flyer	?	Prototype Model E700. Standard 40-foot, 51 pass. diesel bus modified for use as trolley bus. Motor & controls rebuilt from retired bus. Double stream rear exit doors.
"	Nov '69	Jul '70	151	Flyer-TTC	$34,700	Model E700A. Flyer supplied new bodies ($27,000). TCC rebuilt and installed motors & controls from retired buses ($7200). Project extended over 3 years. Double stream rear exit doors.
"	"	---	?	?(Germany)	$50,300	Trolley bus with new motors & controls. Order not placed.
"	"	---	?	?(Italy)	$56,800	" " "
"	"	---	?	?(Switzer-land)	$99,600	" " "
Dayton	? '70	Mar '71	1	Flyer-TCC	?	Model E700A. Built with Toronto order. TCC rebuilt and installed motor & controls. single stream rear exit door.
San Francisco	? '72	Nov '72	1	Flyer	$42,500	Model E700A. Motor & controls from retired Muni bus rebuilt by GE at Emeryville, Calif Single stream rear exit door.

Source: Compiled by De Leuw, Cather & Company

TABLE C-2 (cont'd)

CITY	DATE		NO. OF BUSES	BIDDER	BID PRICE	DESCRIPTION
	Bid or Order	First Delivery				
Hamilton	Mar '72*	Nov '72	40	Flyer-GE	$43,700	Model E700A. Motors & controls rebuilt and installed by Canadian GE. Double stream rear exit doors.
San Francisco	Dec '72*	?	1	Flyer	?	Model E700A. Reguilt motor & controls. Double stream rear exit door.
Edmonton	May '73	Sept '74**	37	Flyer	$47,000±	Model E800 (Large rectangular windows - coachwork same as AM General 40-foot diesel bus). Model designation changed to E10240. Rebuilt motors & controls. Double stream rear exit doors.
Vancouver	Jan '74	Dec. '75	50	Flyer	?	Model E10240. Rebuilt motors & controls. Double stream rear exit doors.
San Francisco	Jun '74	Nov '75	343	Flyer	$75,802	Model E10240. New GE motors & resistor control (of same basic design used on existing 25-year-old buses). Single stream rear exit door. Pilot vehicle arrived Nov. '75 for testing in service. Production begun in Dec. '75. Production buses will have smooth rear roof line. Bid was for 208 buses with option on 135 at same price. Option was taken when order was placed in June '74.

* Date of report in trade press.
** One bus was delivered to Edmonton before a strike closed the Flyer plant from Oct. 2, 1974 to Jan. 22, 1975.

Source: Compiled by De Leuw, Cather & Company.

TABLE C-2 (cont'd)

CITY	DATE		NO. OF BUSES	BIDDER	BID PRICE	DESCRIPTION
	Bid or Order	First Delivery				
San Francisco	Jun '74	---	343	Flxible	$77,500	40-foot trolley bus. Order placed with Flyer.
Boston	Jul '74	Apr '76	50	Flyer	$76,640	Model E10240. New GE motors & resistor control. Double stream rear exit doors on right and left sides (for left hand loading in subway tunnel).
Philadelphia	Sep '74	---	110	Flxible	$116,577	Air conditioning. Double stream rear exit doors. Order not placed.
Dayton	Oct '74	Nov '76	64	Flyer	$104,961	Model E10240. First trolley buses to be built with air conditioning.
Vancouver	Jan '75	---	20	GM (Canada)-Secheron	$162,248	GM Model 5307. 40-foot body with new motors and chopper control. Order not placed.
"	"	---	40 (artic.)	AM General-MAN	$351,000	60-foot articulated trolley bus. Resistor-controlled. Order not placed.
"	"	---	"	"	$404,649	60-foot articulated trolley bus. Chopper-Controlled. Order not placed.
"	Dec '75		20 to 100	Energormac Export (USSR)	$98,360	40-foot trolley bus. Resistor-controlled. (Actual length: 39' 3")

Notes
- Vancouver bids of Dec. 16, 1975 are currently being evaluated by B.C. Hydro.
- All bid prices shown are subject to clarification of factors such as duty, taxes, freight and equipment options.
- Prices for Canadian cities are in Canadian dollars.

Source: Compiled by De Leuw, Cather & Company.

APPENDIX D

AGE DISTRIBUTION OF DIESEL AND TROLLEY BUS SYSTEMS

TABLE D-1. AGE DISTRIBUTION OF NATIONAL DIESEL BUS FLEET INVENTORY (JUNE 1972)

Source: Forecast of Urban 40-Foot Coach Demand, Booz-Allen Applied Research and Simpson & Curtin, Report No. UMTA-IT-06-0025-73-002, December 1972.

	National Age Profile [a]		
	40' Coaches	Other Coaches	TOTAL
1939	0	4	4
1940	0	4	4
1941	0	2	2
1942	0	4	4
1943	0	0	0
1944	0	4	4
1945	0	95	95
1946	0	131	131
1947	0	767	767
1948	0	476	476
1949	0	360	360
1950	130	408	538
1951	221	788	1,009
1952	124	295	419
1953	576	463	1,039
1954	921	522	1,443
1955	804	522	1,326
1956	679	862	1,541
1957	1,108	406	1,514
1958	983	659	1,642
1959	1,000	499	1,499
1960	1,612	1,105	2,717
1961	1,799	656	2,455
1962	1,369	515	1,884
1963	2,695	352	3,047
1964	1,953	499	2,452
1965	2,452	603	3,055
1966	2,874	1,107	3,981
1967	1,159	639	1,798
1968	1,546	566	2,112
1969	1,186	488	1,674
1970	973	433	1,406
1971	1,574	633	2,207
1972	862	333	1,195
Fleet Size	28,600	15,200	43,800
Percent of Total	65.3%	34.7%	100.0%

(a) Includes all licensed transit and suburban coaches owned or leased by operators providing scheduled intra-urbanized area common carrier service in the 50 states, District of Columbia, and Puerto Rico.

TABLE D-2. AGE DISTRIBUTION OF U.S. AND CANADIAN TROLLEY BUS SYSTEMS

Source: Transit Passenger Fleet Inventory, American Public Transit Association, as of June 1975

Reporting System	Model Year	No. Vehicles	Reporting System	Model Year	No. Vehicles
Dayton, OH	1971	1	San Francisco	1972	2
	1951	11		1951	36
	1949	21		1950	109
	1948	32		1949	186
	1947	28			333
		93			
Mean Age: 26.4 years			Mean Age: 25.3 years		
Seattle	1944	15	Vancouver, BC	1954	16
	1943	8		1951	69
	1940	35		1950	92
		58		1949	85
				1948	37
Mean Age: 33.5 years				1947	2
					301
			Mean Age: 25 years		
Boston	1952	50			
Mean Age: 23 years					

TABLE D-3. AGE DISTRIBUTION OF U.S. DIESEL BUS FLEET (1975 (23 Largest Urbanized Areas Reporting to APTA)

Source: _Transit Passenger Fleet Inventory_, American Public Transit Association, as of June 1975.

YEAR	AGE (years)	NO. VEHICLES	CUMULATIVE PERCENT
1975	0	970	3.9
1974	1	1862	11.4
1973	2	1142	16.0
1972	3	1556	22.3
1971	4	1474	28.2
1970	5	480	30.1
1969	6	1157	34.8
1968	7	1179	39.6
1967	8	829	42.9
1966	9	2273	52.1
1965	10	2039	60.3
1964	11	1405	66.0
1963	12	1957	73.9
1962	13	1112	78.4
1961	14	1550	84.7
1960	15	1094	89.1
1959	16	430	90.8
1958	17	530	92.9
1957	18	405	94.5
1956	19	168	95.2
1955	20	294	96.4
1954	21	286	97.5
1953	22	204	98.3
1952	23	35	98.5
1951	24	35	98.7
1950	25	52	98.9
1949---	>25	178	99.6
		24697	

APPENDIX E

COST ESTIMATES FOR OVERHEAD TROLLEY POWER LINE AND DISTRIBUTION SYSTEM

TABLE E-1

TROLLEY COACH VEHICLE ELECTRIFICATION COSTS

Study: Energy Storage - Propelled Transit Vehicle Application Study - Final Report, John M. Woods and Louis J. Lawson, April 1975.

TROLLEY COACH VEHICLE ELECTRIFICATION
Estimated Cost-Overhead System
One Mile-Two Way Operation

Item No.	Description	No. Req'd.	Est. Unit Price	Extension
1.	F & I ATEA #520 Poles	100 ea.	$ 500.00	$ 50,000
2.	F & I Std. Spans	26 ea.	200.00	5,600
3.	F & I Pos. Feed Spans	6 ea.	320.00	1.920
4.	F & I Neg. Feed Spans	6 ea.	320.00	1,920
5.	F & I Pos. Equal Spans	6 ea.	275.00	1,650
6.	F & I Neg. Equal Spans	6 ea.	275.00	1,650
7.	Install Pos. Feeder Risers	450 ft.	3.00	1,350
8.	Install Neg. Feeder Risers	450 ft.	2.50	1,125
9.	F & I Riser Conduit	900 ft.	11.00	9,900
10.	Construct Manholes	11 ea.	2,650.00	29,150
11.	F & I 6 Way Duct	5,100 ft.	25.00	127,500
12.	F & I 2/0 Trolley Wire	21,120 ft.	1.00	21,120
13.	F & I 500 MCM Pos. Feeder	5,350 ft.	4.25	22,738
14.	F & I 500 MCM Neg. Feeder	5,350 ft.	4.00	21,400
15.	Painting Pole	100 ea.	75.00	7,500
			Subtotal	$304,523
			10% Contingencies	30,452
			Total	$334,975
			Use	$335,000

Note: Ten percent for contingencies is included in above estimate because of unforeseen conditions.

TABLE E-1 (cont'd)

TROLLEY COACH SYSTEM
LIFE CYCLE COSTS PER MILE

Initial Cost	
Tangent Overhead	$ 335,000
Curves & Special Work	65,000
Rectifier Station	160,000
	$ 560,000
Useful Life 30 years	
Annual Maintenance Cost	
Trolley Coach Overhead	$ 10,000
Rectifier Station	$ 2,165
Operating Expense	
Rectifier Station	$ 8,000
Lifetime Maintenance Cost	$ 364,950
Lifetime Operating Cost	$ 240,000
Lifetime Cost	$1,164,950
Annual Trolley Coach Miles/mile O.H.	99,000
Lifetime Trolley Coach Miles/mile O.H.	2,970,000
Vehicle Cost per Vehicle Mile	$ 0.39

TABLE E-2

TROLLEY OVERHEAD AND POWER SYSTEM UNIT COSTS

Study: TRI-MET Trolley Bus Evaluation Study, DeLeuw Cather and Company, March 1976.

TROLLEY OVERHEAD AND POWER SYSTEM UNIT COSTS
(Estimated Unit Prices Installed - March 1976)(a)

Code	Item	Estimated Cost
Trolley Overhead		
EB	Eyebolt	210 ea
PW	Trolley Pole - Wood	375 ea
PH	Trolley Pole - Steel (Tangent Spans - Hard Suspension)	1,260 ea
PS	Trolley Pole - Steel (Tangent Spans - Soft Suspension)	1,880 ea
PX	Trolley Pole - Steel (Special Work - High Strength)	3,080 ea
PB	Pole Bracket Assembly (Mast Arm)	450 ea
T1	1 Way Tangent Span	320 ea
T2	2 Way Tangent Span	390 ea
TF	Tangent Span - Feeder	440 ea
C1	1 Way Curve Segment Incl. Pulloff (Max. 30°)	890 ea
C2	2 Way Curve Segment Incl. Pulloff (Max. 30°)	1,780 ea
S1	1 Way 90° Turn	2,830 ea
S2	2 Way 90° Turn	5,650 ea
S3	1 Way Branchoff	5,650 ea
S4	1 Way Merge	4,160 ea
S5	1 Way Fork	4,820 ea
S6	Joining Fork	3,300 ea
S7	1 Way Crossover	2,320 ea
S8	1 Way Branchoff with Crossing	9,920 ea
S9	1 Way Merge with Crossing	6,550 ea
S10	1 Way Merge with 2 Way (2 Turns)	10,400 ea
S11	2 Way Branchoff to 1 Way (2 Turns)	8,920 ea
S12	2 Way Crossover	9,240 ea
S13	2 Way Crossover (1 Turn)	28,200 ea
S14	2 Way Crossover (1 1/2 Turns)	32,000 ea
S15	Half Grand Union	31,300 ea
S16	Terminal Loop	23,200 ea
W2	2/0 Grooved Bronze Trolley Wire	1.44/ft
W4	4/0 Grooved Copper Trolley Wire (Feederless System)	1.87/ft
Feeder System		
MH	Manhole	$ 2,800 ea
DB	Underground Duct Bank	27.00/ft
RP	Feeder Riser Cable - Pos.	3.20/ft
RN	Feeder Riser Cable - Neg.	2.70/ft
RC	Riser Conduit	12.00/ft
FP	500 MCM Feeder Cable - Pos.	4.50/ft
FN	500 MCM Feeder Cable - Neg.	4.25/ft
Substation		
	2000kw Rectifier Station (Incl. Building)	$340,000 ea
	300 kw Underground Rectifier Station (Feederless System) (b)	85,000 ea

Notes:

(a) Costs for spans, curve segments and special work are based on conventional hard suspension systems currently in use on U.S. and Canadian systems. Costs for European soft suspension components would be somewhat higher. Estimated cost shown for higher strength poles required for soft suspension tangent spans (coded PS) are based on a planned installation in Seattle.

(b) Includes vault, 200 feet of d-c feeder duct and cables, 100 feet of high voltage duct and cables and remote alarm system.

Source: Prepared by De Leuw, Cather & Company, based on recent bid prices and estimates in San Francisco and Seattle.

TABLE E-3.

TRI-MET OVERHEAD TROLLEY ELECTRIFICATION COSTS

Source: TRI-MET Trolley Bus Evaluation Study, DeLeuw, Cather and Company, March 1976.

ESTIMATED COST OF TROLLEY OVERHEAD AND POWER SUPPLY (a)

Line 53-23rd Avenue/8-Jackson Park		Mall to Thurman Term.		Industrial Branch		Transit Mall		Mall to VA Hospital	
Route Length		16,800 ft (3.18 mi)		3,400 ft (0.64 mi)		2,900 ft (0.55 mi)		15,900 ft (3.01 mi)	
Trolley Overhead	Unit Cost								
2/0 Trolley Wire	$ 1.44/ft	67,200 ft	$96,700	13,600 ft	$19,600	11,600 ft	$16,700	63,200 ft	$91,000
Tangent Poles - Total Req'd	1,260 ea	300	378,000	61	76,800	110	138,500	261	329,000
Special Work Poles - Total Req'd	3,080 ea	30	92,400	13	40,000	---	---	80 (c)	246,000
Pole Bracket	450 ea	--	---	16	7,200	---	---	102 (c)	45,900
Utilize Exist. Wood Pole (b)	(1,260 ea) cr	72	(90,700)	26	(32,700)	---	---	54	(68,000)
Utilize Exist. Steel Pole (b)	(1,260 ea) cr	1	(1,260)	---	---	---	---	10	(12,600)
Eyebolt Location (b)	(1,050 ea) cr	6	(6,300)	---	---	72	(75,600)	4	(4,200)
Tangent Span (1-way)	320 ea	1	320	5	1,600	55	17,600	40	12,800
Tangent Span (2-way)	390 ea	142	55,400	9	3,500	---	---	61	23,800
Feeder/Equalizer	440 ea	38	16,700	8	3,500	13	5,720	48	21,100
Curve Segment (1-way)	890 ea	---	---	---	---	2	1,780	17	15,100
Curve Segment (2-way)	1,780 ea	10	17,800	---	---	---	---	32	57,000
Special Work									
S-1 90° turn (1-way)	2,830 ea	2	5,660	4	11,320	---	---	4	11,320
S-2 90° turn (2-way)	5,650 ea	6	33,900	1	5,650	---	---	2	11,300
S-3 Branchoff (1-way)	5,650 ea	---	---	---	---	---	---	2	11,300
S-5 Fork	4,820 ea	---	---	---	---	---	---	4	19,300
S-7 Crossover (1-way)	2,320 ea	1	2,320	1	2,320	---	---	1	2,320
S-16 Terminal Loop	23,200 ea	1	23,200	---	---	---	---	1	23,200
Overhead Utilities	100 ea	50 locations	5,000	9	900	---	---	48	4,800
Signalized Intersection & Signs	1,000 ea	17 locations	17,000	1	1,000	---	---	23	23,000
Modify Terminal Loop	L.S.	L.S.	16,000	---	---	---	---	L.S.	5,000
Thurman St. Trestle Pole Bracing	L.S.	L.S.	16,000	---	---	---	---	---	---
St. Helens Rd. Special Suspenders	L.S.	---	---	L.S.	5,000	---	---	---	---
Case 1 - Max. util. of exist. poles			$678,140		$145,690		$104,700		$868,440
Case 2 - All new steel poles			$770,100		$173,390		$104,700		$949,040
Feeder Distribution									
Substation Capacity (@150 kw/mi)	$ 170.00/kw	480 kw	$81,600	96 kw	$16,300	600 kw(d)	$102,000	450 kw	$76,500
Crossarms	30.00 ea	100	3,000	28	840	---	---	93	2,790
Feeder Cable	4.40/ft	33,600 ft	148,000	6,800 ft	29,900	11,600 ft	51,000	37,200 ft	164,000
Undergrounding		(Burnside-1.17 mi)				(5th & 6th-1.10 mi)		(CBO-1.29mi)	(Terwil-0.42mi)
Duct Bank	27.00/ft	5,950 ft	160,600	---	---	5,800 ft	156,600	9,000 ft	243,000
Feeder Risers	600 ea	13	7,800	---	---	13	7,800	20	12,000
Manholes	2,800 ea	13	36,400	---	---	13	36,400	20	56,000
			$437,400		$47,040		$353,800		$554,290
Feederless Distribution									
Rectifier Stations (@1.0 mi)	85,000 ea	3.2	272,000	0.6	51,000	2.0(d)	170,000	3.0	255,000
4/0 Trolley Wire (Cost over 2/0)	0.43/ft	67,000 ft	28,900	13,600 ft	5,850	11,600 ft	5,000	63,200 ft	27,200
			$300,900		$56,850		$175,000		$282,200

TABLE E-3 (cont'd)

Line 14-Sandy Boulevard		Transit Mall to 82nd		Grotto Branch		Parkrose Branch to 122nd		122nd to 133rd	
Route Length		28,000 ft (5.30 mi)		1,600 ft (0.33 mi)		14,800 ft (2.79 mi)		5,000 ft (0.95 mi)	
Trolley Overhead	Unit Cost								
2/0 Trolley Wire	1.44/ft	112,000 ft	$161,000	9,600 ft(e)	$13,800	63,600 ft(f)	$91,600	20,000 ft	$28,800
Tangent Poles - Total Req'd	1,260 ea	470	593,000	17	21,400	245	308,700	71	89,500
Special Work Poles - Total Req'd	3,080 ea	4	12,300	22	67,700	36	111,000	18	55,500
Pole Bracket	450 ea	46	20,700	14	6,300	15	6,750	19	8,550
Utilize Exist. Wood Pole (b)	(1,260 ea) cr	234	(295,000)	15	(18,900)	122	(153,800)	12	(15,100)
Utilize Exist. Steel Pole (b)	(1,260 ea) cr	55	(69,300)	---	---	4	(5,050)	---	---
Eyebolt Location (b)	(1,050 ea) cr	4	(4,200)	---	---	---	---	---	---
Tangent Span (1-way)	320 ea	1	320	---	---	---	---	---	---
Tangent Span (2-way)	390 ea	213	83,000	12	4,680	103	42,100	19	7,400
Feeder/Equalizer	440 ea	64	28,200	2	880	34	15,000	11	4,850
Curve Segment (1-way)	890 ea	---	---	2	1,780	6	5,340	---	---
Curve Segment (2-way)	1,780 ea	4	7,120	2	3,560	5	8,900	5	8,900
Special Work									
S-1 90° Turn (1-way)	2,830 ea	1	2,830	6	17,000	4	11,320	5	14,150
S-2 50° Turn (2-way)	5,650 ea	---	---	---	---	5	28,200	3	16,950
S-3 Branchoff (1-way)	5,650 ea	2	11,300	1	5,650	---	---	1	5,650
S-4 Merge (1-way)	4,160 ea	1	4,160	---	---	2	8,320	1	4,160
S-7 Crossover (1-way)	2,320 ea	---	---	---	---	1	2,320	1	2,320
S-8 Branchoff with Crossing (1-way)	9,920 ea	---	---	---	---	2	19,840	---	---
S-9 Merge with Crossing (1-way)	6,550 ea	1	6,550	1	6,550	---	---	---	---
Morrison Bridge (Trolley Bridge)	L.S.	L.S.	10,000	---	---	---	---	---	---
Overhead Utilities	100 ea	16	1,600	---	---	136	13,600	3	300
Signalized Intersections & Signs	1,000 ea	31	31,000	---	---	3	3,000	---	---
Case 1 - Max. util. of exist. poles			$604,580		$130,400		$517,140		$229,830
Case 2 - All new steel poles			$968,680		$149,300		$675,990		$247,030
Feeder Distribution									
Substation Capacity (@150 kw/mi)	$ 170/kw	795 kw	$135,000	50 kw	$ 8,500	420 kw	$ 71,400	142 kw	$ 24,200
Crossarms	30 ea	234	7,000	12	360	153	4,600	14	420
Feeder Cable	4.40/ft	56,000 ft	246,000	3,200 ft	14,100	29,600 ft	130,000	10,000 ft	44,000
Undergrounding		(Burnside & Bridge-0.60 mi)						(Residential Area-0.64 -	
Duct Bank	27.00/ft	750 ft	20,200	---	---	---	---	3,400 ft	91,800
Installation on Bridge	25.00/ft	2,400 ft	60,000	---	---	---	---	---	---
Feeder Risers	600 ea	7	4,200	---	---	---	---	8	4,800
Manholes	2,800 ea	2	5,600	---	---	---	---	8	22,400
			$478,000		$22,960		$206,000		$187,620
Feederless Distribution									
Rectifier Stations (@1.0 mi)	85,000 ea	5.3	450,500	0.3	25,500	2.8	238,000	1.0	85,000
4/0 Trolley Wire (Cost over 2/0)	0.43/ft	112,000 ft	48,200	9,600 ft	4,130	63,600 ft	27,400	20,000 ft	8,600
			$498,700		$29,630		$265,400		$ 93,600

TABLE E-3 (cont'd)

Line 12-Foster		Transit Mall to 84th		Foster Branch		Harold Branch		Garage Access	
Route Length		34,800 ft (6.60 mi)		5,600 ft (1.06 mi)		7,000 ft (1.33 mi)		9,000 ft (1.70 mi)	
Trolley Overhead	**Unit Cost**								
2/0 Trolley Wire	$ 1.44/ft	139,200 ft	$200,500	22,400 ft	$ 32,200	28,000 ft	$ 40,300	36,000 ft	$ 51,800
Tangent Poles - Total Req'd	1,260 ea	686	865,000	91	114,800	111	140,000	177	223,000
Special Work Poles - Total Req'd	3,080 ea	37	114,000	5	15,400	23	70,800	22	67,700
Pole Bracket	450 ea	31	13,950	45	20,200	14	6,300	39	17,550
Utilize Exist. Wood Pole (a)	(1,260 ea) cr	336	(423,000)	40	(50,400)	66	(83,100)	83	(104,600)
Utilize Exist. Steel Pole (a)	(1,260 ea) cr	40	(50,400)	---	---	---	---	2	(2,520)
Eyebolt Location (a)	(1,050 ea) cr	3	(3,150)	---	---	---	---	---	---
Tangent Span (1-way)	320 ea	66	21,100	---	---	---	---	30	9,600
Tangent Span (2-way)	390 ea	252	98,200	24	9,360	43	16,750	41	16,000
Feeder/Equalizer	440 ea	79	34,760	13	5,700	16	7,000	20	8,800
Curve Segment (1-way)	890 ea	7	6,220	6	5,340	---	---	10	8,900
Curve Segment (2-way)	1,780 ea	26	46,100	---	---	1	1,780	2	3,560
Special Work									
S-1 90° Turn (1-way)	2,830 ea	2	5,660	---	---	4	11,320	---	---
S-2 90° Turn (2-way)	5,650 ea	2	11,300	---	---	2	11,300	2	11,300
S-3 Branchoff (1-way)	5,650 ea	1	5,650	---	---	---	---	3	16,950
S-4 Merge (1-way)	4,160 ea	1	4,160	---	---	1	4,160	3	12,500
S-7 Crossover (1-way)	2,320 ea	1	2,320	---	---	1	2,320	2	4,640
S-8 Branchoff with Crossing (1-way)	9,920 ea	---	---	---	---	1	9,920	---	---
S-16 Terminal Loop	23,200 ea	---	---	1	23,200	---	---	---	---
Hawthorne Bridge (Trolley Bridge)	L.S.	L.S.	5,000	---	---	---	---	---	---
Overhead Utilities	100 ea	41	4,100	10	1,000	94	9,400	51	5,100
Signalized Intersections & Signs	1,000 ea	25	25,000	4	4,000	---	---	7	7,000
Modify RR Crossing Gates	L.S.	---	---	---	---	---	---	L.S.	4,000
Case 1 - Max. util. of exist. poles			$ 986,470		$180,800		$248,250		$361,280
Case 2 - All new steel poles			$1,459,870		$231,200		$331,350		$468,400
Feeder Distribution									
Substation Capacity (@150 kw/mi)	$ 170/kw	990 kw	$168,300	160 kw	$ 27,200	200 kw	$ 34,000	255 kw	$ 43,400
Crossarms	30 ea	281	8,500	69	2,070	57	1,710	118	3,500
Feeder Cable	4.40/ft	77,600 ft	342,000	17,200 ft	75,600	14,000 ft	61,600	26,000 ft	114,400
Undergrounding									
Duct Bank	27.00/ft	1,600 ft	43,200	---	---	---	---	---	---
Installation on Bridge & Ramps	25.00/ft	5,200 ft	130,000	---	---	---	---	---	---
Feeder Risers	600 ea	14	8,400	---	---	---	---	---	---
Manholes	2,800 ea	3	8,400	---	---	---	---	---	---
			$708,800		$104,870		$97,310		$161,300
Feederless Distribution									
Rectifier Stations (@1.0 mi)	85,000 ea	6.6	561,000	1.1	93,500	1.4	119,000	1.7	144,500
4/0 Trolley Wire (Cost over 2/0)	0.43/ft	139,200 ft	59,900	22,400 ft	9,640	28,000 ft	12,000	36,000 ft	15,500
			$620,900		$103,140		$131,000		$160,000

Notes: (a) Preliminary estimate based on brief field reconnaisance of routes, typical unit costs, and appropriate allowances for special conditions noted.

(b) Deduct from total tangent poles req'd.

(c) Includes poles with 2-way brackets on Terwilliger Blvd. Each counted as two brackets.

(d) Use 600 kw nominal substation capacity for 0.55 mi. Transit Mall. Includes allowance for additional lines.

(e) Quantities include loop at N.E. 86th Avenue.

(f) Quantities include alternate routes via N.E. Prescott to 85th and via N.E. 118th and Sandy to 122nd.

APPENDIX F

COST ESTIMATES FOR THE FLYWHEEL PROPULSION SYSTEM COMPONENTS

This section discusses the procedures, the data sources, and the assumptions utilized in developing cost estimates for the flywheel vehicle propulsion system components. The primary components considered for each of the three flywheel vehicle systems are:

- flywheel disks and housing assembly,
- flywheel motor,
- traction motor, and
- the power control unit.

The cost estimates developed below were based on the weight and/or the power rating of the respective components. Table F-1 summarizes the characteristics of the propulsion system components for each of the three flywheel vehicle systems considered in this analysis:

TABLE F-1. FLYWHEEL PROPULSION SYSTEM CHARACTERISTICS

Component	All-Flywheel	Flywheel/ Diesel	Flywheel/ Battery
Flywheel Energy Storage (kw-hr)	20.0	6.0	7.0
Flywheel/Flywheel Motor and Housing Assembly Weight (lb)	4200	2060	2230
Traction Motor Weight (lb)	1450	1450	1750
Power Control Unit Weight (lb)	250	250	250
Battery Weight (lb)	--	--	13200
Starting Eqpt/Switchgear Wgt (lb)	400	--	250
Other/Misc Weight (lb)	150	300	200
Diesel Engine (75 hp) (lb)	--	1200	--
Total Propulsion System Wgt (lb)	6450	5260	17880

Source: Ref. 3-11

Flywheel and Flywheel Housing Assembly:

The cost of the flywheel disks and the flywheel housing assembly was determined based upon the weight of the component and unit cost data cited in two independent flywheel energy storage cost studies. In one study (Ref. 3-12) the cost of a 12 kw-hr flywheel unit weighing 2200 lbs was $10,300 (1976 dollars); while a second study (Ref. 3-9) estimated the costs of a 6 kw-hr and a 20 kw-hr flywheel unit at $7,200 and $13,500, respectively. In this analysis, we estimated the costs of the flywheel and the flywheel housing assembly components for each of the vehicle systems as follows:

	All-Flywheel (20 kw-hr)	Flywheel/ Diesel (6 kw-hr)	Flywheel/ Battery (7 kw-hr)
Flywheel (disks, shaft)	$10,000	$5,000	$6,000
Containment Ring & Housing	4,300	2,200	2,200
Bearings	500	300	300
Vacuum Seals	100	50	50
Lubrication System (pump, lines, etc.)	600	300	300
Shock Mounts	200	100	100
Hardware	100	50	50
Assembly & Test	600	300	300
TOTAL COST (1977 Dollars)	$16,400	$8,300	$9,300

Flywheel Motor:

The cost of the flywheel induction motor was determined based upon its steady state power rating and unit cost data presented in a 1975 study (Ref. 3-14) on propulsion system equipment costs.

In this analysis, we assumed the steady state power rating of the flyweel inductor motor to be two-thirds of its peak power rating. As an example, for the all-flywheel vehicle system which has a useable energy capacity of 15 kw-hr and a charging time of 2 minutes, the peak power requirement on the flywheel motor to charge the flywheel is:

$$\frac{15 \text{ kw-hr} \times 60 \text{ min/hr}}{2 \text{ min.}} = 450 \text{ kw or } 603 \text{ hp}$$

The assumed steady-state power rating of the all-flywheel inductor motor would then be 300 kw or 402 hp.

The cost of the flywheel inductor motor was developed from the following cost equation (expressed in 1973 dollars) (Ref. 3-14) for a DC traction motor adjusted to a comparable cost of an inductor motor.

cost = [25(HPM) + 2750] (f) (I)

where: hpM = steady state horsepower rating of the motor
f = adjustment factor to convert from a DC to an inductor motor (.85)
I = cost adjustment factor to convert 1973 to 1977 dollars (1.3)

Thus, for each of the three flywheel systems, the cost of the flywheel inductor motor is as follows:

	All-Flywheel	Flywheel/Diesel	Flywheel/Battery
Flywheel Motor Steady-State Rating	402 hp	120 hp	140 hp
Capital Cost (1977 dollars)	$14,200	$6,400	$7,000

DC Traction Motor:

The cost of the DC traction motor was determined based on the power rating of the motor and the unit cost equation (expressed in 1973 dollars) from the referenced study (Ref. 3-14).

Cost = [25(hpM) + 2750] (I)

where: hpM = horsepower rating of the motor
I = adjustment factor to convert 1973 dollars to 1977 dollars (1.3)

The assumed horsepower rating and capital cost of the DC traction motors for each of the three flywheel vehicle systems is as follows:

	All-Flywheel	Flywheel/Diesel	Flywheel/Battery
DC Traction Horsepower Rating	300 hp	300 hp	350 hp
Capital Cost	$13,300	$13,300	$15,000

Power Control Unit:

The capital cost of the power control unit was determined based upon the power rating of the traction motor. A unit cost equation (expressed in 1973 dollars) from the study (Ref. 3-14) was used and then adjusted to account for the fact that the proposed power control unit designs utilizes line commutation techniques. For the flywheel/diesel bus system, the cost of the power control unit was further adjusted since it does not require starting commutation.

The generalized equation utilized to determine the cost of the power control unit is as follows:

$$\text{Cost} = [35(\text{hpM}) + 20{,}000 - f_1](f_2)(I)$$

where: hpM = horsepower rating of the DC traction motor
f_1 = cost adjustment factor for systems that do not require starting commutation (all flywheel and flywheel/battery = 0, flywheel/diesel = $6,000)
f_2 = cost adjustment factor for PCU uses line commutation techniques (.75)
I = cost adjustment factor to convert 1973 dollars to 1977 dollars (1.3).

The estimated capital cost of the power control units for each of the flywheel vehicle systems is as follows:

	All-Flywheel	Flywheel/Diesel	Flywheel/Battery
Power Control Unit	$29,700	$23,800	$31,400
Controls (15%)	3,400	2,700	3,600
Total Cost	$33,100	$26,500	$35,000

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