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A Preliminary Assessment of the Impact of Flywheel Energy Storage Technology on Taxicab Fleet Operation in a Large Metropolitan City

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FOREWORD

This report represents an analysis conducted by the Los Alamos National Laboratory in support of the Mechanical Energy Storage Technology (MEST) Project conducted by the Lawrence Livermore National Laboratory. Mr. T. M. Barlow is the MEST Project Leader and serves as the technical contact for the Los Alamos effort. The analysis program has been identified as Task 7.203 within the MEST project and is funded under Lawrence Livermore National Laboratory order SANL 820-020, August 29, 1980.

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SUMMARY OF CONCLUSIONS

This report describes a preliminary assessment of the economic, environmental and energy-savings impacts related to the introduction of flywheel energy storage systems (FESS) into automotive (taxicab) fleets in a large metropolitan city (New York City). The authors have identified institutional barriers to implementation. The data and conclusions are presented below.

- The automotive fleet market exhibits characteristics that set it apart from the personal vehicle user group. Paramount among these is its value as a technological test market for new vehicles and new component technology such as FESS. Automotive fleets represent a significant economic component of the transportation industry.

- Because of a wide diversity of purpose, the fleet market can be conveniently divided into several sectors, one of which is taxicabs. In considering the purchase of vehicles, each sector emphasizes select criteria. For the taxicab sector, the primary purchase criterion appears to be maintenance and parts availability with life-cycle costs and reliability running a close second.

- Characteristics unique to the taxicab sector include: very high annual mileage accumulation (50 000-80 000 miles); relatively short vehicle lifetime (18-36 months); urban stop-go driving and significant braking; low average speed (~7-11 mph) and low average gasoline mileage (~10 mpg) in central business districts (CBD).

- Nationally, ~207,000 vehicles are classified as taxicabs. These vehicles generate revenue and employment levels far in excess of what may be expected on the basis of numbers alone.

- Characterization of taxicab operation in New York City is difficult because there are several taxi systems. The city has ~12,000 licensed taxicabs of which ~60% operate as fleets and minifleets and the remainder as independent owner/drivers. There is also a substantial but indeterminate number of livery service vehicles (gypsies) operating within and without the city limits and not controlled by the New York City Taxi and Limousine Commission. Data obtained and used for the economic analysis reflect primarily that relating to fleet operation.

- The characteristics of New York City taxicab operation strongly suggest that evaluations of new technologies such as FESS be conducted under New York City taxicab drive cycles in addition to the federal urban drive cycle usually considered. Such cycles have been generated recently by the city and others.

- In this study we compared levelized life-cycle costs for three cases in the taxicab standard internal combustion engine vehicle (ICEV) and FESS/ICEV categories with data obtained from New York City regulatory and private sectors. Under the assumptions used and the given data, we obtained the following results:

a. In fleet operation, the life-cycle cost for FESS/ICEV is 3.3¢/paid mile less than that of the ICEV.
b. Capital costs are a small fraction of the total and are less than fuel costs in both categories. A sensitivity study suggests that capital costs for the FESS/ICEV can be increased significantly before matching the ICEV life-cycle cost. Therefore additional capital investment may be justified to achieve potential gains in fuel economy.
c. The cost of driving (labor) and dispatch is the major cost in all systems, 47-57 percent.
d. The FESS/ICEV fuel cost is less than that of the standard ICEV. This is implicit in the analysis.

- We performed sensitivity studies on several parameters. These include levelized life-cycle costs vs: utilization factor; FESS/ICEV-ICEV fuel economy ratio; FESS/ICEV-ICEV capital cost ratio; fuel cost; and taxicab lifetime. The results generally emphasize the value of including FESS in taxicab operation in New York City.

- This report briefly discusses the viability of retrofitting taxicabs with FESS. We give several qualitative thoughts regarding viability of a retrofit operation. A suggestion is also made concerning future production of FESS/ICEV for the relatively small taxicab market.

- A 50% increase in fuel economy (miles per gallon) has been assumed in this study. In New York City, this translates to a 33.3% savings in fuel purchases for the same annual accumulated mileage by the licensed taxicabs. For ~12,000 vehicles at $1.20/gal, the annual savings is ~25 x 10^6 gallons or ~$30 x 10^6/year. At ~1.25 x 10^5 Btu/gal (automotive gasoline), the savings are ~3.1 x 10^{12} Btu.

- Environmental improvement in the form of reduced emissions is to be expected with the introduction of FESS/ICEV taxicabs. Because New York City also regulates noise levels, any noise problems presently encountered in development should be solved before introduction into the city environment.

- There are a number of institutional issues that may visibly affect rapid deployment of FESS/ICEV vehicles in the taxicab market sector. These include: the automobile industry production infrastructure as it relates to the small market for taxis; lack of maintenance and service information for the taxicab industry, which prefers relatively short downtime periods; the ownership of patent or commercial rights relating to component development by contractors using government funds; and the necessary education of regulators, insurers, and the public with regard to the safety of FESS. More positively there is already a precedent in New York City regarding taxicab fleet technology demonstrations, diesel engine-powered taxicabs having been tested previously. Generally, regulations do not appear to be restrictive.

- To more accurately evaluate the benefits of FESS/ICEVs to taxicab fleets and to independent owner/drivers we suggest the following steps: (1) an in-depth study of New York City's taxicab operation data, especially with respect to the independent owner/driver who represents a significant fraction of the total fleet; and (2) a large-scale demonstration test similar to a recently-completed diesel engine taxicab test. These would be preliminary studies only, because data obtained for New York may not be applicable to other cities. Similar studies could be performed for other cities or districts.

ABSTRACT

The incorporation of flywheel energy storage systems (FESS) into automotive vehicles has been under consideration for some time. Previous studies have suggested that FESS can yield substantial benefits in automotive vehicle operation, particularly for urban driving.

This study describes a preliminary assessment of the impacts resulting from incorporation of FESS into automotive fleets in a large metropolitan city. Specifically, the case of taxicab fleet operation within New York City is examined. The report gives parameters descriptive of national automotive and taxicab fleets, notes unique features of taxicab fleets, and details taxicab operational characteristics within New York City. Based upon available New York City operational data, a levelized life-cycle cost comparison between a standard internal combustion engine vehicle (ICEV) in present use as a taxicab and a projected FESS/ICEV taxicab has been generated. Potential energy-savings and environmental benefits are discussed, and potential institutional barriers to FESS implementation are identified.

The levelized life-cycle cost comparison suggests that: (a) FESS/ICEV costs are 3.3¢/paid mile less than that of the ICEV; (b) the capital costs represent a small fraction of the total and are less than fuel costs in both categories; (c) the cost of driving and dispatch is the major cost in both categories. Implicit in the analysis is the fact that the FESS/ICEV fuel cost is less than that of the ICEV. Sensitivity studies performed on several parameters emphasize the value of FESS in taxicab operation in New York City.

An assumed 50% increase in fuel economy (miles/gallon) translates to a 33.3% savings in fuel purchases for the same annual accumulated mileage by New York City licensed taxicabs. For ~12,000 vehicles at \$1.20/gallon, annual savings amount to ~\$30 x 10^6 (~25 x 10^6 gallons).

Environmental improvement in the form of reduced emissions is to be expected with the introduction of FESS/ICEV taxicabs.

A PRELIMINARY ASSESSMENT OF THE IMPACT OF FLYWHEEL ENERGY STORAGE TECHNOLOGY ON TAXICAB FLEET OPERATION IN A LARGE METROPOLITAN CITY

by

Milton C. Krupka and Sydney V. Jackson

I. INTRODUCTION

A. General

The most important challenge facing the future development of the automotive vehicle is the issue of energy conservation. Stringent fuel economy and emissions control goals have been mandated through federal legislation for the forthcoming decade. Achievement of these goals will require funding to support new research and development, design and production engineering, and the successful demonstration of those new energy-saving technologies that can be introduced into automotive vehicles.

Automotive vehicles are the single largest users of petroleum in the nation; they account for 28% of the total petroleum consumed and 58% of the petroleum used for all passenger and freight transportation.[1] Reductions in the use of petroleum can be achieved by: (a) improving engine and transmission efficiencies; (b) reducing rolling and aerodynamic drag; (c) reducing vehicle weight; (d) developing efficient alternate engines, e.g., stirling or gas turbine; (e) using energy storage systems coupled with any or all of the preceding alternatives; (f) speed limit regulation; (g) improving traffic management; and (h) improving driver habits.

B. Flywheel Energy Storage System (FESS)

The use of this system in transportation applications has been advocated for some time.[2,3] Only relatively recently, however, has interest in flywheel technology increased. This is due primarily to both the overall energy situation and the major advancements in materials science and engineering as applied to flywheel system development.

The basic physical principles of the flywheel have been discussed in many physics and engineering texts, summaries of which are provided in handbooks.[4] Major developmental programs relating to flywheel applications within the transportation sector have been conducted during the past decade and are presently continuing.[5-9] Studies and practical demonstrations have shown that the FESS can yield substantial benefits to automotive vehicle operation provided: (a) care is taken to minimize parasitic losses in the various components of the FESS-transmission system; (b) operation and driving patterns of the vehicle are accomplished in select modes, e.g., urban driving; and (c) engine designs are optimized.

The flywheel stores rotational kinetic energy. Rapid charge/discharge rates at high power levels are characteristic. Thus, the system provides a load-leveling function for the prime energy mover and the mover design can be optimized. In addition, the flywheel can recover the kinetic energy that otherwise would be rejected during deceleration (regenerative braking). Thus, additional energy will be available for later use, which again relieves the load on the prime energy mover. Figure 1 shows schematics of a conventional internal combustion engine vehicle (ICEV) and a flywheel-hybrid vehicle (FESS/ICEV). Table I gives specifications for an experimental advanced state-of-the-art flywheel system.*

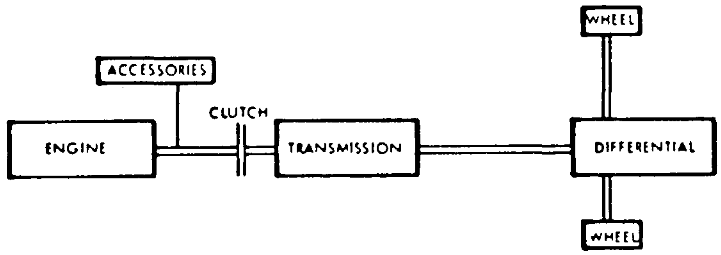
A CVT is required for matching speeds of the vehicle and FESS. Development engineering is proceeding on this type of transmission. Current systems that appear promising include: (a) hydrostatic power-split (b) Van Doorne steel V-belt and (c) traction drive.[10]

C. Objective and Scope

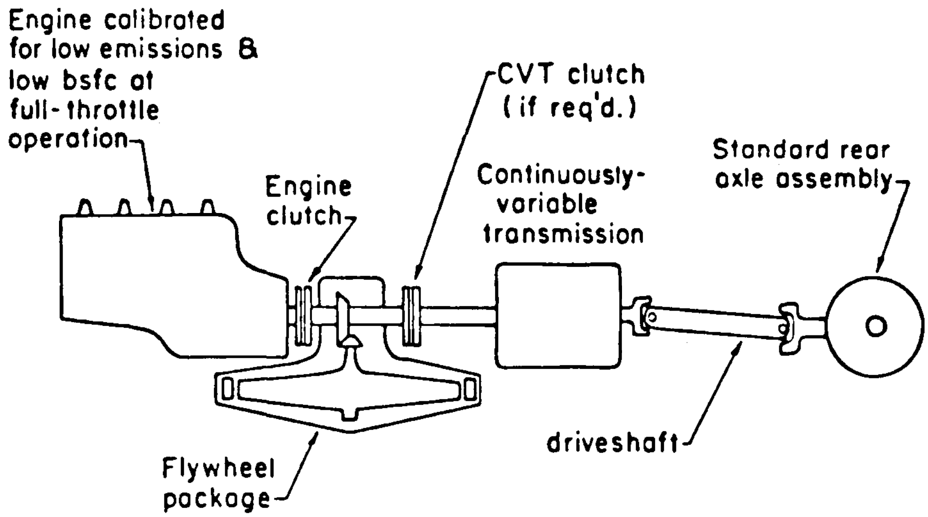
The objective of this study is to present a preliminary assessment and evaluation of the economic, environmental, and energy-savings benefits of the introduction of a flywheel energy storage system into a standard internal combustion engine vehicle. In particular, because benefits are presumably maximized for urban driving, the taxicab fleet operating in New York City is examined.

The study generates levelized life-cycle costs on the basis of available operating costs of the present-day taxicab ICEV and projected costs of a taxicab flywheel-hybrid (FESS/ICEV). Sensitivity studies for select parameters important for economic viability are made. In addition, the report determines the relative potential improvement in emissions and energy savings,

*This particular unit was intended for use in electric vehicle applications.



(a) Schematic of a conventional ICEV.



(b) Schematic of a flywheel-hybrid ICEV.[10]

Fig. 1. Schematics of automotive vehicles.

TABLE I

SPECIFICATIONS FOR FESS EXPERIMENTAL UNIT[11]

Specification	Value
Total energy storage unit capacity	0.250 kWh
Specific energy[a]	3.16 Wh/lb (6.97 Wh/kg)
Peak power transfer	45 kW
Energy density-flywheel rotor	17.25 Wh/lb (37.5 Wh/kg)
Composite material	Kevlar/Epoxy
Pressure (operation at maximum flywheel speed - 42 000 rpm)	1.4 microns
Total packaged weight	79 lb (35.8 kg)
Maximum diameter of package	15.1 in. (38.35 cm)
Life cycle (deep discharge)	$>10^5$

[a]Current state of the art is ~1.1 Wh/lb (~2.4 Wh/kg)

discusses other environmental factors, and identifies institutional barriers to implementation.

II. AUTOMOTIVE FLEET VEHICLE MARKET

A. Importance of the Fleet Market

This section briefly describes the general characteristics of automotive fleet vehicles. Much of the data has been taken from industry periodicals[12,13(a)] and a special Brookhaven National Laboratory report.[14] We have made no attempt to reproduce all of the fleet data. Excerpts are presented when appropriate.

The fleet market exhibits selected characteristics that set it apart from the personal vehicle user group. These relate more to economic and institutional than to technical aspects. A recent study has detailed some of these characteristics[14] including the following:

1. The market accounts for a significant share of new car sales (~12%).

2. The market's response to policies initiated by the government and to changes in economic criteria is liable to be different from those of the household user group.

3. Because of income tax regulations, fleet owners can absorb greater cost increases (resulting in larger net income) than can the personal user group.

4. A fleet market is valuable as a technological test market for new vehicle and component design because:

   (a) availability of professional management and fiscal resources permits a higher degree of risk involvement;

   (b) bulk buying practices enable fledgling manufacturers of new components to concentrate on a limited product line and a limited number of customers;

   (c) conscientious maintenance,* vehicle control, and record-keeping practices exist;

   (d) vehicles can be assigned to specific and well-defined missions;

*It is implied here that mechanics will accept a new technological device and be motivated to maintain it properly during the demonstration phase for that device.

(e) mileage and operational data accumulate rapidly; and

(f) there is high product visibility

Many of these reasons are applicable to the introduction of new energy storage technology.

B. Definition

Automotive fleet data mentioned herein refers to groups of 10 or more light-duty vehicles operated by corporations or government agencies.* Fleets with less than 10 vehicles obviously exist but their relative importance is declining. This probably is due to the rise of automotive leasing practices and increased costs, a potential significant burden on small companies.

Automobile sizes are also defined for purposes of fleet management. The National Association of Fleet Administrators, Inc. (NAFA) uses the categories shown in Table II. Other groups use terms such as standard, luxury, intermediate and minicompact. Since the industry is presently in the midst of a considerable "down-sizing" and weight-reduction effort, such terminology must be used carefully and in conjunction with other automobile technical specifications. Thus, a mid-size vehicle of tomorrow will most likely have a lower curb weight but still be characterized as mid-size due to relative weight, large internal volume, etc. These features are important to certain fleet sectors (taxicabs, for example).

TABLE II

AUTOMOBILE SIZE CATEGORIES[13(a)]

Type	Wheelbase in	Weight-Curb lb (kg)
Sub-compact	<100	<2500 (<1134)
Compact/Small	101-106	2501-3000 (1134-1360)
Mid-Size	107-114	3001-3500 (1361-1588)
Large	≥114	>3500 (>1588)

*Different sources have different definitions of the word "fleet." For example, statistics quoted by the Motor Vehicle Manufacturers Association (MVMA) include buses and various types of trucks, trailers, and off-road vehicles.[17]

C. Magnitude of the Automotive Fleet

Fleet inventory has grown steadily over the past 35 years, generally growing at a higher rate than the growth of the automobile industry as a whole. This trend is expected to continue. Fleet travel demand is closely linked to economic activity in general, and specifically to the activity within the specialized sectors that make up the total fleet. As of January 1, 1980, the number of vehicles in fleets of four or more vehicles was estimated at approximately 10,500,000 (~10%).[12] This is a substantial market by virtue of numbers alone and because the turnover and acquisition rate of new vehicles is higher than that of the household personal car user group. Fleet purchases account for a significant share of new vehicle sales, presently about 12% and projected to increase.[14]

D. Sectors

Because of the wide diversity of purpose existing within the fleet market, it is convenient to subdivide the fleet into a number of sectors. Different organizations use different breakdowns appropriate to their specific organization. The MVMA describes its sectors as follows: lease/rental; food manufacture/distributing; construction/mining; manufacturing/processing; petroleum; public utilities; retail/wholesale delivery; bus; etc.[17] The NAFA uses as categories: insurance; manufacturing/industrial; manufacturing/ consumer; drug/cosmetic; food/beverage; chemical/petroleum; miscellaneous; government and utilities.[13(a)] Automobile Fleet categories include: business; government (state and local); utilities; government (federal); police; taxi; and rental.[12]

E. National/Regional Fleet Data

The diversity of fleet vehicle usage results in a wide variety of criteria that fleet operators must contend with in selection of vehicles. Several criteria applied to alternative vehicle selection apply equally well to consideration of new component technology within the given vehicle itself.[15] These are shown in Table III.

Fleet vehicle specifications are generally similar to those of the personal car user group except that purchases are in quantity and cost discounts prevail. Manufacturers honor special design requests peculiar to sector operation. Model variability is restricted.

Because this study relates primarily to the introduction of new component technology (FESS) into vehicles limited to urban driving, a discussion of

TABLE III

TRADE-OFF PARAMETERS AND ASSOCIATED VEHICLE ATTRIBUTES OF INTEREST TO FLEET OPERATORS[15]

Trade-Off Parameters	Vehicle Attributes of Interest to Fleet Operators
Cost	Life-cycle Purchase price Depreciation Maintenance Fuel Insurance Labor (driver)
Functionality	Seating capacity Trunk capacity Body design Range Refueling characteristics Acceleration Speed Gradeability Availability of power options Reliability Durability
Amenity	Comfort Styling Ease of driving Image
Safety	Crash avoidance Crashworthiness Nonoperating safety Component safety
Social cost	
Resource consumption	Mpg or mi/kWh
Emissions Noise	Ability to meet federal, state, and local regulations

all types of fleet operational data is not appropriate here. Information is available in the cited references.[12-14,16-17] Brief data summaries are also given in Appendix A. In contrast, Sec. III more thoroughly summarizes the taxicab sector.

In most cases data are received through the use of periodic surveys (by mail) sponsored by automotive industry publications, consultant organizations, the Federal Government, and universities. Information is tabulated, organized into a variety of categories, and statistically treated where possible. We have assumed that reasonably correct data is collected by fleet journals.[12,13(a,b)] Much of this data also is included in government publications.[18] However, many of the questionnaire surveys are not statistically designed, therefore care in interpretation must be exercised. This is especially true of the taxicab sector, which previously has responded poorly to mail survey attempts.

Table IV summarizes results from a recent (1977) survey.[14]

F. Fleet Operating Cost Data-National Averages

The NAFA conducts an annual operating cost survey. Table V gives results for 1979.[13(b)]

III. TAXICAB FLEET SECTOR CHARACTERIZATION

A. National/Regional Data

The taxicab fleet represents a small but significant entity in terms of its contribution to the transportation industry. Data acquisition mail surveys for the taxicab fleet sector have been minimal. An early survey was made in 1970.[19] Additional surveys were made in 1974 and 1976 through the cooperation of the International Taxicab Association (ITA).* This organization maintains up to-date files of taxicab operators in the US, Canada, and certain foreign countries. The file is believed to cover at least 90% of fleet operators. However, it does not include all independents (owner/drivers); hence it underestimates the total number of operating taxicabs in the US, perhaps significantly. The 1974 and 1976 survey data were published by the Department of Transportation (DOT).[20] The ITA is planning a survey to be conducted in approximately one year (1981-1982).[21(a)]

A summary of taxicab fleet survey data is presented in Appendix B. Although the data are from prior years, a number of characteristics are valid today. Taxicab data obtained in the 1977 survey demonstrate differences between the taxicab and other fleet sectors. A high annual mileage accumulates, accounting for maintenance as a primary purchase criterion. The mileage at the time of salvage is equally high, about 144 000 miles.[14] The nature of taxicab operation in either urban or a congested CBD results in very low

*International Taxicab Association, 11300 Rockville Pike, Rockville, MD 20852.

TABLE IV

SUMMARY OF RESULTS OF THE BOBIT SURVEY[14]

	Sector					
	Government Non-Federal	Utility	Police	Taxi	Rental	Business
Primary purchase criteria	Price	Price	Reliability	Maintenance[a]	Maint./Resale	Resale
Annual mileage	15 000	12 000	33 000	57 000[b]	21 000	27 000
Replacement age (yrs)	4.1	6.0	2.1	2.8	1.6	2.2
Av. required seating capacity	4.31	3.43	4.70	4.57	3.85	4.02
Cars:						
% of cars which are large	54	31	91	81	49	66
% needing only 2 seats	26	29	3	3	11	14
% with options:						
Automatic transmission	99	96	100	94	98	100
Air conditioning	51	43	81	51	98	99
% needing >100 mile range	75	66	99	95	67	93
% available for 8-hr refueling	49	51	20	25	18	20
% not needing IH (interstate highway) performance	31	25	9	40	5	24
% available for 8-hr refueling and not needing IH performance	11	15	4	9	3	11

[a]Life-cycle costs, reliability are close secondary criteria for taxicabs.
[b]Annual mileage of ~40 000 miles is given in Ref. 20.

TABLE V

NAFA's 1979 OPERATING EXPENSE REPORT[13(b)]

	Small Cars	Mid-Size Cars	Large Cars	Composite Fleet
Average Miles per Month	1718	1765	1772	1798
OPERATING EXPENSES (Expressed in dollars per car per mile)				
Fuel	0.0481	0.0551	0.0679	0.0548
Oil	0.0011	0.0014	0.0014	0.0011
Tires and Tire Repair	0.0047	0.0060	0.0053	0.0057
Repair and Maintenance	0.0181	0.0118	0.0164	0.0129
Total Operating Expenses	0.0720	0.0743	0.0910	0.0745
INCIDENTAL EXPENSES (Expressed in dollars per car per month)				
License and Taxes	N.A.*	$5.82	N.A.	$7.33
Accident Repairs				
--Less Recoveries	"	7.75	"	7.25
Washing	"	4.10	"	3.02
Parking and Tolls	"	7.29	"	9.43
Miscellaneous	"	1.58	"	1.29
Total Incidental Expenses	"	26.54	"	28.32
STANDING EXPENSES (Expressed in dollars per car per month)				
Interest or Service Charge	"	25.09	"	33.08
Depreciation Reserve	"	147.85	"	128.25
Depreciation Adjustment, if any	"	-.26	"	-2.19
Selling Expenses	"	3.00	"	--
Insurance	"	16.68	"	16.74
Total Standing Expenses	"	192.36		175.88
CREDITS (Dollar return per car per month)				
Personal use chargeback	"	29.72		21.86
NET EXPENSES (Incidental expenses plus standing expenses less personal use credit expressed in dollars per car per month)		$189.18		$182.56

*Not available

gasoline mileage. This factor is discussed in Secs. IV and VI. The total taxicab fleet, estimated at 207 000 (1979)[12], although small compared to other fleets, nevertheless generates revenue and employment levels far greater than all other transport options.[20] Improvement of economic factors relating to taxicab fleets thus is a desirable goal.

Although the main service of taxicabs has been transportation of passengers, the industry is diversifying and including a variety of services categorized as "paratransit" activities. In this report, only passenger transportation is considered.

B. Fleet Operating Cost Data-National Averages

The ITA has compiled taxicab operating cost data over several years. Table VI shows results through 1979.

C. New York City Taxicab Data

Information presented in this section has come from several sources but major contributions have been obtained from the New York City Taxi and Limousine Commission* and the Metropolitan Taxicab Board of Trade, Inc.,** an association of fleet taxicab companies. Both public regulatory and private sector agencies have provided data.

Taxicab operation in New York City is complex, so available data should be interpreted with caution. Operating cost data used in the economic analysis (Sec. V), are primarily those from large fleet operation. For licensed independent owner/driver taxicabs cost data and some operational characteristics

TABLE VI

NATIONAL TAXICAB AVERAGE OPERATING COSTS[21(b)]
(DOLLARS PER MILE)

Cost Type	1972	1975	1978	1979
Driver labor	0.1769	0.1902	0.220	0.260
Other labor	0.0144	0.0231	0.030	0.072
Tires	0.0028	0.0039	0.005	0.008
Parts	0.0078	0.0151	0.020	0.026
Gasoline	0.0229	0.0447	0.050	0.081
Insurance	0.0176	0.0231	0.030	0.034
Depreciation	0.0150	0.0187	0.020	0.028
Dispatching	0.0502	0.0513	0.060	0.044
Miscellaneous	---	---	---	0.079
Total operating	0.3031	0.3701	0.435	0.632

*New York City Taxi and Limousine Commission, 67 Wall St., New York City, New York 10005.
**Metropolitan Taxicab Board of Trade, Inc., 24-16 Bridge Plaza South, Long Island City, New York 11101. This organization controls the fleet operation of ~2200 taxicabs, ~20% of those licensed.

are different in detail. Total operating costs per mile are reasonably similar depending on the assumptions made. General operation information is shown in Table VII. Section V gives specific New York City taxicab operating cost data.

The New York City Taxi and Limousine Commission controls licensed taxicab operation. Taxicab vehicles must meet design criteria and emission specifications (see Sec. VII). In addition to licensed taxicabs, there is an indeterminate number of other vehicles providing passenger services. These are called livery service vehicles (unlicensed) or, in the vernacular, "gypsies." Their number is substantial, estimated between 5 000-15 000, and apparently increasing. Because they operate within and beyond city limits and provide services beyond passenger transportation, overall control is difficult. This report describes the operations of city-licensed vehicles only.

An applicant receives a license (medallion) to operate taxicabs inside the city limits after a thorough investigation of such items as credit rating, sources of funds, and criminal record, if any. Cost of the license is $150 annually. New York City restricts the number of licenses available and such licenses are transferable. The actual driver needs both a state chauffeur's license and a city commission driving license. If a vehicle manufacturer wants to provide vehicles for taxicab service in the city, he must provide a certificate of conformity to all New York City specifications and regulations. If the taxicab commission approves, notice is given to prospective operators and owners that such a vehicle is acceptable.

Fleets operate both as largefleets and as minifleets (two or three vehicles). Operating conditions for the minifleets are probably similar to those for the independents although particular operating costs may well be different. Because of their numbers, independent owner/driver licensed taxicabs may be considered as a fleet; their operating characteristics are by necessity somewhat different.

IV. DRIVE CYCLES

A. General

Fuel economies and vehicle emissions are best estimated through standardized fixed driving schedules (cycles) designed to simulate driving conditions. The cycle is essentially a speed-time history. Cycles have been developed to simulate highway, urban, and composite conditions. In addition, cycles have been developed for conditions applicable to new vehicle design such as the

TABLE VII

NEW YORK CITY TAXICAB OPERATION INFORMATION (1980)[a]

Operational Data	Value
1. Licensed taxicabs	11 784
a. Fleet (large and mini)	6 784
b. Independent	~5 000
2. Cost of license-owner annual fee	$150
3. Operation time	7 days/week; 16 h/day; 365 days/year
4. Passenger Rates	$1.00 - 1st 1/9 mile; $0.10- each additional 1/9 mile
5. Mileage/Day	
a. Fleet	200 miles
b. Independent	150 miles
6. Average trip length	2.3 miles
7. Average trips/car/day	55.4
8. Average payload	1.7 passengers/trip
9. Transport of passengers	~100,000/day
10. Fleet downtime	~10%
11. Type and curb weight preference	Dodge Aspen and Checker;[b] ~3500 lb
12. Primary purchase criteria	Maintenance and parts availability
13. Initial Purchase Price (1980)	
a. Dodge Aspen	$5900
b. Checker	$7800
14. Disposal Method	
a. Fleet	Scrap
b. Independent	Scrap or used-car sale.
15. Salvage Value	
a. Fleet	$200-400
b. Independent	Higher if disposed of earlier than usual lifetime
16. Gasoline Cost (October 1980)	$1.20/gal; $9 626/vehicle/year
17. Gasoline Usage (Licensed)	~200 000 gal/day (Total) ~150 000 gal/day (Fleet)
18. Average Gasoline Mileage	
a. Fleet	10.0 - 10.2 mpg
b. Independent	~11.5 - 12.0 mpg

TABLE VII (cont)

NEW YORK CITY TAXICAB OPERATION INFORMATION (1980)[a]

19. Average Lifetime	
a. Fleet	18-22 months
b. Independent	~30 months (perhaps longer)
20. Annual Mileage	
a. Fleet	80 000 miles
b. Independent	50 000 miles
21. Total Lifetime Mileage	
a. Fleet	120 000 - 146 600
b. Independent	125 000 (minimum)
22. Utilization Factor-Fleet	~75 percent

[a]Fleet operational data unless otherwise noted.
[b]Checker taxicabs are heavier: ~3800-4100 lb (1724-1860 kg).

electric vehicle, and transportation vehicles such as the van and bus. A partial listing of these cycles and their references are given in Table VIII.

The effects of new automotive engineering developments are determined both in the field and through simulation using an appropriate cycle as noted in Table VIII. For most development programs concerned with the FESS/ICEV hybrid, the Federal Urban Drive Cycle (FUDC) has been used as a guide.

B. New York City Drive and Taxicab Cycles

These cycles represent New York City driving more accurately than does the FUDC. Most emphasize the central business district (CBD) type of driving. The New York City cycles are perhaps best characterized by extensive periods of zero velocity (engine idle or stop) and net low average speeds typical of the CBD.* Since the taxicab cycles appear to be extremes of the urban cycle, independent treatment would be justified.

A study attempting to characterize traffic patterns in various metropolitan areas showed that traffic in the New York City/Newark area, compared to three other metropolitan area (Los Angeles, Chicago and Detroit), demonstrated the highest percentage time in the stop mode and the lowest average speeds.[29] These effects were especially enhanced for the roadways in the CBDs. This suggests that if the effects of the introduction of FESS into taxicabs are to

*Average speeds for the taxicab driving cycles range from ~6.9 to 10.5 miles per hour (mph).[29-31]

TABLE VIII

TYPES OF DRIVING CYCLES

Name	Reference
Federal Urban or EPA Urban	22(a,b)
SAE Urban - J227	24
GM - City Suburban	25
New York City Drive	27
New York City Taxicab	23, 26 (a), 27, 28, 31
Federal Highway	23

be properly determined, test procedures and simulations describing New York City taxicab cycles should be emphasized and utilized more routinely. By virtue of its characteristics, New York City driving represents simultaneously a severe and complicated environment and an excellent test bed for observation. Whereas FUDC testing still may show that improvement has occurred, results obtained from the New York City drive cycle may be more definitive.

V. ECONOMIC ANALYSIS

An economic comparison of FESS/ICEVs with ICEVs must take into account the trade-off between increased capital costs and reduced fuel costs. This section describes the levelized life-cycle cost (LLC) methodology that was used to perform the economic analysis and presents the results of the economics comparison. In addition, the results of several sensitivity studies, where key parameters were varied, are also included.

A. Levelized Life-Cycle Cost Methodology

The advantage of LLC is that the total operating cost, including the capital investment, is characterized by a single number. A detailed discussion of LLC and derivation of equations are contained in the user's manual for the computer code (BICYCLE) used in this analysis.[32]

The underlying principle behind LLC is that the income over the life of the taxicab must equal the expenses associated with the taxicab. Income is derived from passenger revenue. Expenses include the recovery of the capital investment, return on the capital investment, interest, fuel costs, maintenance costs, taxes, and labor. The levelized life-cycle cost is the cost per passenger mile that, when multiplied by the number of passenger miles, results in a stream of revenues sufficient to cover the stream of expenses.

B. Economic Assumptions

1. Financial Parameters. LLC calculations were performed for two types of taxicab operations--independent owner/driver and fleet. The key financial parameters needed for economic analyses are: the fraction of the capital investment that is made up of borrowed money (as opposed to equity money), the debt interest rate, the equity return rate, the inflation rate, the income tax rate, and the investment tax credit rate. Unfortunately, it was not possible to obtain values for each of these parameters for New York City taxicabs.

Consequently, for fleet operation, financial parameters representative of US industry as a whole were used. This is a reasonable assumption because the free market system is supposed to work such that, if one industry has higher return rates than another, investors shift their money to the more profitable industry. This results in increased competition, which drives the return rate down. The values used, shown in Table IX, were taken directly from a SERI report.[33]

For the independent owner/driver taxicabs, values for financial parameters are even more difficult to determine. This analysis used financial parameters, shown in Table IX, for residential/remote market applications that were based on SERI data.[33] Although these values can't be rigorously defended, they are at least reasonable. Furthermore, the results are not very sensitive to the financial data because the vehicle lifetime is relatively short.

The financial parameters given in Table IX are inflated values, i.e., they are values which assume the presence of the given inflation rate. In the economic analysis these values are used along with inflated revenues and costs in order to accurately treat income tax effects. However, at the end of the analysis, the resulting LCC values are deflated so that the final reported values are in constant 1980 dollars.

2. New York City Taxicab Cost Data. The description of New York City taxicab operation given in Sec. III suggests that these operations may be conveniently segregated into several categories, viz., fleet, minifleet, independent owner/driver, and "gypsy." Cost data for the minifleet (believed to be somewhat similar to the independent owner/driver) and the "gypsy" categories are not readily available. The assumptions used for the calculations of LLC and the taxicab operating costs for the remaining two categories are given in Tables IX and X. Three separate systems of interest were established within

TABLE IX

LEVELIZED LIFE-CYCLE COST ASSUMPTIONS
(1980$)

Assumptions (Base Case)

	Independent-ICEV	Fleet-ICEV	Fleet-FESS/ICEV
Gasoline Cost ($/gal)	1.20	1.20	1.20
Fuel Cost Escalation (real percent/year)	10	10	10
Dispatch Cost ($/mile)	0.00	0.048	0.048
Fuel Mileage (mpg)	11.5	10.0	15.0
O & M Cost ($/mile)	0.22	0.20	0.21
Taxicab Use (miles/year)	50 000	80 000	80 000
Taxicab Lifetime (months)	36	20	20
Taxicab Utilization (paid miles/travel miles)	0.70	0.75	0.75
Taxicab Cost (Average-$))	7600	7000	7800
Insurance Rate (¢/mile)	4.3	4.3	4.8
O & M Escalation Rate[a] (real percent/year)	1.59	1.68	1.67
Inflation Rate (percent/year)	6	6	6
Debt Interest Rate (percent/year, inflated)	12	9	9
Fraction of Investment in Debt	0.80	0.30	0.30
Equity Return Rate (ROI) (percent/year, inflated)	14	20	20
Income Tax Rate (percent)	22	48	48
Investment Tax Credit Rate (percent)	0	10	10
Salvage Value ($)	300	300	300

[a]Represents average of 2 percent on labor, 1 percent on tires, parts and dispatching, and 0 percent on miscellaneous.

the two categories. The case for the combined independent owner/driver and FESS/ICEV was not considered at this time because there was little confidence in the cost data for these systems.

TABLE X

NEW YORK CITY TAXICAB OPERATIONAL COSTS - 1979[a]

Cost ($/mile)

Operations Parameter	Independent-ICEV[b]	Fleet-ICEV	Fleet-FESS/ICEV[b]
Driver Labor	0.320	0.400	0.400
Other Labor (repair, etc)[d]	0.045	0.040	0.042
Tires[d]	0.008	0.007	0.007
Parts[d]	0.033	0.030	0.035
Gasoline	0.070	0.070	0.047
Insurance[d]	0.040	0.040	0.044
Depreciation	0.025	0.025	0.030
Dispatch	0.000	0.044[c]	0.044[c]
Miscellaneous[d] (parking, tolls, etc.)	0.079[c]	0.079[c]	0.079[c]
Total	0.620	0.735	0.728

[a]1980 costs may be obtained by multiplying by 1.081 (the GNP deflator factor).
Costs relate to total transportation miles. Gasoline and depreciation costs were not used as shown.
[b]Costs based partly on fleet data and estimated.
[c]National taxicab average data.
[d]Included in O & M category.

C. Results

1. Base Case - Intercomparison of ICEV and FESS/ICEV Systems. Levelized life-cycle costs have been calculated for the three systems mentioned previously. Data for the years 1980 and 1985 are given in Table XI and shown graphically in Fig. 2. Notable in the 1980 data are the following:

a. For fleet operation, the life-cycle cost for a FESS/ICEV is less by 3.3¢/paid mile. Although this may be a small percentage decrease relative to total costs, it should be noted that the bulk of the costs making up the total (e.g., driver/dispatcher) has little to do with the FESS system. Also, since the system is new, O & M costs have been increased to reflect a conservative

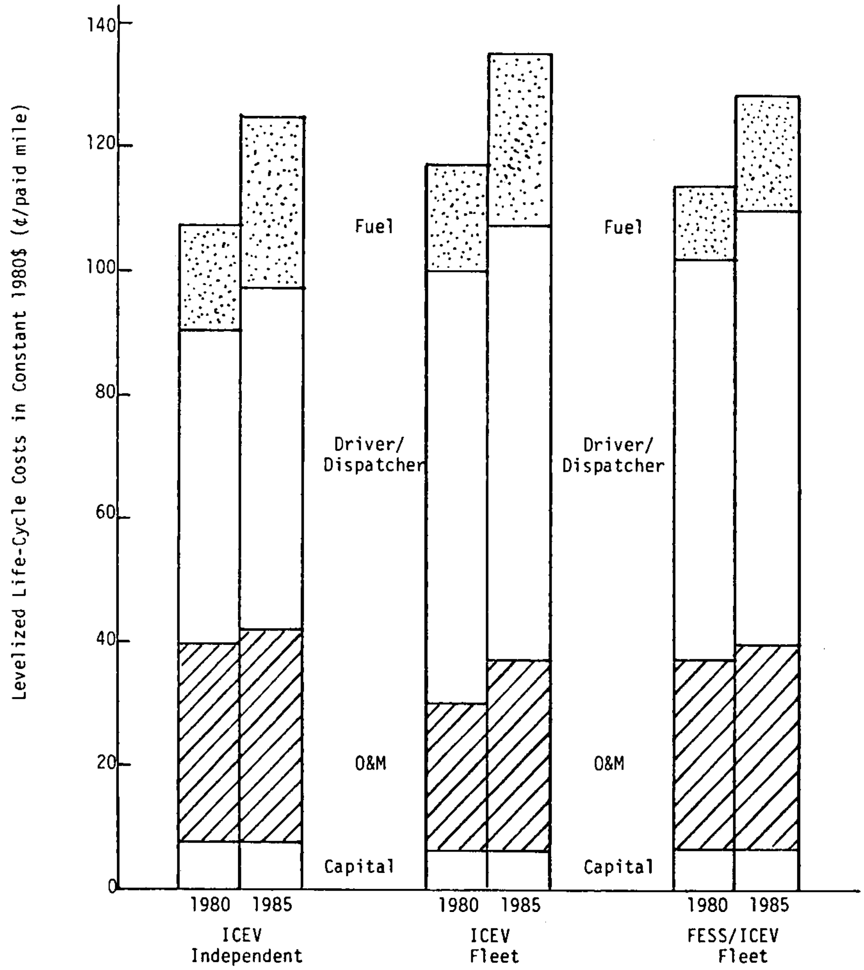


Fig. 2. Comparison of levelized life-cycle costs for three systems of taxicab operation.

viewpoint at least for the early commercialization stage. These costs should decrease in time with due reflection in the life-cycle cost advantage.

b. The FESS/ICEV fuel cost (fleet operation) for the same annual mileage is less. This is implicit in the analysis.

c. The cost of driving and dispatch constitutes the major cost to all systems, 47-57%, depending on the system.

d. The capital costs are a small fraction of the total and are less than the costs of fuel. This suggests that further investments in capital may be warranted to insure additional fuel economy. In other words, should the FESS system be more costly than anticipated, investment may still be worthwhile.

TABLE XI

LEVELIZED LIFE-CYCLE COSTS

(Constant 1980 Dollars)
Cost (¢/paid mile)

Operation Parameter	Independent-ICEV		Fleet-ICEV		Fleet-FESS/ICEV	
	1980	1985	1980	1985	1980	1985
Capital (Depreciation, return on investment, interest, taxes)	7.7	7.7	6.6	6.6	7.4	7.4
O & M	32.2	34.4	28.6	30.6	30.2	30.2
Driver and Dispatch	50.6	54.7	64.8	70.4	64.8	70.4
Fuel	17.1	27.5	17.2	27.7	11.5	18.5
Total	107.6	124.3	117.2	135.3	113.9	128.5

e. Costs are indicated in paid miles, a factor of interest to both industry and regulatory agencies.

f. The life-cycle costs are higher in absolute value than the 1979 operating costs shown in Table X because: (a) paid miles are represented rather than total transportation miles; (b) costs have been inflated to 1980 dollars; (c) fuel and O & M costs have been escalated; and (d) such items as interest, taxes, and return on investment, have been included.

g. Total costs for the independent owner/driver vs fleet ICEV are less primarily because of assumed driver labor and other financial parameter variation.

Data for 1985 are also shown because this date is considered the earliest for introducing any possible quantity of FESS/ICEV taxicabs.

2. Sensitivity Studies. Sensitivity studies were performed on several parameters of interest in this investigation. These include levelized life-cycle costs vs: (a) utilization factor; (b) FESS/ICEV fuel economy ratio; (c) FESS/ICEV-ICEV capital cost ratio; (d) fuel cost; and (e) taxicab lifetime. Results are shown in Figs. 3, 4, and 5. Only fleet operation data were used in these studies.

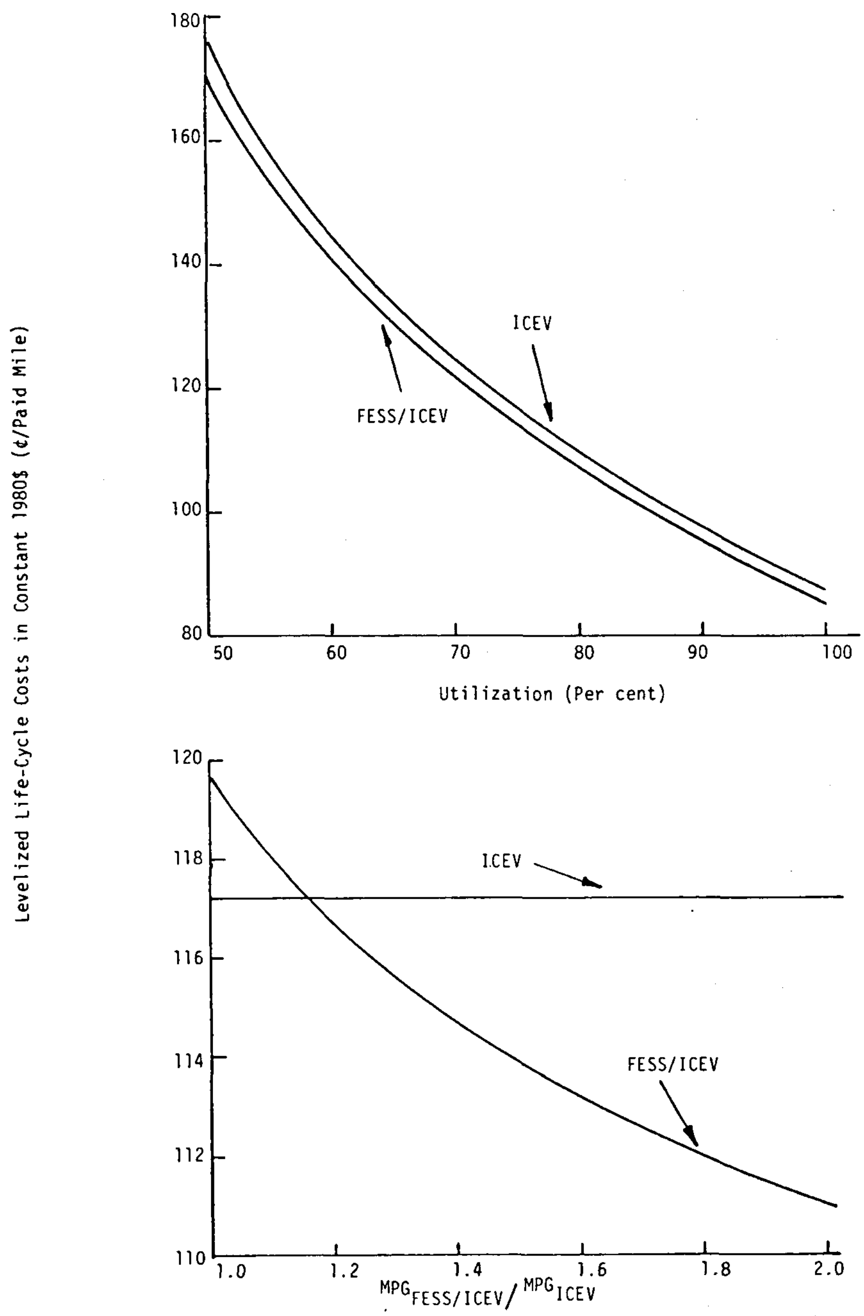


Fig. 3. Life-cycle costs (fleet operation) of taxicab ICEV and FESS/ICEV as a function of the utilization factor and the fuel economy ratio.

Life-cycle costs are somewhat less for a FESS/ICEV system at all utilization factors. At 100% utilization, paid and total transportation miles are coincident. In 1975 utilization averaged about 53-56%.[20] The higher utilization herein is in part due to a heavier concentration of licensed fleet

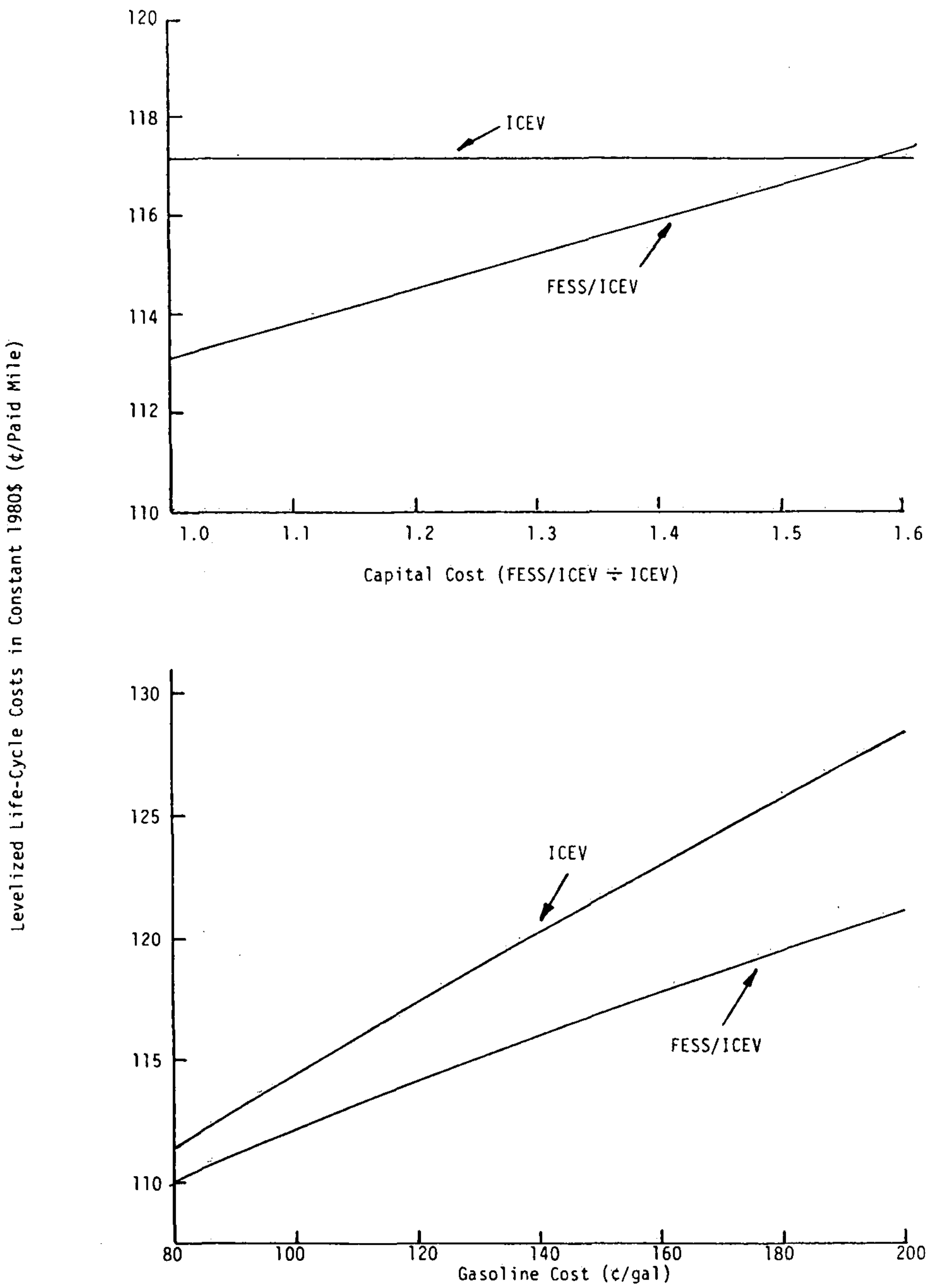


Fig. 4. Life-cycle costs (fleet operation) of taxicab ICEV and FESS/ICEV as a function of the capital cost ratio and the gasoline cost.

vehicles in the CBD whereas the 1975 data represents national averages in many areas. As might be expected, benefits increase with higher utilization rates.

Life-cycle costs of FESS/ICEV are reduced with continued improvement in fuel economy relative to a base value 10 mpg (1.0 ratio) for the ICEV. The

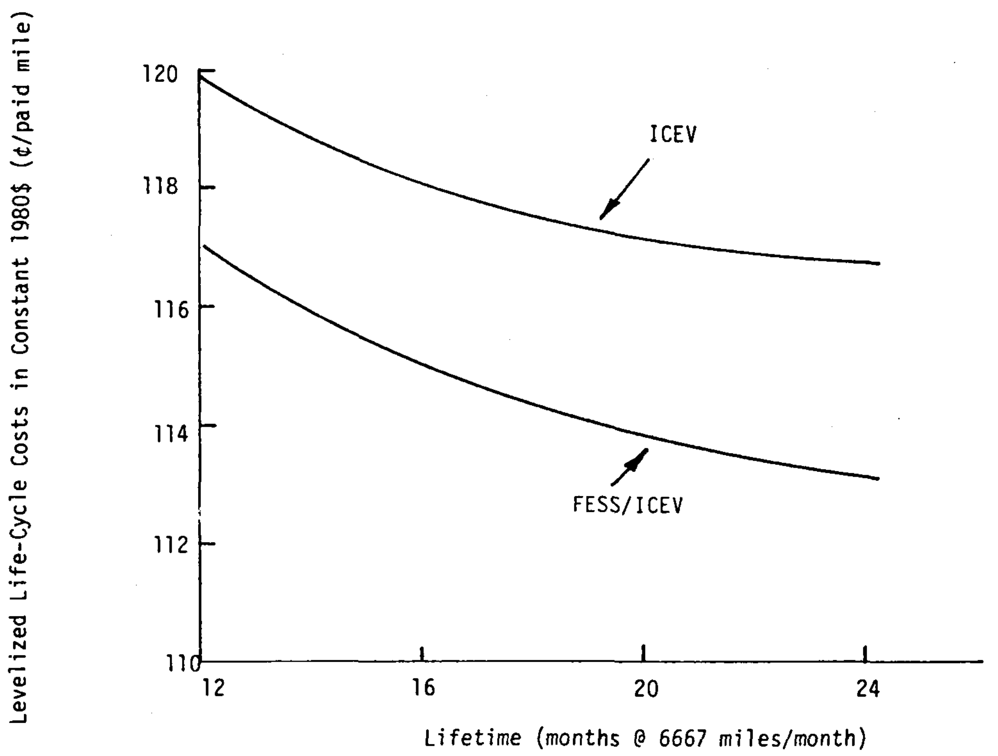


Fig. 5. Life-cycle costs (fleet operation) of taxicab ICEV and FESS/ICEV as a function of operating lifetime.

breakeven gasoline mileage is ~11.8 mpg. Operating costs are higher for FESS/ICEV below the breakeven point.

The life-cycle cost vs the capital cost ratio is of particular interest. It suggests that the capital costs for a FESS/ICEV could be increased as much as 58% before exceeding the ICEV life-cycle costs. This additional capital investment would be warranted to achieve projected gains in fuel economy.

The FESS/ICEV system is less costly at all values of gasoline cost shown in Fig. 4. An interpolation would demonstrate breakeven cost at ~60-65¢/gal in this study. As fuel costs increase, the FESS/ICEV becomes progressively more economical.

The FESS/ICEV system is economical over all of its lifetime as shown in Fig. 5. (The FESS/ICEV life-cycle cost rises more rapidly as lifetime is shortened since it is more capital-intensive.) It is also expected that the behavior for an independent owner/driver FESS/ICEV system would be generally similar.

D. The Case for an Energy Storage System Retrofit of New York City Taxicabs

Implicit in the discussion and cost data presented previously is the assumption that FESS/ICEV taxicabs are factory-produced new at some given production rate. An alternative that has been discussed from time to time concerns the retrofit of existing vehicles. In a physical sense, retrofit is possible as shown by the various experimental vehicles that have been made, but the costs involved in these cases are too high for private or taxicab fleet owners. An estimated cost of retrofitting existing taxicabs, as accomplished by a local mechanics facility or the fleet operators' maintenance group, is not available. We can present, however, some qualitative thoughts which may contribute to any decision concerning viability of the operation. These include the following:

(1) Body designs for the taxicabs did not consider the eventual possibility of including flywheel system components (reference here is to spatial requirements rather than weight). Partial disassembly, modification and realignment of parts of the vehicle will be required. It is generally easier and less expensive to assemble components initially.

(2) The FESS components are new and, at least initially, will require mechanic training for the retrofit process. Besides the FESS-CVT package, new control systems will be required and their installation may require realignment and rewiring.

(3) Retrofitting will necessitate the discarding of original equipment that has some finite and useful life. The loss of this portion of the original investment will be mitigated in part by whatever salvage value can be recovered.

(4) Although only two types of preferred vehicles (Dodge Aspen and Checker) were mentioned in this study, in reality there are a number of other makes of vehicles involved, although in much smaller quantity. These different body designs will complicate the retrofit process. Fleet operations will normally have many vehicles with one body design. Independent owner/drivers use a wider variety.

(5) The retrofit downtime will occur only once during the taxicab lifetime. It is assumed that some fraction of a fleet would be retrofitted at any one time to minimize operating losses. The individual owner/driver must similarly submit to some period of inactivity, the extent of which is presently

unknown. The economic effect may conceivably be greater on the individual owner/driver.

(6) The retrofit process will in most cases be applied to used taxicabs. The time to amortize the capital investment associated with the FESS system and the associated retrofit costs (labor) would be less than in the factory-installed case. Perhaps more importantly, the projected cost of the retrofit would have to be low enough so as to have a payback period within the relatively short remaining service life of the used taxicab, (see Table VII). Payback probability is greater in the case of the independent owner/driver.

(7) It should be noted that maximum energy savings will come about through both the introduction of the FESS and optimization of the engine (prime mover). Some fractional loss in energy savings (fuel economy) potential would be expected if one utilized the available taxicab engine (even with some modifications).

As noted in Sec. VIII, the total number of taxicabs is relatively small and it is questionable whether or not the large manufacturers of vehicles would be interested in producing the necessary components and spare parts required for a retrofit program. On the other hand, small companies and parts manufacturers may very well express interest in doing the job, assuming a retrofit program was viable. For example, consider the Checker Motors Corp.,* well-known for its taxicab production (80-90% of its vehicles in use are taxicabs). In 1979, Checker produced 4,766 vehicles, a very small number by automotive industry standards. One might assume that such a company would be interested in manufacturing the needed components for a retrofit. The production and sales infrastructure already exists, and the assumed conversion of part of its production facilities can probably be done at a fraction of the capital cost necessary for a totally new plant.

In fact, considerations beyond the retrofit suggest that companies such as Checker (given a positive and aggressive attitude) may be interested in producing new FESS/ICEV taxicabs for the relatively small "specialty" market.

*Checker Motors Corp., Kalamazoo, MI 49007. In addition to its own vehicles, Checker produces various parts and assemblies for the automotive industry.

VI. ENERGY CONSERVATION

A. General

Fuel consumption for a given vehicle in specific driving modes is determined by the complex interaction of: (a) several engineering features of the vehicle; (b) traffic control systems; and (c) individual driver reactions to the specific situation that arises. Studies relating these interactions as well as other parameters to fuel consumption have been made.[25, 29, 34]

As noted previously, urban areas and CBDs yield lower average speeds and lower fuel economies (mpg of fuel). Average speed in the New York City CBD (Manhattan) for all types of vehicles (exclusive of trucks) is about 10 mph. Inclusion of urban-type driving (regions other than the CBD) raises this figure to ~13.5 mph.[29] Studies have also been made relating low average speeds to the amount of gasoline consumed per unit distance.[25] These data appear applicable to taxicab operation in New York City.

B. Fuel Economy Data

Fuel economy data of general interest to this study are given in Table XII.

As new vehicles manufactured to meet stricter CAFE standards enter the fleet (national or taxicab), it may be anticipated that the average fuel economy will increase annually, albeit slowly. Additional factors such as curb

TABLE XII

FUEL ECONOMY DATA

Type		Fuel Economy (mpg)	Reference
1. Automotive Fleet-Average	- 1978	15.8	13(b)
2. Automotive Fleet-Average	- 1975	12.7	35
Projection	- 1985	20.8	
3. CAFE Standards for	- 1981	22	16
	- 1982	24	
	- 1983	26	
	- 1984	27	
	- 1985	27.5	
4. New York City			
a. Urban		13.5, 13.9, 15	25, 29, 36
b. CBD		9.2, 10.1	25, 29
c. Taxicab, average		10-12	37

weight, optional equipment, and driver habit, will contribute to the fuel economy actually delivered.

C. Fuel Economy Improvement

The gain in fuel economy projected to come from FESS in a vehicular application is the result of not only the regenerative braking concept but also the concurrent efficient operation of an optimized engine and drive train system. This combined engineered system has been studied by several groups, including the University of Wisconsin, for a number of years. A 3000 lb (1364 kg) vehicle has been built and tested over the FUDC and has demonstrated a mileage improvement of ~50 percent over a corresponding standard production vehicle.[10] Further, simulation studies have shown that a 75% improvement is feasible with currently available system components and that, with continued research and development, a possible 100% may be reached. Applied to the taxicab industry generally and to the operations in New York City, these results are significant.

As a conservative measure, we assume that a 50% gain in fuel economy is realistic for vehicles in the approximate weight class of taxicabs. Two caveats are in order, however. First, at the present time, the New York City licensed taxicab operators have shown a preference for the intermediate-sized vehicle, in the range of the 3500-4000 lb (1588-1814 kg) weight class. This heavier and internally larger vehicle permits reasonable passenger (4-5) comfort and sufficient luggage space. The preference may be traditional but it nevertheless exists. Manufacturers are presently down-sizing new vehicle models. Conceivably, taxicab weights will decrease and with proper design still maintain the requisite operating features. Because fuel economy is, among other considerations, a weight function, projected economies may or may not fully materialize. Continued research and development should raise nevertheless, the improvement percentage. This study therefore assumes that the 50% value is reasonable. Second, both vehicle testing and simulation studies have been done primarily over the FUDC. This drive cycle is not truly representative of the New York City CBD where over 50% of the licensed taxicabs operate.* The nature of an optimized FESS/ICEV system is such, however, that if testing were done over a New York City taxi cycle, results

*A modified New York City taxi cycle was simulated during the diesel taxicab tests briefly discussed in Sec. VII.[31]

would probably demonstrate even further fuel economy improvement. Hence the 50% value would indeed be conservative. In any event, data shown herein can be adjusted if necessary.

Savings in fuel by New York City licensed taxicabs can be shown directly, assuming the 50% gain in fuel economy, i.e., from 10 mpg to 15 mpg for fleets and from 12 mpg to 18 mpg for the independents.* This increase in mileage per gallon translates to a 33.3% savings in fuel purchases annually for the same total annual mileage. There are 11 784 licensed taxicabs in the city, which accumulate 80 000 and 50 000 miles per year (fleets and independents, respectively). A prorated calculation shows the total amount of gasoline saved to be 25 x 10^6 gal/year. The energy equivalent of automotive gasoline is ~125,000 Btu/gal. Thus, about 3.1 x 10^{12} Btu year can be saved. At a cost of $1.20 per gallon of gasoline, the savings for the entire fleet is $30 x 10^6/year. Practically speaking, these savings will be reduced by some fraction because of inclusion of some percentage of extended urban or even highway travel and the other factors mentioned previously in Sec. VI-B.

If one were to include the "gypsy" traffic operating in a manner equivalent to the licensed taxicabs (which they do in part), the savings would almost double.

Although it is tempting to extrapolate these numbers to the national taxicab fleet (~207,000 vehicles), it should be understood that taxicab operation in New York City is by no means equivalent to those in other cities. There are too many other variables such as urban design, traffic control, system variation, and inclusion of available freeway traffic. For example, it has been shown that ~45 percent more gasoline is used in the New York City/Newark CBD compared to the Los Angeles CBD to travel the same distances.[29] The fraction of the national fleet that drives in a manner equivalent to that in New York City is unknown.

During this investigation, one of the authors (Krupka) observed actual New York City taxicab traffic in operation. Stop-go traffic is of course integrated into both the CBD and expanded urban types of traffic, and certain localized regions are perhaps excessive in this respect. On many of the main,

*A detailed engineering energy flow analysis (fuel in-road load out) for a particular design of vehicle is beyond the scope of this study.

but congested, streets, the traffic control system tends to eliminate a significant fraction of block-to-block stop-go traffic. Driver habits are such that there is considerable jockeying for position so as to continue the trip without stopping and to reduce travel time. These maneuvers result in many situations where braking to some degree (but not to a complete stop) is necessary, which brings to mind the regenerative braking feature of the FESS/ICEV. The point of this subjective observation is simply that perhaps some emphasis should be given to optimizing selected design parameters during the engineering of FESS devices so that the energy savings of regenerative braking may be maximized. A previous study has shown that ~15 percent energy savings appears reasonable for city driving.[38]

VII. ENVIRONMENTAL CONSIDERATIONS

A. General

Environmental considerations arising from an assessment of new system technology include such elements as (a) air, water, land quality degradation; (b) resource and ecosystem disruption; and (c) health disturbance (technical safety issues are not discussed in this report).* The introduction of flywheel technology is likely to have its most noticeable effects upon air quality (emissions) and associated health impacts, especially in urban environments.

Noise levels are not expected to be a problem. The use of presently expensive materials such as Kevlar and graphite fiber-epoxy plastic matrices should not reduce available material resources significantly as FESS will not necessarily be introduced into the total automotive market. Because FESS-CVT composite units are partial replacements for today's automatic transmissions, the automobile industry should be able to produce them without difficulty.

B. Emissions

1. Federal Emission Standards. Table XIII gives the federal emission standards as established by the 1977 Clean Air Act Amendments. In 1978, ~34 percent of all automobiles including late-model taxicabs, had some form of emission control system.[17] Table XIV shows emissions from all automobiles in urban areas for the years 1968 and 1975 (before and after 7 years of control). Flywheel technology introduction should reduce these further.

*Safety issues in flywheel design are indeed recognized and fail-safe design is part of the development program. Safety, however, could be an institutional issue (See Sec. VIII).

TABLE XIII

FEDERAL EMISSION STANDARDS

Model Year	Emissions					
	Federal			California(a)		
	HC GM/MI	CO GM/MI	NO_x GM/MI	HC GM/MI	CO GM/MI	NO_x GM/MI
1976	1.5	15.0	3.1	0.9	9.0	2.0
1977	1.5	15.0	2.0	0.41	9.0	1.5
1978	1.5	15.0	2.0	0.41	9.0	1.5
1979	1.5	15.0	2.0	0.41	9.0	1.5
1980	0.41	7.0	2.0	0.41	7.0	1.0
1981	0.41	3.4(b)	1.0(c)	0.41	3.4	1.0
1982	0.41	3.4(b)	1.0(c)	0.41	3.4	0.4
1983	0.41	3.4	1.0(c)	0.41	3.4	0.4
1984	0.41	3.4	1.0(c)	0.41	3.4	0.4
1985	0.41	3.4	1.0	0.41	3.4	0.4

(a) Federal standards applicable to diesel engines
(b) Waiver up to 7 GM/MI possible
(c) Waiver up to 1.5 GM/MI possible (diesel or innovative technology)

2. New York City Emissions. Because CBDs have the highest pollution levels, our emissions study focuses on Manhattan, New York City's prime CBD.

Before the introduction of large numbers of emission control systems, a 1969 study showed that ~7 x 10^6 lb/day CO (~1.3 x 10^6 tons/year) and ~7 x 10^5 lb/day HC (~1.3 x 10^5 tons/year) were emitted in New York City from automobiles alone (trucks were excluded).[27] Corresponding values obtained recently are shown in Table XV. The data are not totally comparable since the later data were determined with more sophisticated computational techniques. The 1980 data are projections. Nevertheless, improvement is obvious.

The New York City Taxicab and Limousine Commission is mandated to establish emission standards. Taxicabs of years 1979 and 1980 must meet emission standards equivalent to those for California (Table XIII).* New York City licensed taxicabs must undergo emission checks three times yearly on both spot check and scheduled bases (noncontrolled livery service cabs - once yearly). This check includes engine idle exhaust analyses (~two minutes).

The introduction of FESS into taxicabs by 1985 and beyond should reduce emissions further (beyond evolutionary engine and automobile design

*NO_x emissions are of minimal concern in New York City. Most emission standards will be equivalent to those in California from 1980 on.

TABLE XIV

ESTIMATED URBAN AUTOMOBILE EMISSIONS[1]

Year	Emission Levels					
	Grams/Mile			Tons/Year (10^6)[a]		
	HC	CO	NO_x	HC	CO	NO_x
1968	8.7	87	3.5	4.2	42.0	1.7
1975	4.1	34	5.0	2.5	21.0	3.1

[a]Assuming 55% of vehicle miles traveled in urban areas.

TABLE XV

NEW YORK CITY AUTOMOBILE EMISSIONS[a26(b)]

Year	Emission Levels Tons/Year (10^6)		
	HC	CO	NO_x
1979	0.068	0.80	Not available
1980	0.059	0.73	Not available

[a]Includes taxicabs

improvement). In particular, a taxicab designed with a control computer to shut off engine and fuel flow when not required should reduce fuel consumption significantly. Although taxicabs are a small fraction of the vehicle population in New York, because of their type of operation they contribute a disproportionate share of the total pollution level in specific areas.

The 50% mileage improvement is equivalent to driving an additional 40,000 miles per year (fleet) or 25,000 miles per year (independent). We further assume that emission levels from the vehicle equal the 1981 federal specifications, i.e., HC, 0.41 grams/mile and CO, 3.4 grams/mile. A prorated calculation shows that the licensed taxicab fleet in New York City would add a potential total of 1.8×10^2 tons/yr of HC and 1.5×10^3 tons/yr of CO to the urban atmosphere. About 50% of this would be in or near the CBD.

The diesel engine taxicab is a potential competitor with the FESS/ICEV taxi. Tests involving 66 diesel taxicabs in New York City have been completed recently.[31] Over 120,000 miles, the diesel taxicabs demonstrated ~50% improvement in fuel economy, lower emissions in all categories, and somewhat lower maintenance. However, there has been recent concern over alleged carcinogenic properties of some components of diesel exhaust (particulates). This problem has yet to be resolved.

C. Other Types of Emissions

The use of FESS, through its regenerative braking function, also reduces particulate pollution from brake systems because brake lining wear should decrease.

Flywheel rotors operate within a vacuum (< 1 torr) so as to reduce, among other effects, aerodynamic heating. Should the pressure rise to ambient while the rotor is spinning rapidly, the potential exists for a gas molecule-surface interaction that will cause overheating and in the case where composite rotors are used, a possible fire. Combustion of organic materials releases gases and particulates. The exact nature of these combustion products or emissions will depend, in part upon the specific parent materials. Proper design engineering should minimize such occurrences.

D. Noise

Noise regulations exist at federal, state, and local (city, county, etc.) levels. Table XVI shows noise level regulation for New York City.

Data showing noise levels emanating from experimental FESS sized for automotive vehicle application are not generally available. Hence comparison to the New York City regulations cannot be made. Present development programs suggest that noise should not be a problem at such time that commercial FESS units will appear.* The basic sound may be different but the absolute level should be within bounds. The University of California's Lawrence Livermore National Laboratory has included development of low-noise-level units in its overall development program.[40]

VIII. INSTITUTIONAL ISSUES

A. General

Institutional factors can be defined in terms of the various social, legal, environmental, and safety ground rules existing within society. In the

*There are, at present, noise problems associated with CVT units. Noise quality associated with the flywheel portion is somewhat similar to the acceleration and deceleration of electric motors.

TABLE XVI

NEW YORK CITY NOISE LEVEL REGULATIONS[39]

	Vehicle Type/Wgt.	Effective Date	Operation[a] < 35 MPH (dBA)	Operation[a] > 35 MPH (dBA)
New York,	>8000 lb	9-1-72	86	90
New York	Motorcycles	9-1-72	82	86
		1-1-78	78	82
	Other Vehicles	9-1-72	76	82
		1-1-78	70	79

[a]Measured at 15.2 m (50 ft)

automotive industry and in the public's use of automotive products, these may include: (a) regulation of vehicle use; (b) product liability of the manufacturer; (c) consideration of environmental and safety factors; (d) items relating to roadway use and construction; and (e) the nature of the automotive industry itself.

B. Potential Barriers

1. Automobile Industry - Production. The number of vehicles classified as taxicabs is small, ~12,000 licensed in New York City* and ~207 000 nationally. Even coupled with replacement unit manufacture, the total FESS market is small by industry and on-the-road vehicle standards. The passenger vehicle industry has huge capital investments, and the research and development activities tend to emphasize evolutionary modifications. The industry is slow to introduce radically new technology particularly where the front-end investment is in a high risk category, i.e., new product acceptance. The automatic transmission took ~10-20 years for full commercial deployment after the basic concepts were worked out. The CVT transmission unit still has engineering problems as does the FESS portion. The use of FESS also implies engine design optimization although these changes should not create any real production problems within the automated production facilities. The economies of large scale production also may inhibit immediate FESS production unless the total market is enlarged, i.e., to levels more consistent with national passenger vehicle

*There is an indeterminate number of other vehicles in the New York City area providing passengers transport service not under the control of the New York City Taxi and Limousine Commission.

numbers. If not, the resulting "specialty" market may produce items with higher price tags and, for the short term, there could be limited availability of components. In a previous survey,[14] the taxicab industry listed initial purchase price as a close second in purchase criteria, the prime criteria being maintenance and availability of replacement parts.

2. Automobile Industry - Service. The basic industry infrastructure for servicing purposes is available, although actual servicing experience for flywheels is presently nonexistent.[6] Considering the general design of the FESS/CVT package and associated controls, additional service requirements may be anticipated including new training and reorientation for mechanics.

3. Automobile Industry - Government Interrelationship. The Federal Government is currently funding the bulk of flywheel technology development. The US automotive industry does not show near term production interest regarding flywheel systems although work is being done in their research laboratories. Foreign manufacturers such as Fiat and Volkswagen are more openly interested in flywheel-powered vehicles. A major problem, one that pervades many other programs sponsored by federal agencies, involves the patent or commercial rights of a finished device developed by a contractor with federal funds. Because the contractor is generally not permitted to retain these, the success of the individual company, especially a small one, may be at stake. The net result is often a delay in market penetration despite the availability of the technology, operating fleet vehicles, etc.

4. New York City Regulations. Procedures are available for running experimental test vehicles in New York City. A recent example is the diesel taxicab test.[31] A follow-on test is in progress. What is generally required is some form of federal certification for the tests and contractual arrangements for conduction of the tests. Federal certification must be presented to the New York City Taxi and Limousine Commission. Assuming that the tests are successful and that major operation of the system is desirable within New York City, a routine type of licensing procedure is required (see Sec. III). The commission is especially concerned with the emission problem and will not license any vehicle that may produce emissions beyond present limits.

5. Petroleum Industry. The use of flywheel technology implies a reduction in gasoline consumption. Opposition to introduction of FESS/ICEV is certainly possible. However, any reduction caused by taxicabs alone, despite

their present large purchases, will hardly create problems for the petroleum industry.

6. Safety. Safety considerations have not been discussed in this report in terms of the technical aspects. Nevertheless, the safety issue cannot be ignored in an institutional sense. The containment problem is still under investigation and probably will be solved before 1985. However, the concept of a shielded high-velocity spinning rotor in the midst of congested districts may not easily be accepted. Demonstration projects must have components that work properly and the tests be essentially free of accidents. Bad publicity regarding breakdown and safety could cause consumer rejection for lengthy periods of time. Insurance companies will want information such as safety test data, crash effects, and damage repairability before issuing liability policies. This is especially important in the New York City area. A question that will be asked is whether or not the flywheel introduces a degree of hazard beyond that of ICEVs. Product liability with respect to the manufacturer also concerns the insurance industry. Some minimal and additional federal safety standards will probably have to be developed for FESS/ ICEV sooner or later, especially if new hazards are shown to exist. At the moment, of course, there is no proven track record for the system, although fail-safe designs may exist. What is needed is a strong educational program for the insurers, the public and the state, and municipal vehicle registration and regulatory agencies.

7. Automotive Fleet Manager Considerations. Although fleet managers have the available test bed to try out innovative technology, actual acceptance of such technology for routine use is another matter. The FESS/ICEV would have to exhibit performance durability and reliability equivalent to, or better than, present ICEVs. Fleet managers will usually permit a tryout of new systems (a small number of test vehicles) at Federal Government request. This has occurred in the New York City diesel taxicab tests thus setting a precedent for future FESS/ICEV tests. A major complaint about such federal testing is that the gross reimbursement is inadequate for the expended effort. Also, fleet managers often view skeptically promised tax incentives and loan guarantees because these may vanish pending the mood of Congress or the political scene. They prefer to operate within the private sector as much as possible.

8. Social Considerations. An initial barrier will be the unfamiliarity of the taxidriver and taxicab mechanic with the FESS/ICEV drive procedure

and drive control system. To ameliorate such a scenario, we assume that vehicle designers will develop procedures as similar as possible to those of the ICEV. Nevertheless, there are bound to be some new procedural aspects. Some reluctance to use the new vehicles is to be anticipated. Mechanics will require some time to develop experience. Taxicab downtime may be above average and possibly unacceptable to the New York City taxicab companies.

As previously noted, there is another element of taxicab operation, the "gypsy" taxicab, that may have ultimate economic effects. The number of these taxicabs are significant. They operate in areas where the licensed industry fails to provide service. Their operating costs are unknown or at least difficult to acquire and there does not appear to be any general spokesman for the group. Operations are probably similar to independent/owner-operators without the control of the city commission. Their large and growing numbers suggest they be included when and if FESS/ICEV are manufactured for routine use. In addition, social issues such as union policies, licensed vs unlicensed competitive maneuvering, and internal city ghetto problems, contribute to potential delays in technology implementation. These latter effects are almost impossible to quantify.[41]

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APPENDIX A

SELECTED NATIONAL AUTOMOTIVE FLEET DATA

The information given in this appendix represents selected descriptions of automotive fleet data. In addition, a summary of a report analyzing some fleet data is reproduced.[14]

TABLE A-I

US CARS IN FLEETS BY TYPE OF BUSINESS[12]

TYPE OF FLEET	CARS (In Thousands)										
Business Fleets-25 or more	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Salesman Owned	438	419	411	392	381	373	364	357	353	350	348
Company Owned.	243	228	236	223	217	209	204	198	195	208	215
Leased by Companies (By Types of Lease)											
Finance & Management	638	706	732	918	1226	1235	1262	1391	1412	1540	1580
Partial/Full Maintenance . .	381	368	373	303	247	272	268	262	258	187	184
Net/Fixed.	84	131	126	134	118	139	136	125	133	123	121
TOTAL Fleet Leased	1103	1205	1231	1355	1591	1646	1666	1778	1803	1850	1885
Business Fleets-10-24 Cars											
Owned.	641	553	563	537	521	506	501	496	488	475	470
Leased	85	99	105	128	153	168	174	211	228	241	256
Individually Leased	697	803	834	925	994	1008	1072	1217	1385	1610	1690
Other Fleets											
Government	594	601	611	592	598	611	628	635	642	648	645
Utilities.	404	416	421	438	467	482	497	508	518	523	529
Police	191	207	218	236	249	261	278	286	292	294	291
TAXI	169	171	174	177	182	185	193	202	202	205	207
Daily Rental.	297	314	319	341	364	361	354	373	385	448	462
Driver School.	27	25	27	29	27	26	25	26	26	24	21
TOTAL (Excluding Business Fleets .	1682	1724	1770	1813	1887	1926	1975	2030	2065	2142	2155
NOTE: Number of Cars in Fleets of 4 or More. . .	9780	9992	10070	10094	10214	10324	10398	10403	10414	10423	10428

TABLE A-II

AMERICAN AUTOMOTIVE LEASING ASSOCIATION (AALA) FLEET COST SURVEY[a][12]

Comparative Statement of Average Per Unit Per Month Costs

			Increase (Decrease)		
Operating Costs:	1979	1978	Amount	Percentage	Percentage of Total
Depreciation	$ 134.66	$ 123.83	$ 10.83	8.7	55.1
Repairs and maintenance	30.15	28.38	1.77	6.2	9.0
Insurance	13.69	13.59	.10	.7	.5
License tags and taxes	7.40	9.53	(2.13)	(22.4)	(10.8)
Finance costs	34.51	27.27	7.24	26.5	36.8
Delivery	2.90	2.90	-		
Total Operating Costs	223.31	205.50	17.81	8.7	90.6
General and administrative	24.67	22.81	1.86	8.2	9.4
Total Costs	$ 247.98	$ 228.31	$ 19.67	8.6	100%

	1979	1978	1977	1976	1975	1974	1973	1972
Total costs per month	$247.98	228.31	$212.01	$198.67	$193.95	$173.71	$164.89	$154.45
Average months in operation	26.6	26.3	26.1	26.0	24.6	23.9	23.6	24.2
Average annual mileage	28,952	30,609	28,568	26,000	31,185	26,384	24,350	24,322

[a]Data shown represent that of a typical large automotive fleet leasing group. Administration costs not included.

TABLE A-III

AVERAGE COMPOSITION OF THE AALA FLEET[12]

Year	Standard Models-%	Intermediate Models-%	Compact Models-%	Air Conditioning-%
1979	45.0	43.0	12.0	98.0
1978	48.0	44.0	8.0	93.0
1977	45.0	47.0	8.0	95.0
1976	46.0	48.0	6.0	95.0
1975	53.0	40.0	7.0	94.0
1974	62.0	33.0	5.0	86.0
1973	70.0	24.0	6.0	83.0
1972	76.0	19.0	5.0	83.0
1971	81.0	15.0	4.0	79.0
1970	97.0		3.0	78.0
1969	96.0		4.0	67.0
1968	97.0		3.0	56.0
1967	96.0		4.0	46.0

The following summary is reproduced from the Brookhaven National Laboratory report analyzing fleet operation data.[14]

SUMMARY

The purpose of this report is to present data pertinent to analyzing the marketability of alternative vehicles. The data deal with the fleet market (i.e., groups of 10 or more light-duty vehicles operated by corporations or government agencies), which is important for three reasons:

1. The fleet market is large, accounting for 12 percent of new car sales.

2. Fleet operators may not respond to government actions in the same way as household vehicle operators, because fleet operators (a) are more dependent on the current pattern of vehicle use, and (b) are partially insulated (by tax deductions and the ability to pass cost increases to customers) from changes in vehicle costs.

3. Fleet operators constitute a valuable test market for alternative vehicles because of their (a) organizational resources, both managerial and monetary, which permit them to accept some of the risk associated with testing new technology; (b) bulk buying practices, which enable a new manufacturer to concentrate on a limited product line and a small number of customers; (c) conscientious maintenance and record-keeping practices; (d) ability to assign certain vehicles to less-demanding vehicle missions; (e) fast mileage accumulation and attendant high visibility of product.

The data presented here were collected via a questionnaire mailed to fleet operators in August 1977, with a partial resample in January 1978. The survey was mailed by the Bobit Publishing Company to readers of Bobit's <u>Automotive Fleet</u> magazine. The data do not represent a statistically designed probability sample. Nor, owing to the lack of a detailed census of fleet vehicles, have any of the data been weighted to correct for potential sampling errors. The sample includes 1267 respondents who control a total of 284,232 cars and 122,676 light trucks. The cars represent an estimated 6 percent of fleet cars in the United States. The questionnaire concentrated on eliciting information about obstacles which might prevent new technologies from penetrating the fleet market. Topics included:

- Market sector and geographic location of respondent.
- Vehicle tenure (i.e., whether vehicles were owned or leased).
- Historical composition of fleet, in terms of vehicle size.
- The relative importance of certain purchase criteria.
- Number of vehicles, by size class, currently in fleet.
- Power options typically ordered.
- Diesel fuel availability.
- Driving range needs.
- Garaging of vehicles.
- Need for interstate highway capabilities (i.e., acceleration and speed).
- Seating capacity needs.
- Annual miles per vehicle.
- Engine selection criteria.
- Disposal criteria.
- Contractual restrictions.

Many inferences can be drawn from the questionnaire data:

Fleet cars tend to be larger than US cars in general. A comparison yields the following:

	Percent of cars	
Car size class	All US cars (1976)	Bobit sample (1977)
Small	27	5
Medium	18	33
Large	55	62

- There is a strong correlation between car size and mission requirements. Small and medium cars generally are not required to have as much range or as many power options as large cars, and are more available for lengthy refueling. Thus, while fleet vehicle missions in general may be very rigorous, there may exist a market for a fleet vehicle with limited capabilities.

- Fleet preference for power options is very similar to the incidence of power options in the total stock of US light-duty vehicles. Fleet cars have a slightly higher incidence of options than do all US cars; fleet light trucks have an incidence which is generally lower than that of the overall stock of light trucks.

- 84 percent of fleet cars and 64 percent of fleet light trucks are required by their operators to be capable of driving 100 or more miles per day.

- 10 percent of fleet cars and 23 percent of fleet light trucks do not need the ability to accelerate and cruise on interstate highways and are also idle each day for 8 or more consecutive hours at a central location.

- 17 percent of fleet cars need only 2-passenger capacity.

- Fleet cars are driven an average of 22,000 miles per year and leave fleet service at an average age of 3.2 years. Fleet cars are generally disposed of in the used car market and many fleet operators seek out vehicles with good resale characteristics.

- Vehicle leasing is common in the fleet market, and leasing companies (i.e., the vehicle owners) can potentially exert a significant influence on vehicle choice.

- Differences between sectors of the fleet market tend to be larger than differences between the fleet market and the non-fleet market. Table IV in the text summarizes key variables for the six sectors identified in the Bobit data.

The Bobit data can be used to estimate applicability rates for hypothetical vehicles entering the fleet market. This is done by comparing attributes (range, passenger capacity, etc.) of a hypothetical vehicle to the expressed needs of individual respondents, in order to estimate the share of the fleet market which would be satisfied with the physical capabilities of the given vehicle. Estimates of market penetration, as opposed to simple applicability, await integration of price data with the Bobit data.

APPENDIX B

SELECTED NATIONAL TAXICAB FLEET DATA

A summary of the report analyzing taxicab fleet data is reproduced below.[20]

SUMMARY

This report presents the combined results of two mail questionnaire surveys of the taxicab industry conducted in 1974 and 1976. The focus is on taxiicab operating characteristics, including

a. Types of operations, vehicles, and services provided
b. Industry structure
c. Passenger operations
d. Utilization of employees and vehicles
e. Cost and revenue relationships
f. Fare structure

Operating statistics and analytical ratios are computed describing the above characteristics for either 1974 and 1976 or 1973 and 1975 depending upon the nature of the data.

SAMPLE CHARACTERISTICS

In the fall of 1974 mail questionnaires were sent to 6,467 taxicab fleet operators; in 1976 the questionnaires were sent to 5,387 operators. Response rates were 10.8% in 1974 and 4.7% in 1976. In spite of these low response rates both samples provide broad geographical and fleet size coverage. However, the samples fall short of being true random samples, and the results should be accepted only as general and tentative indications of taxicab operations in the two years.

GENERAL CHARACTERISTICS

Types of Operations

Taxicab operations are classified according to the following categories:

a. Commission - drivers are paid a percentage of receipts
b. Lease - drivers lease the taxicabs on a daily, weekly, or monthly basis
c. Owner-driver - drivers own the taxicabs. They contract for company services, e.g., dispatching, maintenance
d. Combinations of the above

Although all combinations are represented in the 1974 and 1976 samples, each sample is dominated by exclusively commission operations (66.3% in 1974 and 71.2% in 1976). The percent that was exclusively lease operations increased from 7.7% in 1974 to 12.0% in 1976. Because of changing economic conditions, it is expected that lease operations will eventually represent the majority of the industry.

Types of Vehicles

In both years, taxicabs represented over 85% of the vehicles. Some operators run limousines, buses, school buses, and special vehicles for the handicapped. More operators are acquiring the latter type vehicle in reponse to Federal aid to state and local agencies for transport of handicapped and senior citizens.

About 92% of the operators in 1976 had their entire fleet of taxicabs equipped with two-way radios. Operators in New York and Chicago had less than 50% of their cabs equipped, because in these cities cabs operate in the densely populated center city areas on a "hail" basis. Washington, DC is another example of this type of operation.

Services Provided

The 1974 survey indicated that taxicab operators are ready to provide almost any type of paratransit service on a demand as well as contract basis. In addition to the conventional passenger services, a large percentage (over 71%) provided package delivery services, and 25% provided special services for the handicapped on demand. Emergency services were provided by nearly 50% of the operators. This highlights the fact that because most taxicabs have two-way radios, they are an adjunct to police, fire, and ambulance emergency services and are often used for this purpose.

In addition to demand services, certain special services were provided on a contract or pre-arranged basis. The most frequently mentioned services of this nature were:

Service	Percent Providing Service
School Children	44
Company Employees	43
Hospital Patients	31
Government Employees	11
Senior Citizens/Public aid	10
Blood and Hospital Supplies	5

Industry Structure

Although about two-thirds of the taxicab operators in both samples had less than 25 taxicabs in their fleets, most of the operational activity was concentrated in companies with fleets of 200 or more cabs. In 1975, for example, 4.7% of the operators in the 200 or more fleet size category accounted for 51.8% of the taxicabs, 49.1% of the employees, and 41.8% of the passengers.

The following general statements can be made regarding the relative size of the taxicab industry:

1. Taxicab haul over one-half as many passengers per year as bus transit and over 600 million more passengers than rail transit.

2. The taxicab industry generates more than twice the annual revenue of the bus transit industry and at least $1 billion more than the transit industry as a whole.*

3. Taxicab industry employment is about 3 times that of the bus transit industry and over twice that of the entire transit industry.

These three statements clearly indicate that the taxicab industry can be placed on at least an equal basis with the transit industry in terms of both passenger service provided and significance to the US economy, particularly with respect to the degree of employment.

OPERATING CHARACTERISTICS

Table B-I and the more detailed tables in Ref. 20 that show the various ratios according to size of fleet can be summarized as follows:

1. Passenger productivity increased from 1973 to 1975 for the operations with less than 100 taxicabs but declined for those with 100 or more. The 75-99 fleet size category had the best improvement.

2. The number of vehicle miles per trip--which includes both "deadhead" and paid (revenue miles)--declined generally for all fleet-size categories. The decline was less for the 200-and-over fleet-size category. The general decline possibly could be attributed to sharp increases in fuel costs and efforts of operators to keep excess mileage to the minimum.

3. The number of employees per taxicab increased in all size categories as did the number of W2 forms per taxicab. This undoubtedly reflects the contra-recessionary character of taxicab industry employment.

*In 1977, purchased local taxicab transportation (personal consumption expenditures) amounted to over $1.2 billion dollars (national).[17]

4. Taxicab fleet operators have evidently experienced profit declines from 1970 to 1975. In 1975 the revenues of nearly 50% of the companies did not cover total costs (including capital costs). Revenues of 25% of the companies did not cover out-of-pocket costs. This tends to verify observed conditions in the industry resulting from drastic increases in fuel, insurance, and labor costs. The situation for large operators appears to be worse than for smaller operators. In 1975 the most profitable fleet-size class was 75-99 taxicabs. Operators with fleet sizes smaller than 75 cabs had better profit profiles than those in the 200-and-over category.

5. The use of meters for calculating fares increased from 62.4% of the operators in 1974 to 71.0% in 1976. The zone system is the most prevalent non-meter system.

6. From 1974 to 1976 fare structures for meter systems shifted toward higher initial mileage charges (flag drop charges) and shorter initial mileages. Additional mileage charges remained about the same but for shorter additional mileages; i.e., a typical additional mileage rate change was from 10¢ for 1/5 mile to 10¢ for 1/6 mile.* The net effect of the rate changes was to increase the fare for a three-mile trip about 10-11%.

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*New York City charges are now $0.10 for every 1/9 mile.

TABLE B-I

SUMMARY OF TAXICAB OPERATING CHARACTERISTICS, 1973 AND 1975[20]

Operating Characteristics	Medians 1973	Medians 1975	Arithmetic Means 1973	Arithmetic Means 1975
Passenger Operations				
Annual Passengers per Taxicab (000)	11.0	11.1	11.9	10.9
Vehicle Miles per Passenger	3.34	3.34	3.65	3.53
Passengers per Vehicle Mile	.30	.30	.27	.28
Passengers per Trip	1.49	1.37	1.60	1.46
Trip Distance				
Vehicle Miles per Trip	5.32	4.82	6.05	5.36
Paid Miles per Trip (Trip Distance per Passenger)	NA*	2.70	NA	2.85
Employee and Vehicle Utilization				
Annual Vehicle Miles per Taxicab (000)	40.0	39.4	43.5	40.1
Employees per Taxicab	1.75	2.06	1.84	1.89
W2 Forms per Taxicab	4.13	4.50	4.43	4.66
Costs Versus Revenues				
Costs Less Depreciation as a Percent of Receipts	NA	95.0	83.7 (1970)	94.3
Per Taxicab ($000)				
Costs Less Depreciation	NA	14.2	NA	15.8
Receipts	12.5	15.4	14.5	17.4
Per Vehicle Mile ($)				
Costs Less Depreciation	NA	.38	NA	.41
Receipts	.34	.41	.35	.43
Per Trip ($)				
Cost Less Depreciation	NA	1.78	NA	2.15
Receipts	1.66	1.97	1.97	2.23
Per Passenger ($)				
Costs Less Depreciation	NA	1.23	NA	1.36
Receipts	1.18	1.43	1.30	1.52
Paid Miles per Vehicle Mile (%)	NA	50.0	NA	51.6
Fares				
Fare for 1 Mile Trip	NA	1.20	NA	1.24
Fare for 3 Mile Trip	2.24	2.45	2.27	2.54
Fare for 4.5 Mile Trip	3.09	3.34	3.15	3.51

*NA = not available