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ASSESSMENT OF BATTERY BUSES

July 1977

FINAL REPORT

Prepared for

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16. Abstract

A comprehensive assessment of the performance of battery buses in operational use at various locations in the United States, Europe, Japan, and Australia was carried out. Gathered all available information, quantitative and qualitative, regarding the operation of buses using electric batteries as the primary means of energy storage. The study also included battery-based hybrids such as the trolley-battery and diesel-battery hybrids. The scope included visiting the operating organization, description of buses and propulsion systems, operational profiles, operating experience, and analysis of data and conclusions about the problems and constraints in the procurement and operation of electric buses.

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PREFACE

The assessment of electric battery systems contained in this report was prepared by the Trans Systems Corporation in association with Mr. H. William Merritt and Mr. T. J. McGean. The project was sponsored by the Urban Mass Transportation Administration (UMTA) of the U. S. Department of Transportation. It has been coordinated with the Energy Research and Development Administration (ERDA), Office of Transportation Energy Conservation.

The study addressed electric battery bus systems which are operating in passenger-carrying transit service. It does not include systems which are conceptual or under various stages of research and development. The preponderance of data were obtained from visits to the sites of operating installations. Thus, the assessment reflects the state-of-the-art of technology which can be used in present-day public transit operations.

Mr. H. William Merritt assessed the majority of the systems including those in Europe and Japan. Mr. John C. H. Woo assessed American installations at Roosevelt Island and in Washington, D. C. while Mr. T. J. McGean assessed installations in Long Beach, California and Lansing, Michigan. Visits were made to collect data and review performance at the sites of 16 public transit operating agencies. Because time and travel distances did not permit, visits were not made to Tours, France; Wesel, Germany or Sydney, Australia.

The authors appreciate the guidance and support given by the Urban Mass portation Administration. Those particularly helpful were: Dr. Wilhelm Raithel, Para-transit and Energy Conservation Program Manager; Mr. Bernard J. Vierling, Director, Bus Technology Division; Mr. John Ridgley, Project Manager, and Mr. John Kyle, the Contracting Officer.

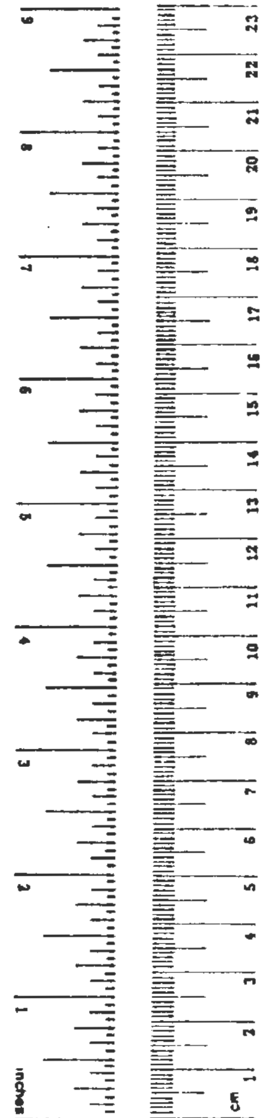
The assessment would not have been possible without the cooperation of many government officials, transit operators and system suppliers in the United States and abroad. These significant contributions are acknowledged in the appendix to this report.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

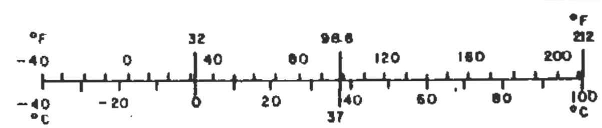
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



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
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

This report is an assessment of electric battery buses operating in passenger-carrying services in the United States and other parts of the world. A total of 16 different systems from 15 suppliers, operating under 18 public transit authorities were studied. These operations varied from single demonstration vehicles to a fleet of 20 buses which provide all the transit service on three routes. The status of electric battery bus development is reflected in the fact that 57 buses have accumulated more than 3.4 million kilometers (2.1 million miles) in passenger-carrying service.

Battery buses as well as hybrid buses using batteries have been addressed by the study. At the end of this section, Tables 1 and 2 summarize the characteristics of the battery and hybrid buses. Tables 3 and 4 summarize the site data for the bus operations.

SURVEY PROCEDURES

The assessment was accomplished primarily through on-site data collection and subsequent data analyses.

- In all, 36 agencies were contacted during the survey. Initial contacts concerning the Sovel bus were made through the Institut de Recherche des Transports in Paris. Data were obtained through the correspondence with the system operator and vehicle manufacturer. Summary data on the hybrid bus in Wesel were furnished by G. E. S. in Düsseldorf; correspondence with Daimler-Benz provided additional details. Data on the Townobile were obtained from discussions with the Managing Director of Elroy Engineering at the Chicago International Electric Vehicle Exposition.

- Data analysis included translating the information acquired from overseas visits and reducing the data on performance and technical features to common terms for comparisons. Where specific data were missing, it was interpolated from available information. The advantages and disadvantages of different systems were assessed. The strengths and weaknesses of key components and certain technical solutions were evaluated.

TECHNICAL FEATURES

Bus Systems

The study observed a variety of approaches for adapting electric battery propulsion to buses for public transport. The following summarizes the significant features.

Chassis, for the most part were made by modifying standard bus designs. The full range of bus sizes -- from 20-25 seat (35-40 passengers) midi-buses to 100 passenger standard coaches -- has been adapted. The frames were strengthened and spaces were created for the batteries and motor controls. This approach saved the cost of developing a new chassis. It also preserved standard arrangements for the drivers' compartment and passenger seating. Since the chassis were not purpose built, they tended to be heavier than was considered necessary. Some compromises in equipment location also had to be made.

Battery location depended upon methods for recharging, available space and the distribution of weight over the frame and between the axles. Three different techniques were found for making battery installations.

- On-board installations are used where batteries remain on the bus for recharging. They are mounted in packs along the sides, under the frame and in the former engine compartment at the rear of a modified bus. The Electrobuses operating in Long Beach and Roosevelt Island have battery packs at the rear. The Chloride "Silent Rider" has seven battery packs mounted on the sides and under the frame between the front and rear axles. Normal servicing is performed while the batteries are on the bus, but repair or replacement requires removal. Replacing these batteries may take from five minutes to one day.

- Trailer installations are used to minimize modifications to the bus chassis. Since the battery weight is not carried by the bus frame, limits on passenger loads are less stringent. Both M. A. N. and Ribble Motor Services Ltd. carry the traction batteries in trailers. For the Ribble bus, batteries are recharged and serviced on the trailer. The M. A. N. bus uses an automatic device (described below) to exchange batteries.

- Quick-change installations enable used batteries to be replaced with freshly charged units in minimum bus turn around time. Three battery exchange methods have been identified.

  -- Automatic devices have been developed for exchanging two batteries laterally from the Mercedes-Benz hybrid bus. The Isuzu EU05, Hino BT900 and Mitsubishi 460 buses use automated exchange equipment which removes and replaces one large traction battery from under the chassis. The bus driver may initiate the exchange or one attendant may service all the batteries for a fleet of buses. The exchange can be accomplished in one to five minutes.

  -- Trailer-mounted batteries on the M. A. N. bus are automatically exchanged. After properly positioning the bus the driver pushes a button on the exchange station. The battery is removed laterally and is replaced with a recharged one. The used battery is automatically topped with electrolyte, recharged and stored in the exchange station until required. The replacement requires three to five minutes during the dwell time between bus runs.

All of these battery installations have advantages and disadvantages.

- Installations for on-board charging are the simplest for recharging and require the least external equipment. They require the bus to be out of service three to eight hours while the batteries are being recharged.

- Battery trailers achieve the greatest passenger payload with the minimum of alterations to a standard chassis. The combined length of the bus and trailer exceed allowable limits for vehicles in some urban areas. While backing is awkward, drivers have had no difficulty in maneuvering the buses. Battery trailers are not exchanged, since safety risks are involved in assuring positive connections of hydraulic line for brakes, electric lines for trailer signals and instruments, and for the traction power cable.

- Battery exchanges, if accomplished manually with fork-lift trucks, involve a degree of personal hazard. Automated equipment is expensive, at present, and requires supervision to insure proper operation. Battery replacement does provide the highest productivity for battery buses, except for the hybrid buses.

Battery charging performed on the buses involves little more than plugging power cables from the charger into receptacles on the bus. Safety interlocks prevent the bus from being driven while the charger is still connected. On the automated exchange devices making connections, topping off with electrolyte and regulating the recharge rate are all performed automatically.

Charging techniques vary. The recharge rate may be governed by the pressure of gas produced, by a "programmed rise in voltage" in which one percent of the remaining capacity is added per minute, or by time limits for staged current levels which depend upon the voltage and discharged condition of the battery.

Motor controls represent one of the significant advancements in electric battery bus technology. Most of the controls used solid-state electronics circuits to regulate power supplied or to vary the performance characteristics of the motors. A few buses used dynamic braking where generator effects of the traction motor during deceleration produced power that was dissipated through resistors. One bus uses contactor controls for changing supply voltages and for shunting motor windings.

The electronic motor controls offer smooth and energy-efficient speed regulation. They also make regenerative braking practical. It has been estimated that regeneration can increase the range on one battery charge up to 25 percent, or can reduce the required battery capacity by approximately 15-20 percent. Regeneration can also extend battery life by avoiding high levels of battery discharge. It is also claimed that maintenance on brake lining is reduced by generation. The electronic motor controls have introduced some maintenance problems of their own. Reverse torque on the drive shaft and gear boxes during regenerative braking has caused failures.

Hybrid Bus Systems

Hybrid propulsion systems offer an intermediate step between existing, conventional systems and all-electric battery bus systems.

- Trolley/battery hybrids combine the desirable features of the trolley with the operational independence from wayside power offered by battery buses. They are not confined to operations only on streets with overhead wires. Batteries are recharged while running with power from the trolley.
- Diesel/battery hybrids offer the high accelerations typical for electric battery buses. Because the diesel operates a generator at optimum speed, they are quieter and less polluting than the conventional diesel bus. When desirable, this hybrid can operate on batteries alone, but the total range need not be limited to the battery capacity.

Hybrid bus systems assessed by this study include the Dornier Duo-Bus, the Mercedes-Benz OE305, and the Tokyo Transportation Bureau models built by Kawasaki.

OPERATING EXPERIENCE

Transit operations, using present-day equipment, have been underway since 1972. The buses used in these operations, 57 in all, have logged over 3.4 million kilometers (2.1 million miles) in passenger services.

Range capabilities of the electric battery bus, in actual transit operations under varying conditions of ridership, terrain, weather and traffic, were up to 80 kilometers (49.7 miles).

Speeds of up to 72 kph (44.8 mph) have been demonstrated under test conditions. Much lower speeds--8 to 24 kph (5 to 15 mph)--are encountered in typical urban traffic. Accelerating characteristics are generally good in the lower speed range. While one bus required 18 seconds to accelerate from zero to 32 kph (0 to 19.9 mph), buses usually required 8 to 10 seconds for the same change in speed.

Power consumption is a function of bus weight, the duty cycle, traffic conditions and temperature. The smaller midi-buses consumed power at the rate of 0.7 to 1.6 kwh/km.* For the larger, standard buses typical power consumption varied from 2.34 to 3.1 kwh/km in transit service. Energy required for heating could add an additional 0.12 to 0.22 kwh/km.

*See "Metric Conversion Factors," page iv.

Energy costs can be presented only in relative terms, since costs varied between geographic locations and over the years during which tests were run. Energy costs for battery buses tended to be comparable to, or in some instances, less than the dual costs for diesel buses performing equivalent services. Heating adds to the energy costs for electric battery buses. Tax rebates on diesel fuel, which are not available to electric power consumers, tend to distort the comparison. Even where electric energy costs are greater, proponents of electric battery buses contend that present trends in the cost and scarcity of petroleum fuels justify the additional costs and benefits offered by the electric bus systems.

Availability, as used in this assessment is defined in either of the following ways:

$$\% = 100 \frac{\Sigma \text{ Actual Operating Days for Each Vehicle}}{\text{Scheduled Operating days X number of Vehicles}}$$

-or-

$$\% = 100 \frac{\Sigma \text{ Actual Distance Operated for Each Vehicle}}{\text{Scheduled Operating Distance X Number of Vehicles}}$$

Availability of the electric battery buses for transit service varied from 50 to 100 percent. Typical rates were from 83 to 95 percent for the in-service tests. Most difficulties were experienced with the batteries and electronic control systems which might be expected since these represent the most advanced technologies employed. Inadequate space heat, on occasion, caused drivers to refuse use of the vehicles. Overall, the availability of electric battery buses has been comparable to that found in a fleet of diesel buses.

SUMMARY FINDINGS

The survey assessed 18 transit systems using electric battery buses in actual passenger service.

- The services were initiated primarily for experimental purposes to collect data on electric battery bus performance.
- While a few of the operations have been discontinued, most are still operating because of favorable public reaction.
- Short runs and peak-hour operations are well-suited to the battery bus capabilities.
- There was little difficulty in finding normal routes and schedules which could accommodate the available models.

The survey also assessed 16 models of battery buses made by 15 manufacturers.

- Most of the buses are adaptations of available equipment rather than "purpose built." None of them are in production.
- Five manufacturers are ready to accept orders.

- Several types were built solely for experimental purposes without the intention of production. One model has been withdrawn from the market, and one built as a prototype has never been operated in regular transit service.

- Transit operators generally like the battery bus operating characteristics.

- Lack of gear shifting and smooth acceleration when leaving a bus stop is appreciated by the drivers.
- Maintenance is reduced on some items, brake linings for example.
- Low noise and low pollution help improve public relations.
- However, routes and duty cycles have to be matched.

Many innovations are in use to enhance the attractiveness of electric battery bus service.

- Their use in automobile-free shopping malls provides mobility while contributing to the quiet, relatively pollution-free ambience of the areas.
- A variety of automatic battery exchange devices has been developed to increase the productivity of the vehicles.
- Solid-state electronic motor controls have improved performance characteristics. Regenerative braking, for example, reduces some maintenance costs, extends battery life and increases the vehicle range per charge.

Hybrid propulsion systems are particularly attractive at the present state of electric battery bus development.

- The range and coverage of trolley buses can be extended without the capital investment in overhead wires.
- Temporary obstacles to traffic can be bypassed without electric trolley contact.
- Hybrid diesel-electric buses can be nearly as quiet and pollution-free as present electric battery buses.

- Costs of battery buses are relatively higher than for diesel buses.

- Most of the equipment studied were prototypes and hence more expensive than production models.
- Diesel fuel is usually not taxed for transit purposes, whereas electric power is taxed.
- Battery capital and replacement costs are high.

Considerable research and development on batteries and related subsystems are taking place which could extend the range and hours of operations while reducing costs of electric battery bus systems.

DEMONSTRATION PROGRAM

This study assembled considerable data on the performance and operations of electric battery buses. Additional information necessary for decisions to deploy these buses in regular revenue service is still lacking. Either the data were not recorded, the experimental design was inadequate, or the results were considered priveleged and were not released to the study team. In order to provide meaningful data that would enable United States transit operators to understand the advantages and disadvantages of battery buses, a demonstration program should have the following objectives:

- Three or more buses of a particular type should be demonstrated in operational service in order to:
  - -- obtain experience and data representative of fleet operations
  - -- ensure availability for the continuity of operations
  - -- allow for adequate training of operating and maintenance personnel
  - -- provide economic incentives for system suppliers to make product improvements
- Conduct parallel operations with electric battery buses and conventional diesel buses in order to:
  - -- compare costs and performance
  - -- determine realistic life cycle costs
  - -- assess passenger and driver reactions to the vehicles
- Structure the in-service tests to evaluate the cost and effectiveness of subsystems, including:
  - -- large, heavy-duty batteries, versus lighter weight, shorter life-cycle batteries
  - -- on-board charging versus battery exchange techniques
  - -- battery chargers
  - -- series-wound versus separately excited shunt-wound traction motors
  - -- contactor control versus a variety of solid-state motor control devices
  - -- regenerative braking, including the trade-offs between energy saving, tire wear and maintenance costs
  - -- space heaters

- Demonstrate a sufficient number of both trolley-battery and diesel-battery hybrid buses in order to:
  - evaluate the effectiveness of trolley-battery hybrid buses in preserving and extending electric trolley service where it presently exists
  - assess the environmental impact of hybrid buses in comparison with diesel and electric battery buses
  - develop data on life-cycle costs for comparison with other public transit systems.

Data developed from the demonstration program should be systematically collected, analyzed and disseminated to interested public agencies.

TABLE 1

BATTERY BUS CHARACTERISTICS

Type No.	Bus Name	Size (m) L	Size (m) W	Size (m) H	Capacity**	Weight (Metric Tons)***	Battery Charge Tech.*	Battery Weight (Metric Tons)	Battery Voltage	Battery Capacity (AH)	Battery Observed Cycle	Motor kw	Motor Type****	Motor Weight (kg)	Controls	Braking	Constant Speed Range (km)	Total Vehicle km (000)
1	Electrobus	7.5	2.4	2.6	40	6.4	A&B	2.0	72	880/6		37	Ser.	380	Cam.	Dyn.	160	220
2	Battronics	5.7	2.2	2.7	22	3.8	A&B	1.3	84	425/6		13.1	Ser.	NA	Thy.	Dyn.	40	26
3	Crompton	6.7	2.4	2.9	26	8.3	A&B	3.0	220	376/5	450	18	Ser.	590	Thy.	--	110	56
4	Lucas	6.4	2.3	2.8	34	7.7	A	2.2	360	220/2		97	Sh.	600	Thy.	Reg.	180	19
5	Chloride	10.1	2.4	3.0	50	13.1	A	4.5	330	329/5		72	Ser.	900	Thy.	Reg.	109	7
6	Ribble	13.6	2.5	3.0	61	18.6	A	7.0	360	516	--	90	--	--	Thy.	Reg.	160	22
7	Sovel (Renault) 3T1	7.9	2.2	2.8	50	10.2	A	4.0	192	--	500	92	--	--	--	Reg.	100	98
8	M. A. N. SL-E	14.06	2.5	2.9	99	15.8	B	6.1	360	455/5	900	90 115	Sh. Ser.	600 700	Thy.	Reg.	140	1,791
9	Isuzu EU05	9.3	2.5	3.1	71	9.9	B	3.5	384	350/5	580	70	Ser.	375	Thy.	Reg.	150	350
10	Mitsubishi TB13	10.5	2.5	3.1	63	12.2	A	3.4	500	250	429	75	Ser.	--	Thy.	Reg.	140	--
11	Mitsubishi ME460	9.4	2.5	3.1	69	10.4	B	3.0	384	310/5	500	72	Ser.	740	Thy.	Reg.	170	325
12	Hino BT900	9.9	2.5	3.1	79	10.8	B	3.5	384	350/5	--	65	Ser.	--	Thy.	Reg.	170	46
13	Townobile	12.2	2.6	2.6	116	7.0	A	1.9	160	540/5	--	45	Ser.	NA	Thy.	Reg.	69	3

*A- On Board; B - Battery Change **Capacity includes standees ***Includes batteries, without passengers

**** Ser. - Series ; Sh. - Shunt

TABLE 2

HYBRID BUS CHARACTERISTICS

Type No.	Bus Name	Size (m) L	Size (m) W	Size (m) H	Capacity*	Weight** (Metric Tons)	Battery Weight (Metric Tons)	Battery Voltage	Battery Capacity (AH)	Motor kw	Motor Type	Controls	Braking	Total Vehicle-km (000)
14	DUO-Bus	11.0	2.5	3.0	82	13.7	2.9	360	230/5	90	Shunt	Thy.	Regen.	13
15	Mercedes OE305	11.1	--	--	100	19	3.5	360	275/5	74 115	Diesel Elec.	Thy.	--	--
16	Kawasaki	10.2	2.5	3.0	79	10.1	--	420	135/5	67 27	Series Diesel	Thy.	Regen.	402

*Includes Standees
**Include batteries, without passengers

TABLE 3

BATTERY BUS OPERATIONAL SITE DATA

Site	Type No.	Population of City (000)	No. of Buses Operated	Route: Number	Route: Length (km) Round Trip	Route: Max. Grade (%)	Route: Ave. No. Stops (per km)	Urban Drvg. Range(km): Per Charge	Urban Drvg. Range(km): Per Change	Vehicle-km(000) Accumulated	Operation Periods: From / To	Vehicle-Months Accumulated	Availability (%)
USA											***		
Long Beach	1	359	3	1	9	2.0	6.3	56		96	8/74-Pres.	96	99
Roosevelt Island	1	11	3	1	4.0	Nil	4	80		99	11/74-Pres.	87	98
National Cap. Park	1	10*	1	1	11.8	3	1.5	95**		24.8	9/74-Pres.	31	--
Lansing, Michigan	2	129	6	3	2.6	5.6	7		40	26	5/73-9/73	24	60
United Kingdom													
D.O.I. (14 cities)	3	N/A	2	14	4.8	14	8		74	55.8	3/72-10/74	62	83
Manchester		542											
	4		1	1	4.3	8	6.8	58		17.1	2/75-1/77	23	96
	5		1	1	14.0	Nil	6.2	42		7.1	4/75-8/76	16	N/A
Sheffield		520											
	3		1	1	3.6	3.3	6.5	--		--	3/77-Pres.	1	N/A
	4		1					42		2.3	1/77-Pres.	3	N/A
	5		1	1	4.8	2.7	7.5	45		1.4	8/76-9/76	1	72
Runcorn	6	54	1	1	20.3	0	0.25	81		22	11/75-Pres.	17	N/A
France													
Tours	7	140	5	1	8	0	5.0	--	60	98	1/76-Pres.	75	72
West Germany													
Mönchengladbach	8	270	7	1	40.0	5	2.4		40	857	10/74-Pres.	210	94
Düsseldorf	8	675	13	2	46.0	0	2.3		68	934	5/75-Pres.	299	93
Japan													
Osaka	9	2,842	2	3	10.0	6	4		82	350	4/72-Pres.	20	95
Kyoto	10	1,500	1	1	23.0	0	2.8	46	--	--	-- - Pres.	--	N/A
Kobe	11	1,339	4	5	23.5	4.5	2.4		50	325	9/75-Pres.	76	N/A
Nagoya	12	2,500	1	1	13.9	11.0	3.2		27.8	46	3/73-Pres.	48	N/A

* Area employment   ** Topped off Twice Daily between Runs   ***Present - 4/77

TABLE 4

HYBRID BUS OPERATIONAL SITE DATA

Site	Type No.	Population of City (000)	No. of Buses Operated	Route				Urban Drvg. Range (km)		Vehicle-km(000) Accumulated	Operation Periods	Vehicle-Months Accumulated
				Number	Length (km) Round Trip	Max. Grade (%)	Ave. Stops (per km)	Per Charge	Per Change		From/To	
West Germany												
Esslingen	14	87	1	1	16	5	2. 5	40		13	12/76	4
Wesel	15	57	1	1	--				50	--	3/77 -Pres.	1
Japan												
Tokyo	16	11,700	2	Var.	11. 0	7. 5	2. 8	55	--	402	11/72-12/76	96
			2								(11/72-Pres.	106

CHAPTER 1

INTRODUCTION

The Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976 (Public Law 94-413) provided a major impetus to the promotion of electric and hybrid vehicle technologies and to demonstrating the commercial feasibility of vehicle systems using these technologies. The Urban Mass Transportation Administration recognized the potential of electric and hybrid power plants as an alternative to diesel fuel for urban transit buses, and in cooperation with ERDA, undertook Contract DOT-UT-70056 to assess the current status of U. S. and foreign electric battery bus systems.

1.1 Objectives

The objectives of this study are twofold:

- To assess public transport systems using electric battery and hybrid buses. Emphasis is on transit operations covering bus service, performance, reliability and maintenance.

- To describe the technical features of the vehicles. Emphasis is on the batteries, charging procedures, power train and other features of the vehicle design affected by the power plant.

By accomplishing these objectives, the project will provide necessary qualitative and objective information required for UMTA funding decisions relating to any future technology development tests and evaluation. The report will also help American transit operators understand the uses, advantages and limitations of available electric battery bus systems.

1.2 Scope

The scope of the report covers the transit performance and technical characteristics of electric battery buses in operating systems as follows:

	Manufacturers	Operations
United States	2	4
United Kingdom	4	4
France	1	1
West Germany	1	2
Japan	3	4
Australia	1	0
Sub Total	12	15

Because of the unique operations made possible by hybrid trolley/battery or diesel/battery power plants, the report also covers three of these systems, as follows:

	Manufacturers	Operations
West Germany	2	2
Japan	1	1
Sub Total	3	3
Total Systems	15	18

Trolley-diesel hybrid buses are under development in both France and Germany. Since neither use batteries for electrical energy storage, they were considered outside the scope of this assessment. Transporters (vans) and other similar small electric buses are receiving considerable development attention, but are not covered by this study.

Cost data on equipment purchases and operations were collected where available. However, many of the systems are the result of private developments or have received government support through arrangements that permit private interests to retain proprietary rights. While project sponsors were most generous with technical information, cost data were not consistently released. It must also be realized that cost information which has been used is based on available equipment which has been modified for electric battery use, or on first or second generation prototypes. Operations using this equipment are necessarily first-time experiences. It was beyond the scope of this assessment to forecast trends which the costs of future installations may take. Present indications are that "purpose-built" equipment and lessons learned from existing system operations should make electric battery buses competitive with other conventional transit systems.

1.3 Interest

There was considerable interest on the part of foreign electric battery bus developers in opportunities to demonstrate their systems in the United States. Many suggestions were offered on arrangements which could be made with public agencies, transit operators, or industrial counterparts to introduce this equipment to the United States. Considerable experience has been gained from the experimental use of electric battery buses in transit systems. With mutually acceptable arrangements, this experience and many improvements in the equipment could be made available for in-service testing in the United States. These arrangements and the objectives of such a testing program are discussed in the final chapter of the report.

CHAPTER 2

VEHICLES

This chapter presents the technical characteristics of the battery and hybrid buses studied. A total of 16 vehicles (13 battery buses and 3 hybrid buses) made by 15 manufacturers are described. None of the vehicles are in commercial production, though manufacturers of five of the vehicles are ready to accept orders. The vehicles assessed in this study have been made from available subsystems and components ; their performance in passenger-carrying service has established the technical feasibility of the systems.

2.1 Battery Buses

2.1.1 Electrobus Model 20 (Vehicle Type No. 1)

This vehicle was originally manufactured by the Electrobus Division of the Tork-Link Corporation. The Electrobus has since been acquired and then divested by the Otis Elevator Corporation. Electrobus itself is no longer in business, but rights to the bus design were acquired by Electric Vehicle Associates of Cleveland, Ohio.

a. Technical Description

Chassis

Passengers:	30-42; 20-22 seated, 10-20 standing
Weight:	6,455 kg curb; 9,545 kg gross
Dimensions:	WB 411 cm; L 754 cm; W 241 cm; H 257 cm
Floor Height:	First step 39 cm above ground; 2nd step 20 cm; total 59 cm
Turn Radius:	9.1 m
Features:	Light-weight steel frame covered with aluminum skin and fiber glass front section. Adaptable for transporting wheelchair patrons.

Battery

Type:	Lead-acid industrial
	Unit consisting of 2 independent packs, each containing 18 cells connected in series; the unit is enclosed in a single steel casing.
Rating:	72 v; 880 amp-hours for 6 hours
Weight:	2,045 kg
Location:	Rear
Features:	Two quick-disconnect plugs No ventilation or temperature controls

Battery Change

Equipment:	Fork lift truck
Time:	3 to 5 minutes per exchange

Battery Charger

Procedure:	Batteries may be charged on the bus or removed and charged separately
Equipment:	Silicon controlled rectifier (SCR) output is regulated to decrease the current as battery voltage or temperature increases. Current is limited to about 290 amps.
Time:	8 hours at 200 amps; 5 hours at 300 amps

Propulsion

Motor:	Electrobus Model 12Al (custom designed by Electrobus)
--Type:	Series wound dc traction
--Rating:	50 hp, 37 kw, at 2,000 rpm, 72 v and 600 amps
Controller:	Conventional contactor control with electro-mechanical relays providing 36 or 72 volt power supplies from the battery and by regulating the field strength of the traction motor through changes in resistance and motor circuitry. No solid state, electronic control devices are used.
Transmission:	Directly coupled to rear wheels through a 6.8:1 reduction, automotive-type, differential

Braking

Service:	Air-assisted hydraulic drum-type brakes on four wheels
Parking:	Caliper-type which engages a 12-inch disc on the drive shaft at the rear of the traction motor. Hand brake holds bus without rolling on a 10% grade.
Dynamic:	First inch of brake-pedal travel connects traction motor as a 3-phase alternator; electrical energy is dissipated in resistance grids.

Suspension

Tires:	Four 8:25-15, 14 or 18-ply steel-belted, radial
Springs:	Four, longitudinal, semi-elliptical leaf springs, 127 cm long
Shock Absorbers:	Telescoping hydraulic type on front wheels only. No independent front suspension.

Accessories

Heating:	Southwind Model 8316 gasoline-burning. Draws 9 amps at 12 v dc, consumes 1.1 liters per hour. Augmented by blower air from the starting/braking resistors

Defroster:	Separate electric heating elements and blower
Steering:	Manual, worm and roller type, with no power assistance
Air Compressor:	3/4 hp, 2.5 cfm, supply for door operators and power assisted brakes
Other:	Conventional exterior and interior lighting, windshield wipers and washers, horns, and passenger pull-cord chimes

Accessory Power

Battery:	Lead-acid, 12 v, 205 amp-hour
Charger:	Motor generator, dc to dc converter, supplied from 72 v traction battery

b. Test Performance

Range:	160 km @ 40 kph constant speed 145 km @ 60 kph constant speed
Maximum Speed:	60 kph, full charge; 56 kph 40% charge
Acceleration:	0-48 kph in 30 sec.; charge: 40% to 100% 0-40 kph in 20 sec.; charge: 40% to 100% 0-32 kph in 10 sec.; charge: 40% to 100% 0-24 kph in 6 sec.; charge: 40% to 100%
Braking:	Stop from 60 kph in 29.9 m (Meets Motor Vehicle Safety Standard 105)
Gradeability:	5% @ 32 kph; 10% @ 26 kph
Maximum Grade:	25%

c. Safety Features

Power Supply:	Each 36 v battery pack is protected by a 1,500-amp fuse. If power is interrupted for any reason, a lockout relay prevents reapplication of power until accelerator pedal is returned to the first step.
Brakes:	Interlocks prevent motor operation while either the service or hand brakes are applied.
Doors:	If either the rear passenger door or battery compartment doors are open, interlocks prevent motor operation. The rear passenger door interlock also sets the service brake to keep the bus from rolling while the door is open.

ELECTROBUS MODEL 20

Figure 2-1. Electrobus Model 20

Figure 2-2. Electrobus Battery Location

2.1.2 Battronic (Vehicle Type No. 2)

The Battronic Truck Corporation is a subsidiary of the Boyertown Auto Body Works located in Boyertown, Pennsylvania. The following description is based on six buses purchased by the Capital Area Transportation Authority, Lansing, Michigan in January 1973. The Battronic Truck Corporation continues to market a battery bus with improvements made since 1973.

a. Technical Description

Chassis

Passengers:	20-22; 13-15 seated, up to 7 standing
Weight:	3,750 kg curb; 5,136 kg gross
Dimensions:	WB 389 cm; L 572 cm; W 216 cm; H 269 cm
Floor Height:	First step 33 cm above ground 2nd step 24.1 cm; 3rd step 24.1 cm; total 81.2 cm
Turn Radius:	8.1 m
Features:	Single passenger boarding area on right front side Two biparting doors, with two folding panels each, provide a 122-cm clear opening.

Battery

Type:	Lead-acid industrial Two iron-clad packs contain 21 two-volt cells each, connected in series.
Rating:	84 v; 425 amp-hours for 6 hours
Weight:	1,323 kg
Location:	Under floor, in center of the bus
Features:	Access through hinged panels on each side. Quick-disconnect plugs for electrical connections. No ventilation or temperature controls.

Battery Change

Equipment:	Fork lift truck
Time:	5 minutes

Battery Charger

Procedure:	Batteries are recharged after removal.
Equipment:	Excide silicon rectifier, 3 phase 440 volts ac. Initial current is 77.5 amps maximum, adapting to state of discharge, then decreasing as recharging progresses.
Time:	8 hours

Propulsion

Motor:	General Electric Model 5BT-1368A6
--Type:	Series wound dc traction
--Rating:	17.6 hp, 13.1 kw, at 1,679 rpm, 84 v and 194 amps

Controller:	General Electric Model 500 SCR Pulse frequency is varied to control speed.
Transmission:	Directly coupled to a 1.96:1 gear reducer which drives the rear wheels through a reduction, automotive-type, differential

Braking

Service:	Dual, master-cylinder, hydraulic drum brakes with separate lines to front and rear wheels.
Parking:	Cable-controlled, caliper-type disc brake acting on the drive shaft between gear reduction case and differential
Dynamic:	By moving the direction lever to reverse the motor field is reversed, producing a generator effect to provide additional braking. This energy is not returned to the batteries.

Suspension

Tires:	Four 7.50 x 16, 8 or 10 ply
Springs:	Four semi-elliptical leaf springs are mounted longitudinally inboard of each wheel.
Shock Absorbers:	Heavy duty, telescoping hydraulic shock absorbers are provided for front and rear wheels.
Axle:	A solid 'I" beam Ford truck axle is used with conventional kingpins.

Accessories

Heating:	Hupp Model PB15A, propane-fired, with blower for space heating and defrosting.
Steering:	Manual
Other:	Conventional exterior and interior lighting, windshield wipers and electrically actuated doors.

Accessory Power

Battery:	Lead-acid, 12 v automotive type
Charger:	Solid state, 84 v to 12 v dc to dc converter

b. Test Performance

Range:	40 km @ 8 kph average speed with 7 stops per kilometer
Maximum Speed:	32 kph on full charge
Acceleration:	0-32 kph in 18 sec., full charge, level grade
Gradeability:	2%: 0-32 kph in 26.5 sec. 5%: 0-32 kph in 30 sec.
Maximum Grade:	5.6%

Figure 2-3. Battronic Bus, Showing 122-cm Wide Doors.

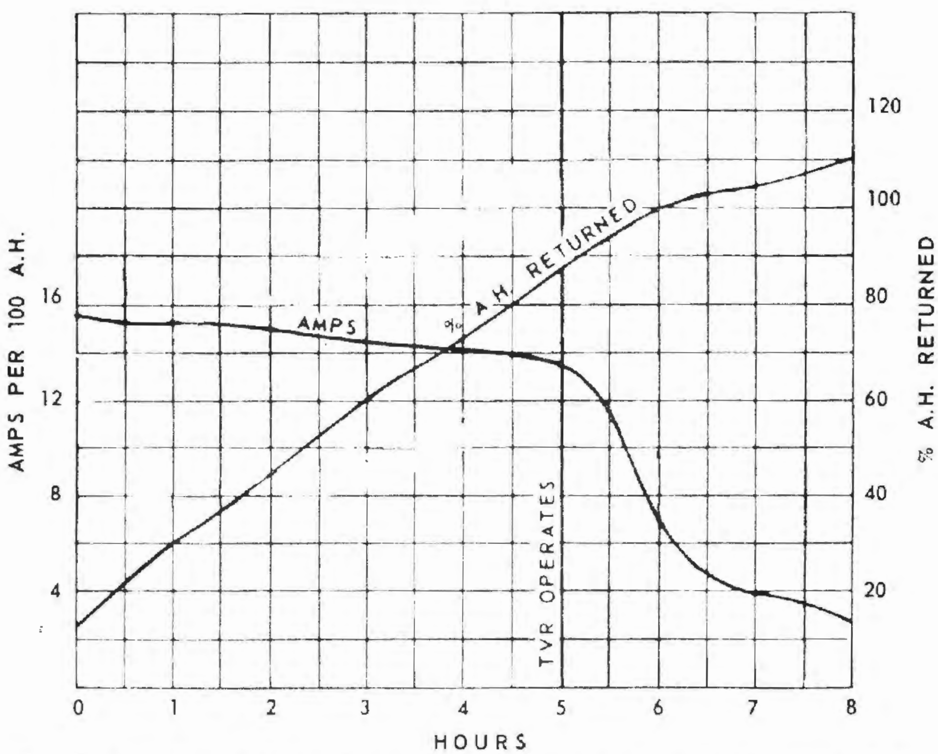


Figure 2-4. Excide Solid State Charger Characteristics as Used with the Battronic Bus.

2.1.3 Crompton (Vehicle Type No. 3)

The United Kingdom, Department of Industry (DOI) Battery Electric Bus Project resulted from interest in small electric buses by the West Yorkshire Passenger Transport Executive and other bus operators. This interest stemmed from a desire to provide bus service into and within pedestrian and shopping areas of city centers. The objective of the project was to provide two vehicles for evaluation by bus operators so that they could put into perspective what could be achieved with existing electric battery vehicle technology.

Manufacture of the two buses by Crompton Electricars, Ltd., began in late 1970. Test track evaluations were conducted by the Transport and Road Research Laboratory (TRRL). Tests of the first vehicle were completed in April, 1972; testing of the second vehicle was completed in June, 1972. Concurrent in-service test programs were carried out in 14 cities and towns. Operating periods in fare-paying services were from three to four months at each site.

The vehicles did not purport to be pre-production prototypes. Because the vehicles were experimental, operating costs were not considered relevant to practical electric battery bus economics and were not reported by DOI. For the same reason, detailed data on failure rates and system availability were not published, though general information on operational expense has been reported and is included in this study.

a. Technical Description

Chassis

Passengers:	26; 9 seated, 17 standing
Weight:	8,260 kg curb; 9,950 kg gross
Dimensions:	WB 420 cm; L 670 cm; W 245 cm; H 290 cm
Floor Height:	90 cm total
Turn Radius:	Not available
Features:	A standard truck chassis was strengthened and adapted for coach use with a metal frame and panelled with glass-reinforced plastic.

Battery

Type:	Five separate, iron-clad heavy-duty, lead-acid battery packs (Chloride)
Rating:	220 v, 376 amp-hours for 5 hours
Weight:	2,960 kg
Location:	On sides and at rear under the frame
Features:	Battery is of tubular plate construction

Battery Change

Equipment:	Hand fork trucks and steel pallets
Time:	15 to 17 minutes per exchange

Battery Charger

Procedure:	Recharging may be accomplished either on the bus or separately after removal.
Equipment:	Legg Industries, 2-rate taper charger
Time:	Overnight

Propulsion

Motor:	Electric Power Engineering, Ltd.
--Type:	Self-ventilated, dc series wound
--Rating:	24 hp, 18 kw, at 1,350 rpm
Controller:	Fixed pulse width, variable pulse rate, thyristor without regenerative brakes.
Transmission:	Direct coupling through driveshaft and differential.

Braking

Service:	Hydraulic/vacuum
Parking:	Mechanical
Regenerative:	None

Suspension (No data available)

Accessories

Heating:	Original thermal units augmented electrically were replaced by LPG fired heaters with blowers.
Steering:	No power assist
Other:	Conventional lighting, windshield wipers and door operators

Accessory Power

Battery:	24 v taps from traction battery
Inverter:	12 v

b. Test Performance

Range: Fully laden for 80% battery discharge
-- 110 km @ 32 kph constant speed
-- 55 km on the following duty cycle: Start/stop at a rate of 8 stops per km. Accelerate hard to 32 kph. At 8 m from the start, brake to a stop 125 m from the starting point. After a 10-second stop, repeat the cycle.

Maximum Speed: 37 kph on level ground, fully laden

Acceleration: 0-16 kph in 4 sec., level, fully charged
0-24 kph in 9 sec., level, fully charged
0-32 kph in 21 sec., level, fully charged

Gradeability: 12.5% @ 14 kph
4% @ 22.5 kph
4%, 0-16 kph in 5 sec.
4%, 0-25 kph in 21 sec.

Maximum Grade: 15%

Figure 2-5. Crompton City Clipper

2.1.4 Lucas (Vehicle Type No. 4)

Joseph Lucas, Ltd. does not manufacture buses. Their aim is to develop and market standardized components and modules by which families of commercial vehicles can be equipped with battery-electric drive systems. The bus described in the following summary uses a Seddon-Atkinson Pennine IV chassis, modified to accommodate the Lucas batteries, traction motor and controls. The Special Projects group of the Lucas organization has taken the initiative in developing and demonstrating this bus.

a. Technical Description

Chassis

Passengers:	34; 19 seated, 15 standing
Weight:	7,720 kg curb; 9,870 kg gross
Dimensions:	WB 293 cm; L 635 cm; W 229 cm; H 284 cm
Floor Height:	78 cm
Turn Radius:	13.0 m
Features:	Composite, light alloy frame with fiberglass reinforced plastic body.

Battery

Type:	Lead acid traction battery
Rating:	360 v; 220 amp-hrs for 2 hrs
Weight:	2220 kg
Location:	3 pallets each side, 4 pallets at rear
Features:	Lightweight, polypropylene-cased, 6 v cells arranged in 10 pallets with 6 cells each.

Battery Change

Purpose:	Exchanged only for servicing
Equipment:	Fork lift truck
Time:	15-30 minutes

Battery Charger

Procedure:	Batteries are normally charged in place through a charging plug at the rear of the bus.
Equipment:	Three-phase, thyristor phase control, with maximum output of 440 v charging current at start is 40 amps, automatically adjusted to battery voltage and to time limits. Fans powered from main batteries, and connected by the charge plug, vent the compartments during charging.
Time:	8 to 12 hours (overnight)

Propulsion

Motor:	C. A. V. , a Lucas company
--Type:	Separately excited, four-pole, dc commutator
--Rating:	134 hp, 100 kw, at 2270 rpm, 360 v and 300 amps
Controller:	SCR chopper controls motor armature current at a maximum repetition rate of 300 Hz for maximum current of 700 amps. Field excitation current is controlled by a transistor chopper, repetition rate of about 200 Hz, with nominal field current of 5. 6 amps. Regenerative braking is achieved through armature contactors which reverse the armature current. Peak armature current in braking is 300 amps.
Transmission:	Standard rear-axle unit with a 5. 57:1 reduction ratio, driven directly from the motor through a short driveshaft.

Braking

Service:	Conventional Clayton Dewandre air-pressure system with separate circuits to front and rear axles
Parking:	Spring-loaded units on rear wheels
Regeneration:	Deceleration rate of 0. 05 g, about one-third of available regenerative effect.

Suspension

Tires:	Michelin 9-22. 5 tubeless radials
Springs:	Semi-elliptic leaf springs and telescopic dampers fitted at each axle.

Accessories

Heating:	Two Webasto paraffin-fired heaters; one for windshield de-misting and driver's cab, the other for passenger spaces
Steering:	Marks triple cam and roller
Air Compressor:	100 psi, 1. 5 hp, 1. 1 kw, 360 v dc motor-driven compressor for brakes and doors
Other:	Conventional 24 v system for lights, windshield wipers and horn.

Accessory Power

Battery:	Lead acid, 24 v
Charger:	Single phase auxiliary charger contained in the main charger cabinet. Recharging is accomplished through the same plug. Maximum charge voltage is 29. 4 v and maximum current is 20 amps.

b. Test Performance

Range:	180 km on flat track, unladen, at constant 48 kph 147 km on undulating country roads, unladen, at average speed of 43 kph
Maximum Speed:	72 kph, full charge
Acceleration:	0-48 kph in 15 sec., fully laden
Maximum Grade:	17% for a restart, unladen

c. Safety Features

Recharging:	An interlock on the charge plug keeps the charger inoperative until safely connected to the bus. An interlock on the bus keeps it immobilized if the charge plug access door is open.

Figure 2-6. Rear View of Lucas Bus Showing Batteries and Controls

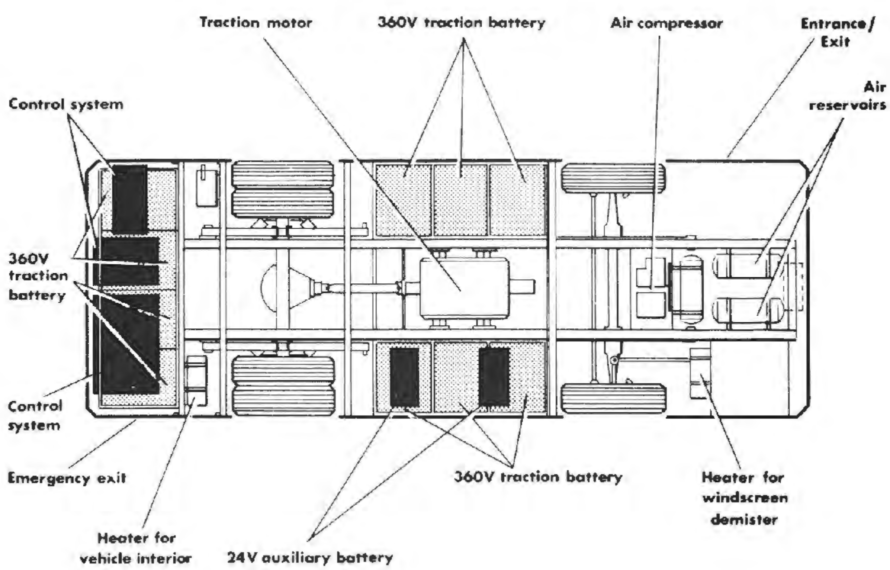


Figure 2-7. Component Arrangement in Lucas Bus

2.1.5 Chloride--Silent Rider (Vehicle Type No. 5)

Chloride Technical, Ltd. is primarily a manufacturer of batteries. The Chloride Motive Power Projects Group, along with several other equipment suppliers, developed Silent Rider for demonstration and evaluation in conjunction with transit operations under the South East Lancashire and North East Cheshire (SELNEC) Passenger Transport Executive.

a. Technical Description

Chassis

Passengers:	50; 41 seated, 9 standing
Weight:	13,056 kg curb; 16,260 kg gross
Dimensions:	WB 506 cm; L 1,006 cm; W 245 cm; H 300 cm
Floor Height:	First step 38 cm above ground; 2nd step 22 cm; 3rd step 21 cm; total 81 cm
Turn Radius:	Not available
Features:	Chassis was made by Seddon Motors, Ltd. A standard RU33 coach frame was strengthened and covered with an aluminum alloy shell.

Battery

Type:	Chloride tubular lead-acid traction battery
Rating:	330 v; 329 amp-hrs for 5 hours
Weight:	4,470 kg
Location:	Seven battery packs, 3 on right side, 2 in center and 2 on left side under the frame
Features:	165 cells in polypropylene cases are interconnected with an automatic topping off device which controls rising electrolyte by air pressure in the top of each cell.

Battery Change

Purpose:	Exchanged only for maintenance or replacement
Equipment:	Vehicle hoist and fork lift truck
Time:	One day

Battery Charger

Procedure:	Power lines from charger plug, into a hatch behind the right front wheel
Equipment:	Chloride Legg Programmed Rise in Voltage (PRV) charger reduces excessive gassing by restoring 1% of the remaining capacity per minute. 170 amps maximum charging current.
Time:	3 to 3.5 hours from nominal battery conditions.

Propulsion

Motor:	Electro Dynamic Construction, Ltd.
--Type:	Series wound, dc traction motor
--Rating:	96 hp, 72 kw, at 2100 rpm with peak output of 215 hp, 160 kw at 800 amps
Controller:	Thyristor type, modified pulse width system. Current rating: 1,000 amps for 5 min, 300 amps continuously. Regenerative braking is provided.
Transmission:	Direct drive from motor shaft to the 6.21:1 single speed rear axle.

Braking

Service:	Air-operated wedge brakes, 0.25 g deceleration
Parking:	Spring loaded, hold on 25% grade
Regenerative:	First half of brake pedal travel gives up to 0.1 g deceleration.

Suspension

Tires:	Dunlop 11/70R 22.5 low profile
Springs:	Stiffened leaf springs with hydraulic damping

Accessories

Heating:	Paraffin-fired space heaters
Steering:	Power assisted, hydraulic pump driven by 2 kw, 24 v compound motor
Air Compressor:	10 cfm air-cooled, 2 kw, 24 v series motor

Accessory Power

Battery:	Lead acid, 24 v, 141 amp-hrs at 5 hr for vehicle lights and indicators
Charger:	Floated across 330 v/24 v dc/dc converter to remain 100% charged.

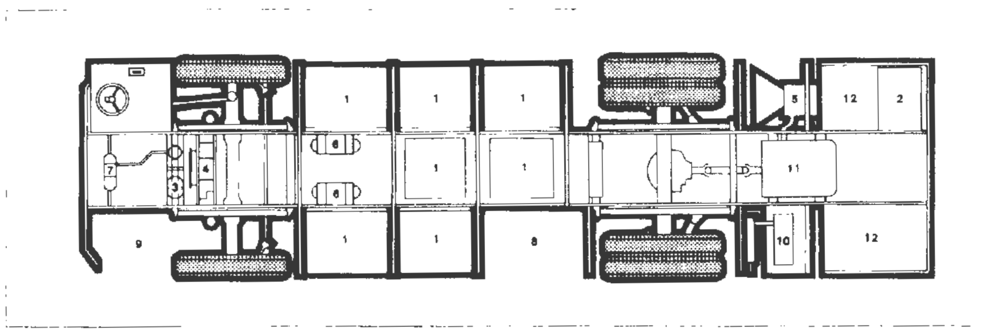
b. Test Performance

Range:	109 km @ 48 kph constant speed 72 km @ 64 kph constant speed
Maximum Speed:	67 kph, fully charged
Acceleration:	0-16 kph in 4.5 sec. 0-32 kph in 11 sec. 0-48 kph in 21 sec. 0-67 kph in 50 sec.(maximum)
Deceleration:	0.25 g (Meets U.K. standards)
Gradeability:	10% @ 24 kph
Maximum Grade:	12.5%

c. Safety Features

Recharging:	Interlocks prevent energizing charger until plug connection senses battery voltage
	Micro-switches on bus recharging hatch prevent motor operation while plug is attached
Auxiliary Power:	If 330 v main battery fails, 24 v accessory battery can power the bus at 6 kph for 1 to 2 km.
Doors:	No safety edges are provided.
Grounding:	No gauge indicates current leakage to the chassis.

Figure 2-8. Chloride Silent Rider



1. Main 330 Volt Battery
2. Auxiliary 24 Volt Battery
3. Power Steering Pump and Motor Assembly
4. Air Compressor and Motor Assembly
5. Motor Cooling Fan
6. Main Air Tanks
7. Auxiliary Air Tank
8. Exit
9. Entrance
10. Bus Heater
11. Motor
12. Control Panels

Figure 2-9. Silent Rider Component Arrangement

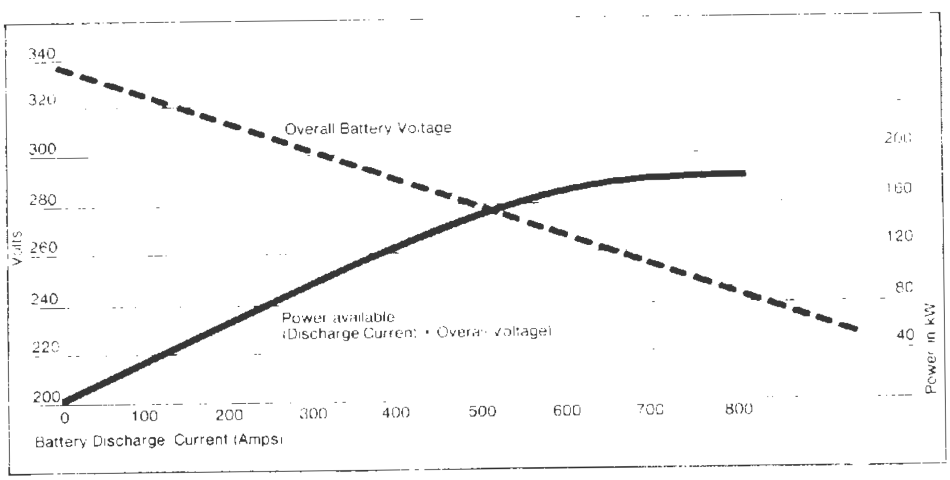


Figure 2-10. Chloride Battery Discharge Characteristics

2.1.6 Ribble (Vehicle Type No. 6)

The Department of Transportation initiated development of the electric battery bus in 1971 through an engineering design contract with Ribble Motor Services, Ltd. Operations in Runcorn started in November, 1975. There are no plans at present for further development of this bus.

a. Technical Description

Chassis

Passengers:	61; 41 seated, 20 standing
Weight:	18,588 kg curb; 21,942 kg gross
Dimensions:	WB 508 cm; L 1,362 cm (with trailer); W 250 cm; H 326 cm
Floor Height:	83 cm
Turn Radius:	16.8 m
Features:	Standard, 10 meter Leyland National Bus was modified for electric operation. No interior changes in the bus were required. Conversion of the drive train and strengthening the frame for the trailer yoke comprised the major modifications.

Battery

Type:	Chloride lead-acid traction battery
Rating:	360 v; 516 amp-hrs for 5 hours
Weight:	7,010 kg, battery 9,448 kg, battery and trailer
Location:	Fixed on a two-axle trailer
Features:	Two separate battery packs are mounted longitudinally. Air cooling is by convection and forced draft fans.

Battery Change

Purpose:	Change required only for replacement at end of life cycle. All servicing and recharging is accomplished on the trailer.
Connections:	The trailer is not detached as a means of replacing batteries for safety reasons. Frequent connections of the trailer hitch, power cables, compressed air lines for brakes, trailer lights and instrumentation wiring are considered too great a risk.

Battery Charger

Equipment:	Two external battery chargers are used--one for each battery pack. Each charger is rated at 36 amp, 440 v, 3-phase input and 100 amp output
Time:	8 hours

Propulsion

Motor Type:	Series wound dc traction motor
Rating:	120 hp, 90 kw, continuous at 4,100 rpm 240 hp, 180 kw, intermittent
Controller:	Thyristor chopper with two-stage regenerative braking
Transmission:	Direct drive through 2.1:1 reduction gear and 5.8:1 differential.

Braking

Service:	Normal air brakes for bus and trailer
Parking:	Separate drum brakes
Regenerative:	Two stage for maximum 0.15 g deceleration

Suspension

Tires:	Radial, low profile (standard for Leyland)
Springs:	Air bags

Accessories

Heating:	Webasto fuel-fired hot water heater
Steering:	Power assisted
Air Compressor:	360 v, 10 amp, motor drives both the power steering pump and air compressor for brakes and doors

Accessory Power

Alternator:	Bosch, 28 v, 55-amps, driven by 360 v, 5-amp motor which also drives the main motor cooling fan.

b. Test Performance

Range:	160 km, fully charged, unladen 80 km at average speed of 35 kph, fully charged and loaded
Maximum Speed:	63 kph, fully charged
Acceleration:	0.08 g (2.82 kph per sec)
Braking:	0.25 g (U.K. emergency standard)
Maximum Grade:	13.3%, fully laden

c. Safety Features

Power Supply:	Gauges for both battery packs to indicate leakage to chassis
Charging:	Driver-controlled key for charger plug hatch doors to prevent operation during recharging
Backing:	Warning buzzer alerts driver to sharp turns which could "jackknife" the bus and trailer.

Figure 2-11. Ribble Bus with Battery Trailer

Figure 2-12. Ribble Two-Axle Battery Trailer

2.1.7 Société Sovel 3T1 (Vehicle Type No. 7)

The Sovel 3T1 electrobus is made by T.R.E.G.I.E. (Renault Vehicle Industries). The Société Anonyme d'Economie Mixte des Transports Publics de Voyageurs de L'Agglomeration Tourangelle (SEMITRAT) operated five Sovel 3T1 buses since January, 1976.

a. Technical Description

Chassis

Passengers:	50; 19 seated, 31 standing
Weight:	10,200 kg curb weight
Dimensions:	WB 270 cm; L 790 cm; W 225 cm; H 285 cm

Battery

Type:	Lead-acid traction battery, FULMEN TPL 10
Rating:	192 v; 640 amp-hours
Weight:	4,000 kg
Location:	Under floor
Features:	Uses external charger approximately 800 charge/discharge cycles.

Battery Change

Equipment:	Fork lift
Time:	5-10 minutes

Battery Charger

Procedure:	Utilizes external charger; 5 to 10 minutes to exchange
Time:	8 hours

Propulsion

Motor:	
--Rating:	92 kw

Braking

Service:	Hydraulic with air assistance
Parking:	
Regenerative:	Yes

b. Test Performance

Range:	100 km (80% discharge in city use)
	60 km in urban traffic
Maximum Speed:	60 kph

Figure 2-13. Sovel 3T1 Battery Bus

2.1.8 M. A. N. SL-E--Elektrobus (Vehicle Type No. 8)

The world's largest electric battery bus program has been coordinated by Gesellschaft für Elektrischen Strassenverkehr (G. E. S.) (Electric Road Transport Company) in the Federal Republic of Germany. Two systems involving 20 Elektrobuses have been under evaluation in Mönchengladbach and Düsseldorf since October 1974.

Sponsors of the program include:

Ministry for Research and Technology
Ministry of the Interior
Nordrhein-Westfalen State Ministry
of Labor, Health and Welfare

Participants in developing and evaluating the system include:

G. E. S. --Project management
Maschinenfabrik Augsburg Nurnberg AG
(M. A. N.)--Bus chassis
Robert Bosch GmbH--Separately-excited motors and controls
Siemens AG--Compensated, series-wound motors and controls
Varta Batterie AG--Batteries
J.M. Voith Gmbtt--Battery exchange and charging stations
Brown, Boverie & Cie--Battery charging equipment
Peter Bauer Fahrzeugwerke--Trailers
Rheinisch Westfalisches Elektrizitatswerk AG--Primary electric
power supply

a. Technical Description

Chassis

Passengers:	99; 33 seated, 66 standing, plus driver
Weight:	15,800 kg curb, 23,400 kg gross
Dimensions:	WB 560 cm; L 1,406 cm with trailer; W 246 cm; H 294 cm
Floor Height:	74 cm
Turn Radius:	21. 2 m
Features:	Standard M. A. N. Line bus, adapted for electric drive with frame strengthened for trailer yoke. Minimal modifications required for bus interior, since batteries are towed in the trailer.

Battery

Type:	Varta lead-acid traction
Rating:	360 v, 455 amp-hours for 5 hours

Weight:	6,980 kg battery with tray and equipment 7,400 kg battery, tray and trailer
Location:	On trailer
Features:	Two battery packs of 90 cells each are mounted in a removable tray. Cells are light-weight polypropylene Each tray incorporates fuse protection, electrical insulation, automatic temperature control and gas dispersion

<u>Battery Change</u>

Procedure:	Batteries are automatically exchanged after each block of runs for recharging and servicing.
Equipment:	Exchange stations contain primary power switchgear, transformers, chargers and automatic mechanical devices for removing and replacing batteries on the trailers. Batteries are recharged, topped off with electrolyte and stored in the change station until required by another bus.
Time:	3 to 5 minutes

<u>Battery Charger</u>

Equipment:	Two 400-amp rectifiers with programmed charge rates having a total output of 360 kva
Time:	4 hours

<u>Propulsion</u>

Motor:	Bosch	Siemens
--Type:	Separately excited, shunt	Compensated, series
--Rating:	122 hp, 90 kw, continuous	156 hp, 115 kw, continuous
	147 hp, 108 kw, hourly	183 hp, 135 kw, hourly
	245 hp, 180 kw, peak	239 hp, 176 kw, peak
	360 v, 600 amps maximum	360 v, 800 amps maximum
--Torque:	2, 350 nm	2,250 nm
--RPM:	4,800	4,000

Controller:	Two-step electronic impulse control with variable impulse frequency and variable impulse duration. Regenerative braking included.

Transmission:	Bosch	Siemens
--Gear Ratio:	2. 118:1	1. 72:1
--Rear Axle:	6. 32:1	6. 32:1

<u>Braking</u>

Service:	Two-circuit air brakes on all bus wheels Two-line air brakes for trailer wheels
Parking:	Pneumatic release, spring loaded
Regenerative:	1. 3 mps^2 (0. 13 g) deceleration 14 to 20% energy recovery

Suspension

Tires:	10:00 - 20" Super, 6-ply (single front, double rear) 8:25 - 20" Super for trailer
Springs:	Air bellows with front and rear level control valves.
Shock Absorbers:	2 on front, 4 on rear

Accessories

Heating:	DBW 2003, diesel-oil fired, hot water space heater. Consumption--70 liters per day
Steering:	Power assisted, hydraulic
Air Compressor:	Door operators and air brakes Pump and air compressor are continuously driven by a 360 v, 2. 2-4. 6 kw, motor powered from the traction battery.
Main Motor Cooling:	Radial fan, 0. 3 m^3/s
Dynamo:	Lighting, 28 v, 55 amps Cooling fan and dynamo operate continuously from a 360 v, 2. 2-4. 6 kw motor powered from the traction battery

Accessory Power

Battery:	Traction batteries
Alternator:	28 v, 55 amp dynamo supplies lighting

b. Test Performance

Range:	140 km @ 50 kph constant speed, discharged to 25%. 80 km, 4 hours operations in traffic
Maximum Speed:	70 kph
Acceleration:	0-30 kph in 10 sec. , 50% laden 0-50 kph in 23 sec. , 50% laden
Braking:	0. 25 g emergency stop
Maximum Grade:	12%

c. Safety Features

Power Supply:	Protective circuit to prevent battery overload and deep discharge.
Motor Drive:	Emergency off button for the main contactor
Doors:	Open doors prevent operation of drive motor
Reverse:	Emergency braking and an alarm bell prevent jackknifing when backing up.
Grounding:	Gauges indicate current leakage to chassis.

M. A. N. SL-E

Figure 2-14. M. A. N. Bus and Trailer

Figure 2-15. M. A. N. Bus with Automatic Battery Exchange

2.1.9 Isuzu EU05 (Vehicle Type No. 9)

The Osaka Transportation Bureau has been operating two prototype battery buses since April, 1972. Designed to run in parallel with diesel buses on existing routes, the EU05 retains parts interchangeability with the diesels for many running gear components, i.e. air compressor, hydraulic brake system. The vehicle's design and construction was planned by the Osaka Transportation Bureau in cooperation with the Osaka Environmental Protection Agency and Isuzu Automobile, Ltd. Other participating developers included Kawasaki Heavy Industry, Ltd., for the drive-train and body, Fuji Electric Manufacturing, Ltd., for the electrical equipment, and Shin Kobe Electric, Ltd., and Yuasa Battery, Ltd., for the batteries.

a. Technical Description

Chassis

Passengers	70; 24 seated, 46 standing; incl. driver
Weight:	9,895 kg curb, 13,745 kg gross
Dimensions:	WB 430 cm; L 925 cm; W 248 cm; H 306 cm
Floor Height:	97 cm
Turn Radius:	7.7 m
Features:	Body of frameless monocoque construction; lightweight seats and aluminum interior and exterior panels; 25 cm ground clearance, designed for battery bus system.

Battery

Type:	Lead-acid paste, lightweight steel case holding 64 monoblock 6 v batteries
Rating:	384 v; 350 amp-hours for 5 hours
Weight:	3,500 kg
Location:	Under floor between front and rear axles
Features:	580 cycle life, 42 watt-hour per kg energy density

Battery Change

Procedure:	Bus driver pulls onto bus positioning pads
Equipment:	Automated conveyor system completes entire exchange procedure.
Time:	3 minutes

Battery Charger

Procedure:	Batteries are removed and charged by automatic sequence control mechanism, including rate of charge monitoring and cell water refill.
Equipment:	Specially designed conveyor system; chargers are automatically regulated three-phase full-wave thyristor rectifier type charging to 120 amps at 230 v to 20 amps at 260 v
Time:	6 hours in 3 stages, regulated for constant current or voltage

Propulsion

Motor:	
--Type	Series wound dc traction with interpole control;
--Rating:	70 kw for 1 hour; 360 v; 220a; 3,000 rpm; 22. 7 kg-m torque
Controller:	Max. 450 v thyristor chopper with regenerative brake circuit; rated 420 amp power current and 265 amp regenerative; automatic weak-field control; separate forced ventilation
Transmission:	Direct gear ratio 18. 7:1, permanently meshed two-stage reduction
Features:	Reverse operation limited to 10 kph; "soft" starting control with acceleration limited to . 12 g for standing passenger safety.

Braking

Service:	Conventional air assisted split hydraulic system with drum brakes
Parking:	Lever control sets caliper band on drive shaft
Regenerative:	Provides controlled engine braking on accelerator pedal release from 55 kph to near stop and regenerative speed braking with brake pedal depression.

Suspension

Tires:	Six 9. 00-20-14PR
Springs:	Eight leaf elliptical at each wheel; front L 140 cm, W 8 cm, T 1. 2 cm; rear L 160 cm, W 10 cm, T 1. 2 cm (2 leaves), 1. 4 cm (6 leaves)

Accessories

Ventilation:	Top opening sliding windows and roof hatches; no heating or air conditioning
Steering:	Auxiliary dc motor drives oil pump for power steering
Others:	Circuit breakers for power, braking and auxiliary circuits;

instrumentation for current leakage to earth ground, dc/dc convertor failure, voltage drop alarm; public address system.

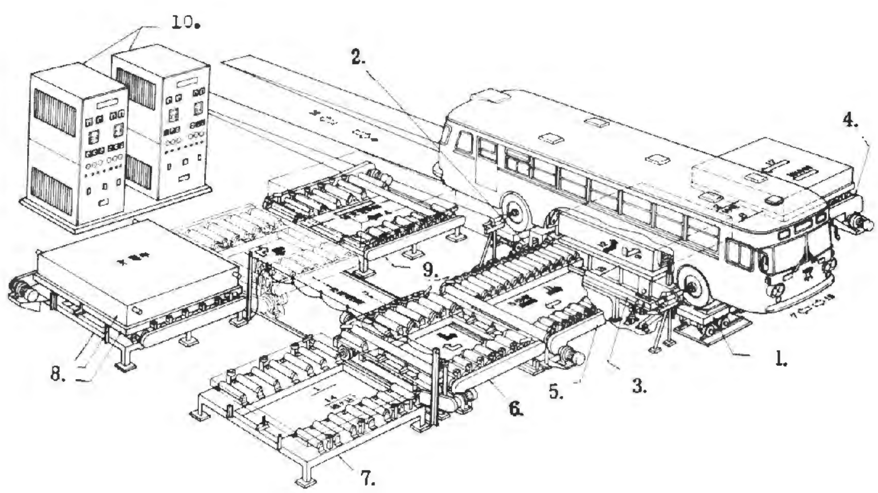
Accessory Power

Battery:	24 v lead-acid; 24 amp-hour rating
Inverter:	360 v/26 ± 2 v, 900 w rating
Auxiliary Motor:	900 w (cont.), 2.85 kw (1 hr) rating; 360 v shunt wound dc motor for air compressor, power steering oil pump, and traction motor cooling fan
Compressed Air:	Operates brake servos and door opener/closers; 5 minute air tank charging time

b. Test Performance

Range:	150 km at 40 kph constant speed; 82 km with 4 stops per km· both at 40% passenger capacity
Maximum Speed:	60 kph with full passenger load
Acceleration:	Limited to .12 g at any load; at full load: 0-10 kph in 3.0 sec. 0-20 kph in 5.2 sec. 0-30 kph in 7.6 sec. 0-40 kph in 12.4 sec. 0-50 kph in 24.0 sec.
Braking:	Braking performance not available, complies with Japanese Transportation Ministry Standards
Gradeability:	6% at 35 kph with full passenger load
Maximum Grade:	Performance not available
Noise Level:	72 phon at full acceleration 71 phon at normal coasting

Figure 2-16. Isuzu Battery Bus



(1) & (2) Positioner
(3) Exchange Elevator
(4) Receiving Stand
(5) Waiting Stand
(6) Conveyor
(7) Set Aside Stand
(8) Charge Stand No. 1
(9) Charge Stand No. 2
(10) Charger

Figure 2-17. Automatic Battery Exchange for the Isuzu Bus

2.1.10 Mitsubishi TB13 (Vehicle Type No. 10)

One Mitsubishi TB13 has been operated in Kyoto since November, 1972. Kyoto is considering the use of electric battery buses for a nearby new town of 40,000 to be completed in 1983. The experimental vehicle was converted from a standard production trolley bus to ascertain the costs and performance of a minimal conversion.

The Kyoto Transportation Bureau was assisted in the conversion by Kansei Electric, Ltd., Mitsubishi Fuso Automobile, Ltd., Aruna Industry, Ltd., Nippon Battery, Ltd., and Yuasa Battery, Ltd.

a. Technical Description

Chassis

Passengers:	63; 30 seated, 33 standing
Weight:	12,250 kg curb; 15,800 kg gross
Dimensions:	WB 503 cm; L 1,052 cm; W 249 cm; L 312 cm
Floor Height:	First step 38 cm above ground, interior floor height not available
Turn Radius:	9.1 m
Features:	Vehicle was converted from trolley bus; perimeter seating with wide central aisle

Battery

Type:	Lead-acid, six units in series
Rating:	500 v; 250 amp-hours for 5 hours
Weight:	3,400 kg
Location:	Under floor on each side between front and rear wheels
Features:	Heat and gases produced by on-board charging are dissipated by compressed air cooling; average life for two batteries observed at 429 charge/discharge cycles

Battery Charger

Procedure:	Vehicle with batteries in place is connected to external charger
Equipment:	Fixed voltage regulated charger
Time:	4 to 5 hours

Propulsion

Motor:	
--Type:	Series wound dc traction motor
--Rating:	75 kw

Controller:	Thyristor chopper for traction current and braking current
Transmission:	Direct drive with 11.554:1 reduction

Braking

Service:	Air brakes
Regenerative:	Returns braking energy to batteries

Suspension

Tires:	Six 11.00-20-14 PR
Springs:	Elliptical leaf springs at each wheel
Shock Absorbers:	Heavy-duty telescoping hydraulic

Accessories

Instrumentation:	Conventional bus gages, plus traction current, battery charge, battery temperature gages; warning lights for inverter, low voltage, excess current and charger connection
Ventilation:	Top opening sliding windows; no heating or air conditioning
Steering:	Power steering
Others:	Public address system and tape-recorded stop announcements

Accessory Power

Battery:	Two 12 v lead-acid batteries in series
Inverter:	500 v/24 v dc/dc inverter

b. Test Performance

Range:	140 km at 40 kph constant speed 60 km in start/stop city traffic
Maximum Speed:	55 kph
Acceleration:	0-40 kph in 23.5 sec.
Braking:	Performance not available, complies with Japan Ministry of Transportation Standards
Gradeability:	Performance not available
Maximum Grade:	13.3%

MITSUBISHI MODEL TB13

Figure 2-18. Mitsubishi Battery Bus

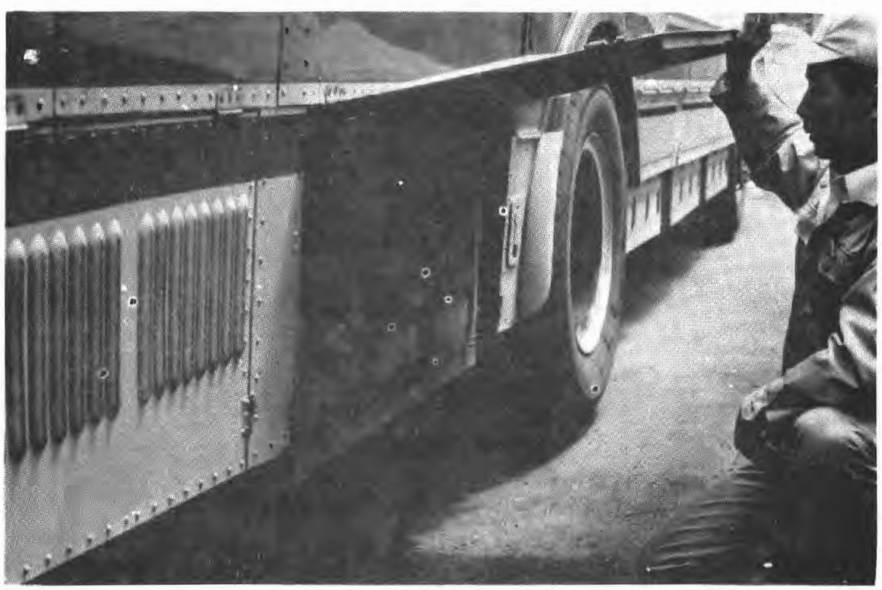


Figure 2-19. Battery Location, Mitsubishi Bus

2.1.11 Mitsubishi ME460 (Vehicle Type No. 11)

The Kobe Transportation Bureau has operated four ME460 production prototype battery buses since September, 1975. The KTB has emphasized the public benefits of the vehicles, focusing on pollution, efficiency, and safety aspects.

a. Technical Description

Chassis

Passengers:	69; 26 seated, 43 standing
Weight:	10,350 kg curb; 14,200 kg gross
Dimensions:	WB 437 cm; L 938 cm; W 249 cm; H 306 cm
Floor Height:	First step 32.5 cm from ground; 2nd step 24 cm; 3rd 24.5 cm; total 81 cm
Turn Radius:	8.1 m
Features:	Frameless chassis; front and rear automatic doors

Battery

Type:	Lead-acid, 64 units of 6 v each in quick release case
Rating:	384 v; 310 amp-hours for 5 hours
Weight:	3,050 kg
Location:	Under floor between front and rear axles
Features:	500 cycle charge/discharge life observed

Battery Change

Equipment:	Automatic roller conveyor system in garage floor removes discharged battery and installs charged unit
Time:	68 seconds

Battery Charger

Procedure:	Vehicle is pulled over exchanger mechanism and discharged battery is removed and conveyed to charger station while fresh battery is installed.
Equipment:	Thyristor rectifier type
Time:	5 hour recharger

Propulsion:

Motor:	
--Type:	Series wound dc; Class F insulation
--Rating:	72 kw (1 hr rating); 224 a; 360 v; 73 kg-m torque @ 2,100 rpm

Controller:	Thyristor chopper for traction power and regenerative braking
Transmission:	None; two-stage constant mesh reduction of 16.6:1

Braking

Service:	Conventional hydraulic system
Regenerative:	Returns recovered braking energy to battery

Suspension

Tires:	Six 9.00-20-14PR
Springs:	Elliptical; front-L 145 cm, W 9 cm, 7 leaves; rear-L 170 cm, W 10 cm, 12 leaves

Accessories

Ventilation:	Top opening windows; no heating or air conditioning
Steering:	Power steering
Others:	Public address system

Accessory Power

Battery:	24 v lead-acid
Inverter:	360 v/24 v dc/dc inverter operates accessories, air compressor, power steering pump, and reverse drive motor

b. Test Performance

Range:	170 km at 40 kph constant speed 50 km in start/stop traffic
Maximum Speed:	60 kph at full charge
Acceleration:	0-10 kph in 2.5 sec. 0-20 kph in 4.0 sec. 0-30 kph in 7.0 sec. 0-40 kph in 14 sec.
Braking:	Performance not available; complies with Japan Transportation Ministry Standard
Gradeability:	7% at 29.5 kph
Maximum Grade:	15%

MITSUBISHI MODEL ME460

Figure 2-20. Mitsubishi Battery Bus

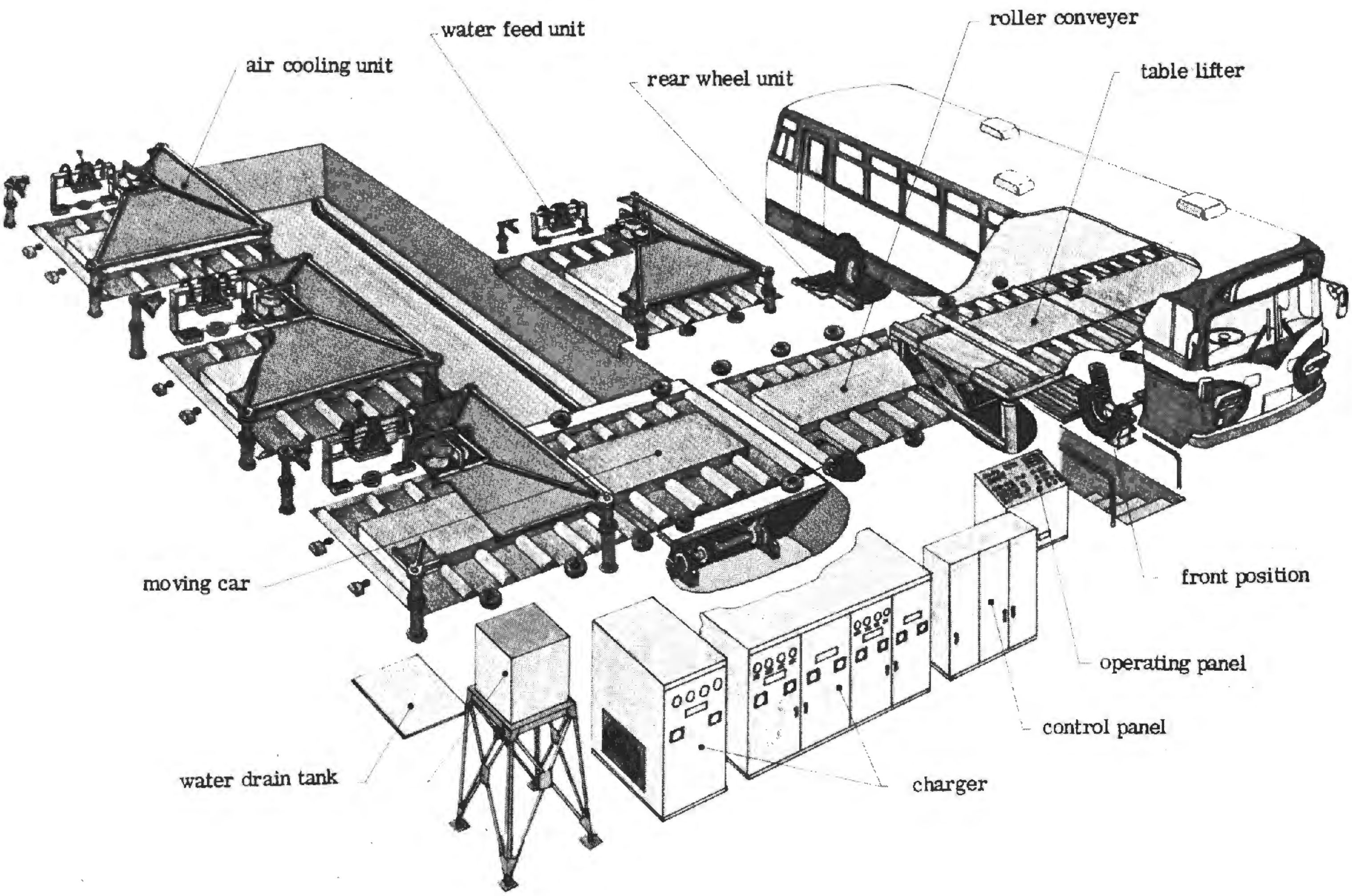


Figure 2-21. Automatic Battery Exchange for Mitsubishi ME460

2.1.12 Hino BT900 (Vehicle Type No. 12)

The one Hino BT900 battery bus has been operating in Nagoya since March, 1973. Toshiba Electric Co., Ltd., and Hino Automobile Co., Ltd., developed the prototype battery bus. This bus is potentially marketable and production versions have been offered for sale.

a. Technical Description

Chassis

Passengers:	79; 26 seated, 53 standing; plus driver
Weight:	10,835 kg curb; 15,235 kg gross
Dimensions:	WB 480 cm; L 994 cm; W 246 cm; H 308 cm
Floor Height:	102.5 cm
Turn Radius:	8.4 m
Features:	Aluminum semimonocoque construction; front and rear automatic bi-fold doors

Battery

Type:	Yuasa paste-type lead-acid, 64 cells of 6 v each in quick exchange case
Rating:	384 v; 350 amp-hours for 5 hours
Weight:	3,500 kg
Location:	Under floor between front and rear axles

Battery Change

Equipment:	Automated conveyor in garage floor exchanges batteries.
Time:	3 to 5 minutes

Battery Charger

Procedure:	Vehicle is pulled over floor conveyor mechanism; discharged battery case unit is automatically delivered to charger.
Equipment:	Thyristor rectifier type
Time:	Overnight

Propulsion

Motor:	Toshiba SE 616
--Type:	Series wound dc
--Rating:	360 v; 65 kw (140 kw max); 440 amp for 59 kg/m maximum torque at 2,280 rpm

Controller:	Two-stage thyristor chopper with field weakening and regenerative control
Transmission:	None; direct drive two-step constant mesh helical/spiral gears with 19. 713:1 overall reduction

Braking

Service:	Conventional spring loader air servo system
Parking:	Mechanical expansion type
Regenerative:	Returns recovered braking energy to battery

Suspension

Tires:	Six 10. 00-20-14PR
Springs:	Elliptical; Front-L 133 cm, W 9 cm, T 1 cm, 10 leaves Rear-L 164 cm, W 10 cm, T 1. 2 cm, 13 leaves
Shock Absorbers:	Single actuated hydraulic telescoping type

Accessories

Ventilation:	Top opening windows and roof hatches, no heating or air conditioning
Steering:	Power steering
Others:	Public address system

Accessory Power

Battery:	24 v lead-acid
Inverter:	384 v/24 v dc/dc inverter

b. Test Performance

Range:	170 km at 50 kph constant speed 70 km in start/stop service
Maximum Speed:	80 kph in actual trial; 60 kph design maximum
Acceleration:	3. 3 km/hr/sec. 0-30 kph in 8. 5 sec. 0-40 kph in 12 sec.
Braking:	Performance not available
Gradeability:	8 kph on 12. 7% grade
Maximum Grade:	12. 7%

HINO MODEL BT900

Figure 2-22. Hino Battery Bus in Nagoya

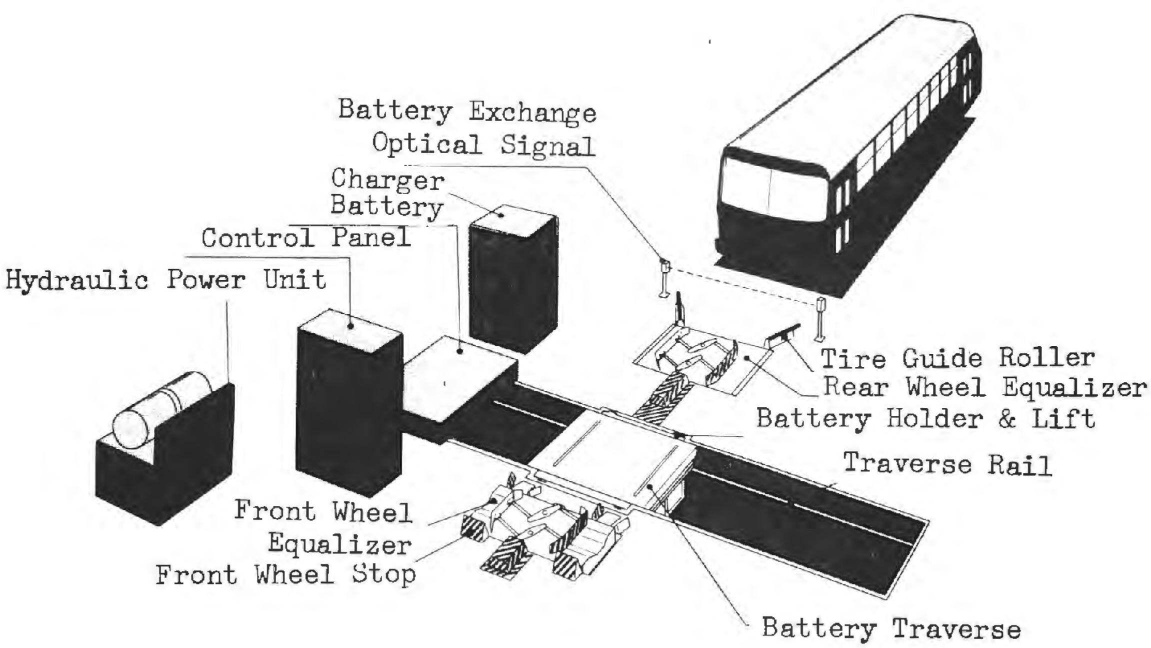


Figure 2-23. Automatic Battery Exchange for Hino BT900

2.1.13 Townobile T120A (Vehicle Type No. 13)

The Townobile was developed over a seven-year period by Elroy Engineering Pty., Ltd., Sidney, Australia, to achieve a total electric vehicle system. The system envisages ready component accessibility and a modular "curbside service center" package to provide all maintenance needs. A fleet of up to 20 vehicles could be handled by a 20-by-60-foot service area staffed with one mechanic and two battery handlers/cleaners per shift. Under present plans, production could begin in late 1977.

Although the vehicle has not been in passenger service, it is included in this report because of two interesting features:

(1) 20-inches floor height, which is lower than Transbus.

(2) Use of two traction motors, one in each rear wheel, which eliminates the need for a separate differential.

a. Technical Description

Chassis

Passengers:	116-129; 48 seated, 68 to 80 standing
Weight:	6,550 kg curb; 14,000 kg gross
Dimensions:	WB 700 cm; L 1,220 cm; W 250 cm; H 250 cm
Floor Height:	First step 25 cm above ground; 2nd step 25 cm; total 50 cm
Turn Radius:	22 m
Features:	Spacious, lightweight body of monocoque stressed skin design combines floor, sides and roof in a tubular structure with inner and outer seamless corrugated skins closely riveted to the all-welded frame. Flow-through interior configuration combines 18" contoured fiberglass perimeter seating with central stanchions and handrails in wide aisle from front to rear doors.

Battery

Type:	Lead-acid industrial
Rating:	160 v; 540 amp-hours for 5 hours
Weight:	2,090 kg, total
Location:	Side compartments just forward of rear wheels
Features:	Battery consists of two 80-cell packs, connected in series with minimum length leads to controls and traction units.

Battery Change

Equipment:	Transfer table on rollers to charger
Time:	5 minutes per exchange

Battery Charger

Procedure:	Batteries are removed for charging
Equipment:	Three phase, 415 v, solid state control with two-rate sequence or pulse-charging
Time:	8 hours with two-rate sequence 3-4 hours with pulse-charging

Propulsion

Motor:	Two motor-in-wheel units incorporate traction motor, gear reduction, suspension and braking elements in concentric unit inside each dual rear wheel. These replace conventional axle and differential configurations.
--Type:	Series wound, dc traction
--Rating:	22.5 kw each; 45 kw total
Controller:	Stepless thyristor and pulse frequency circuits control 1,250 amperes for traction and regenerative braking.
Transmission:	Direct drive by constant mesh 10:1 ratio planetary gears annular with dual rear wheels.

Braking

Service:	Dual servo-hydraulic system operates drum front and disc rear service brakes for emergency and completion of stop below 5 kph effective limit of regenerative system
Parking:	Lever action handbrake holds on up to 20% grade.
Dynamic:	First 50 mm of brake pedal travel modulates dynamic braking to .7G limit of deceleration.

Suspension

Tires:	Six low-profile radial ply tubeless, 1100 x 22.5 with lightweight drop center one-piece rims, reduce floor height and rolling resistance.
Springs:	Air bags on wide centers at each wheel with driver selection of five-step air bag pressure at both front and rear to maintain constant step height and optimum ride. High-pressure air reservoir holds one-day supply.
Shock Absorbers:	Heavy-duty telescoping hydraulic.

Accessories

Heating:	Four lightweight heat banks under seats with overnight re-heating from off-peak supply.
Lighting:	Two sets of 3 x 40 w Rapid Start Fluorescent Tubes
Ventilation:	Top-opening side windows, roof hatches, and blowers

Accessories (cont.)

Steering:	Low ratio recirculating ball mechanism; 5 turns lock to lock
Other:	Optional wheelchair lift; front and rear remotely operated bi-fold doors have safety edges and 10 lb limited closing pressure.

Accessory Power

Inverter:	Up to 1.5 kw auxiliary power supplied from main traction batteries through 160 v/24 v dc inverter.

b. Test Performance

Range:	65 km @ 20 kph constant speed 60 km @ 10 stops per km
Maximum Speed:	60 kph, full charge
Acceleration:	(with seated capacity load) 0-10 kph in 2 sec. 0-20 kph in 4 sec. 0-30 kph in 8 sec. 0-60 kph in 20 sec.
Braking:	Stop from 60 kph in 20.1 m
Gradeability:	10% @ 30 kph
Maximum Grade:	20%

Figure 2-24. Townobile

2.2 Hybrid Buses

In the hybrid bus systems assessed, other sources of power are used to supplement battery electric power. The Dornier Duo-Bus uses overhead trolley wires to augment battery propulsion. The Mercedes-Benz OE305 and Kawasaki hybrid buses both use diesel-engine generators to complement the battery power supply. Other hybrid bus systems have been developed by Sovel and Dornier which combine trolley-electric operation from overhead conductors with diesel-electric propulsion for use away from the wires. Since these two systems do not use batteries, they have been omitted from this study.

Hybrid buses can extend the ranges available from battery buses. Battery propulsion can enhance the flexibility of trolley buses by extending the ranges beyond the limits of electrification and by skirting obstacles that would otherwise impede conventional trolley buses. Augmentation by continuously operating diesel-engine generators optimizes fuel consumption and reduces noise and pollution emission from the levels generated by conventional diesel buses.

2.2.1 Dornier (Duo-Bus) (Vehicle Type No. 14)

In a cooperative development program supported by the West German Ministry for Research and Technology, the firms Dornier Systems GmbH, R. Bosch GmbH, Daimler-Benz AG, and Varta Batterie AG and the city of Esslingen completed a prototype vehicle, the Duo-Bus Model OE 302, in April, 1975. After tests, passenger operations began in Esslingen in December, 1975. Esslingen's 8 km trolley wire system also powers a conventional trolley fleet.

a. Technical Description

Chassis

Passengers:	80; 43 seated, 37 standing, plus the driver
Weight:	13,700 kg curb; 19,000 kg gross
Dimensions:	WB 560 km; L 1,100 cm; W 250 cm; H 300 km
Floor Height:	First step 15 cm above ground, total 72.9 cm
Turn Radius:	Not available
Features:	Trolleys can be automatically engaged or disengaged by push-button control from the driver's cab. Sensors on the trolleys locate the overhead conductors and advise the driver when electrical contact has been made.

Battery

Type:	Fifteen Varta lead-acid batteries
Rating:	24 v each, 360 v in series; 230 amp-hours for 5 hours

Weight:	2,900 kg
Location:	Under floor between axles
Features:	Batteries comprise 15% of total vehicle weight.

Battery Change

Equipment:	Not available
Time:	Batteries are not removed in daily service

Battery Charger

Procedure:	Batteries charged on-board when vehicle engages overhead trolley wires. One km of battery capacity is added for each km of travel on overhead conductors.
Equipment:	Two dc 24 v servomotors control each of the two trolley arms. Each elevating motor is rated at 200 w and each horizontal control motor is rated at 50 w. Overhead voltage of 540 v to 750 v is fed, through filters, to an on-board charger with a rated capacity of 100 kw and a maximum charging current of 280 amps. During travel, voltage is limited at the battery terminals so that it does not exceed 2. 35 v per cell.
Time:	Vehicle must engage supply during at least 50% of the daily route; batteries are given two-hour charge each night at garage.

Propulsion

Motor:	
--Type:	Shunt wound, separately excited dc traction; one armature current and one field current regulator each for 4-quadrant operation.
--Rating:	75 kw (150 kw short time): 360 v
Controller:	Uses a thyristor regulator to control charging operations. The battery charger contains an unregulated inverter, an isolating transformer and a rectifier to provide galvanic protection between the battery circuit and the overhead wire circuit. The controls give priority to regenerative braking energy such that 40% is recovered.
Transmission:	Direct drive through 5. 996:1 differential

Braking

Service:	Conventional air brakes supplement regenerative engine braking
Parking:	Mechanical spring-loaded air lift

Regenerative:	Controller switches braking energy to battery charging for deceleration up to 1. 5 m/s^2

Suspension

Tires:	Six radial 10. 00R20
Springs:	Elliptical
Shock Absorbers:	Not available

Accessories

Heating:	12 kw thermal accumulator stores heat during overhead wire travel for 1/2 to 1 hour battery operations
Steering:	Servo-assisted
Other:	Two-way radio to dispatcher; public address system

Accessory Power

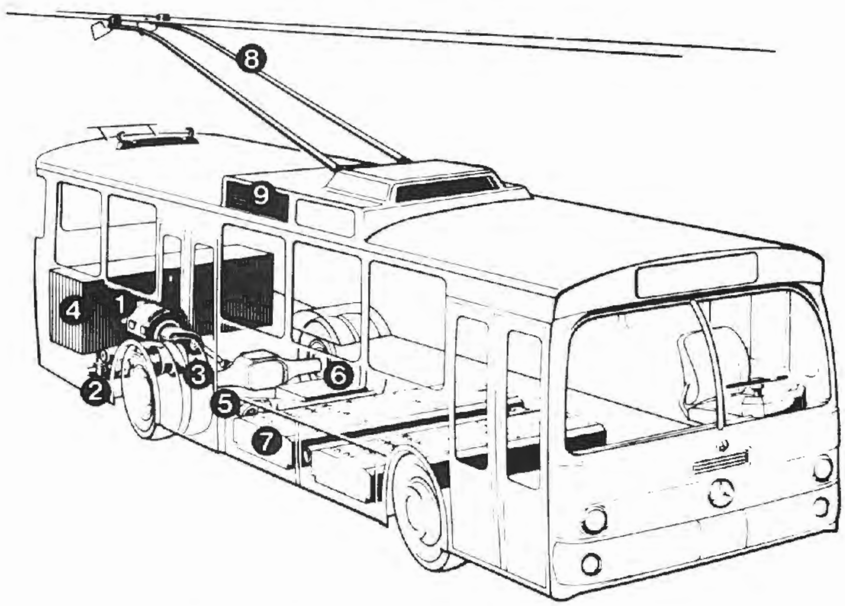
Battery:	24 v lead-acid
Inverter:	24 v dc alternator

b. Test Performance

Range:	Up to 40 km while disengaged from overhead supply in stop/start traffic; requires an equivalent distance traveling with trolleys engaged to recover battery charge
Maximum Speed:	70 kph
Acceleration:	0-50 kph in 23 seconds (0. 6 m/s^2) 1. 2 m/s^2 maximum
Braking:	0. 8g dry pavement; 0. 3 wet pavement
Gradeability:	12% at 25 kph
Maximum Grade:	16%

DORNIER DUO BUS

Figure 2-25. Battery-Trolley Hybrid Bus, Dornier



1 Electric traction motor
2 Air compressor and pump for servo-assisted steering
3 Cooling fan for traction motor
4 Power supply unit
5 Fan for batteries
6 Electronic control unit
7 Batteries
8 Automatically operated trolley
9 Cooling system for batteries

Figure 2-26. DUO Bus Equipment Arrangement

2.2.2 Mercedes OE305 (Vehicle Type No. 15)

Developed by Daimler-Benz, AG with Bosch electric motor and controls, the OE305/1 utilizes a small 100 hp, 6 cylinder diesel engine operating a 74 kw generator at constant output to extend the range from a battery alone of 50 km - 75 km to a hybrid range of 300 km. The first prototype began three month tests in March, 1977. By the end of 1977, regular operations are expected with 20 buses serving two or three lines.

a. Technical Description

Chassis

Passeners:	100
Weight:	12,000 kg curb
Dimensions:	L 1,111 cm; Others not available
Floor Height:	N/A

Battery

Type:	Lead-acid (Varta Battery, AG)
Rating:	360 v; 275 amp-hours for 5 hours
Weight:	7,000 kg (two batteries)
Location:	Under floor between front and rear axles

Battery Change

Time:	4 minutes

Battery Charger

Procedure:	On-board charging during service from diesel driven generator
Equipment:	74 kw Daimler-Benz AG OM352 diesel engine· R. Bosch GmbH generator

Propulsion

Motor:	
--Type:	Shunt wound dc traction
--Rating:	115 kw
Controller:	Two stage thyristor chopper with regenerative braking control
Transmission:	None; direct drive through rear axle differential

Braking n/a

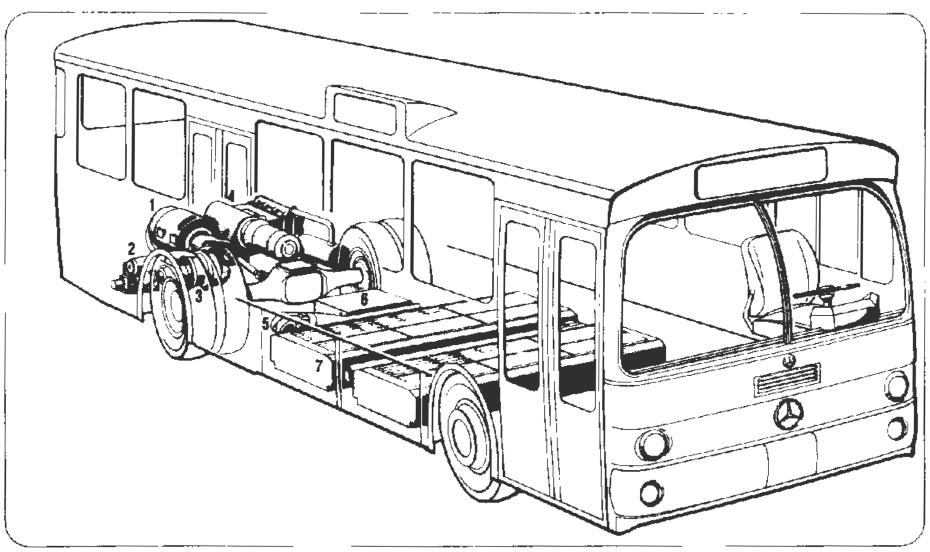
Suspension n/a

Accessories n/a

Accessory Power n/a

b. Test Performance

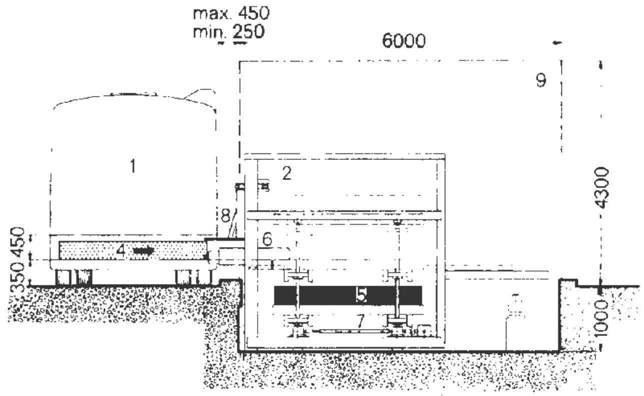
Range:	300 km with diesel-driven generator 50-75 km battery alone, in stop/start traffic
Maximum Speed:	70 kph
Acceleration:	0-50 kph in 13 to 17 seconds, based on state of charge
Braking:	n/a
Gradeability:	n/a
Maximum Grade:	16%



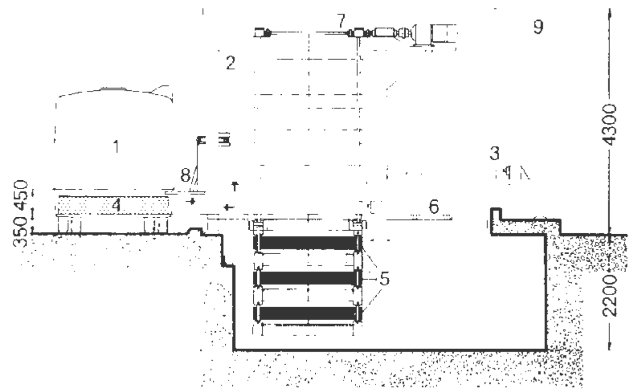
1. Electric Drive Motor
2. Air Compressor and Power Steering Pump
3. Cooling Air for the Drive Motor
4. Diesel Motor with Generator
5. Air for Battery Ventilation
6. Electronic Control
7. Traction Battery

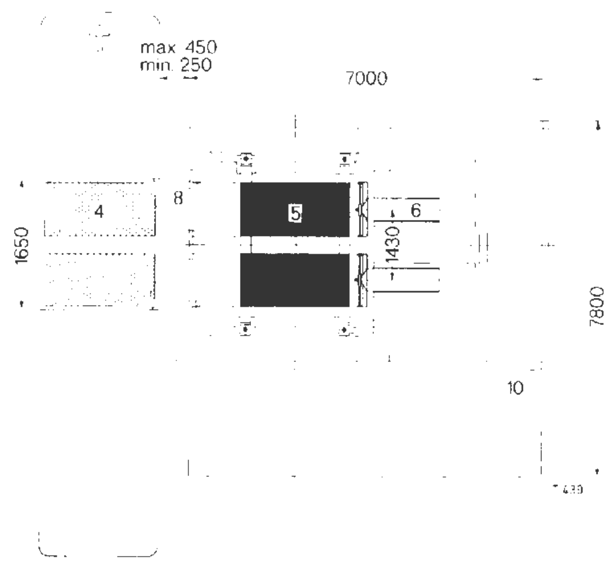
Figure 2-27. Diesel-Battery Hybrid Bus, Mercedes-Benz

Configuration A
Station with 2 Bays
For Each Bay:
2 Storage Positions
1 Loading Position



Configuration B
Station with 2 Bays
For Each Bay:
3 Storage Positions
1 Loading Position





1. Elektro-Bus
2. Battery Storage
3. Battery Servicing Position
4. Discharged Battery
5. Charged Battery
6. Transfer Equipment
7. Lifting Equipment
8. Bus Positioner
9. Building
10. Power Control Room

Figure 2-28. Battery Exchange Station for Mercedes-Benz OE305 Diesel-Battery Hybrid Bus

2.2.3 Kawasaki (Vehicle Type No. 16)

The Transportation Bureau of the Tokyo Metropolitan Government originally had four hybrid, diesel-electric buses in operation starting in November, 1972. There are now only two in use--one in the Fukagawa Branch and one in the Otsuka Branch.

a. Technical Description

Chassis

Passengers	79; 29 seated, 50 standing; plus driver
Weight:	10,147 kg curb; 14,547 kg gross
Dimensions:	WB 480 cm; L 902 cm; W 228 cm; H 196 cm
Floor Height:	Data not available
Turn Radius:	8.5 m
Features:	Frameless monocoque construction; hybrid operation derives battery recharge from 3-phase ac generator

Battery

Type:	Lead-acid
Rating:	420 v; 135 amp-hours for 5 hours
Weight:	Data not available
Location:	Under floor behind front axle
Features:	Battery life is 1.5 years

Battery Charger

Procedure:	Recharging is accomplished both on-board during duty cycle and externally at night. In on-board charging, 3-phase diesel-driven ac generator output is rectified and directed to battery except when peak acceleration is needed.
Equipment:	27 kva; 380 v clamp generator
Time:	5 to 6 hours on-board, 3 hours external

Propulsion

Motor:	Fuji Electric
--Type:	Series wound dc
--Rating:	67 kw (158 kw peak); 400 v; 189 amp for 65 kg-m max. torque at 2,370 rpm
Controller:	Thyristor chopper with traction and regenerative control; directs battery and rectified ac generator output
Transmission:	None; direct drive constant mesh with 18.7:1 reduction

Braking

Service:	Conventional spring-loaded air servo system
Parking:	Mechanical
Regenerative:	Returns recovered braking energy to battery

Suspension

Tires:	Six 9.00-20-14PR
Springs:	Elliptical; front L 150 cm, W 8 cm, T 1.2 cm, 8 leaves; rear L 166 cm, W 10 cm, T 1.2 cm (2 leaves), T 1.4 cm (6 leaves)
Shock Absorbers:	Hydraulic telescoping type

Accessories

Ventilation:	Sliding windows, no heating or air conditioning
Others:	Public address system

b. Test Performance

Range:	Beyond 180 km per day (limit by 120 liter diesel fuel tank) Battery alone range is 55 km.
Maximum Speed:	60 kph
Acceleration:	0-40 kph in 13.5 sec.
Braking:	Performance not available
Gradeability:	Not available
Maximum Grade:	14%

Figure 2-29. Diesel-Battery Hybrid Bus, Kawasaki

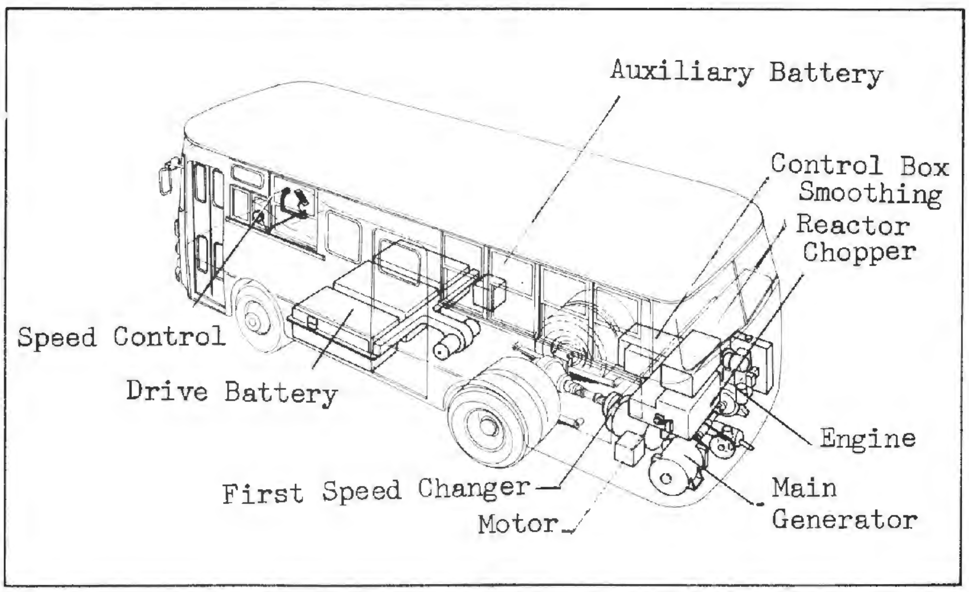


Figure 2-30. Component Arrangements in Kawasaki Diesel-Battery Hybrid Bus

CHAPTER 3

OPERATIONAL DEPLOYMENTS

Since 1972, electric battery bus systems using 58 vehicles have been deployed in public transit service throughout the United States, Europe, and Japan. The assessment studied 18 transit operations--15 using battery buses and 3 with hybrid buses. This chapter describes the transit system, the operational profile and experience with using these vehicles at each of the sites.

3.1 Battery Buses

3.1.1 Long Beach, California

The Long Beach Public Transportation Company (LBPTC) has been using three Model 120 Electrobuses in regularly scheduled service since August 1974. The buses were purchased with capital grant assistance from the Urban Mass Transit Administration (UMTA) in June of 1973. Capital costs for the three buses were $109,500, including batteries, charger and support equipment. LBPTC operates a fleet of 138 buses over 18 routes, serving more than 8 million route-kilometers and 13.8 million passengers annually. Existing maintenance facilities were adequate for serving the Electrobuses.

a. System Description

The electric bus operation serves the Long Beach downtown shopping area, civic center, parks, churches and nearby semi-residential areas. The route runs parallel to the downtown segment of the extensive LBPTC diesel bus system routes. The existence of alternative conventional service has provided interesting information concerning the preferences of different segments of the riding public. Wage earners and younger riders choose the more reliable, faster and more frequently scheduled conventional service. It is the elderly who choose the electric bus because they appreciate the quiet, unhurried atmosphere which encourages the socializing that is an important part of their daily activities.

The gentle climate of Long Beach has attracted a high percentage of elderly and retired people in the population of 359,000 residents. This group of patrons has adopted the Electrobuses because they are quiet, provide relatively easy boarding and unboarding, and because their convivial, unhurried atmosphere encourages socializing. The local population's enthusiastic response to the DASH (Downtown Area Short Hops) service can be attributed to the elderly population, local environmental concern, and transit management's sympathetic public-relations-oriented attitude toward the practical limitations of the electric buses.

The Long Beach Electric buses have added handholds to assist the elderly in climbing the stairs. Though no ramps or lifts are provided, the elderly and infirm use the buses frequently and without apparent difficulty. The LBPTC has a special DASH schedule that lets drivers adjust to the special needs of its patrons.

b. Operational Profile

The Long Beach DASH service runs two buses along a single 9.0-km route (Figure 3-1). Service starts at 1000 and continues for 6 1/2 hours at 30-minute intervals, six days a week. The round trip requires about 50 minutes; each bus makes 6 round trips and travels about 58 km a day. The route has one mild grade which does not exceed two percent. The buses are recharged each night for about eight hours.

Two buses carry 33 to 42 passengers per run, or 400 to 500 passengers per day. In the 34 months since operations began, the three buses have accumulated 96,000 km in transit service.

The schedule speed for the system averages 10.7 kph. Cruise speeds range from 16 kph in the downtown area to 25-30 kph in the outlying semi-residential areas. The bus does not run during the rush hours, and has a fairly uniform patronage level throughout the day.

The electric vehicle route characteristically has many stops. On a typical run, a driver may stop at 35 of the 45 authorized bus stops along the route to pick up or drop off passengers. In addition, each bus averages 21 unscheduled stops for traffic lights and stop signs. Typically, the bus stops once every 0.16 km for an average of 20 seconds at each stop. Information on the Electrobus in Long Beach is summarized on page 3-4.

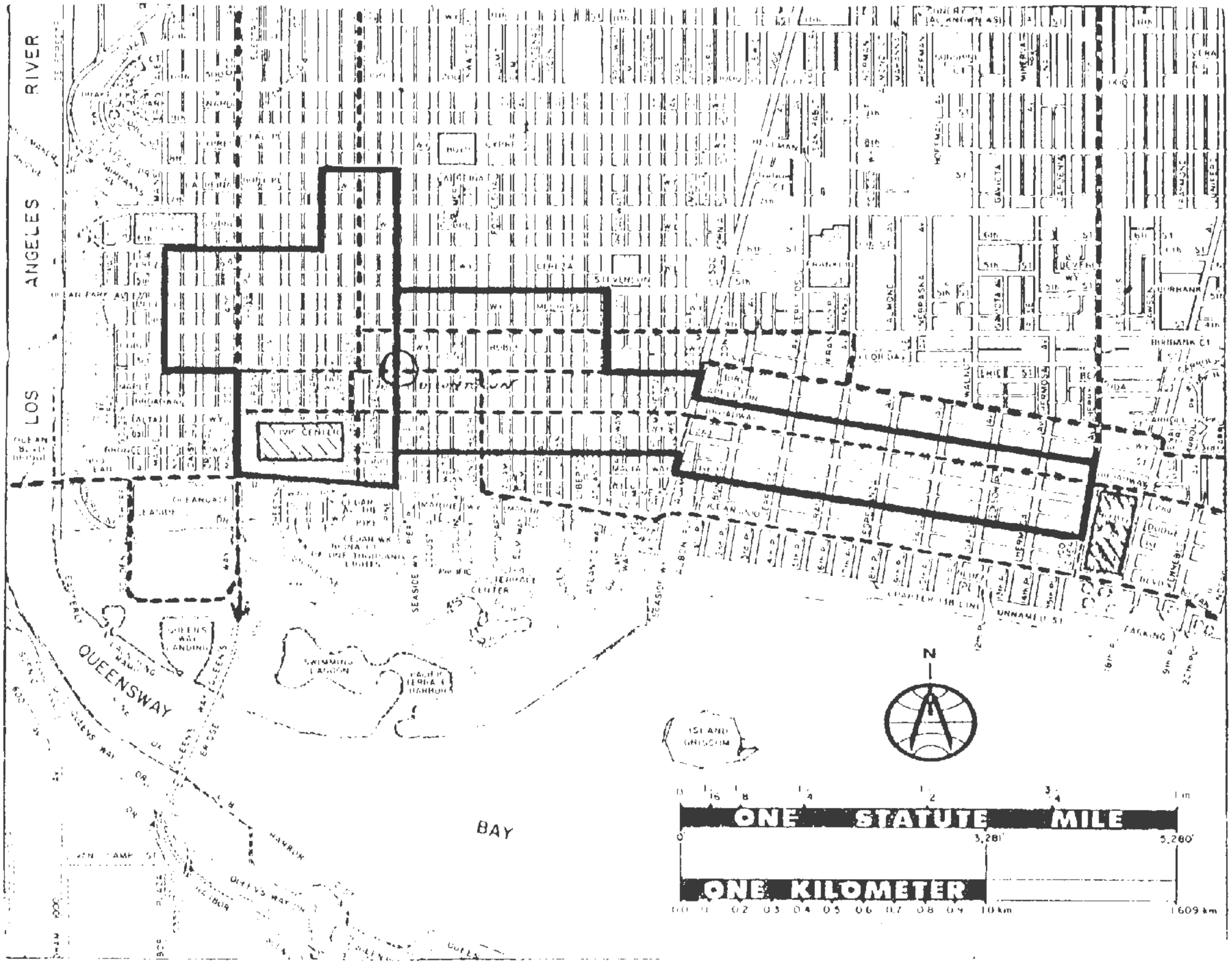


Figure 3-1. Electric Bus Route in Long Beach (solid line)
Parallel Diesel Bus Routes Shown as Dashed Lines

Scheduled stops per kilometer	3. 9 (typical) 5 (maximum)
Unscheduled stops per kilometer	2. 4
Total stops per kilometer	6. 3 (typical)
Schedule speed	10. 8 kph
Cruise speed	
Semi-residential	25-30 kph
Downtown	15
Percentage of time	
Stopped for passengers	30%
Stopped in traffic	10%
Accelerating	15%
Braking	15%
At cruise speed	30%

c. Operational Experience

Range

According to the manufacturer's literature, the traction battery provides 880 ampere-hours at 72 volts--enough to run the bus for four or five hours on each charge. Long Beach requires each bus to operate for six hours covering a total distance of approximately 56 km. The Electrobus is clearly marginal for this mission, and approximately three times a month the battery discharges to the point where the bus cannot complete its last run. When this happens, the driver radios back to the office and the spare Electrobus is sent out to complete the mission. After being left idle for a while, the empty bus will recover enough battery capacity to be driven directly back to the maintenance yard under its own power.

Performance

Actual speeds encountered in normal traffic of 25-30 kph are within the maximum capability of 37 kph on level terrain. The purchase specification required a fully loaded bus to accelerate from 0 to 32 kph in nine seconds. Observation of the bus performance demonstrated that it is considerably more nimble than a standard 53-passenger coach at the low speeds involved in urban traffic.

Handling Characteristics

Minimum turn radius of 9.1 meters makes the Electrobus reasonably maneuverable. The long front overhang (2.2 meters from front axle to front bumper) does not seem to bother the drivers. It has been reported that the heavy weight of the batteries over the rear wheels tends to make the vehicle unstable at speeds of about 80 kph. There were no stability problems at the speeds encountered in the Long Beach deployment.

Energy Consumption

Data compiled by LBPTC during the months of December 1974 through September 1975 are summarized below.

Energy consumed, kwh	43,840
Hours operated	3,054
Distance traveled, km	31,039
Scheduled speed, kph	10.16
Rate of consumption, kwh/km	1.41

In Long Beach, the Electrobuses operate only during daylight hours. Thus, the rate of energy consumption does not include power for headlights or interior lighting.

Availability

Availability is high (98 to 99 percent) for the Long Beach system. One bus is always in reserve, and well-trained maintenance personnel are available to provide service. Examination of operating records for the months of January through September 1975 disclosed no day when two buses were not operating the full scheduled six hours apiece. This achievement is due to the sound maintenance management practiced by LBPTC.

Maintenance

The only special facilities provided for maintaining the electric vehicles are the battery charge stations shown in Figure 3-2. Other maintenance is done in the regular facilities provided for the diesel bus fleet.

The major maintenance activity is associated with the batteries. The voltage and electrolyte level of one cell must be checked daily. The electrolyte level in all cells is checked and filled once a week. The batteries are also washed and cleaned periodically. Each night the batteries must be recharged for use the following day. The battery charger is also checked and adjusted daily to be sure it delivers no more than 300 amps.

Long Beach is now using a second set of batteries--lifetime has been less than three years. Both Gould and Exide have been battery suppliers.

Figure 3-2. Battery Maintenance Facilities, Long Beach

3.1.2 Roosevelt Island, New York

Roosevelt Island is a new town for 6,000 residents built on the former Welfare Island in the East River. Two hospitals add more than 4,000 employees and patients. Automobile traffic is restricted on the island. An aerial tramway provides the main access. Transit buses also serve the island, but only one franchised bus is permitted to make stops within the new town. Other buses stop at the Motorgate which also provides parking for 1,000 automobiles. Automobiles may park for limited periods within the area, but long-term parking is restricted to the Motorgate.

a. System Description

Three Model 20 Electrobuses are the primary means of internal circulation. The Roosevelt Island Service Corporation started operations with two of the buses in November 1974; the third was added in October 1976. A diesel mini-bus is held in reserve.

About 400 residents are over 62 years of age. These, plus the hospital patients, have prompted the Roosevelt Island Service Corporation to equip two of the Electrobuses with steel ramps and motorized hoists for accommodating wheel chairs.

Capital costs for the Roosevelt Island system were $85,000 for the three buses (two new, one used) and $70,000 for the battery-charging equipment and maintenance facilities.

b. Operational Profile

The route covers a single loop of 4 km serving Motorgate, the tramway, apartments, shops and other community facilities. Headways of five to seven minutes are provided during peak hours from 0700 to 0900 and 1600 to 1900, Mondays through Fridays. Frequency is reduced to 8 to 10 minutes during off-peak periods until 2200. Service is maintained at 10 to 15 minute intervals until the tramway is shut down (about 0300), and then bus service is on call only. The frequency of service on Saturdays and Sundays depends upon the number of visitors to the new town, but is usually provided at 8 to 10 minute intervals. The travelling speed is kept at a leisurely 16 kph so that riders may enjoy the sights through the large safety glass windows. Ridership varies from 30,000 to 40,000 per week. The bus fare is free. The buses each carry an average load of 45 passengers during the peak hours and an average of 15-20 during the off-peak hours.

The Roosevelt Island Electrobus route is shown in Figure 3-3. One of the Electrobuses is shown at a bus stop in Figure 3-4.

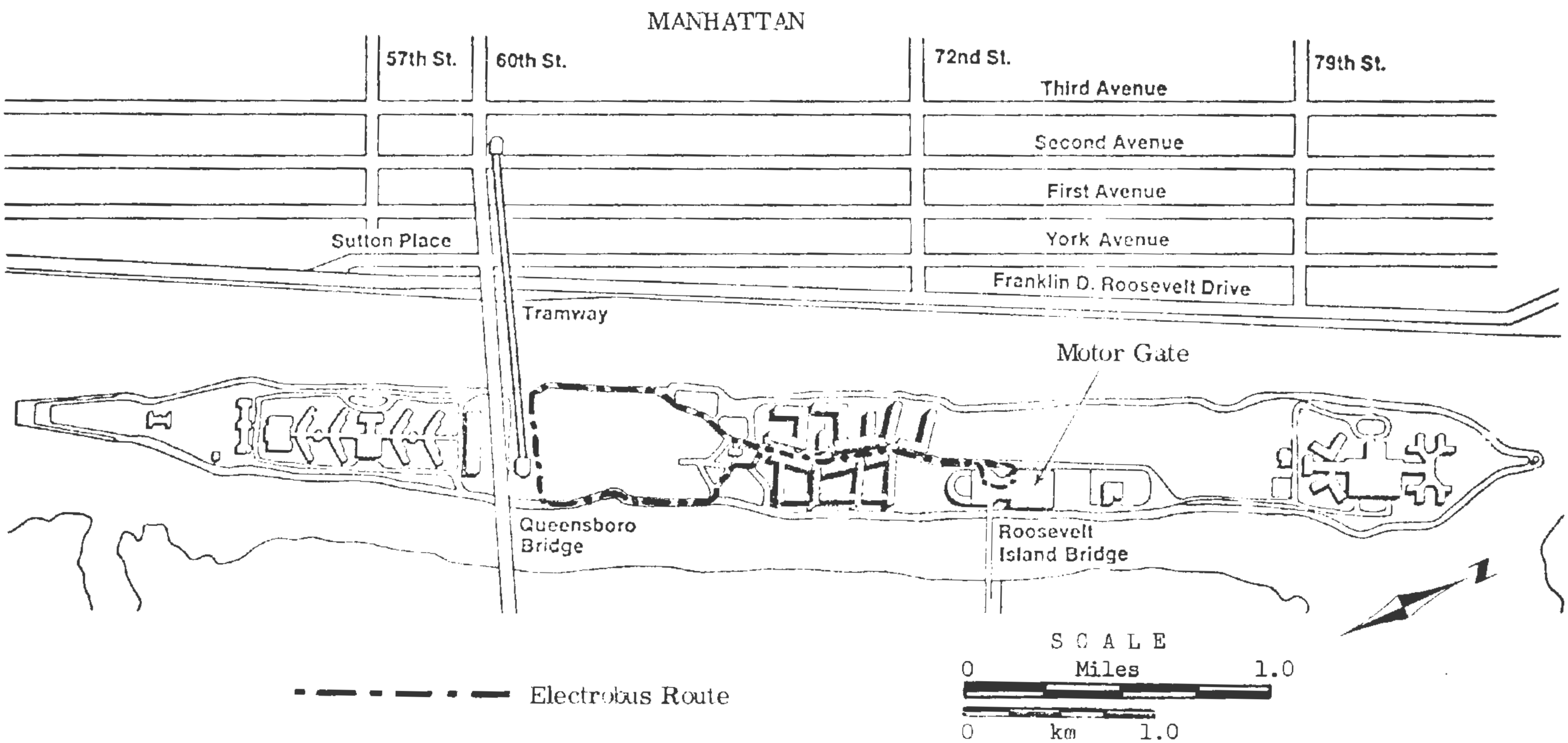


Figure 3-3. Roosevelt Island Electrobus (Mini-Bus) Route

Figure 3-4. Roosevelt Island Electrobus Loading Point

c. Operational Experience

Range

On Roosevelt Island the range varies from 55 to 80 km per charge, depending upon fluctuations in passenger loads. There are only 2 or 3 stops per kilometer and very little other traffic interference. Speed is fairly constant, but limited to 16 to 25 kph by choice.

Performance

For the type of service required, performance of the Electrobuses has been more than adequate. Speed limits established on the island are well within the bus capabilities. There is virtually no traffic to impose high acceleration and deceleration demands on the buses.

Handling Characteristics

There are virtually no grades on the route. The drivers have little difficulty in operating the buses in this "new town in town."

Energy Consumption

The Roosevelt Island bus system averages 2.5 to 2.8 kwh/km. Nighttime operations to meet the tramway and generally higher passenger loads contribute to this above-normal consumption rate for buses this size.

Availability

A standby bus and specially trained maintenance personnel devoted only to a four-bus fleet have made availabilities of 98 to 99 percent possible. It should be noted that, as a result of the unique nature of the Roosevelt Island complex, the bus system schedules late at night and on weekends are largely determined by what equipment is available.

Maintenance

As with the Long Beach system, maintenance activities are primarily concerned with the batteries. Batteries are removed by forklift truck for servicing and recharging. Figure 3-5 shows Roosevelt Island Maintenance Center. Three batteries are assigned for each Electrobus -- one for using aboard, the second one for charging, and the third one for cooling. Controller contacts are replaced approximately every 300 to 400 miles due to arcing. Driver selection is important in maintaining buses: drivers are always required to watch for contact points and loose terminal wires.

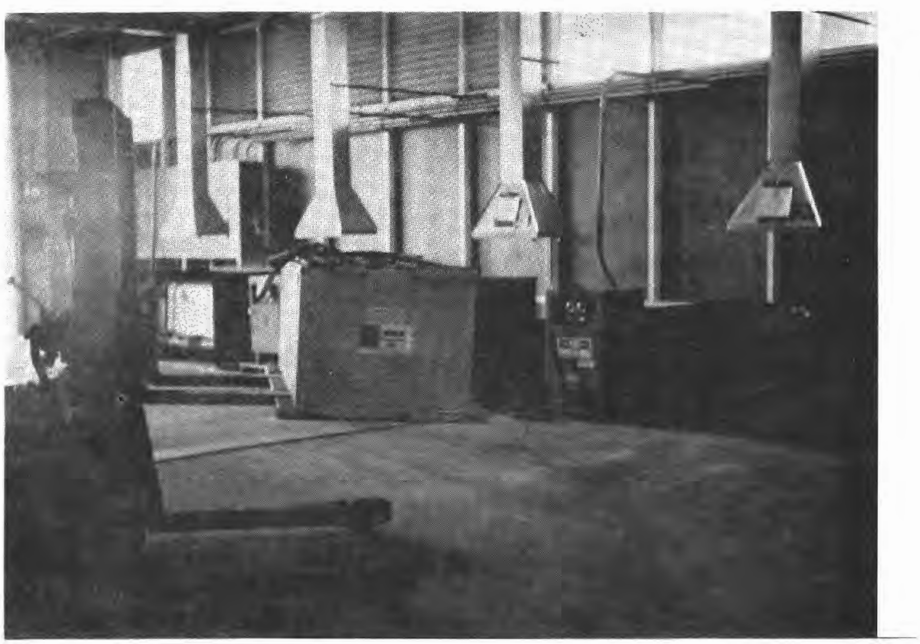


Figure 3-5. Electrobus Maintenance Center with Charger and Forklift, Roosevelt Island

3.1.3 Washington, D.C.

One Electrobus Model 20 has been in regular use by the National Capital Park Service (NCPS) in Washington, D.C., for an employee shuttle service since September, 1974. The bus was purchased by the Office of Transportation Research, National Park Service, to evaluate its adaptability for use in other park services.

a. System Description

Headquarters of the NCPS are located in Potomac Park--a point of land between the Washington Channel and the Potomac River. The bus currently provides daily shuttle service between the Headquarters, the Department of Interior and other offices in downtown Washington. A map of the shuttle service route is shown in Figure 3-6.

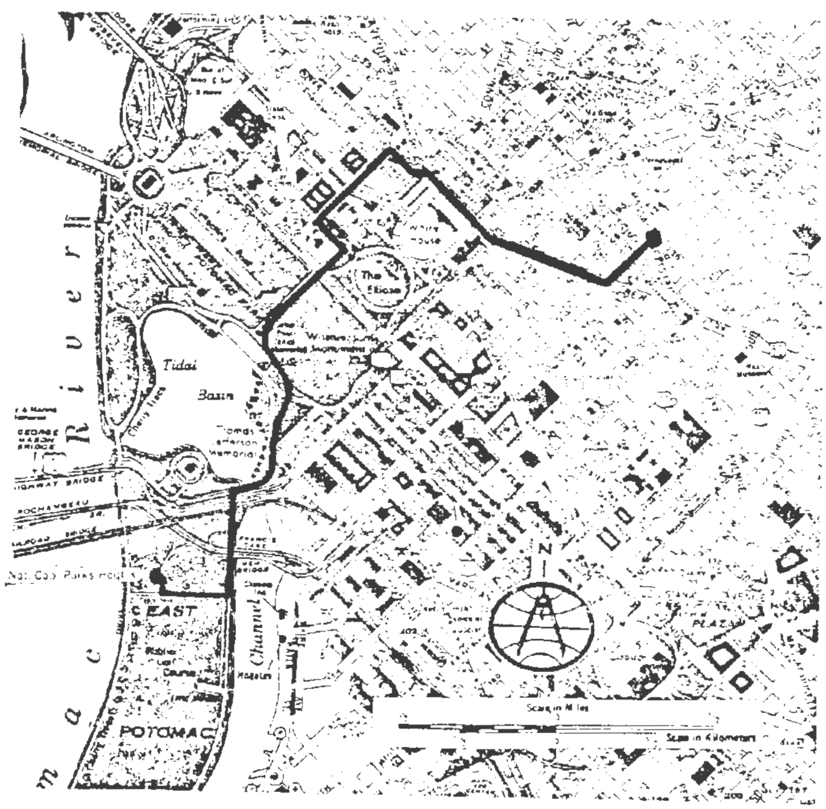


Figure 3-6. National Park Service Electrobus Employee Shuttle Service Route

The NCPS paid $49,000 for the bus, two batteries, and a battery recharge station. The Park Service already had a comprehensive maintenance facility for its diverse fleet, which includes electric cars and electric service vehicles.

b. Operational Profile

The route is about 11.8 km long and requires an hour per round trip. Eight trips a day, five days a week, are made between 0700 and 1700. The bus travels about 95 km and carries an average of 200 passengers each day.

The schedule speed for the system varies from 30 kph in the downtown Washington, D.C., area to 50 kph enroute to Potomac Park. The vehicle averages 10 passengers during off-peak hours, with early morning and late afternoon peaks of over 30 riders.

c. Operational Experience

Range

The NCPS is able to extend the range to 95 km per day by charging the batteries in place for 20 minutes during morning, noon and afternoon breaks. Higher speeds (40 to 50 kph) and fewer stops also contribute to the longer daily range.

Performance

Speeds of 55 to 60 kph have been achieved on level terrain. The vehicle responds well to one block-long three-percent grade on the route, even when fully loaded. A maximum speed of 29 kph on a 6.7-percent grade has been demonstrated on Independence Avenue. Heavy passenger loading results in noticeably decreased, but still satisfactory, acceleration.

In general, the quiet, pollution-free riding experience has satisfied the NCPS employees. The driver and passengers are also pleased with the vehicle's superior visibility.

Handling Characteristics

No difficulties have been reported in maneuvering the vehicle in heavy Washington traffic or along the expressway between downtown Washington and Potomac Park.

Energy Consumption

As the buses operate only in the daytime, energy consumption has varied between 0.93 and 10.6 kwh/km.

Availability

Though lower than reported for the other two Electrobus systems, availability for the NCPS bus has still been acceptable for the type of service provided.

Maintenance

While the driver was trained by Con Edison, maintenance personnel were not as well prepared. Inadequate preventative maintenance has caused controller contact wear, battery sulfate buildup and loose rear wheel mounting bolts. One battery has been overcharged.

Figure 3-7 shows the Electrobus being recharged from an outdoor station in the parking lot next to the NCPS Headquarters.

Figure 3-7. Electrobus Shuttle Service Route, National Capital Area Park Service, Washington, D. C.

3.1.4 Lansing, Michigan

After the city of Lansing obtained funding through a Federal Model Cities grant in cooperation with the Michigan State Bureau of Transportation, the Model Cities Policy Board and the Board of Water and Light, six Battronic electric buses were placed in service in the downtown area (Figure 3-8) in May, 1973, as a part of the Model Cities Demonstration Program. The Capital Area Transportation Authority (CATA), which was assigned responsibility for operation and maintenance of the vehicles, had little involvement in the original inception of the program. The operation was plagued with problems, and by August service was reduced to only two buses. Failure to resolve serious problems involving vehicle safety and reliability, inappropriate operating conditions, and lack of trained maintenance staff caused the remaining buses to be withdrawn from service in September, 1973, after which operation was never resumed.

a. System Description

Lansing, with a population of 129,000, is a major automobile production center, the home of Michigan State University, and capital of Michigan. The climate is severe, with extremes of -28° F to 98° F in temperature. The topography includes occasional short grades of from 6 to 8 percent.

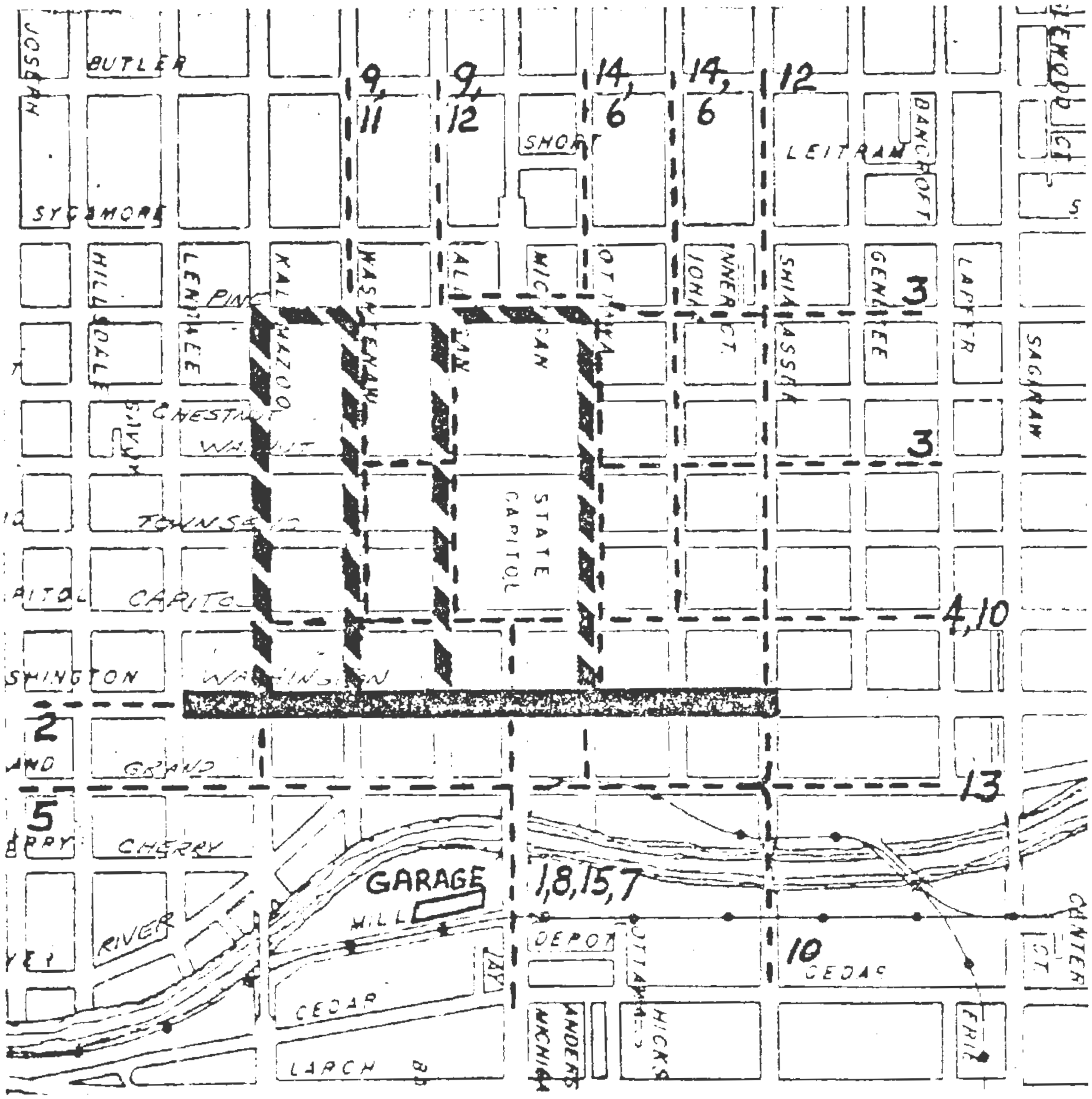
The demise of this unfortunate experiment is attributed to several factors. The project was not implemented by those who conceived it. The equipment was not adequately tested before beginning revenue service. Sufficient training was not provided for operating and maintenance personnel. The duty cycle was confused and imposed severe demands on the electric buses.

Attempts to repair the vehicles and restore service in June, 1974, were unsuccessful. The project was officially ended in September, 1974.

b. Operational Profile

As originally implemented, four buses were operated on a north-south shuttle, which included a pedestrian-only mall. During noon hours, an additional bus was added to extend the route around the state capital area, with one held in reserve. The combined round-trip length of the routes was 2.6 km. The major function of the buses was to provide circulation within the downtown shopping area and between this area and the state capital complex, with a six-day per week schedule from 0730 (0900 on Saturdays) to 1745 (2130 on Monday and Friday evenings).

Ridership was excellent on the electric bus routes during the first two weeks of operations. The buses were novel and service was free. When a 10¢ fare was charged, ridership dropped to about 150 passengers per day during June and July. The reduction of service to two vehicles in August because of



Mall Route

Noon Hour Route

Conventional Bus Route

Figure 3-8. Battronic Battery Bus Routes in Lansing, Michigan equipment problems led to a further decrease in ridership, to about 60 passengers per day.

The 15 conventional diesel-served bus routes in the area provided some downtown circulation.

Severe duty cycle demands were imposed by the slow speeds and maneuvers on the pedestrian mall, which had not been planned for bus operations. Drivers had to thread their way around large planters, parking attendant kiosks, signposts, pedestrians and parked cars. Since curb cuts were not provided, the buses had to climb up and down 4-inch curbs. Speeds of up to about 8 kph could be maintained in this area, and passengers were picked up and discharged on demand. Overall schedule speed had been planned to be 7.7 kph, with an average of 7 stops per kilometer. A duty cycle analysis of the planned route time showed 42% stopped for passengers, 10% stopped for traffic, 20% accelerating, 15% braking, and 11% at cruise speed.

c. Operational Experience

The limited operation of these buses provided useful performance data and extensive experience with maintenance problems.

Range

Range in route service was 40 km over a three-to-five-hour period. This range was affected by a 5.6% grade on the route and low scheduled speeds. Experience with a similar Battronics bus in Merrill, Wisconsin, indicates that range is cut approximately in half during sub-zero weather.

Performance

Speeds of 32 kph were achieved with full charge. Acceleration was 1.8 kph/second; 18 seconds were needed to accelerate from 0 to 32 kph on level terrain. A speed of 32 kph was achieved on a 5% grade in 30 seconds. Low speed performance was found to be more of a problem, based on cooling deficiencies in the controller mechanism.

Handling Characteristics

The truck-type suspension provided marginal rider comfort. Minimum turning radius of 8.0 m gave good maneuverability, but serious problems developed in the steering mechanism. Inspection by the Michigan Public Service Commission revealed excessive steering play and binding. Loose steering gears, bent tie rods and steering gear failure were also reported.

Energy Consumption

Average power consumption over 25,000 km was 1.14 kwh/km, over mostly level terrain. While this result was greater than that specified by the manufacturer, the inefficiency of the controller at low speeds was cited as a factor.

Availability

Availability during the six months of operation was about 60 percent. SCR overheating, motor and steering gear failures, and problems with the 12-volt auxiliary power system compounded by the inadequate maintenance training contributed to the low availability. Figure 3-9 shows fleet availability in Lansing.

Maintenance

The major scheduled maintenance tasks were checking and filling battery cells and removing and recharging batteries. An Exide #ETS-42-3-500 SCR charger was employed, with characteristics shown in Figure 2-4. Training for maintenance personnel was inadequate in this system, resulting in considerable repair delays in some instances, and possibly contributing to failure rate by lack of proper preventative maintenance. Man-hours charged to electric bus maintenance were 158.5 in July (with four vehicles in daily service) and 53.5 man-hours in August (two vehicles in service). Unscheduled repairs were frequently necessary. SCR overheating was a major problem that caused main rectifiers to burn out. Electrical wiring was undersized and caused fires. Other problems included motor splice failures and steering gear failures. There were many problems with the 12-volt auxiliary power system until a separate DC/DC converter was installed.

Costs

The price for six Battronic electric buses in January 1973 was $136,340.04, broken down as follows:

6 buses @ $14,944.21 =	$89,665.26
12 sets Exide #42TSC-11 batteries @ 2,664.24 =	31,970.88
6 Exide battery chargers #ETS-42-3-500 @ $1,182.35 =	7,094.10
1 battery lift truck =	3,409.80
Freight to Lansing =	4,200.00
Total	$136,340.04

This is equivalent to a total price of $173,152 in 1976 dollars based on the wholesale price index for motor vehicles and equipment.

The electric vehicles in current dollars cost about $28,859 each with needed support equipment. Direct operating costs (excluding administrative and other indirect charges) were apparently in excess of $2. 66 per vehicle km. Of this, over three-quarters were attributable to drivers' costs because of the low speeds involved. With typical daily ridership taken as 150 riders and typical daily mileage during the same period of 218 miles, the break-even fare would have been $6. 22 per rider. It is clear that the Lansing experiment, which charged a fare of $. 10 per rider, was not an economically viable proposition.

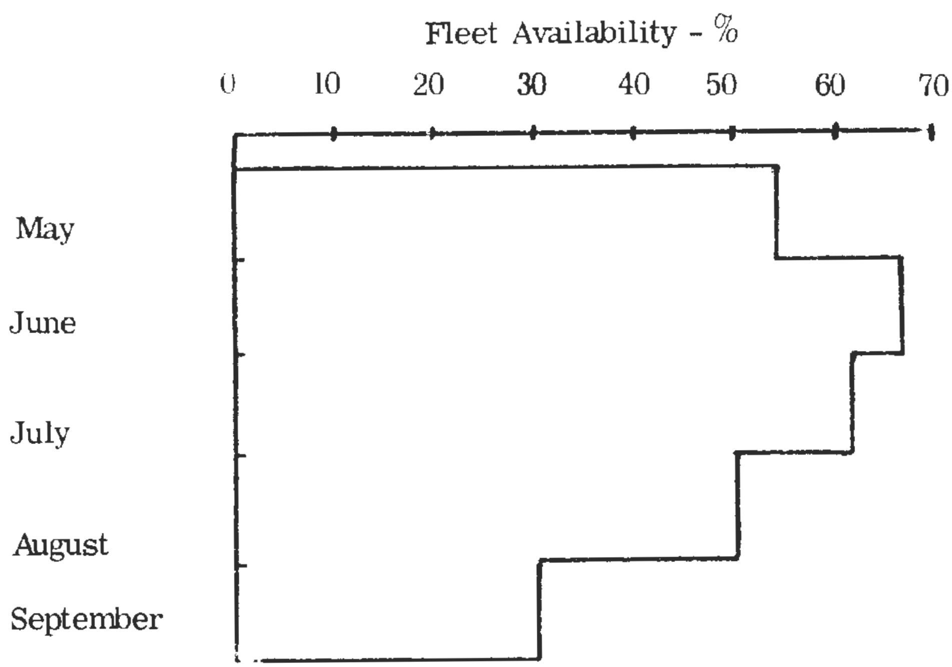


Figure 3-9. Battronic Bus Fleet Availability in Lansing, Michigan

3.1.5 Department of Industry--DOI (14 Cities) England

As described in Chapter 2, the DOI Battery Electric Bus Project was intended to give transit operating agencies experience with battery-powered buses. The two buses built by Crompton Electricars used conservative technology as it was understood in 1970. The attempt was not to advance the state-of-the-art, but to apply existing technology and years of experience with electric delivery vehicles to public transport operations. The objective was to put the quoted benefits of electric buses into perspective.

a. System Description

The primary interest in small electric buses arose from a need to provide service in city centers. Transit operators wanted buses that were quiet and unobtrusive in pedestrian areas, easy to board and alight from, and which used proven equipment insofar as possible.

Fourteen routes were assigned for the two buses; seven were existing bus routes, seven were to be utilized for the first time. The seven new routes were selected to test the design capabilities of the buses. The routes varied in length from 0.9 to 11.3 km. Two of the routes provided urban transit; the other 12 furnished city center circulation. The daily range of the buses for each route was a function of duty cycle, topography, and passenger loads.

The characteristics of the routes and load factors encountered varied widely among the deployments, and a correlation between these factors and the range achieved on one battery charge was not attempted by the British investigators.

b. Operational Profile

Buses were assigned to the transit operators for periods of three to four months. The assigned routes were on fare-paying services. The practical limits of the vehicle were recognized. Table 3-1 summarizes the operational profiles of routes in the 14 cities which participated in the in-service tests.

c. Operational Experience

Table 3-2 summarizes the operational experience with the two Crompton buses.

Range

On the newly assigned routes, the vehicle was able to meet range requirements on six out of the seven. Of the existing routes, the bus was able to meet

TABLE 3-1. OPERATIONAL PROFILE OF 14-CITY DOI IN-SERVICE TESTS

Place of Operation	Route Characteristics	Maximum Grade (%)	Route Length (km)	Scheduled Average Speed (kph)
Leeds	Undulating	4	4.0	10.1
Sheffield	Hilly/Undulating	8	6.1	11.1
Birmingham	Hilly, Undulating	10	3.5	10.5
Edinburgh	Gently Rising	3	4.7	9.4
Nottingham	Undulating	14	3.4	10.2
Warrington	Flat	0	11.3	11.3
Chester	Gently Rising	3	3.1	12.5
Liverpool	Gently Rising	2	4.8	8.0
Bourenmouth	Dead Flat	0	4.8	9.2
	Hilly/Undulating	6	0.9	6.4
Bolton	Flat/Undulating	-	2.9	10.1
Norwich	Undulating	12	6.8	13.6
Peterborough	Flat	0	3.2	12.8
Blackburn	Undulating	5	2.0	12.0
Manchester	Flat	0	10.6	12.0-13.8

* Scheduled Average Speed is defined as the distance covered in one hour of schedule.

Source: Battery Electric Bus Project; Final Report, D. A. Saunders, Department of Industry, London, England; 1976.

TABLE 3-2. SUMMARY OF OPERATIONAL EXPERIENCE, DOI IN-SERVICE TESTS

Place of Operation	Actual Maximum Daily Range on One Battery Charge (km)	Distance Scheduled (km)	Distance Operated (km)	Availability (%)	Energy Consumption (kwh/km) Traction	Heating
Leeds	72	5,430	4,290	79	1.35	-
Sheffield	72	3,370	3,175	94	1.55	-
Birmingham	53	2,875	2,025	70	1.55	0.12
Edinburgh	58	4,430	4,170	94	1.55	0.22
Nottingham	64	2,265	1,740	77	1.5	-
Warrington	80	9,020	7,060	78	0.95	0.16
Chester	100	8,700	6,620	75	1.25	-
Subtotals/Averages	71	36,090	29,080	80.5	1.3	0.17
Liverpool	100	4,340	3,050	70	1.3	-
Bournemouth	69 56	4,980	4,550	91	0.70 1.37	-
Bolton	85	6,890	5,630	82	1.1	0.16
Norwich	56	5,700	4,970	87	1.1	-
Peterborough	75	1,580	1,580	100	1.0	-
Blackburn	88	3,240	3,120	96	1.1	0.12
Manchester	84	4,480	3,770	84	1.1	-
Subtotals/Averages	77	31,210	26,670	85.5	1.1	0.14
Overall Totals/Averages	74	67,300	55,750	82.8	1.2	0.16

Source: Battery Electric Bus Project; Final Report; D. A. Saunders, Department of Industry, London, England; 1976 the range requirements of only three out of seven. Thus, the buses were able to satisfy the ranges scheduled by nine of the fourteen routes operated. The actual distances traveled on one charge varied from 63 km to 100 km.

Performance

No difficulties were reported in meeting the speed and acceleration requirements of the routes. Surveys of passengers' attitudes toward the vehicles, though response was limited, found them consistently sympathetic. The operators regarded lack of emissions and low noise as desirable, but were unwilling to fix a premium for these qualities.

Handling Characteristics

Some features of the DOI buses were criticized by all operators. However, details of these criticisms were not made available. The battery weight to gross weight ratio (29.7%) was the highest for the midi buses and one of the highest for all buses studied. It also has the highest curb weight of the midi buses. These factors, plus the use of a reinforced truck chassis, would tend to make handling of these buses "stiff." The "automatic transmission effect" of the electric buses, not usually found on conventional midi buses, was greatly appreciated by the drivers.

Energy Consumption

Energy consumption averaged 1.2 kwh/km for traction and 0.16 kwh/km for heating. Particularly because of the heavy weight of the vehicle for its passenger capacity, consumption was found to be greater than for conventional diesel buses. In addition, regenerative braking was not provided.

The lowest energy consumption was recorded on two routes that were essentially flat. There was also an indication that a Spegal-type charger may have been more efficient, accounting for the difference in energy consumption between the two vehicles, but no direct test comparisons were made.

Availability

Vehicle distance for the two buses was 55,750 km out of 67,300 scheduled km during the 31 months of passenger carrying operations. One prototype operated 29,080 km out of 36,090 scheduled km. Availability ranged from 70 to 94 percent, averaging 80.5 percent. The other bus operated 26,670 km out of 31,210 scheduled km. Availability ranged from 70 to 100 percent, averaging 85.5 percent. The overall average availability during the 31-month project was 83 percent. This figure can be compared with the conventional diesel bus availability rate of 90 percent.

The two primary factors adversely affecting the DOI electric bus availability rate were:

- o The experimental nature of the vehicles involved utilizing many weaker developmental components that would not be expected in production vehicles.
- o The 3-4 month schedule of rotating the vehicles to new operating sites reduced the availability of spare parts and trained maintenance personnel.

DOI concluded that when considering these two factors the electric battery buses should easily be comparable to conventional diesel buses in fleet availability.

Four defect types accounted for 83 percent of all lost duty.

1. Faults with the controller varied from difficulties with the foot switch to of electronic components. A similar controller had been used on electric milk delivery vehicles with a high record of reliability. The high failure rate on DOI buses was attributed to the particular units.

2. Faults were found in the handbrake, the vacuum pump drive, the vacuum-motor control system, the hydraulic system and linkages in the rear wheels. The requirement for considerable design improvement, and closer attention to the braking system in general, was acknowledged.

3. Battery/electrical system problems included defective battery cells that had to be replaced, and inadequate insulation between the battery poles and chassis. The overall solution is the complete insulation of battery boxes from the chassis. Isolation of low-voltage auxiliary power supplies from the higher voltage traction supply would also improve reliability.

4. The original vehicle design used electric thermal storage convection heaters charged during the night. The high loss of service was due to inadequacies in the heating system other than defects. The heat output of the equipment was half that available to drivers of conventional buses. During cold weather, drivers often refused to operate the buses. Modifications provided some relief, but energy for space heating in electric battery buses continues to be a problem.

<u>Maintenance</u>

The number of hours of maintenance carried out on the two Crompton vehicles was considered high in comparison with conventional buses. However, the maintenance effort was not regarded as representative of production vehicles since there were needs for recording data and experience, battery maintenance tended to err on the safe side, and maintenance time included correction of faults not likely to be found on production vehicles.

While battery exchange was considered as a way of giving the buses an extended range, the technique was not extensively used. It was tried as an exercise in Birmingham and used in Norwich as a regular procedure. The design of the Crompton vehicle did not allow the efficient use of battery exchange for recharging, as five battery cases must be removed and replaced with hand-operated pallet trucks for each exchange.

Scheduled maintenance activities centered around the electric systems. DOI concluded that the battery electric traction system for buses should require no more attention than the systems in the 40,000 electric delivery vehicles used throughout Great Britain. It was estimated that routine maintenance of the vehicle traction and other electrical systems (excluding component replacement) should require approximately 140 man-hours per year. Routine battery maintenance comprises the largest part of this effort. Use of an automatic topping-up technique was considered to have the potential for reducing electrical systems maintenance by 70 percent.

3.1.6 Manchester, England

The Greater Manchester Passenger Transport Executive (GMPTE), including Lancashire United Transport, operates 572 bus routes. These services were formerly provided by the South East Lancashire and North East Cheshire (SELNEC) Passenger Transport Executive and the County Borough of Wigan.

a. System Description

Several surveys performed by SELNEC of the operating areas revealed the following:

- o The average speed of buses engaged in city center services between 0630-1000 and 1530-1830 is about 14 kph.
- o Approximately 45 percent of the vehicle fleet is utilized for less than 7 hours in every 24.
- o Between the peak hours of 0630 and 1000, and again between 1530 and 1830, 90 percent of the buses on routes which pass through city or large town centers cover less than 65 km. Nearly 50 percent of the buses cover less than 40 km.

These factors generated interest in the development and use of electric battery buses and GMPTE took on the task in 1974. A Lucas midi-bus was acquired for service on February 28, 1975. Operations with the Chloride "Silent Rider" were initiated on April 14, 1975.

b. Operational Profile

1. Lucas Midi-Bus

The Lucas bus was assigned Route 4, Centreline, which provides circulation service in the heart of Manchester and connects two railway stations and two bus stations. The round trip is 4. 3 km with 4. 5 stops per km and an 8 percent grade 100 m long. The electric bus was one of 17 assigned the route, providing three-minute headways during peak hours, five days a week. Patronage per trip amounted to about 27 riders during peak hours and 17 during the off peak.

Figure 3-10 depicts the Centreline Route. The Lucas Mid-bus, in service on this route, is shown in Figure 3-11.

MANCHESTER, ENGLAND

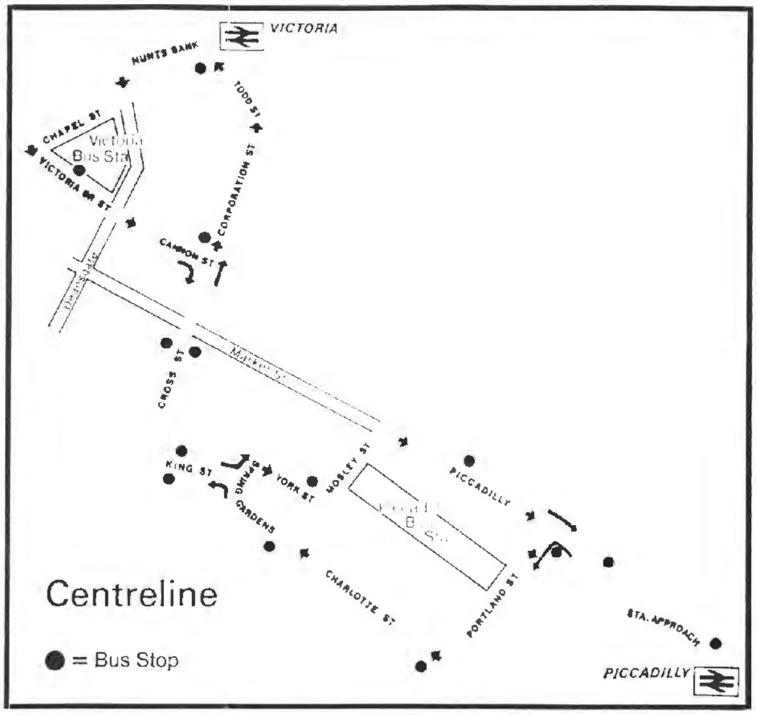


Figure 3-10. Centreline Route in Manchester, England

Figure 3-11. Lucas Midi Bus on Centreline Route

2. Chloride "Silent Rider"

Because the Silent Rider is a larger bus, unwieldy for the Centreline Service, it was assigned to commuter service on Route 203. This transit route is 7 km long (14 km round trip) and connects the Victoria Railway Station with the town of Reddish across Manchester. Silent Rider was assigned three round trips during the morning and evening peak hours and carried approximately 25 passengers per trip, weekdays only.

c. Operational Experience

The Lucas Midi-bus could achieve a range in excess of 58 km on the route. However, in actual practice it completed two runs daily of about 29 km per charge each. An average of 6 round trips over the 4.3 km route were made on each run between charges.

Silent Rider made commuter runs for 2 1/2 hours in the morning and evening peak periods. Each run achieved three round trips totaling 42 km on one charge.

Performance

Both vehicles were able to meet the speed and acceleration requirements of the assigned routes.

The Lucas bus was moved to South Yorkshire for operation in Doncaster starting in January 1977. The Chloride bus was also moved to Doncaster in August, 1976. While in Manchester, the two battery buses accumulated the following vehicle-kilometers.

Lucas --	17,055 km	(includes all services)
Chloride--	7,080 km	(includes 1,610 km in demonstrations)
Total	24,135 km	

The Lucas bus was able to match the performance of the diesel midi buses on the same route. The passenger reactions were very favorable, particularly since there was a complete absence of vibrations. The drivers observed that the buses were so quiet that patrons frequently whispered to keep from being overheard.

The Chloride bus was found completely satisfactory in matching the performance of equivalent diesel buses.

Handling Characteristics

Drivers of both buses appreciated the lack of gear shifts and the rapid acceleration in leaving bus stops. The Lucas bus, being smaller, is more maneuverable, but handling characteristics of both buses were considered acceptable.

Energy Consumption

Operations of the Lucas bus in Manchester averaged about 1.9 kwh/km. For the Silent Rider, the average energy consumption was about 3 kwh/km. From comparisons with fuel consumption of equivalent diesel buses, it was concluded that energy requirements were about the same.

Availability

During a four-month period for which adequate data were available, the Lucas bus recorded an availability of 96 percent. Availability for the Chloride bus was not readily determined, because it was frequently diverted for demonstrations and modifications associated with the experimental program. For both buses, considering all the days out of service for all reasons--including demonstrations, modifications, routine and unscheduled maintenance--the availability was probably less than 50 percent. This figure compares with a vehicle availability of 80 percent for the diesel buses in the same fleet.

Maintenance

Regenerative braking was the major maintenance problem on the Lucas bus. By reducing the regenerative braking rate, problems of excessive reverse torque on the axle were alleviated. Inadequate space heating and failures of the heaters caused the drivers to refuse to operate the buses on some winter days. Space on the midi bus for equipment is minimal. Adequate room for heaters and fuel was not provided in the original configuration.

The main cause of failures on Silent Rider was the motor controller. This item was the newest development on the bus and the regenerative feature created maintenance problems. Regeneration was essential for adequate ranges of operation, but problems in switching circuitry and high reverse torque initially limited performance. The rear axle was a standard unit, not designed for high braking torques. Replacement with a heavy-duty unit and modifications in the circuits have reduced these problems.

3.1.7 Sheffield, England

a. System Description

In 1975, at the conclusion of the Department of Industry Battery Electric Bus Project, the two Crompton buses were purchased by the South Yorkshire Passenger Transport Executive (SYPTE). The buses were redesigned and rebuilt. One bus was placed in service; the other was still at Cableform, Ltd., being modified (March, 1977). The Lucas and Chloride electric battery buses at Manchester were also borrowed. The plan was to consolidate the available electric battery buses under one operation by the SYPTE.

b. Operational Profile

The midi-buses (one Lucas and one rebuilt Crompton) were assigned to the Inner Circle Route (No. 160). The second rebuilt Crompton bus will also operate on this route when it is placed in service. The Inner Circle Route is 3.6 km long, and serves two bus stations, the railway station and shopping facilities in the town center. There is one 3.3 percent grade, 50 meters long, on the route. Average stops, including traffic lights, amount to 6.5 per km. Scheduled trip time is 15 minutes, with buses operating at 10-minute intervals. The electric buses serve the peak hour from 0730 to 1050, are recharged during the midday break, and are then out again for the afternoon peak from 1530 to 1855. Patronage for a 6-day week operation is about 3,500 riders. Figure 3-12 shows the bus route near Sheffield.

The full size Silent Rider has been assigned to Route 173, Hyde Park Circle. This is a combination line haul and circulation service. The route length is 4.8 km with 7.5 stops per km. There is one 2.7 percent grade 220 meters long. Scheduled trip time is 20 minutes. The intervals between buses are generally 10 minutes on weekdays and 20 minutes on Sundays, starting at noon. Silent Rider is assigned the morning peak from 0630 to 0845 and the evening peak from 1600 to 1800. The route is shared with other conventional Seddon RU type buses. Ridership on the route averages about 12,000 passengers per week.

c. Operational Experience

(1) Crompton Midi-Bus

Range on a single charge over the Inner Circle Route is 72 km, with the batteries 50 percent discharged.

Speed on this route is 17 kph.

Since the bus has been recently introduced on the route, there are no data on energy consumption, availability or accumulated vehicle-kilometers. Passengers liked the electric bus. A survey of passengers showed that they also preferred the electric vehicle, mainly on the smoothness of operation and the reduction in noise levels.

The drivers became aware that operation of the quiet buses required caution. They frequently approached to within a meter of pedestrians without alerting them to the bus' presence.

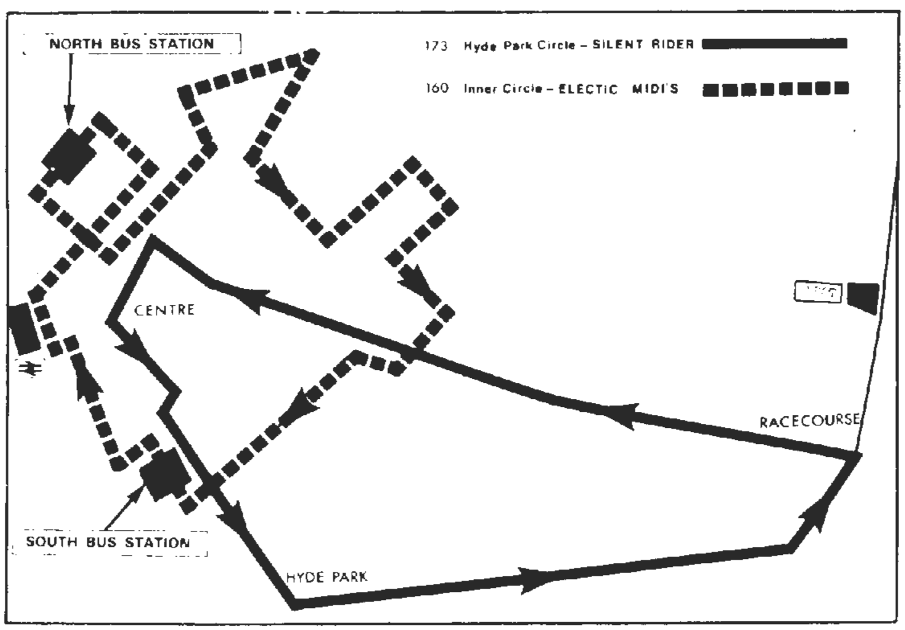


Figure 3-12. Route Map for Electric Battery Buses in Doncaster District Near Sheffield

(2) Lucas Midi-Bus

Range on the Inner Circle Route is about 43 km per charge. Two runs are made each day. Figure 3-13 shows the Lucas Midi-Bus on the Inner Circle Route.

Speed on the Inner Circle Route averages nearly 17 kph.

Energy Consumption remains about 1.9 kwh/km.

Availability has dropped slightly to 88 percent from introduction of a newly designed, flat-plate cell, lightweight battery.

Vehicle-kilometers for three months of operations are approximately 2,250 km.

(3) Chloride "Silent Rider"

Experience is based on operations performed from August through October, 1976. Figure 3-14 shows the "Silent Rider" on the Hyde Park Route.

Range required was initially 71 km and subsequently increased to 85 km. This range was well within the demonstrated capability of 120 km for this type of service. Figure 16 shows that nearly half the total buses on city center routes during morning and evening peak periods cover less than 40 km, and that an additional 40% cover less than 64 km. A study shows that a battery-operated bus has a potential range of 64 km in this system. A system was conceived in which battery-powered buses could be used during the two peak periods. The Chloride Legg PRV charging was developed so that batteries could be charged in less than 6.5 hours.

Speed on the Hyde Park Circle Route averages over 19 kph.

Energy consumption--measured over 1440 km in operating service-was estimated at 1.76 kwh/km.

Availability, based on 27 days of operations, was over 72 percent.

Vehicle-kilometers operated were 1446 km, of which 1250 km were on the Hyde Park Circle Route.

Cumulative distances performed in service for the Lucas and Chloride buses in the two PTE's are tabulated below:

PTE/Bus	Lucas	Chloride	Total
Manchester	17,055	7,080	24,135
Sheffield	2,253	1,446	3,699
Total	19,308	8,526	27,834

Figure 3-13. Lucas Midi Bus on Inner Circle Route

Figure 3-14. Silent Rider on Hyde Park Route

3.1.8 Runcorn, England

a. System Description

The Department of Transportation initiated development of the electric battery bus in 1971 through an engineering design contract with Ribble Motor Services, Ltd. Operations in Runcorn started in November, 1975. See Figure 3-15.

This new town is located near the west coast of England on the Irish Sea, south of Liverpool. It is planned for a population of 100,000 and now has over 54,000 residents. A 24 km exclusive busway serves Runcorn in such a way that 90 percent of the people who live and work there are within a five-minute walk of bus service; Crossville Motor Services, Ltd., operates the transit system.

b. Operational Profile

Bus service on the exclusive busway is at 5-minute intervals during peak hours and 30-minute in the off-peak hours. Nearly 49,000 passengers per week use the bus system. Average running speeds on the exclusive busway are 32 kph -- twice the speed a bus can achieve in normal traffic. The bus operates four hours each morning, of which two hours, 41 minutes, are actual running times. The route extends more than 80 km which the electric bus covers with a battery discharge of 70 to 75 percent.

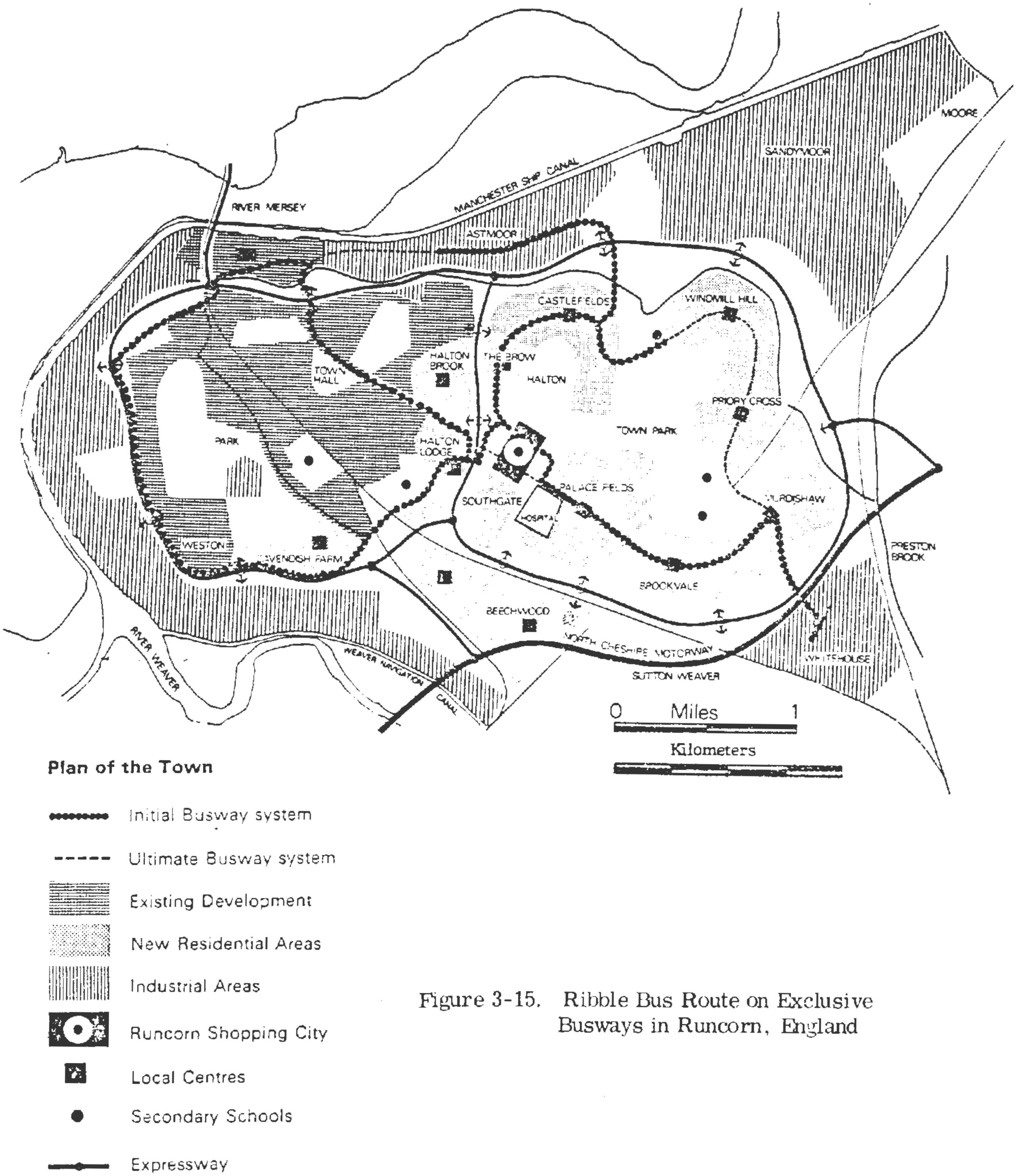


Figure 3-15. Ribble Bus Route on Exclusive Busways in Runcorn, England

3.1.9 Tours, France

a. System Description

The Societe Anonyme d'Economie Mixte des Transports Publics de Voyageurs de L'Agglomeration Tourangelle (SEMITRAT) began an electric battery bus service in Tours, France, employing five Renault Sovel buses, in January, 1976. Operation is provided six days a week in the mid-town area on Route #12, serving municipal buildings, markets, depots, and other public facilities. Service is suspended during July and August. Ridership averaging 400 per day is composed of 60% using monthly passes and 40% buying individual tickets each day.

The five vehicles run at approximately 15-minute intervals around the 7.6-km route shown in Figure 3-16 with loading and unloading stops made on passenger demand. These average five per kilometer, except in congested areas where established stops are used. Daily operation, except Sundays, is provided from noon to 8:00 p.m. The buses each travel about 60 km per day on an overnight battery charge, with maintenance being performed each morning. Route speeds are under 10 kph in congested midtown areas and 13 to 14 kph over the rest of the route.

c. Operational Experience

The vehicles have accumulated 98,370 km (through June, 1977) while transporting 189,415 passengers. Energy consumption has averaged 2 kwh/km for the five buses. The dependability of the prototype vehicles has been inferior to conventional combustion engine buses, but the operators expect an ultimate reliability equivalent to that of electric trolleys, which are relatively trouble-free. Details of operating problems and necessary repairs have not been made available. The suppliers of various subsystems have generally participated in maintaining the vehicles and training of mechanics for electrical repairs. Operating costs have been tabulated below comparing battery and conventional buses in Tours.

Battery Bus Costs, Francs per Km	
Recharging	.17
Battery replacement	1.25
Capital costs	1.21
Maintenance (parts & labor)	.71
Driving	3.96
Total	7.30 F per Km

Conventional Bus Costs, Francs per Km	
Fuel	.54
Capital costs	.95
Maintenance	.90
Driving	3.96
Total	6.35 F per Km

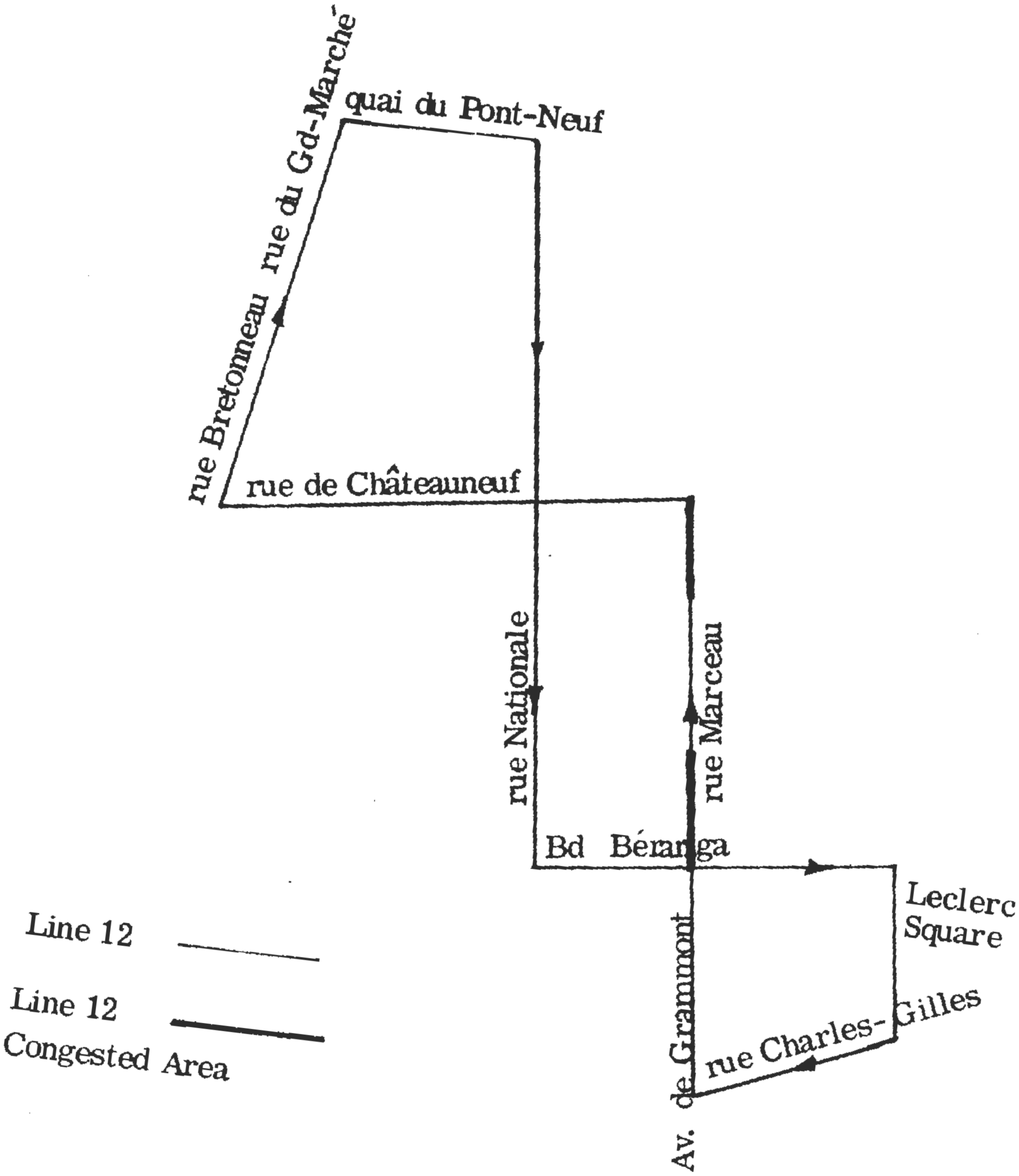


Figure 3-16. Sovel Battery Bus Route 12 in Tours, France

3.1.10 Mönchengladbach, West Germany

a. System Description

Batteries are carried on a one-axle trailer to avoid major modifications to the bus chassis. The bus carries 99 passengers with 33 seated and 66 standing. Development was coordinated by G. E. S. in Düsseldorf. Twenty-two buses have been built; seven M. A. N. buses operate on one line in Mönchengladbach. Operations began in Mönchengladbach in October, 1974.

b. Operational Profile

Line No. 9 is served exclusively by seven electrobuses. The route is 40 km long, out and back, with 94 bus stops. It provides transit service through residential areas, an auto-free shopping mall, and express service to a suburban square. The buses run from 4:30 p. m. -1:00 a. m. Each round trip requires 2 hours and 20 minutes. Batteries are exchanged at one change station after each run, even though battery capacity remains, to prevent excessive discharge. Bus intervals are scheduled at 20 minutes during peak hours, 30 minutes during off peaks and on Sundays. Each bus travels 280-320 km per day. In 1975, 4,227,000 passengers used this line; 4,014,000 rode the electrobuses in 1976. Figure 3-17 shows Elektrobus Line No. 9, and Figure 3-18 shows M. A. N. bus on Line No. 9 in Mönchengladbach.

c. Operational Experience

Range on Line 9 is 40 km for each battery charge at less than 50 percent discharge.

Speeds of 70 kph have been achieved in tests.

Energy Consumption is 2. 34 kwh/km, mean, for 20 buses.

Availability has been 94%, discounting battery and charger problems.

Vehicle-kilometers were 857,000 km through April, 1977.

Experience with the vehicles confirmed that use of a well-proven bus body adapted to electric drive could reduce developmental problems. It was found that thyristor controller failure could produce a dangerous accelerative jerk forward before original fuses were blown. A fast-acting electronic circuit breaker has eliminated this potential hazard, and an added temperature-controlled fan holds controller temperature at an acceptable level.

During the program, maintenance of conventional vehicle components has been performed by the operator, with the electrical system servicing by G. E. S. and the manufacturers.

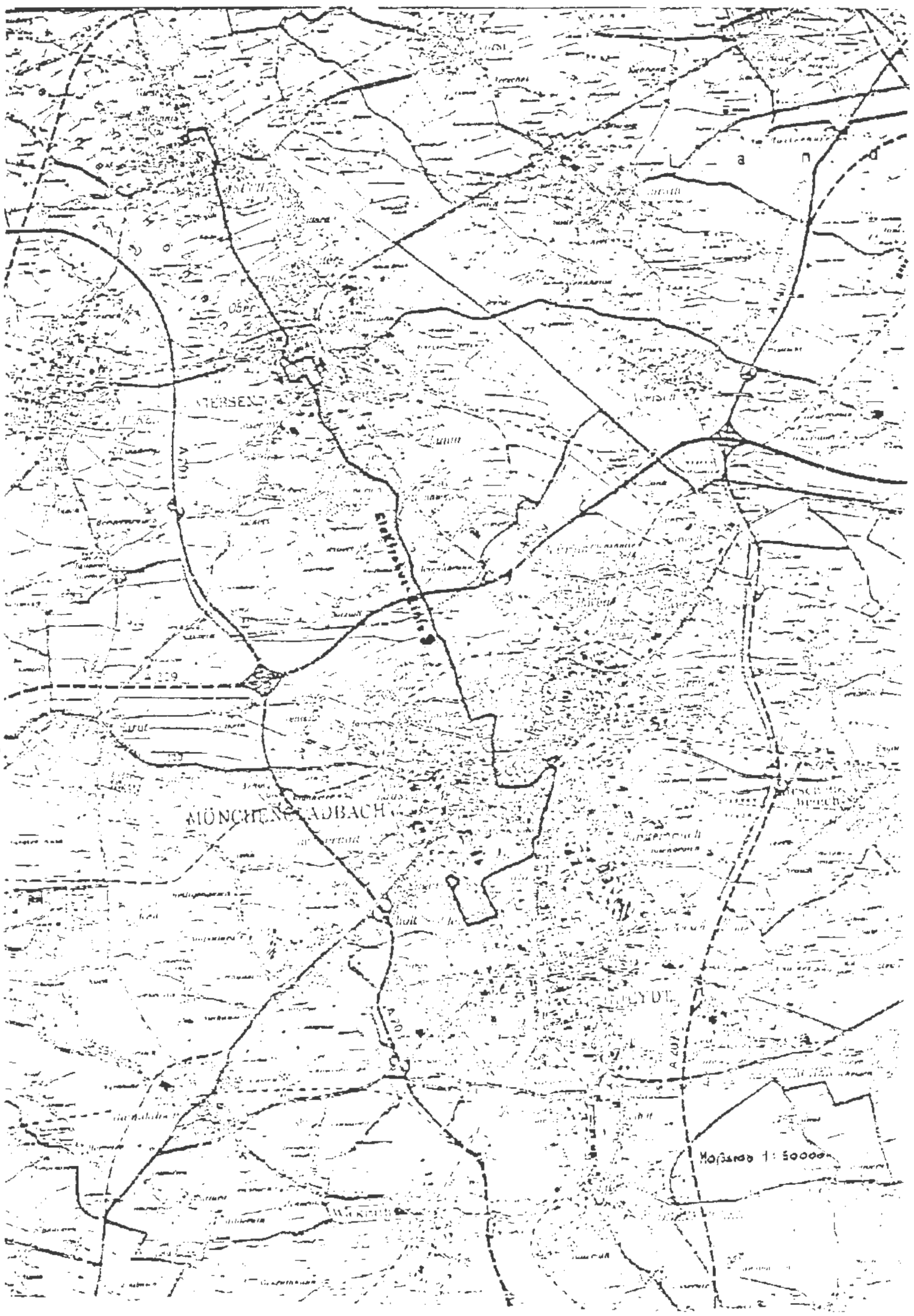


Figure 3-17. Elektrobus Line No. 9 in Mönchengladbach

Figure 3-18. M. A. N. Bus on Line No. 9 in Mönchengladbach

3.1.11 Düsseldorf, West Germany

a. System Description

The largest electric battery bus system in the world operates in the Nordheim-Westfalen area of West Germany. Operations started in Mönchengladbach with seven buses on 15 October 1974. In May, 1975, 13 more electrobuses started service in Düsseldorf. The development and operational demonstration of the system has been under the coordination of the Gesellschaft für Elektrischen Strassenverkehr (G.E.S.) (Electric Road Transport Company). The electric bus development plan includes a five-year large-scale testing program.

b. Operational Profile

The schedule for the electric buses was adopted from the diesel bus time table. Two lines in Düsseldorf are served entirely by 13 electrobuses. Line 39 provides local circulation over a round-trip route 10.5 km long, connecting a residential district with the transport system of the Federal Railway and the S Railway. There are 26 scheduled stops along the route. From three to ten electrobuses maintain intervals varying from six minutes in peak hours to 30 minutes during off hours and on Sundays. Each bus normally makes five round trips before returning to the change station for a battery exchange. One bus is kept in reserve. Figure 3-19 shows M.A.N. Bus Line 39, and Figure 3-20 shows a M.A.N. bus in Düsseldorf.

Line 62 provides a line-haul service over a round-trip route 28.8 km long connecting Monheim with Benrath. The trip travel time is 1 hour, 18 minutes, with 60 scheduled stops. Two electrobuses are assigned to the route. Buses are spaced 30 minutes apart with both buses during peak periods and one hour apart with one bus at other times. Each bus makes two round trips on one battery exchange.

There are three change stations in the maintenance yard near Genrath for both lines. Each station holds two spare batteries and one empty slot for the exchange battery.

c. Operational Experience

For Line 39 the range is 60 km, since the buses make five round trips and must also travel 1.5 km each way from the terminal to the charge station. The batteries are more than 50 percent discharged on these runs. Two round trips on Line 62 extend the range to 68 km with batteries approximately 75% discharged.

Speeds of 70 kph have been achieved in tests. Cruise speeds in traffic average 26 kph, and increase to 30 kph on express runs on Line 62.

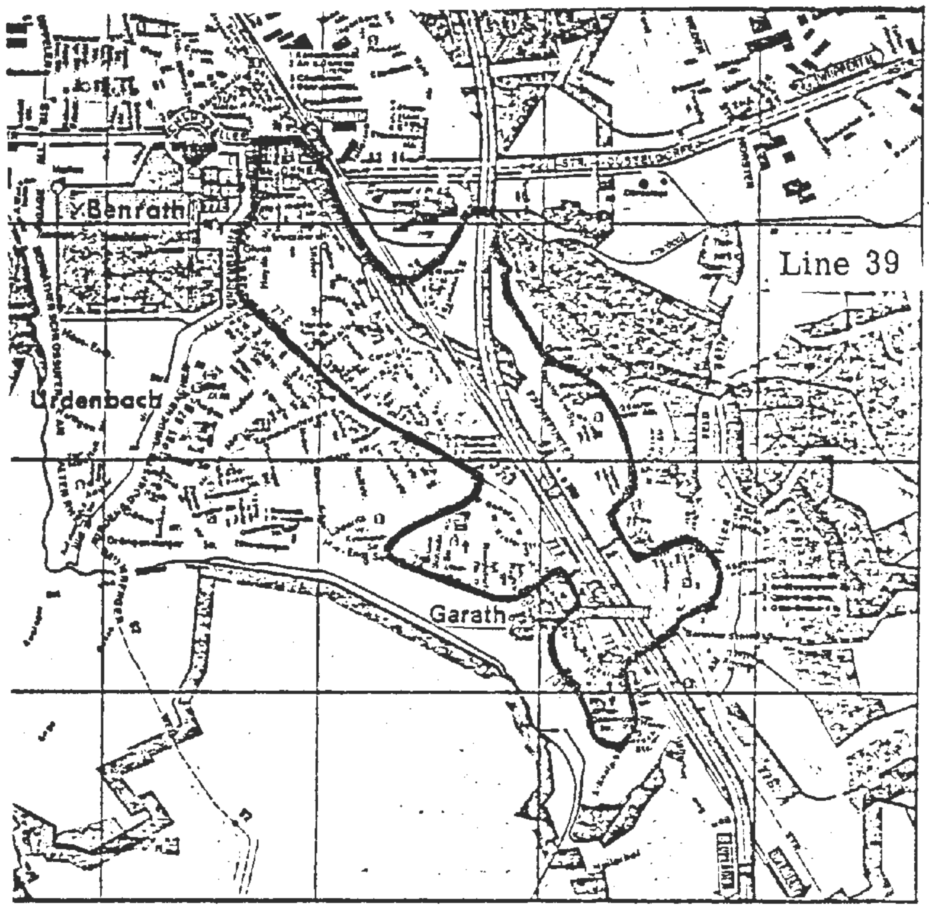


Figure 3-19. M. A. N. Bus Line 39 in Dusseldorf

Figure 3-20. M. A. N. Bus on Line No. 39 in Düsseldorf

Energy consumption is 2.34 kwh/km as a mean value for the 20 buses.

Availability discounting battery and charge station problems has been 94 percent at Mönchengladbach and 93 percent at Düsseldorf.

Vehicle-kilometers accumulated in passenger-carrying service have been 857,000 km in Mönchengladbach and 934,000 km in Düsseldorf, a total of 1,791,000 km through April, 1977

Maintenance problems with air compressor noise, trailer line wear, and the cooling and lubricating systems were corrected without much effort. The motor brush life is presently 20,000 km. Further tests with various types of carbon are planned, and the brush life is expected to double. The regenerative braking system, while provided 13.8-19.5% power regeneration, caused greater rear tire and rear axle wear than diesel bus brakes do. Tests to reduce the torque on the axle are currently being conducted. Traction motor temperature overload protection was added.

The diesel hot water heating system for the cab uses an extremely high amount of fuel (70 litres) - enough to power a standard 192 HP diesel engined bus up to 200 km. First tests with a water temperature dependent on external temperature have been made by the G. E. S.

3.1.12 Osaka, Japan

a. System Description

The Osaka Transportation Bureau has been operating two Isuzu EU05 battery buses since April, 1972. The buses run in parallel with diesel buses on existing routes. Osaka had electric bus experience during World War II when Japan turned from oil to alternate battery source of energy.

a. Operational Profile

The buses alternate among four different routes where the runs do not exceed 75 km. Schedules originally called for operations seven days a week with no operations during the noon period on Wednesdays, Thursdays, and Sundays. Transit speeds average 15 kph. The garage has an automatic battery exchange and recharge installation. See Figure 3-21 for battery bus and 3-22 for battery exchange.

b. Operational Experience

Energy consumption is about 1.98 kwh/km in urban driving cycles.

Range in an urban driving cycle with 4 stops per km, and 40 percent of rated load, was 82 km. In actual usage, the range between battery exchanges was from 20 to 60 km.

Availability is 95 percent.

The buses have operated 30,000 to 40,000 km per year.

Vehicle-kilometers are estimated at 350,000 km for both buses--assuming they have continued to operate for the five years since April, 1972.

Figure 3-21. Isuzu Battery Bus in Operation

Figure 3-22. Automatic Battery Exchange for Isuzu Bus

3.1.13 Kyoto, Japan

a. System Description

The one Mitsubishi TB 13 has been operating in Kyoto since November, 1972. This battery bus is a converted trolley bus. This bus was apparently an experiment to ascertain the costs and performance of a minimal conversion. Kyoto is considering the use of electric battery buses for a nearby new town of 40,000 to be completed in 1983.

a. Operational Profile

The TB 13 bus runs a 11.5 km route in the heavily congested downtown area of the city. The TB 13, currently in its infant stage, is expected to provide efficient service in pollution-critical downtown areas where rider volume is high and typical route lengths do not tax the vehicles' optimum range.

b. Operational Experience

Range for the TB 13 is approximately 60 km in normal traffice, and 140 km at a constant speed of 40 kmh.

Speed capability is 55 kmh maximum on a full charge. The acceleration rating is 0-40 kmh in 23.5 seconds. The maximum grade capability is 13.3%.

Energy consumption has not yet been established.

Availability has not yet been established.

Vehicle-kilometers in passenger service has not yet been established.

3.1.14 Kobe, Japan

a. System Description

The Kobe Transportation Bureau (KTB), Kobe, Japan, has been running four Mitsubishi ME 460 buses since September, 1975. The KTB has publically emphasized the benefits and care in the production and operation of the ME460, focusing particularly on the pollution, effieiency, and safety aspects.

a. Operational Profile

The four buses run five routes, with a 23.5 km route (round trip) in the downtown area. An intricate battery exchange/recharging station has been built which automatically removes a battery from under the bus and replaces it with a fully charged one. Figure 42 depicts the detailed charge station diagram. The maximum grade is 4.5%. Average number of stops per kilometer is 2.8.

b. Operational Experience

Range is 50 km in actual transit operations and 170 km at a constant speed of 40 km.

Speed capability is a maximum of 61.2 kmh at a full charge. The acceleration rating is 0-30 kmh in 6.9 seconds; 0-40 kmh in 15.0 seconds. The gradeability is 7% at 29.5 kmh; the maximum grade capability is 15%.

Availability has not been established.

Vehicle-kilometers accumulated by the four electric battery buses operating in Kobe from September 1975 to February, 1977, averaged 38,552 km each for a total cumulative running distance of about 154,000 km.

The following energy consumption comparisons are shown:

Diesel bus -- Yen 23.28/km (fuel)

Electric bus--Yen 31.40/km (electricity) and Yen 148.30/km (battery replacement)

Note: One U.S. dollar equals Yen 275.

3.1.15 Nagoya, Japan

a. System Description

The one Hino BT900 battery bus has been operating in Nagoya since March, 1973. Toshiba Electric Co., Ltd., and Hino Automobile Co., Ltd., developed the prototype battery bus. This bus is potentially marketable and production versions have been offered to SEPTA.

a. Operational Profile

Heavy downtown traffic congestion has been moderated by recent provision of police-enforced special bus lanes. Typical bus stops are 460 meters apart, or every two blocks. Average route length is 64.3 km.

b. Operational Experience

Range is approximately 70 km in urban transit service. 170-km range is attainable at a constant speed of 50 kph.

Speed of 60 kph is achieved on level terrain with fully charged battery. Vehicle can negotiate a 12.7% grade at reduced speed. Average route speed is 13.1 kph.

Vehicle-kilometers. Approximately 14,200 km have been recorded since March, 1973.

3.2 Hybrid Buses

Three systems are considered in which battery energy is supplemented with an additional power source. In the Dornier vehicle, at Esslingen, Germany, a roof-mounted trolley automatically engages overhead wires on a portion of the route to accomplish recharging during travel for a maximum off-wire range of 10 km after 10 km of trolley operation.

Mercedes-Benz and Kawasaki hybrid buses each incorporate a small fixed-output diesel engine which operates an electric generator interconnected through control circuits to both the battery (for charging) and the traction motor (for peak power demands). Design of diesel engine for narrow speed and output range permits deployment of more effective pollution-reduction measures.

3.2.1 Esslingen, West Germany

Esslingen, east of Stuttgart, is one of three German cities with overhead-wire trolley-bus service.

In a cooperative development program supported by the German Ministry for Research and Technology, the firms R. Bosch GmbH, Daimler-Benz AG, Dornier Systems GmbH and the city of Esslingen completed a prototype vehicle, the Duo-Bus Model OE302, in April, 1975. This vehicle draws power from overhead wires where they have been installed, and operates on battery supply when away from the overhead system.

a. System Description

Esslingen is a rapidly expanding city with a number of nearby suburbs and villages. The existing overhead-wire system supports a number of conventional electric trolley-busses, which are limited to wire-only service. System expansion without further trolley-wire installation has been the objective of the operators, as well as the eventual elimination of expensive street tracks and special right-of-way routes.

The city of Esslingen has taken advantage of the unit's flexibility to extend route segments and to institute express service, since the vehicle can pass conventional trolleys while running on battery. Changes in routing and detours around construction sites or traffic accidents are possible without modification of the overhead system. If the trolleys become disengaged while going through a switch or while bypassing an obstacle, propulsion is automatically switched to the batteries until the trolley is automatically re-engaged by the driver at the next stop. Power source transitions are not sensed by the passengers. The Duo-Bus system can eliminate the need for unsightly and complex switches or crossovers in the overhead wiring system at intersections--a major detraction of conventional trolleys--by passing these points on battery power.

b. Operational Profile

Esslingen route (see Figure 3-23) includes 8 km equipped with overhead lines and 25 km of battery-only detours off the line into suburban and old-town areas. The longest route segment away from the wires is 10 km. Operations are kept to under 16 hours per day to prevent overheating of the batteries. Some old-town segments of the off-wire route replace service previously supplied by diesel buses.

Since batteries are recharged concurrently with trolley operations on a 50/50 basis--1 km off-wire for every 1 km on--route was planned to take full advantage of charging possibilities.

c. Operational Experience

Three months of experience, through March, 1977, have accumulated about 13,000 km total running distance with an energy consumption of 1.8 kwh/km. Availability has been above 90%. Short period in operation to date has not permitted evaluation of battery or other components' service life and maintenance record.

Battery heating in continuous service was not alleviated by intensive air-cooling. Plans are being made for liquid battery cooling and cell water refilling devices. Electromagnetic radio interference at 800 Hz from the thyristor controller and charging circuits will be reduced with a high-frequency filter. The possibility of thyristor interference with implanted heart pacemakers has been mentioned, but no data is available.

Performance and handling characteristics have been trouble-free, with improvement obvious over trolley-buses.

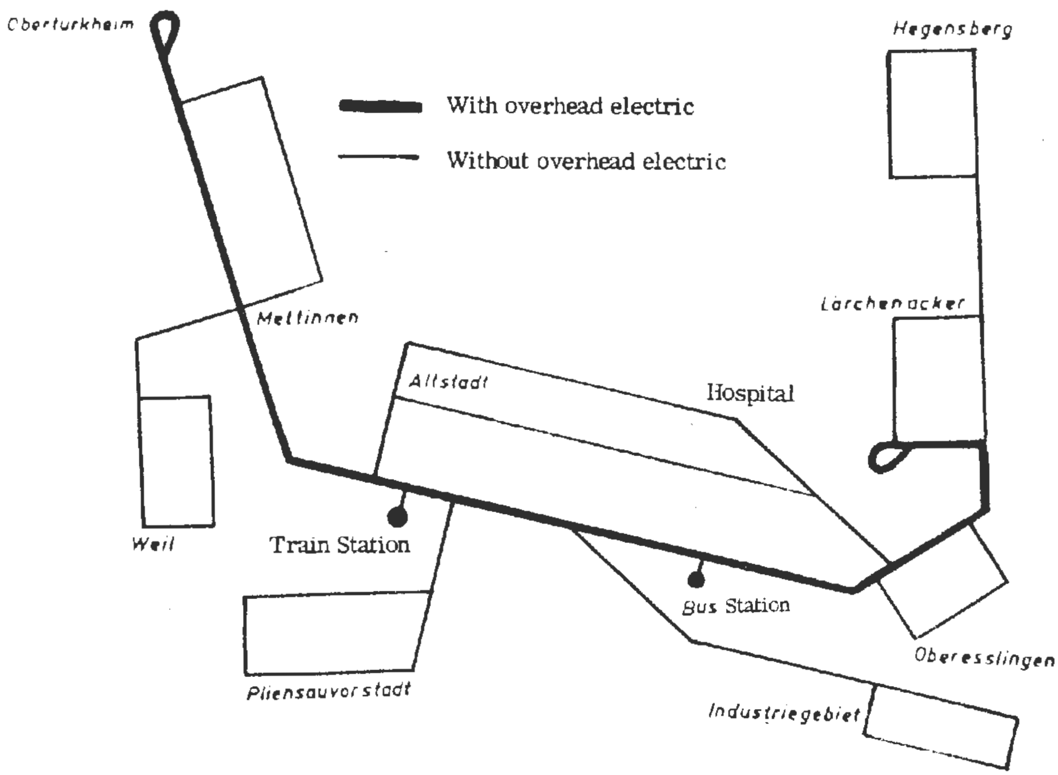


Figure 3-23. Traffic Route in the City of Esslingen

3.2.2 Wesel, West Germany

a. System Description

Developed by Mercedes-Benz with Bosch electric motor and controls, the OE305/1 utilizes a small 100 hp, 6-cylinder diesel engine operating a 74-kw generator at constant output to extend the range from battery-alone value of 50 km to 75 km to a hybrid range of 300 km. The first prototype began three-month tests in March, 1977. By the end of 1977, regular operations are expected with 20 buses serving two or three lines.

b. Operational Profile

In March, 1977, Gesellschaft fur Elektrischen Strassenverkehr (G. E. S.) (Society for Electric Street Traffic) supervised a three-month test of the OE305. The bus operated Monday through Friday from 7:00 a. m. to 12:00 noon. on Wesel bus route number 5. Figure 3-24 shows a Mercedes-Benz OE305 in Wesel.

c. Operational Experience

Range

On a 29-km test route, with 50 bus stops and a 3-km-long 8% grade, the bus range on batteries alone was 40 km; the range using the hybrid system 45% of the time was 100 km.

Performance

Data from the test operations started in March, 1977, is not yet available.

Figure 3-24. Mercedes-Benz OE305 Diesel Battery Hybrid Bus Operating in Wesel

3.2.3 Tokyo, Japan

a. System Description

The Transportation Bureau of the Tokyo Metropolitan Government originally had four hybrid, diesel-electric buses in operation starting in November, 1972. There are now only two in use--one in the Fukagana Branch and one in the Otsuka Branch.

a. Operational Profile

Vehicle travels for seven hours along a 104.3 km route through Tokyo at an average route speed of 14.9 kph. The diesel engine is stopped and the bus proceeds on the battery alone in the vicinity of schools, hospitals and residential areas, for up to 55 km per charge.

b. Operational Experience

Energy consumption for daily 104.3 km route through Tokyo is 58.2 liters of diesel fuel and 23.3 kwh of nighttime charging for a rate of 0.56 liters per kilometer and 0.22 kwh/km.

Availability has been about 70% for the four prototypes, operated from November, 1972, through 1976, when operation of two buses was discontinued.

Vehicle-kilometers accumulated by the four buses are approximately 320,000 km.

CHAPTER 4

SYSTEM ASSESSMENTS

If electric battery buses are to be successfully introduced into use for urban public transportation, consideration should be given to the following:

o Planning for the use of battery buses should recognize the capabilities of existing systems. Advantages offered by the vehicles can be exploited, while allowances can be made for their disadvantages.

o Procurement of available equipment presents some problems and constraints. Attention should be given to warranties and to servicing required during the early stages of operations.

o Implementation of battery bus systems affords unique opportunities to build on the experiences of other transit operators. Product improvements as well as comparative data on costs and performance can be obtained from adequate program implementation plans.

These matters were reviewed with suppliers and operating agencies during the assessment. Results from this phase of the system assessments are discussed in the following sections.

4.1 Capabilities of Existing Systems

4.1.1 Battery Buses

Buses adapted for electric-battery propulsion ranged from 22-passenger midi-buses to standard 100-passenger transit coaches. They were used for a variety of services from city center circulation to line-haul transit service. Routes, schedules and duty cycles were designed to fit the capabilities of the particular buses that were available.

4.1.1.1 Performance

Range

Under ideal test conditions, the buses demonstrated ranges of 40 to 180 kilometers on a single battery charge. In actual transit operations, the ranges utilized were 24 to 80 kilometers. The test results are indicative of the potential capabilities of these systems. The actual operations reflect traffic conditions, terrain, temperatures, and variations in passenger load. The block of runs (the total number of trips made by the bus from the time it left the garage until the time it returned) for one battery charge was usually planned by most transit operators to insure that the batteries were not discharged more than 50%. This helped to prolong battery life. Where discharges of more than 80 percent occurred (for example on the DOI tests and in Long Beach battery performance and life cycle were adversely affected.

A study conducted by the South East Lancashire North East Cheshire Passenger Transport Executive (SELNEC) in England found that nearly 50 percent of the buses on city center trips during peak periods cover less than 40 km. An additional 40 percent cover no more than 65 km, which means that 90% of all buses in this district could be battery buses based on presently available range capabilities. Studies in U. S. cities indicate that there, too, appears to be a large potential for using battery buses.

Speed and Acceleration

Battery buses showed capabilities for speeds from 32 to 72 kph. Acceleration from 0 to 32 kph could be achieved in 8 to 10 seconds. The grades which the buses could ascend at reasonable acceleration rates varied from 5 to 16 percent. These capabilities generally exceeded the actual demands placed on the buses. Local speed limits and traffic conditions were well within the performance capabilities of the buses. Drivers appreciate the ability of these buses to accelerate away from bus stops and into traffic. They appreciate the absence of manual gear shifts to achieve cruise speeds.

Noise

The electric battery buses are relatively quiet. Noise measurements inside the buses found typical decibel (dB) levels of 60 to 70 -- attributed to air compressors and cooling motor fans. These values increased to ranges of 65 to 80 dB while accelerating due to the sounds from the traction motors, gear boxes and chopper controls. While running, the noise levels inside were typically 65 to 70 dB. On the exterior, the highest value noted was 80 dB during deceleration to a stop. The senior citizens in Long Beach favor the electric buses because they are quiet. Drivers on the Centerline Route in Manchester noticed that passengers frequently whispered to keep from being overheard.

Assessment -- Performance

o Advantages

- Saving of petroleum resources

- High acceleration rates from 0-25 kph demonstrated by most electric battery buses give them advantages over diesel buses where there are many stops.

- Electric battery buses are comparatively quiet and are virtually pollution free.

- The performance characteristics are particularly well suited for providing public transit services in city centers and automobile-free shopping malls.

o Disadvantages

- Limitations in the performance of existing electric battery buses, particularly in range, require planning in assigning routes and schedules.

- Drivers must be sensitive to the limitations of equipment and performance in order to obtain the best utilization.

- Temperature extremes can adversely affect bus performance.

4.1.1.2 Duty Cycle

The duty cycle assigned an electric battery bus, including the route length, number of runs, operating hours and rest periods between runs, depends on the performance of the bus and the battery recharging procedure. The SELNAC study mentioned above also found the following:

o The average speed of buses engaged on city center service driving during the peak hours between 0630-1100 and 1530-1830 was less than 14 kph.

o Approximately 45 percent of the vehicle fleet is utilized for less than 7 hours in every 24 hours.

On the basis of this type of utilization, there is ample opportunity to recharge batteries on board the bus during off-peak periods, when the buses are not in use. Batteries can be fully recharged overnight before the morning runs. Since sound practice does not result in discharging the batteries more than 50%, the interval during the noon period provides sufficient time to recharge the batteries for evening operations. Variations in the duty cycle also permit short periods of on-board recharging in order to top off the battery capacity. By adapting the duty cycles to these strategies for on-board charging, urban running distances of 42 to 100 km can be achieved each day.

In an endeavor to obtain greater utilization of the vehicles, devices have been developed and successfully demonstrated in Germany with the M.A.N. buses and in Japan with the Isuzu, Mitsubishi ME460 and Hino buses which automatically exchange batteries. The exchange requires less than five minutes and can be made during waiting periods between runs. The duty cycle can be planned to insure that the number of runs per charge does not discharge the battery more than an acceptable level. Though there is usually enough time between runs for a battery exchange, the duty cycle for a fleet of electric battery buses must stagger the exchanges so that exchange facilities are not over-taxed. Buses continue in service while the off-loaded batteries are recharged and have achieved total running distances each day of up to 350 km.

Battery Charging Methods

The methods of recharging or exchanging batteries affect the duty cycle and operations with electric battery buses. The advantages and disadvantages are discussed below.

Assessment -- On-board Charging

- Advantages
  - Recharging is simple, involving little more than plugging the charger into the bus.
  - Batteries can be topped off by charging for short periods of time between runs, thus extending both the range and battery life.
  - Cutting bus runs is simpler, because it does not involve scheduling battery exchanges.
- Disadvantages
  - Operations are limited to one or two peak periods during the day. The vehicle is unproductive at other times (as are a high percentage of the conventional fleet).
  - Flexibility in assigning routes or making substitutions on runs is restricted by the capability of the fixed battery installation.
  - Faults in the battery bus may keep the vehicle out of service for extended periods of time.

Assessment -- Battery Exchange

- Advantages
  - Full use can be made of the electric battery bus throughout the operating day.
  - Duty cycles can be made more flexible -- more options are available in assigning runs and in substituting trips.
  - Batteries can be serviced and recharged on cycles independent of bus operations.
  - Drivers and maintenance personnel can be better utilized.

- Disadvantages

  - Initial investment in spare batteries and exchange facilities is considerable. Locations must be planned to minimize dead-heading for each exchange. Sites must be arranged to accommodate the number of scheduled exchanges.

  - At least three spare batteries must be kept serviceable and charged for each two buses in operation.

  - Battery exchange mechanisms, automatic chargers and the consequences of frequent battery replacements contribute to system down time.

4.1.1.3 Availability

As used in this report, availability is a measure of actual performance in transit service as a percentage of scheduled requirements. Either days of service or kilometers travelled have been the basis for determining availability. These percentages depend upon three factors: 1.) the reliability of components which comprise the system; 2.) adequately trained operating and maintenance personnel; and, 3.) the availability of spare parts.

The availability of the electric battery buses for passenger-carrying service was reported to be from 50 to 100 percent. Typical rates varied from 83 to 95 percent. The experimental nature of the vehicles used for the in-service demonstrations made a higher than normal rate of defaults almost certain. The comparatively high degrees of availability reported are attributed to the special servicing given these vehicles before each run, as well as the inherent reliability of most of the propulsion elements.

The low availabilities reported for some operations had little to do with electric battery bus technology, per se.

o Space heating devices, either stored thermal heaters or fuel-fired hot water heaters, were not adequate or reliable. Passengers making short trips were not seriously affected. However, drivers who were expected to stay with the vehicle for extended periods eventually refused to take the battery buses on a run unless the heating systems were satisfactory.

o Maintenance and repairs often required the services of specialized personnel where time, or the scope of a one-bus test program did not warrant training regular maintenance personnel. The specialists were not always available and the buses waited until they could be assigned. Frequently spare parts were unavailable at the test site. Repairs occasionally required the redesign or special manufacture of replacement parts. In either case, the buses waited until personnel or parts could get them running again.

The batteries and electronic control systems, with regenerative brakes, caused the most difficulties with sustaining operations. These items represent the most advanced technologies used in the buses and it is reasonable to expect that they would exhibit the most problems. The faults are understood -- solutions are largely a matter of engineering and production quality control.

4.1.1.4. Energy Consumption

Typical values for energy consumption ranged from 0.93 to 2.64 kwh/km for the midi-buses and 1.64 to 3.1 kwh/km for the regular transit buses. The least consumption was reported by the National Capital Area Park Service Electrobus. Duty was light and batteries were topped off between runs. Consumption for the Roosevelt Island Electrobus at 2.64 kwh/km reflects nighttime service and the consistently high patronage levels.

For the regular transit buses, the four Mitsubishi ME460 buses operating in Kobe reported the lowest consumption rate. The highest rate was attributed to Silent Rider on the Reddish to Victoria run in Manchester.

Heating

The above energy consumption figures do not include heating requirements. The DOI project with the Crompton vehicles found that energy consumption by the heaters when averaged over the year added between 0.12 and 0.22 kwh/km.

The M.A.N. buses consumed as much as 70 liters of fuel oil daily to meet space heating needs. For a standard transit bus with a 192 hp diesel engine, this fuel consumption for heating is equivalent to 200 km of operations on a city route. The need for finding rational and economic heating methods on electric battery buses is clear.

Motor Type

Results of test comparisons between types of traction motors indicated that the separately excited, shunt-wound, motor can reduce energy consumption. Data from the M.A.N. program are summarized below.

Specific Battery Charge Consumption	Mönchengladbach	Düsseldorf
- Separately excited motor	4.30 amp-hrs/km	4.20 amp-hrs/km
- Series-wound motor	4.92 amp-hrs/km	5.01 amp-hrs/km
Specific Battery Consumption		
- Separately excited motor	1.42 kwh/km	1.39 kwh/km
- Series-wound motor	1.62 kwh/km	1.65 kwh/km

Tests conducted by Chloride Technical, Ltd., for typical operating cycles with a series-wound traction motor averaged 0.131 kwh per 1,000 kg per km. With a separately excited motor, results averaged 0.110 kwh per 1,000 kg per km.

4.1.1.5 Life-Cycle Costs

No life-cycle cost analyses of electric battery buses were uncovered during this study. Neither were adequate data available on capital and operating costs for any one system on which to make such an analysis. The Final Report of the DOI Battery Electric Bus Project presents a comparison of costs for 1,250 kg electric, gasoline and diesel delivery trucks. Data are based on a table published by the Electric Vehicle Association of Great Britain. Amounts are in pounds or pence as of December 31, 1972. A summary of this comparison is presented below.

	Electric	Gasoline	Diesel
Capital costs	2,003.50	983.00	1,088.00
Standing charges per year	334.50	305.89	332.09
Running costs--pence/km	0.86	2.75	2.22
Total operating costs/week			
Standing charges--pounds	6.48	5.88	6.38
Running costs--pounds	2.08	6.63	5.36
Total--pounds	8.51	12.51	111.74
Cost per km--pence	3.54	5.18	4.87
Comparison index	100.00	100.00	137.00

The following assumptions were used in the above comparison:

--The electric vehicle was depreciated over 15 years; the other two were depreciated over 5 years.
--A five-year life was assumed for the battery and 15 years for the charger.
--Interest on capital was calculated at 8 percent.
--Operations were assumed at 240 km/week.
--Electricity was estimated at 0.40 p per unit.
--Tires were considered to have a 24,000 km life.

Proponents of electric battery bus systems contend, with some supporting evidence, that operating energy costs for equivalent battery and diesel buses are comparable. The considerable experience in England with electric delivery trucks indicates that an electric vehicle can be substantially more reliable than a conventional internal combustion engined vehicle. It is argued that this reliability, coupled with the prospects of relatively more expensive and scarcer petroleum fuels, can offset the higher first costs. If so, an electric battery bus should be more cost-effective than a diesel bus over the life of the equipment. The definitive test comparisons and analyses have yet to be made.

4.1.2 Hybrid Buses

Three hybrid bus systems were assessed under this study. These systems offered most of the advantages inherent in battery bus, with few of the disadvantages.

4.1.2.1 Performance

Range

Since the buses do not depend entirely on batteries, their ranges are limited by other considerations.

a. The Dornier Duo-Bus operates from overhead electric trolley conductors. In theory, the range is limited only by the extent of electrification. Practically, the power supply, through an on-board charger, keeps the battery at full capacity. To prevent the battery from overheating, operations are limited to 16 hours a day. With alternative provisions for battery cooling, the range could be extended.

On batteries alone, the Duo-Bus can run 40 km at 15 kph in traffic. The batteries are recharged while running on the overhead conductors. One km of battery capacity is replaced for each km of trolley operation.

b. The Mercedes-Benz OE305 hybrid operations are 60 to 65 percent diesel electric and 35 to 40 percent battery electric. At this ratio, the bus can operate up to 300 km a day on one tank of fuel and without exchanging batteries. On batteries alone, in normal city traffic, the range is 50 to 70 km.

c. The Kawasaki hybrid bus has a range of 180 km, limited by a 120-liter fuel tank. The range per charge on batteries alone is 55 km.

Speed and Acceleration

The Mercedes has a maximum speed of 70 kph; the other two can reach 60 kph. Acceleration capabilities vary from 2.5 to 3.8 kph/sec. The maximum grade for the Kawasaki is 14% and 16% for the other two hybrid buses.

Noise

Measurements inside the Duo-Bus while at rest found 60 dB due to the air compressor. During acceleration, the chopper and transmission noises measured 65 to 70 dB. Inside the Kawasaki bus, noise levels were reported at 67 to 71 phons in stopping, 76 phons in starting and up to 81 phons cruising at 52 kph. Exterior noises for the Kawasaki under battery operations while accelerating were 67 to 70 phons and 73 to 76 phons under hybrid operations. No data were available for the Mercedes.

Special Features

a. The Dornier Duo-Bus is equipped with motorized trolleys that can be automatically engaged, or disengaged from the overhead conductors. The operator can restart them, or if they accidentally lose contact with the wires, the trolleys are automatically returned to the roof of the bus. Operations continue on batteries to the next bus stop where the driver can reengage the trolley without leaving his cab.

b. The Mercedes-Benz OE305 can have its batteries exchanged automatically. The two batteries are removed and replaced laterally from under the bus by equipment similar to that used for the M. A. N. trailer-mounted batteries.

Assessment -- Performance

o Advantages

- The hybrid buses have almost unlimited range capabilities, considerably more than the battery buses.
- The Dornier Duo-Bus can make use of existing trolley-wire installations, but is not confined to their use exclusively.
- The diesel hybrid buses have virtually no restrictions on the duty cycles and routes that can be assigned.
- The performance capabilities exceed the requirements of transit operations.

o Disadvantages

- The diesel hybrids emit some noise and exhausts, but much less than conventional diesel buses.
- The weight of batteries and special cooling problems tend to limit the present performance capabilities of the Duo-Bus.

4.1.2.2 Energy Consumption

For the Kawasaki buses, energy consumption is reported at 1.8 km per liter for diesel fuel and 0.24 kwh/km for battery charging. The Duo-Bus uses 1.8 km per liter for diesel fuel and 0.24 kwh/km for battery charging. No data are available on energy consumption for the Mercedes-Benz OE305.

4.1.2.3 Life Cycle Costs

Cost comparisons were made in 1976 by Dornier of the Duo-Bus, a trolley bus and a diesel bus. These comparisons are based on operations totaling 72,000 km per year for each vehicle. Costs were converted from marks to dollars at the rate of $0.40 per mark. The data are summarized in Table 4-1.

TABLE 4-1. COST COMPARISON OF DUO-BUS, TROLLEY BUS AND DIESEL BUS

		Duo-Bus	Trolley Bus	Diesel Bus
Capital Costs ($)				
Vehicle only (1)		68,800	118,200	72,000
Electronics and power collector		58,400	-	–
Tires		1,300	1,300	1,300
	Total (2)	128,500	119,500	73,300
Half cost without battery		64,200	57,700	36,600
Capital reserves		4,500	4,500	4,500
Operating Capital		68,700	64,200	41,100
Fixed Costs ($/yr)				
Interest on capital, 7.5%		5,100	4,800	3,100
Depreciation		16,100	14,800	9,000
Depot garage		300	300	300
Driver costs		14,800	14,800	14,800
	Total, per year	36,300	37,300	27,200
	Total, per km (3)	0.50	0.48	0.38
Operating Costs ($/km)				
Energy		0.086(4)	0.119	0.037
Battery (5)		0.195	-	-
Lubricants		0.006	0.006	0.006
Tires		0.027	0.027	0.027
Labor and parts		0.073	0.073	0.080
Insurance and taxes		0.009	0.009	0.009
Overhead		0.033	0.033	0.033
Depreciation, controls and rectifier		0.040	0.081	-
	Total, per km	0.47	0.35	0.19
Total Costs ($/km)		0.97	0.83	0.57
Comparison Index		170	146	100

(1) Value based on production of 100 buses per year
(2) Without battery
(3) Performance based on 72,000 km per year and 8-year life
(4) Test track averages, using 20% lower, off-peak, power costs
(5) Battery life one year with 10% salvage valve

Source: Dornier-System GmbH, Friedrichshafen, Federal Republic of Germany.

The Transportation Bureau of Tokyo has also completed a cost comparison of the Kawasaki hybrid bus and a conventional diesel bus. Operations assume 23,862 km of vehicle travel each year or 104. 3 km per day for the hybrid and 39,000 km for the diesel. These costs were converted at the rate of 300 yen per dollar. The results of this analysis indicate total annualized costs for the diesel to be $0. 11 per km and $0. 37 per km for the hybrid.

These analyses show costs of the hybrid buses to be greater than the diesel buses -- 1. 7 times for the Duo-Bus and 3. 3 times for the Kawasaki. Neither analysis reflects changes in the costs of electricity and diesel fuel over the projected life of the vehicles. The Tokyo analysis places no salvage value on the batteries. If reclaimed at 10 percent, the operating cost would be reduced approximately $0. 02 per km.

4. 1. 3 Appraisal

The reasons generally advanced for the development and demonstration of electric battery buses emphasize the following considerations.

- Reduction in petroleum use. The 1973-1974 petroleum crisis emphasized the need to reduce dependence on this energy source. In Japan, 93 percent of the energy supply is derived from petroleum, most of which is imported. Petroleum supplies about 55 percent of the energy for West Germany, but 95 percent of the petroleum used is imported. Electric vehicles can use energy generated from other sources--hydraulic, coal or nuclear--thereby reducing requirements for petroleum.

- Environment and pollution concerns. Electric battery buses have already demonstrated their quiet, pollution-free characteristics. These attributes are especially important in environmentally conscious Japan. They have been a prime consideration in the installation of electric battery bus services in automobile-free zones in England and Germany.

- Extend the usefulness of existing electric transit systems. Many cities with electric trolley rail or bus systems desire to keep these systems, for the two reasons given above. Where at-grade traffic interference and maintenance of way costs suggest the abandonment of trams, consideration is being given to replacement with electric trolley buses. The hybrid trolley buses are particularly attractive for several reasons. They can operate in areas beyond the electrified routes, saving the cost of extending catenaries and overhead contact wires. These buses can operate without trolleys around street construction or traffic obstacles. They can also operate in urban centers without wires where the maze of overhead conductors for intersections and corners often proves unsightly. One version, the trolley/battery hybrid bus, is designed to recharge the batteries concurrently with operation from the electric conductors so that its range is restored as transit service continues.

- o <u>Other performance advantages.</u> Electric battery buses offer certain performance improvements over diesel buses that are recognized by the drivers and system managers who have used them. They accelerate better as they move into traffic away from bus stops. There is no burst of exhaust fumes during acceleration, as there is with diesel buses. Regenerative braking reduces brake lining maintenance. Direct drive transmissions reduce driver fatigue from gear shifting, still found on many foreign buses. Little energy is consumed while waiting in traffic or at bus stops. The electric bus interiors are quiet--an especially attractive feature with many elderly and handicapped patrons. There are disadvantages, but these are sufficiently offset by the features cited above to make electric battery buses worth trying in operational service.

These reasons have been sufficient to sustain both private and government-sponsored developments and demonstrations to date. There are constraints and problems with the manufacture and use of electric battery buses. Some of the more significant ones are discussed below.

- o <u>Costs.</u> As with all new systems, the lack of a large market and sizeable production runs tend to make initial capital costs high, or at least uncertain. Indications are that life cycle costs should be comparable to conventional transit equipment. However, there has been neither the experience nor the data developed to substantiate this contention. The initial cost and subsequent replacement costs of batteries continue to be high. Until the life cycle advantages of electric battery buses are established, equipment initial costs are likely to remain the determining factor in making system choices.

- o <u>Energy costs.</u> Where data were available, the energy consumption for electric buses was comparable to that for diesel buses. Costs were different because diesel fuel for public transit systems is generally untaxed, whereas electrical power was purchased at the prevailing commercial rate. Several changes could be advantageous for electric battery bus systems.

  - -- Subsidies in the form of tax relief on electric power could reduce direct operating costs.

  - -- Technological advances under development could improve the efficiency of energy use for both recharging and battery power conversion.

- Operations. The battery buses perform well within compatible areas where operations have been planned to suit their capabilities. However, they do have limitations, particularly in range, that are affected by passenger loads, terrain, scheduled speed, and temperature. Operators must be sensitive to these limitations and plan equipment accordingly in order to take advantage of other attributes offered by the battery buses.

- Maintenance. Because of the large numbers in use and many years of experience, daily maintenance of a diesel bus is fairly routine. Nevertheless, typical diesel bus availability requires 10 to 20 percent spare vehicles in a bus fleet to meet public service standards. Comparable vehicle availabilities were achieved with many of the electric battery bus systems assessed. To achieve an availability of better than 90 percent on an electric battery bus will require special daily attention to battery maintenance. Care in charging, checking and refilling electrolyte and cleaning terminals are functions foreign to diesel bus maintenance. Developments are underway that could automate many of the battery maintenance items. Ultimately these functions could become just as routine as they are for a diesel fleet.

4.2 Systems Procurement

Discussions with systems operators and suppliers found a variety of ways in which procurement, warranties and servicing of the battery buses were handled. These practices provide a basis for the alternative procurement procedures described in Section 4.2.2.

4.2.1 Present Procurement Practices

Lucas

Joseph Lucas, Ltd., does not make buses. Their aim is to develop a family of drives and controls for battery buses that will fit a family of commercial vehicles. It is expected that these components could be installed with a minimum of modifications to production-line vehicles. Lucas now uses Sedon bus chassis, though there is no firm, exclusive licensing agreeement. Each is free to make other arrangements with other suppliers.

The warranty agreement for the in-service test program in Manchester provided the following:

- During the first year, Lucas provided all servicing and repair parts.

- o During the second year, Manchester serviced the vehicle and Lucas maintained the batteries, propulsion and control systems.

- o For the final year, Manchester did most of the maintenance-- Lucas assisted with major technical problems.

For operations in the Doncaster area of South Yorkshire, Lucas will provide most of the technical support.

For delivery vans converted with electric drive units for the U.K. Post Office, Lucas performed all work on the electric systems. The Post Office performed all other vehicle maintenance.

The success of these arrangements depends upon mutual understandings that will equitably resolve unforeseen problems, such as traffic accidents that damage components and premature battery failures from inadvertent overcharging.

Chloride

Chloride Technical, Ltd., is not a vehicle supplier. Like Lucas, Chloride would not build the bus chassis, but would supply the electric drive system and related components for an electric battery bus. Chloride has North American licensees through which the components and bus system integration could be obtained. The usual warranty practice, depending upon terms offered a particular supplier, is to give a one-year unconditional guarantee on those components and subsystems supplied by Chloride, or their licensees.

GES

The program manager for the M. A. N. Elektrobus Program in the Nordhein-Westfalen area recommended a feasibility study as a prelude to the purchase of an electric battery bus system. The scope of such a study would include:

- o Selection of a suitable site, depending on a cooperative transit agency and public service needs.

- o Identification of one or more transit lines compatible with the performance.

- o Definition of the route characteristics to be served, including patronage, number and location of stops, grades, hours of operation, headways and scheduled speeds for peak and off-peak operations.

- o Determining the number of buses, batteries and spares; number, location and capacity of exchange stations; and maintenance facilities.

- o Planning the schedule of operations, including driver assignments, bus runs, battery charge/exchange schedules, and periodic routine maintenance.

- o Estimating capital costs for buses, batteries, change stations, power substations, and shops.

- o Preparing a budget estimate for operating costs, including drivers, maintenance personnel, replacement parts, and electric power.

Results would provide a rational basis for deciding whether or not to proceed with a local transit project using electric battery buses. This procedure assumes that a decision could be made to proceed without an alternative analysis as currently required by DOT policy.

M. A. N.

The M. A. N. Elektrobus system could probably be purchased through licensees in the United States. Manufacturing, spare parts and servicing could be accomplished through U.S. suppliers. It was recommended that consideration be given to the following:

- o Select the initial demonstration site such that runs could be made in the peak hours only on one battery charge. The high cost of automatic exchange stations could adversely affect a decision to use a battery bus system.

- o Use separately excited traction motors, since both regeneration and specific energy consumption are superior to the series-wound motor.

- o Require thorough training of operating and maintenance personnel in the use, care and special requirements of the equipment.

M. A. N. is continuing to improve the Elektrobus design. A new battery trailer has already been developed and tested. If the program continues, M. A. N. expects by 1980 to have a system with batteries and components that a normal transit operator could maintain as a routine matter.

4.2.2 Alternative Procurement Procedures

Discussions with suppliers and transit operators produced several suggestions for ways battery buses, ancillary equipment and warranty service could be acquired. These alternative procurement procedures are presented without assessment, since they are contingent upon the project size, timing, availability of suppliers and local policies which are unknown at this time.

To avoid the problems which beset the Lansing, Michigan project, a study of the type outlined above should precede any equipment procurement. Furthermore, the system operator should be sympathetic towards the battery bus system and should be amenable to giving operating and maintenance personnel the special training required.

Direct Purchase

Vehicles and equipment could be purchased from suppliers under a competitively awarded contract. Procurement specifications, warranty provisions and other project requirements could be prepared under the preliminary study. If the project sponsor is legally qualified, capital costs could be found eligible for UMTA financial assistance. The Long Beach Electrobuses were purchased under this procedure. UMTA R&D funds could be used to monitor system performance, energy consumption and to make comparative analyses with equivalent conventional vehicles.

Lease Purchase

To avoid the high first costs and the uncertain price of preproduction vehicles, leasing them for a demonstration period of 2 or 3 years would be desirable. Leasing could be by UMTA or by the public transit agency. Provisions would be made for purchase of the equipment at a depreciated value by the local authority at the conclusion of the demonstration. Terms of the lease would cover the amounts of periodic payments, technical services and repairs--including parts--to be provided, provisions for battery replacement and the methods by which the residual value of the equipment would be determined.

Battery Lease

Vehicles could be purchased under a competitive contract, awarded on the basis of the most advantageous offer responding to a performance specification. The batteries would be leased, not purchased, to insure that they continued to meet performance requirements. The battery supplier, conceivably a subcontractor to the system supplier, would retain responsibility for battery servicing and replacement. He would retain proprietary rights to any patents or developments on the batteries first reduced to operating practice under the project. He would assume the risks of premature battery replacement, but would keep the salvage value of any expended batteries.

Equipment Lease

To retain a greater vested interest in the outcome of an electric battery bus project, some suppliers may wish to merely lease their equipment for use on a project. The terms of the lease would cover the provision of vehicles and ancillary equipment, repair parts, batteries, technical support and maintenance. The supplier would retain ownership of all equipment furnished and any proprietary material. The public agency would have full data on the performance, operating costs, maintainability and attitudes of drivers and public.

Turnkey

The public agency, with UMTA participation, would determine the levels of service for tentative, but appropriate battery bus operators. Proposals covering three phases would be made by teams consisting of planners, engineers, vehicle and equipment suppliers, and operators. The first phase would undertake a feasibility study to define the scope and cost of the project. The second phase would furnish vehicles and equipment and conduct acceptance tests. The third phase would operate the system to meet public agency requirements and would furnish data on performance, costs and other aspects of the system required by the sponsor.

4.3 Systems Demonstration

A systems demonstration program for electric battery buses should satisfy two criteria:

- o The program should build on experience already acquired from in-service tests and operations in the United States and abroad.
- o The program should fill the gaps in data on costs, performance, maintainability and reliability. These data are necessary prerequisites for expanding the role of electric battery buses in public transit service.

To satisfy these criteria, planning a systems demonstration program should consider the following elements.

Fleet Size

A demonstration project should include enough vehicles -- at least three -- to sustain dependable operations on a routine basis. The fleet size should be large enough to justify the special personnel training required. Locating sources for repair parts becomes easier if the project does not rely on a single, unique vehicle. Data developed from operations of several vehicles is more representative if the experience which could be expected from a fleet of battery buses than if the data reflects experience from a single vehicle. A large enough demonstration fleet would provide economic incentives to system suppliers to make product improvements in the currently available buses.

Battery Capacity

Many private and public developments are underway to improve battery capacity, reduce weight, extend battery life and increase the efficiency of energy conversion. The demonstration program should be used creatively by providing incentives for the practical application of these developments.

One unresolved issue concerns the cost-effectiveness of large, heavy-duty, long-life batteries versus smaller, lighter-weight batteries with shorter life cycles. One facet of the demonstration program should be structured to obtain comparable cost and performance data on these two types of batteries when used in equivalent vehicles and services.

On-Board Charging Versus Battery Exchange

Both methods have been used to restore electrical energy, but not with systems sufficiently similar to make judgements about which method is the better or whether they both have useful roles. The consequences affect the number of buses held in reserve to assure meeting schedules, the number of replacement batteries, investments in exchange stations and the layout of maintenance shops and depots to accomodate either on-board battery charging or exchanging. An in-service test of these two procedures could establish the kinds of service and the criteria which govern the use of either method.

Battery Chargers

A variety of battery charging technologies are in use with present bus systems. These involve different schemes for automatically monitoring and regulating increases in battery voltage. No definitive comparisons of these different charging techniques are known. The demonstration program offers an excellent opportunity to test these various battery chargers, under operational conditions to determine their safety, efficiency, reliability and the effect which each technique has on battery life.

Motor Types

Two of the system suppliers reported marked improvements in energy consumption and regeneration with separately excited shunt-wound motors. While the results are significant, detailed data are proprietary and are not generally available. Given the long and reliable history of series-wound d. c. traction motors, the demonstration program should make an independent assessment of the relative advantages and disadvantages of the two motor types.

Motor Controllers

There is presently a large variety of motor controller options in use in electric battery buses. These include the traditional resistor contactor control and newer solid state devices which also use a variety of regulating techniques. The demonstration program should consider an evaluation of these different types of controllers. Information is needed on the energy efficiencies of the devices, their effectiveness in regulating speed and acceleration, their capability in returning regenerated power to the battery, and on their reliability the demonstration program could develop data on the characteristics of the various controllers to guide utilization and product improvement.

Regenerative Braking

While regenerative braking has been made technically feasible by the new solid state motor controllers, it has created other problems. For example, switching circuits have been major contributors to vehicle failures. Regenerative braking has significantly increased tire wear and has strained rear axles. The demonstration program should assess the trade-offs between high levels of power regeneration and the consequences on other features of the drive system.

Space Heating

A rational and energy-efficient method for heating driver and passenger compartments is required. The demonstration program can provide incentives for improvements over available heaters and can assess their effectiveness under operating conditions.

Hybrid Buses

Both diesel-battery and trolley-battery hybrid buses offer an intermediate step to battery bus operations. For certain applications, the hybrid bus may be totally adequate. Because of the small number of buses of this type in public service, there is not enough experience or data available to assess all aspects of their performance. By demonstrating hybrid bus systems in conjunction with diesel and battery buses, comparative and performance data could be acquired.

Throughout an electric bus demonstration program, data should be systematically developed, recorded, reduced and analyzed in order to realize the full benefit of the effort. Provision should be made at the onset of the program for this data collection and dissemination so that public and private agencies concerned with these systems can be informed of electric battery bus capabilities and limitations.

APPENDIX A

Contributors to the Electric Battery Bus Assessment

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APPENDIX B

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