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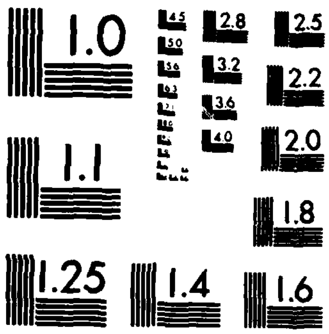

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Monterey, California

THESIS

DECISION MODELS FOR CONDUCTING AN
ECONOMIC ANALYSIS OF ALTERNATIVE FUELS
FOR THE ICE ENGINE

by

Clifton F. Garrison Jr.

March 1983

Thesis Advisors: D. C. Boger

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Decision Models for Conducting an Economic Analysis of Alternative Fuels for the ICE Engine

by

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Lieutenant, United States Navy
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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

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ABSTRACT

An economic analysis is made of vehicles powered by compressed natural gas (CNG), alcohol, and electric vehicles (EV's) as possible replacements for gasoline-powered vehicles. Advantages and disadvantages of vehicles powered by the various fuels are discussed and determinations of their suitability are made based on vehicle performance characteristics and fuel availability. CNG and EV's are determined to be viable alternatives based on current state-of-the-art technology. Alcohol is not retained as a viable alternative because of limited fuel availability. Models are presented for determining the total life cycle cost for gasoline, CNG, and EV's. A fleet of seventy-two vehicles at the Naval Postgraduate School is used as an example to compare the cost of each alternative. A linear program is used to determine the mix of gasoline, CNG, and electric vehicles that satisfy mission requirements for the least total fleet life cycle cost and to perform sensitivity analysis on the cost determinants. A generalized formulation is also presented to allow a vehicle fleet manager to use the methodology of this thesis as an aid to evaluating the potential of alternatively-fueled vehicles in different situations.

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I. INTRODUCTION

The cost of maintaining and operating a fleet of vehicles is a significant item in any Public Works Department budget. Invariably there is an interest in alternatives to the gasoline-powered internal combustion engine (ICE) as a means of reducing these costs. Two factors dampen this interest and usually terminate any further inquiry. The first is a lack of consolidated information on the feasibility of using alternative fuels and the second is the lack of capital required for the initial investment. National interest in alternative fuels stems from a desire to reduce our dependence on petroleum-based fuels and reduce the level of emissions from automobiles. This thesis presents an assessment of the feasibility of employing several alternative fuels in non-tactical, on-the-road passenger vehicles used by Naval activities and presents decision models for determining the total life cycle costs (LCC) and the optimal mix of vehicles using alternative fuels. The vehicles at the Naval Postgraduate School (NPS) are used as a representative sample for comparing LCC of each alternative.

The optimal mix of vehicles is determined by a linear program. Linear programming is used to determine the optimal allocation of limited resources among competing demands. The advantage of linear programming lies with sensitivity analysis. The range of values of the cost coefficients and constraint variables over which an optimal solution remains optimal can be determined. The uncertainty of various cost elements can be better evaluated with linear programming.

A. PROBLEM STATEMENT

The increasing life-cycle cost of operating gasoline-powered ICE vehicles has stimulated an interest in alternative fuels. Local activities lack a consolidated source of information with which to evaluate alternative fuels against their mission needs, determine life cycle costs, and determine the optimal mix of vehicles employing alternative fuels.

B. OBJECTIVE

The research objective is to formulate a procedure for performing an economic analysis of the use of alternative fuels in motor vehicles. Underlying this objective are three sub-objectives.

1. Present an overview of the current state-of-the-art of alternative fuels and develop an effectiveness model with which to evaluate the feasibility of using each alternative.
2. Develop a model for determining total life cycle costs.
3. Develop a mathematical program for determining the optimal fleet configuration of vehicles using gasoline or alternative fuels. Optimality is defined as the least total cost for procuring, operating, and maintaining a fleet of vehicles.

C. ALTERNATIVES

Alternatives considered are natural gas, alcohols, and electric vehicles. These alternatives are currently in use and cost and performance data is readily available. Natural gas is primarily methane (CH_4) but can contain up to 20 percent higher hydrocarbons, such as ethane, propane, and butane. Dual fuel systems are designed to operate on either compressed natural gas (CNG) or gasoline. Dual fuel systems offer savings in operating and maintenance costs without the range limitations of natural gas systems. Subsequent analysis of natural gas will pertain to dual fuel systems, commonly refered to as compressed natural gas or CNG. Methanol and ethanol are the most common forms of alcohol used in the automotive industry, however, interest in alcohol stems primarily from reducing petroleum consumption rather than cost savings. Electric vehicles range in size from golf carts to buses and may be designed specifically for electric propulsion or they may be conversions of currently produced ICE vehicles. This analysis focuses on electric vehicles designed for commercial use. Electric hybrid vehicles which combine electric propulsion with ICE engines are not included in this analysis.

Vehicles using alternative fuels or propulsion systems may have inferior performance characteristics or other limitations when compared to gasoline-powered vehicles. Vehicles with high usage rates, required to travel on highways, or required to travel long distances between refueling would not be viable candidates for replacement with low performance alternatives. Conversely, many ICE vehicles are over-powered for the task assigned and could be replaced with lower performance alternatives [Ref. 1]. When considering these alternatives it is important to define the mission to which each vehicle is assigned and the environment in which it operates.

Gasoline-powered vehicles are the baseline against which other alternatives are compared. By definition, they are high performance vehicles with range and power characteristics that enable them to fulfill all mission requirements of an activity. A mission is defined as the task a vehicle is required to perform. Although the only standards for vehicle procurement pertain to engine size and gross vehicle weight, users have general a expectation of the performance characteristics of gasoline-powered vehicles. Low performance vehicles are characterized by shorter ranges, slower cruising speeds, and lighter load capacities and would not satisfy all mission requirements.

To identify high and low performance alternatives, measures of effectiveness are established that reflect the areas where performance may be degraded. A high performance vehicle is, at a minimum, capable of performance in each measure at a level equal to or exceeding that of a gasoline-powered vehicle. An alternative is feasible for low performance vehicles if it is technically viable as determined by successful use by domestic or foreign fleets. Minimum values are assigned to high performance measures for the purpose of identifying vehicles that are not suitable for low performance alternatives. These values are derived from the maximum performance capabilities of low performance alternatives.

D. ALTERNATIVE SELECTION CRITERION

In order to evaluate alternatives it is necessary to have a criterion for selecting the best alternative. With high and low performance alternatives the least cost alternative may not be able to satisfy all mission requirements; therefore, it is feasible that more than one fuel type, gasoline included, may be selected. The criterion is to employ the alternative or alternatives which provide the least total life cycle cost of procuring and operating a fleet without compromising an activity's ability to accomplish its mission.

E. MEASURES OF EFFECTIVENESS

The measures of effectiveness for each category of vehicles are described below. The minimum values for high performance vehicles are derived in Chapter II.

1. Range - The distance in miles a vehicle can travel between refueling or recharging. Using natural gas or electricity necessitates returning to the base for refueling or recharging thereby restricting the maximum distance a vehicle may travel away from its base to one half its range. Given the ubiquity of gasoline stations, gasoline and dual fuel vehicles are not constrained by range.
2. Usage rate - The number of miles traveled by a vehicle in one year. Vehicles are assumed to be used on work days only. For this analysis 240 work days per year was assumed.
3. Minimum acceptable speed - The speed that an activity considers to be a minimum to safely perform its mission. Vehicles with requirements to travel on freeways would have higher minimum acceptable speeds than a vehicle only required to travel on base. Some electric vehicles are capable of achieving speeds greater than 55 mph but at the expense of range. Electric vehicle manufacturers use cruising speed rather than maximum speed when citing range.
4. Load Capacity - The carrying capacity of the vehicle including passengers. The carrying capacity equals the gross vehicle weight less the curb weight of the vehicle.
5. Fuel Availability - The measure of whether a ready source of fuel exists to operate the fleet. The supply should be sufficient to operate the entire fleet each work day.

F. ASSUMPTIONS

The following assumptions are integral to the analysis. Although some represent significant departures from actual practices they are necessary to formulate the cost models and the linear program. Lesser assumptions are noted where applicable.

1. The number of vehicles required to perform a mission remains fixed regardless of the fuel type. Employing any alternative would not increase or decrease the size of the fleet.
2. The annual mileage traveled by each vehicle is necessary for the accomplishment of its mission and can expected to be at or near the same level in future years.
3. The vehicle population in each category (high and low performance) is homogenous with respect to purchase price, operating and maintenance costs, usage rate, and miles per gallon.
4. All vehicles are operational on each work day.
5. Gasoline-powered vehicles are replaced by vehicles with the same load capacity. The load capacity is fully utilized and the vehicle can not be replaced with a lower rated vehicle. With today's trend toward smaller trucks, it is conceivable that lower rated vehicles will replace a larger share of the fleet in the future than they could today.
6. Any non-integer solution to the linear program is a close approximation to the integer solution. The number of vehicles in the final solution is rounded to the nearest whole vehicle.
7. All vehicles are procured in year one and disposed of at the end of the life cycle. Phased replacement of vehicles would result is higher total costs as the fleet progresses toward optimality.

G. RESEARCH METHODS

A literature review was conducted to determine the current state of the art of each alternative. Vehicle characteristics and performance data were analyzed to determine limitations that would prohibit or restrict their use. Limitations noted were range, usage rate, speed, load capacity, and fuel availability. Measures of effectiveness were established that reflected reductions in performance imposed by each alternative and distinguished high from low performance alternatives. Each alternative was evaluated against the effectiveness model and either retained as a high or low performance alternative or rejected entirely.

The analysis was conducted using vehicles at the Naval Postgraduate School as a sample population. The population was limited to all on-the-road passenger vehicles and trucks with a gross vehicle rating of one ton or less. This division encompassed vehicles that were potential candidates for alternative fuel and facilitated analysis by cost account codes. Seventy-two vehicles fell within these parameters.

The literature review was supplemented by telephone interviews with fleet managers and manufacturing representatives to obtain current cost data. All costs are stated in 1982 dollars. Cost models to determine total life cycle costs per unit and total fleet life cycle costs were developed for each alternative. Procurement, operating, maintenance, and salvage values were based on the weighted average cost for vehicles in the fleet.

A linear program was formulated to determine the optimal mix of vehicles using alternative fuels. The approach was similar to one applied to capital budgeting. Each decision variable represented an alternative which could be considered as an investment project. Constraints indicated the capital consumed by each alternative in each year of the life cycle. Budget constraints are determined by the activity. Additional constraints insured that the final solution was feasible.

H. SUMMARY

This thesis evaluates the potential of using compressed natural gas, alcohol, and electric vehicles as replacements for gasoline-powered vehicles. Measures of effectiveness are established that reflect the inherent differences in performance for each alternative. These measures are range, usage rate, speed, load capacity, and fuel availability. Minimum values are assigned to these measures based on performance limitations discussed in Chapter II, and are used to distinguish between high and low performance alternatives.

Chapter II evaluates the advantages and disadvantages of each alternative and categorizes them as high performance, low performance, or infeasible replacements for gasoline-powered vehicles. Chapter III identifies the costs associated with each alternative and displays the determinants in total cost models. Chapter IV presents a linear programming model for determining the optimal mix of vehicles and for performing sensitivity analysis. The data obtained for NPS is used for comparing alternatives.

II. ALTERNATIVES

This chapter examines the advantages and disadvantages of compressed natural gas, alcohol, and electric vehicles. Generally, advantages are savings in operations and maintenance. Disadvantages are a reduction in one or more measures of vehicle performance. Each alternative is evaluated against the effectiveness model and is considered feasible if it meets the minimum level of effectiveness defined for each category.

A. MINIMUM LEVELS OF EFFECTIVENESS

The gasoline powered ICE vehicle provides a baseline for comparing the operating performance of other alternative fuels. The Federal Standards for Automobiles and Light Trucks contain the minimum gross vehicle weight, engine size, and other characteristics of vehicles generally procured by the Federal government. Their purpose is to achieve a practical degree of standardization in the Federal automobile fleet. These standards do not preclude the use of alternative fuels that do not meet the minimum requirement.

The average range of an electric vehicle at 30 miles per hour is 45 miles which clearly eliminates electric vehicles as a high performance alternative (Table V). The range of a vehicle with dual fuel capabilities is equal to its range on gasoline plus its range on compressed natural gas. A vehicle with two CNG fuel cylinders and averaging fourteen miles per gallon has a range of approximately 70 miles. The range with alcohol is approximately equal to the range with gasoline. A vehicle that travels 45 miles a day or less is categorized as a low performance vehicle.

Usage rates vary by mission assignment, however, the standard for passenger vehicles and light trucks ranges from 6,000-10,000 annual miles. Annual mileage on a particular vehicle may not meet the minimum standard, however, the average mileage on all vehicles of that type should meet or exceed the annual utilization standard [Ref. 2]. With the exception of motor pool vehicles which use trip tickets, a record of daily miles is not maintained. Annual mileage or usage rate is the only indicator of daily usage. Usage rate limitations stem from daily range limitations. A daily range limitation of 45 miles with electric vehicles necessitates a annual usage rate limitation of 10,800 miles assuming one driving cycle per work day. A vehicle with an annual usage rate of 10,800 or less is categorized as low performance.

It is important to distinguish between maximum speed and minimum acceptable speed. Maximum speed is a function of engine size and vehicle friction coefficients, however, vehicles are not designed to operate continually at this speed. Minimum acceptable speed is defined as that which an operator deems appropriate to safely accomplish the mission and can be maintained for the duration of the period between refueling or recharging. This may also be termed cruising speed. Electric vehicles are capable of speeds of 60 miles per hour but they cannot maintain this speed for any appreciable length of time. An arbitrary, but reasonable, compromise between speed and range is 30 miles per hour. This would allow an electric vehicle to operate on Naval activities or in most localities without impeding traffic and still have a useful range. A high performance vehicle, unquestionably, should be capable of highway speeds; therefore, 55 miles per hour suitably differentiates between high and low performance vehicles.

A minimum load capacity of 1000 pounds is prescribed in the Federal Standards for Automobiles and Light Trucks. Commercial electric vehicles can be designed for heavy loads but at the expense of range and speed capabilities. Typical load capacities range from 370 pounds to 1770 pounds [Ref. 3]. This limited load capacity alone does not preclude replacing some high performance vehicles with electric vehicles.

Any viable alternative should have a plentiful and reliable source of fuel or power. Gasoline is available in sufficient quantities across the nation. Natural gas and electricity are also available although their supplies are not as evenly distributed as that of gasoline and prices across the United States are more variable. Methanol and ethanol are not yet available in sufficient quantities to support their widespread use as motor fuels [Ref. 4].

The performance characteristics, advantages, and disadvantages of each alternative are described below. Their evaluation against the effectiveness model is displayed in Table I.

B. COMPRESSED NATURAL GAS

1. Characteristics

Natural gas is composed primarily of methane but can contain up to 20 percent higher hydrocarbons such as ethane, propane, and butane. The composition of natural gas varies from source to source and its physical properties vary accordingly. Natural gas has lower heating values ranging between 18,800 to 21,300 Btu per pound compared to 18,200 to 19,200 Btu per pound for gasoline. Heating values measure the energy content per unit of volume. A small amount of refining is necessary before the gas is distributed. An odorant is added for leak detection since methane is odorless in its pure form.

TABLE I

Effectiveness Model

Alternative \ Criterion	Low Performance: Range	Low Performance: Usage Rate	Low Performance: Speed	Low Performance: Load Capacity	Low Performance: Fuel Availability	High Performance: Range	High Performance: Usage Rate	High Performance: Speed	High Performance: Load Capacity	High Performance: Fuel Availability
Gasoline	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Dual Fuel Systems (CNG)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Electric Vehicles	Y	Y	Y	Y	Y	N	N	N	Y	Y
Alcohol	Y	Y	Y	Y	N	Y	Y	Y	Y	N

Source: Text.
Y: Satisfies the criterion established for category of vehicle.
N: Does not satisfy established criterion.

At atmospheric pressure and ambient temperature natural gas exists in a gaseous state. Natural gas can be stored or transported in a liquid state at atmospheric pressure only at temperatures lower than -259 degrees Fahrenheit.

The energy content of natural gas is measured in British thermal units (Btu) which is the amount of heat required to raise one pound of water one degree Fahrenheit. Volume is measured in cubic feet. To compare characteristics of natural gas to gasoline, Btu's are converted to gallon equivalents, hereafter refered to simply as gallons. 100 Btu equals one therm and one therm is approximately equal to one gallon of gasoline. At atmospheric pressure, 1020 Btu of natural gas occupies 1000 cubic feet. The industry rule of thumb is 100 cubic feet of gas is equivalent to one gallon of gasoline. Properties of natural gas and gasoline are compared in Table II.

For vehicle use, natural gas is compressed and carried in one or more cylinders. Most ICE vehicles can be modified to run solely on natural gas or propane. Alternatively a dual-fuel or tri-fuel system may be used that operates on natural gas or propane until the carrying capacity is exhausted at which time the operator may switch to gasoline. Subsequent analysis of compressed natural gas (CNG) will pertain to dual fuel systems.

2. Components

Conversion kits for converting to CNG consist of a gas/air mixer which replaces the air filter, pressure regulator, fuel guage and selector switch, piping, and one or more gas cylinders. No internal engine modifications are involved with dual fuel conversions. Spark timing is usually readjusted slightly to obtain minimum exhaust emissions during both natural gas and gasoline operation.

Cylinders are available in various sizes from 200 to 372 standard cubic feet and gas is stored in them at a normal pressure of 2400 psi. The cylinders are permanently mounted in the trunk of a car or the back of a van or they may be bracketed to the underbody of vehicles with

TABLE II

Properties of Natural Gas and Gasoline

	CNG	Gasoline
Composition	Primarily methane (CH4) but can contain up to 20% C2H8 hydrocarbons	Mixture of C4 to C14 hydrocarbons
Physical state during storage	gas	liquid
Lower heating value[a]		
Btu/lb	21,300	18,920 (average)
Btu/gal	19,760	11,540
Octane Ratings:		
Research	120	91-100
Motor	120	82-92

Source: Reference 13.

[a] The number of Btu's obtained by the complete combustion of one unit of mass or volume.

sufficient ground clearance. Cylinders are about 10 inches in diameter and range from 44 to 62 inches in length. Each CNG cylinder adds 125 lbs to the weight of the vehicle [Ref. 5].

Fuel/air mixers are designed to fit specific-sized carburetors. The mixer is diaphragm controlled and operates on the Venturi principle, metering the proper quantity of natural gas into the air stream over the full range of engine air flow demands.

The CNG refueling station consists of a multi stage compressor that receives the natural gas via a 1-2 inch line from the local gas main and compressess it at 3500 psi into a storage cascade of 20 cylinders which then becomes the holding tank from which the fleet is refueled. Each cylinder has a 450 cubic feet capacity for a total of 9000 cubic feet. A pressurized refueling nozzle connects to a fill valve located under the hood. Refueling is either quick fill which, for a vehicle with two cylinders, takes about the same amount of time it takes to refuel at a gasoline pump, or time fill which permits 25 or more vehicles to be refueled overnight. The compressor used in this analysis is capable of supplying 45 gallons of CNG per hour or 270 gallons in a six hour day. A pressure regulating switch starts the compressor when the pressure drops to approximately 3450 pounds per square inch.

3. Advantages

The primary advantage with CNG lies with its plentiful and inexpensive supply [Ref. 6], however future gas price savings are uncertain. The nation has enjoyed modest prices of natural gas due to government price controls. However, the Natual Gas Policy Act of 1978 calls for a gradual phase out of price controls on gas produced from new wells by 1984. Deregulation has encouraged producers to drill new and expensive wells rather than sell cheaper gas from existing fields and these costs are passed on to the consumer [Ref. 7]. Suppliers have agreed to long term contracts obligating them to pay higher prices even in times of low gas demand [Ref. 8].

Currently the price of gas per thousand cubic feet at the well head varies from a low of about 27 cents for old gas to as much as $11 for deep gas which has already been removed for price controls [Ref. 9]. The U.S. Department of

Energy forecasts that gas prices in 1983 will rise an average of 20 percent across the U.S. and in some areas as high as 40 percent [Ref. 10].

World oil supplies are ample and the price of crude oil is more likely to fall than rise, at least over the short term. In an effort to raise cash, several members of OPEC have been overproducing and selling at discounts below the $34 per barrel official price [Ref. 11]. A survey of gasoline prices at 19,000 service stations nation wide conducted in December 1982 indicate the average price per gallon of regular gasoline was $1.127, and regular unleaded was $1.199 [Ref. 12].

Because CNG is a clean burning fuel and enters the cylinders in a gaseous state, substantial savings may be realized in maintenance. Motor oil, filters, spark plugs, exhaust system, and engine parts all are reported to last longer. Unburned liquid fuel does not dilute motor oil or foul spark plugs. Replacement intervals are doubled for oil, filters, and spark plugs.[1] One distributor claims a 50 percent to 60 percent reduction in maintenance costs. Savings are reduced when the vehicle is operated on gasoline or if a used vehicle is converted to CNG.[2] .

CNG fueled vehicles have demonstrated up to a 10 percent improvement over gasoline in energy efficiency during trips of less than 5 miles and low ambient temperatures in the neighborhood of 20 degrees Fahrenheit [Ref. 13]. The primary reason is that CNG vehicles operate more efficiently during the cold start and warmup portions of the driving cycle.

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[1]Interview with Mr. Larry Frew, Public Works Department, Naval Education and Training Center, Great Lakes, Illinois, 9 December 1982.

[2]Interview with Mr. James McCord, Compressed Natural Gas (CNG) Vehicle Equipment Company, Ft. Collins, Colorado, 13 December 1982.

Several characteristics of natural gas make it an inherently safer fuel than gasoline. It is lighter than air and will dissipate into the atmosphere if a leak should occur as opposed to liquid fuels which puddle on the ground presenting a potential fire hazard. Its ignition temperature is 300-400 degrees Fahrenheit higher than gasoline and combustion will occur only in a very limited ratio of air to fuel. CNG is non-toxic, non-reactive, and does not form smog [Ref. 14].

4. Disadvantages

The restricted operating range is the primary objection to CNG. Actual range is dependent on the size of the CNG cylinders and the miles per gallon achieved by the vehicle. A vehicle equiped with two 300 cubic foot cylinders and achieving thirteen miles per gallon would have a range of 78 miles between refueling.

The additonal weight of two cylinders and associated equipment reduces the performance of the vehicle. In a 1979 test conducted by the General Services Administration acceleration from 0-60 MPH was reduced by 25 percent to 40 percent and fuel economy was 5 percent to 10 percent less [Ref. 15].

Vehicles with dual fuel capabilities cannot be tuned to achieve maximum efficiency without sacrificing gasoline performance. The compression ratio needed to obtain the lowest fuel comsumption using natural gas is higher than that which could be tolerated by gasoline. Spark timing should be advanced to compensate for the slow flame speed but causes knocking when the vehicle is run on gasoline.

Further disadvantages of CNG include conflict with car warranties, possible valve seat wear in engines without hardened seats and highway tunnel and bridge prohibitions.

5. Summary

While vehicle performance and efficiency may be reduced, it should not prohibit a vehicle from performing its mission. With dual fuel capabilites range is not a limiting factor. Savings in operations and maintenance may outweigh the inconvenience of CNG although the uncertainty of future natural gas and gasoline prices should be considered when comparing alternatives. CNG vehicles meet the minimum level of effectiveness and CNG is considered a feasible alternative for both categories of vehicles.

C. ALCOHOLS

1. Characteristics

Research and development of alcohol as an automotive fuel have been limited to methanol and ethanol. Impetus for their use has been oil shortages and farm surpluses.

Alcohol may be used as a blending stock with gasoline or in its pure or neat form. Blends are commonly in concentrations of 10 percent due to exemption from Federal excise tax on gasoline containing more than 10 percent alcohol, with the maximum benefit at 10 percent. The Environmental Protection Agency exempts alcohol blends of 10 percent from the minimum standards of the Clean Air Act [Ref. 16]. Alcohol is also exempt from all or part of state gasoline taxes in ten states: Arkansas, Colorado, Iowa, Kansas, Maryland, Missouri, Nebraska, North Dakota, South Dakota, and Wyoming.

At concentrations greater than 10 percent, engine modifications to the carburetion system and compression ratios are required to obtain proper fuel/air mixture and uniform cylinder to cylinder distribution. Modifications, once made, would prohibit operating on gasoline.

Methanol and ethanol have similar properties and are contrasted with gasoline in Table III. The differences in boiling point, flash point, heating value, heat of vaporization, combustion air/fuel ratio, and water solubility are responsible for most of the problems encountered when mixing

TABLE III

Properties of Ethanol, Methanol, and Gasoline

	Ethanol	Methanol	Gasoline
Chemical formula	CH_3CH_2OH	CH_3OH	Mixture of C_4-C_{12}
Composition, wt percent			
Carbon	52.2	37.5	85-88
Hydrogen	13.1	12.6	12-15
Oxygen	34.7	49.9	0
Boiling temp C	78.5	65	27-225
Flash point C	13	11	-43
Lower heating value			
Btu/lb	11,565	8,582	18,920
Btu/gal	7,580	5,660	11,560
Latent heat of Vaporization Btu/lb	396	507	50
Stoichiometric A/F [a]	9.0	6.4	14.2-14.8
Water Solubility	Infinite	Infinite	Insoluble

Source: References 16, 19.

[a] Air/fuel ratio for complete combustion.

or replacing gasoline with alcohol. Most of the properties of ethanol are intermediate to those of methanol and gasoline. These differences, as well as vehicle tests and evaluations indicate that potential problems with the use of ethanol would be less severe than those encountered with methanol [Ref. 17].

2. Advantages

Savings from using alcohol as a blending stock may be realized but would be minimal unless petroleum shortages induce large gasoline price increases. Alcohol delivery, storage, and dispensing systems would not be substantially different than gasoline systems beyond the possible need for a vapor recovery system and corrosion resistant storage tanks and lines [Ref. 18].

3. Disadvantages

Problems associated with alcohol are grouped by distribution and handling, vehicle performance, and compatability with materials. Problems are further identified by their probability of occurance in absence of corrective measures and the relative seriousness if the problem occured. A summary of potential problems with methanol and ethanol are contained in Table IV. Problems associated with methanol are similar or more severe than with ethanol [Ref. 19].

a. Distribution and handling

Phase Separation: Phase separation in the presence of water or at low temperatures is the most disturbing problem with alcohol blends. In phase separation the ethanol becomes separated from the gasoline with which it was blended. Water is commonly present in gasoline storage tanks and more can be absorbed from the air. The rate of water absorbtion of ethanol blends is markedly influenced by the alcohol content and by surface to volume ratio. The addition of as little as 0.2 percent water to blends containing 10 percent ethanol has been reported to cause phase separation. In additon to unpredictable stalling, phase separation would also upset the operation of the

TABLE IV

Potential Problems with the Use of Alcohol

Problems	Probability of Occurance	Consequence[a]
Distribution and Handling		
Phase Separation	Definite	1
Hygroscopicity	Definite	2
Storage Stability	Possible	2
Renaturing	Definite[b]	2
Vehicle Performance		
Cold Startability, Neat	Definite	1
Warm-up Driveability	Definite	1
Vapor Lock	Probable	3
Volumetric Fuel Economy	Definite	2
Compatability with Materials		
Metal Corrosion	Definite	1
Non-Metal Compatability	Definite	1
Lubricant Compatability	Possible	2
Engine Wear	Possible	2
Paint Damage	Probable	3
Filter Plugging	probable	3

Source: References 16, 19.

[a] 1 = Major problem, 2 = Moderate problem, 3 = minor problem.

[b] Ethanol only.

distribution system, the aqueous phase would be difficult to dispose of, and corrosion would be aggravated.

Hygroscopicity: Hygroscopicity is a measure of the tendency of fuel to absorb moisture from air, which if severe, can cause phase separation.

Storage Stability: Studies indicate a tendency for alcohol/gasoline blends to form more gums during storage than the base gasolines from which they were made, although one study has reported that ethanol inhibits the formation of gums in some kinds of cracked gasoline. Gasoline is susceptible to attack by certain microorganisms in the presence of water bottoms. Ethanol is toxic to these organisms and would remedy this condition.

Renaturing: The widespread use of ethanol/gasoline blends could lead to illicit ethanol recovery. Ethanol can be separated from a gasoline blend with the addition of water and the separated ethanol can be further purified with charcoal treatment. This problem can probably be solved with the addition of denaturants which give the recovered alcohol an objectionable taste.

b. Vehicle Performance

Cold Startability: The vapor pressure of ethanol is so low at ambient temperatures that it cannot vaporize sufficiently to provide a flammable mixture and enable a cold engine to start below about 15 degrees Celsius. Cold starting problems with neat ethanol can probably be alleviated by the addition of light hydrocarbons. Ethanol/gasoline blends have adverse effects on cold starting below 0 degrees Celsius.

Drivability: Addition of ethanol to gasoline increases the oxygen content of the fuel necessitating an adjustment of the carburetor to achieve a richer air/fuel mixture. Problems with drivability increase with increased leaning and alcohol content. The problems include stalling during warmups, surges, and vapor lock at higher temperatures.

Vapor Lock: Vapor lock results when the fuel pump cannot meet the fuel demand of the engine because the fuel is vaporizing in the fuel line. This occurs on hot days with high volatility fuels and heavy engine demand. Methanol and ethanol increase the volatility increasing the probabiltiy of vapor lock.

Fuel Economy: Blending ethanol with gasoline reduces the fuel energy content, and if carburetion is not adjusted, leans the air/fuel mixture. Recent tests using 10 percent alcohol blends have shown an average loss in fuel economy of 3 percent.

c. Compatability with Materials

Metal Corrosion: Ethanol can cause moderate to severe corrosion to distribution and automotive fuel systems. Metals susceptible to ethanol corrosion are zinc, galvanized iron, iron, brass, copper, and lead. Corrosion with alcohols is aggravated by the presence of water and the problem is compounded when phase separation occurs.

Non-metal Compatibility: Ethanol, because it is a good solvent, may be incompatable with polyester bonded-fiberglass laminates which are used in underground storage tanks, and with polyurethane, cork, and leather.

Lubricant Compatability: Crankcase emulsions have occurred with straight methanol during bench engine tests. Emulsion problems with ethanol have not been reported. Research is continuing in lubricant compatability with gasoline blends.

Engine Wear: Very few incidents of engine wear have been reported with straight ethanol. Ethanol blends have been shown to cause increased cylinder wear in a fleet of vehicles used intermittently. Fuel pumps have been reported to lose pressure from internal wear when used with methanol although no problems have been reported with ethanol.

Paint Damage: Ethanol can cause damage when spilled on paint finishes.

Dirt Loosening and Filter Plugging: The ability of alcohol to dissolve gum and loosen dirt can lead to plugged filters and screens when alcohol is initially introduced.

4. Summary

Research and development is likely to solve the technical problems associated with alcohols. Because of the limited availablity and high cost of ethanol, along with Federal and state subsidies for blends containing 10 percent volume of alcohol, the primary use of ethanol in the U.S. will probably be in blends to supplement rather that substitute for gasoline [Ref. 20]. The limited availability and incompatability with storage tanks and vehicle components eliminated alcohol as a feasible alternative for this study.

D. ELECTRIC VEHICLES

1. Characteristics

The largest single user of electric vehicles (EV's) in the United States is the U. S. Postal Service [Ref. 21]. They operate 352 DJ-5E Electrucks manufactured by American Motors Corporation and provide the best source of user operating and maintenance data. Utility companies are the second largest users of EV's [Ref. 22]. EV's have been used in Great Britian for more than 20 years, primarily as delivery trucks.

Most EV manufacturers in the United States are small businesses. Manufacturers of EV's and EV components world wide are listed annually in the February issue of Electric Vehicle News. A survey of U.S. manufacturers revealed that only three companies, Jet Industries of San Antonio, Texas, Taylor Dunn of Anaheim, California, and Battronic Truck Corporation of Boyerton, Pennsylvania are currently marketing EV's. The recession and low consumer demand has curtailed production although research to improve EV technology continues.

An excellent source of EV performance data is contained in Electric and Hybrid Vehicles, Energy Technology Review No. 44 published by Noyes Data Corporation. It summarizes data on characteristics, cost, maintenance, and energy consumption compiled from track tests, user surveys, and current literature. Data is presented for two classes of EV's, those designed for personal use and those designed for commercial use.

EV performance differs greatly from one vehicle to another due to the variety of vehicle chassis, propulsion systems, and components used. Track and dynamometer results provide consistent comparisons of vehicle types but vary from data reported by users.

Noyes Data Corporation's performance tests were conducted in accordance with the Society of Automotive Engineers Electric Vehicle Test Procedures. The tests included measurements of range at constant speed, range when operating over prescribed driving schedules, acceleration, maximum speed, gradeability (hill climbing ability), and braking. The driving schedules are: Schedule B - cruise speed of 20 mph, fixed route, stop and go operation, Schedule C - cruise speed of 30 mph, variable route, stop and go operations, and, Schedule D - cruise speed of 45 mph, intended to represent suburban driving patterns. The performance data presented below is a result of track tests and user surveys. Performance data for selected vehicles is presented in Table V. Characteristics are presented in Table VI.

TABLE V

Electric Vehicle Performance Data

Manufacturer/ Vehicle	Max Speed	Range at constant speed		Acceleration from standing start to	
		Range Miles	Speed mph	Speed mph	Time Sec
AM General/					
DJ-5E Electruck	40	45	30	30	20
Battronic Truck/					
Minivan 75	60	30	50	30	8
Minivan 96	60	30	50	30	8
Volta Pickup	60	30	50	30	8
Jet Industries/					
Dodge Van 1000	55	50	25	50	14
Dodge Van 1400	55	50	25	n.a.	n.a.
Ford Courier 750	60	50	25	n.a.	n.a.
Electrica	55	50	25	n.a.	n.a.
Grumman-Olson/					
Minivan	55	43	30	n.a.	n.a.

Source: Compiled from literature search and telephone inquiry

n.a.: Data not available

a. Range

For almost all vehicles tested, range decreased linearly with increasing speed. Tests were terminated when the vehicle could no longer accelerate to 45 mph in 28 seconds as required by schedule D. At this point the vehicle is still fully operable but at a reduced acceleration capability. It is estimated that ranges could be extended another 10-15 percent before overall performance would be seriously impaired. Track data is generally 25 percent lower than that found in the literature owing to

TABLE VI

Electric Vehicle Characteristics

Manufacturer/ Vehicle	Number of passengers	Payload lbs	battery voltage & weights - lbs
AM General/			
DJ-5E Electruck	1[a]	670	54/1300
Battronic Truck/			
Minivan 75	2	1000	112/2300
Minivan 96	2	1400	112/2300
Volta Pickup	2	1000	112/2300
Jet Industries/			
Dodge Van 1000	n.a.	1000	144/960
Dodge Van 1400	n.a.	1400	144/960
Ford Courier 750	n.a.	750	120/810
Electrica	n.a.	n.a.	144/960
Grumman-Olson/			
Minivan	2	550	84/1000

Source: Compiled from literature search and telephone inquiry.

[a] Configured for U.S.Postal Service

Note: All vehicles had series wound DC motors and silicon-controlled rectifier choppers.

test procedures which require testing the vehicle at gross vehicle weight and terminating when the acceleration criteria could not be met. User results are significantly lower and more variable due to weather, hills, driver's skill, and vehicle condition and age. Speed is measured in mph and range in miles.

b. Energy Consumption

The amount of energy required to move an EV one mile is dependent on numerous variables. Vehicle weight and frontal area, component efficiencies, age of batteries, speed, terrain, temperature, and number of stops are all significant factors. Energy, in kilowatt hours (Kwh), is measured at the input side of the charger. Energy demand is measured in Kwh per mile. Energy consumption per mile depends on the range achieved per driving cycle and the amount of energy required to recharge the batteries. The amount of energy needed to recharge the batteries depends on the depth of discharge and the efficiencies of the charger and batteries [Ref. 23].

Noyes Data Corporation conducted road tests to measure the effect of vehicle weight, speed, resistive acceleration and driveline efficiency on energy consumption. Resistive acceleration is the sum of tire friction and aero-dynamic drag, and driveline efficiency is inversely proportional to the total loss of energy between the battery and wheels [Ref. 24]. They found the energy consumption to be proportional to the mass of the vehicle and the resistive acceleration, and inversely proportional to the driveline efficiency. The effect of speed on energy consumption varied by vehicle from little or no affect to substantial increases as speed increased. Track data ranged from 0.10 to 0.28 watt-hour per mile per pound of vehicle weight. Field experience fell within the range of 0.25-0.50 Wh/mile-lb. Energy consumption in Kwh/mile as a function of vehicle weight in pounds is shown in Figure 2.1.

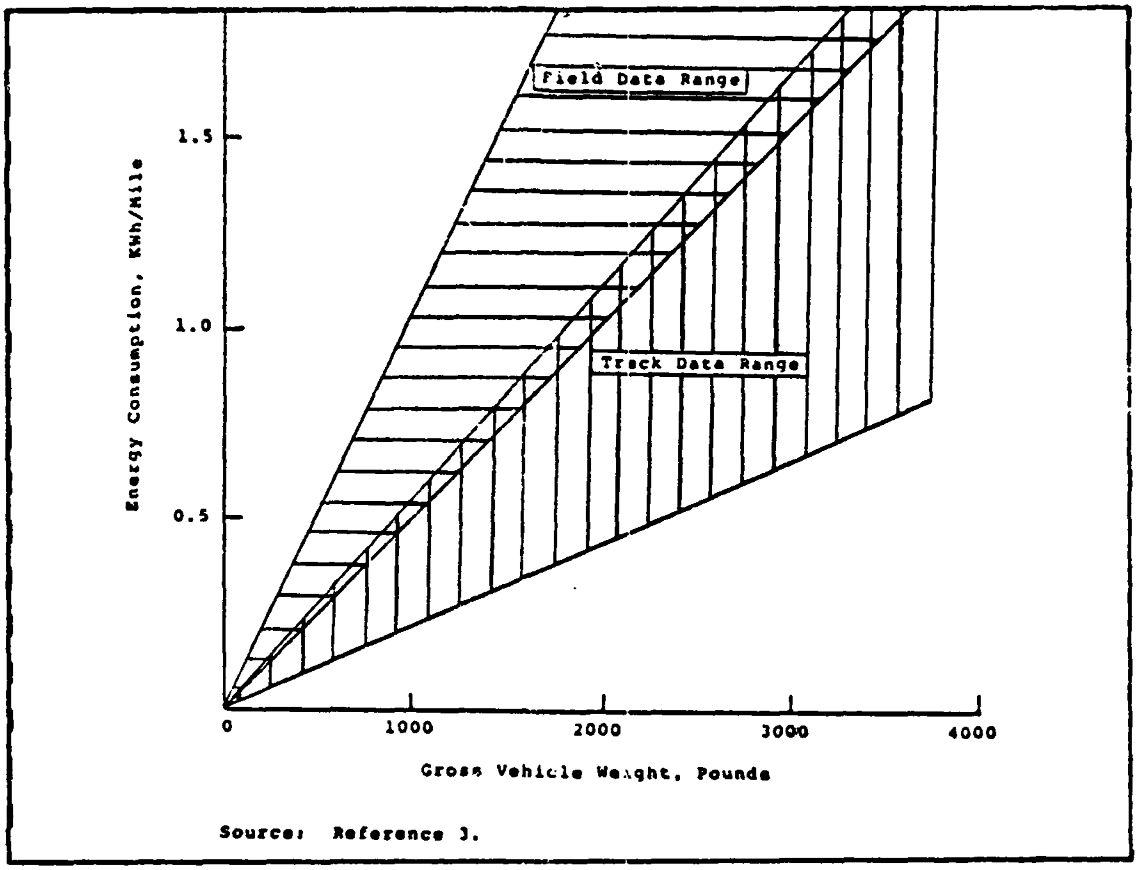

Figure 2.1 Electric Vehicle Energy Consumption.

c. Acceleration, Maximum Speed, and Gradeability

In general, acceleration, maximum speed, and gradeability were lower than those of conventional vehicles. Acceleration from 0 to 30 required 14 to 34 seconds and maximum speed ranged from 35 to 56 mph. Most EV's can climb steep grades at slow speeds but most vehicles had difficulty climbing more than a 5 percent grade at 25 mph.

d. Payload

Personal vehicles are designed for only two passengers with nominal payload. Commercial vehicles have capacities ranging from 370 to 1770 pounds with most exceeding 900 pounds.

2. Components

The description of EV components is presented in the order in which power flows from the source to the electric motor where electrical energy is converted to mechanical energy. From the receptacle, the power flows to the battery charger, motive power battery, magnetic contactor, controller, and the electric motor.

a. Receptacle

For small EV's the receptacle is a 15 amp 125 volt, two pole, three wire, grounding type receptacle with attachment plug. For heavier commercial EV's the receptacle is a 250 volt, 2 pole, 3 wire, grounding type receptacle and attachment plug **[Ref. 25]**. The required power source is 208-230 volt line, 30 amps, with a 30 amp breaker. This is equivalent to two 115 volt lines and a ground. The number of receptacles required depends on the size of the fleet and frequency and length of charging.

b. Battery Charger

The battery charger is an integral component of the EV system. It must be compatible with the voltage and current of the electrical receptacle and the voltage and acceptance current of the battery. As a result of the variety of battery types and voltages, general-purpose commercial battery chargers generally are not suitable and the chargers must be custom designed for the individual vehicles.

The battery charger may be either on-board the vehicle or located at the charging station. On-board chargers enhance the flexibility of the vehicle by allowing charging at multiple locations and minimize the chance of the vehicle being stranded away from its charging station, but add to the weight of the vehicle. An on-board charger weighs approximately 115 pounds. Off-board chargers may be larger and more versatile. These chargers can be programmed to charge when low voltage is sensed, charge at preset intervals which keeps the battery warm thereby extending battery life, and complete charging shortly before vehicle use.

The battery charger accepts alternating current from the power source and converts it to direct current at the voltage required by the battery. Charging at a greater current may cause gassing where the battery electrolyte is chemically dissociated into hydrogen and oxygen gasses. Gassing necessitates more frequent watering of the batteries. Overcharging may also cause the batteries to overheat, shortening their life. The voltage required to charge a battery varies over the charging time, gradually decreasing as the cell nears its full charge.

c. Motive Power Batteries

Power to the motor is supplied from a pod of 6 or 12 volt lead acid batteries connected in series. The voltage available is a function of the number of cells in the pod. Each fully charged cell has a voltage of 2.35 Volts. Other types of battery systems have been proposed and some have been developed and tested in EV's, but none is commercially available today. Batteries are "deep cycle" allowing them to be discharged to 20 percent and recharged without damaging the plates.

Two types of lead acid batteries are suitable for EV use. The golf cart battery is designed for relatively low initial cost, high power, and high specific energy. The industrial battery is designed to provide long life and high energy, but it is heavier and more expensive than a golf cart battery.

Battery life is measured in discharge cycles, the number of cycles being dependent on the depth of discharge. A commercially available golf cart battery has a useful life of 350 cycles when discharged to 80-90 percent of its capacity.[1] Its useful life increases to over 750 cycles when the depth of discharge is decreased to 50 percent. Industrial batteries have a cycle life of 750-2000 deep cycles [Ref. 26].

The attainable energy density (Whr/lb) is dependent on the discharge rate of the battery. The capacity of the battery is also temperature dependent. Lower temperatures reduce the capacity of the battery.

d. Magnetic Contactor

A magnetic contactor is an electrical switch operated by an electromagnet placed between the battery and the controller. When open, no current flows from the battery. The circuit is closed by turning on the ignition key or by operating in sequence the ignition key and the accelerator.

e. Controller

The speed at which the electric motor turns is governed by the controller which is operated by the accelerator pedal. The controller controls the flow of power from the batteries to the motor and if regenerative breaking is

----

[1]Interview with Mr. Conrad Weinlein, Globe-Union, Milwakee, Wisconsin, 17 January 1983.

used, the controller also controls the energy flow in the opposite direction. It is designed to provide smooth, efficient, safe, and reliable operations during acceleration and constant speeds, and provides overload protection to the motor.

Four types of controllers are currently used.

1. Resistance types: A resistor is inserted in the circuit which limits current. This method is inexpensive but causes energy loss. This loss is prohibitive in vehicles larger than golf carts.
2. Voltage Switching Type: The starting current is limited by the application of a low initial voltage across the motor contacts. As the rotor gains speed successively higher back electromotive force (emf) is generated in the armature limiting the current. As the accelerator is depressed further, a successively higher voltage is applied to the motor. This method is relatively inexpensive but results in jerky acceleration and increased maintenance.
3. Voltage Switching and Resistance Insert Type: This method combines the features of the above two methods. A resistor is inserted between the steps resulting in smoother acceleration.
4. Solid State Chopper: A solid state control device chops the power from the battery into discrete time blocks. A lightly depressed accelerator provides relatively widely spaced energy blocks. As the accelerator is further depressed the energy blocks are spaced closer together. This is the prefered method of control for larger vehicles.

f. Electric Motor

The most commonly used motor is a direct current, series wound type because of its high starting torque and simplicity. The high starting torque may obviate the need for a transmission. Under heavy loads the torque-ampere ratio is higher than that of other types which reduces battery drain during acceleration or while negotiating grades. In a series motor the field windings consist of a few turns of large cross section conductors which are connected in series with the armature. The shunt motor consists of many turns of smaller wire which are connected to a field controller. Because of the extra shunt windings, it offers more flexibility and control than does a series motor. A cumulative compound wound motor combines the features of series and shunt motors. It provides high starting torque and greater flexibility in control. Regenerative braking requires the capability to vary the shunt field current. This requires an additional control circuit that cannot be incorporated into a series motor. Efforts to incorporate regenerative braking into EV's have resulted in a trend towards shunt or compound motors.

g. Auxiliary System

Auxiliary equipment, such as lights, horn, and heat are provided by a 12 volt auxilary electrical system similiar to that used in an ICE vehicle. The auxiliary battery may be charged in three ways: from the same charger used for the motive batteries, from the motive batteries using a step-down oscillatory circuit, or a belt-powered alternator. Electric heaters are inadequate for large EV's and have been supplanted by petroleum-based heaters using gasoline or propane.

h. Regenerative Braking

In regenerative braking, a portion of the kinetic energy of motion of a vehicle when stopped or slowed is transformed from mechanical energy to electrical energy and reintroduced into the battery. The benefits of regenerative braking are:

1. An increase in vehicle range, or, less battery is required to obtain a given range.
2. Less energy cost per mile.
3. Prolonged battery life owing to a decreased depth of discharge required for a given range.
4. Less wear on mechanical braking surfaces.

A study conducted by the National Battery Test Laboratory demonstrated that a 20-30 percent increase in range is possible with regenerative braking [Ref. 27].

3. Advantages

EV's provide a viable alternative to petroleum-dependent ICE vehicles. Although procurement costs are high relative to ICE vehicles, operating costs per mile may be less depending on driving conditions and the price of electricity and gasoline.

The simplicity of EV's should offer increased reliability and decreased maintenance costs. Currently, failure rates in the United States are high but this is attributable to the lack of maturity in the industry. Where EV's are well established, for example, in Great Britain, their reliability and maintainability have been excellent [Ref. 28]. Other advantages are decreased noise, and thermal and air pollution.

4. Disadvantages

Decreased range, speed, and payload lessen EV versatility, however, EV's remain suitable for low performance missions.

Acquisition costs and battery replacement are significant and not likely to be offset by lower operating and maintenance costs. Purchase prices are twice that of comparable ICE vehicles and the useful life of a battery pack is approximately one to two years.

The batteries and electric motors may present a safety hazard to personnel involved with their use and maintenance. Voltages in EV's range from 48-216 volts. The elctrclytes present a possibility of chemical burns and battery charging produces explosive hydrogen gas necessitating additional ventilation.

5. Summary

Range, usage rate, speed, and load capacity are less than conventional vehicles but do not preclude EV's from accomplishing low performance missions. They are ideally suited for short-range delivery or utility vehicles with missions characterized by low speeds and multiple stops. EV technology will produce substantial improvements in performance and expand their mission capabilities.

Acquisition costs are high owing to low production volumes stemming from low consumer demand. Operating costs may be lower for specific applications and when compared to inefficient ICE vehicles. Energy consumption is minimal when the driving pattern is characterized by frequent stops, coasting, and deceleration which do not consume energy. Regenerative braking returns energy to the battery, further reducing operating costs. The simplicity of an electric motor relative to an ICE motor should reduce maintenance costs. Failure rates are higher than ICE vehicles but are low in Great Britain where EV's have long been established. The major maintenance expense is associated with battery maintenance and replacement but research and development continues to increase the energy density and useful life of batteries.

EV's satisfied the measures of effectiveness for low performance vehicles and were retained as a fleasible alternative.

III. COST MODEL

Department of Defense guidelines direct that all resources required to achieve a stated objective be included in any economic analysis. The two objectives of the cost analysis are to determine the total life cycle cost (LCC) of each alternative and determine the cost coefficients of the decision variables and the input-output coefficients of the constraint variables in the linear program. The LCCelements considered are the relevant investment, operating, and maintenance costs of each alternative over the useful life of the vehicle. Costs not considered are sunk costs, overhead costs, and the cost of stocking support equipment and repair parts. Figure 3.1 is a graphical presentation of cost-quantity relationships.

The cost coefficients express the rate at which the value of the objective function or the total life cycle cost of operating a fleet of vehicles increases or decreases as one additional vehicle using a particular fuel is added or removed from the population. The coefficient is equal to the unit cost of each fuel type.

A. COST ELEMENTS

1. Investment costs

Investment costs are divided into two categories: fixed costs, which remain constant regardless of the number of vehicles using a particular fuel type, and variable costs, which are uniform per vehicle but vary in total in direct porportion to the number of vehicles. Fixed investment costs include infrastructure cost, installation, and training required to support a fleet of vehicles. The

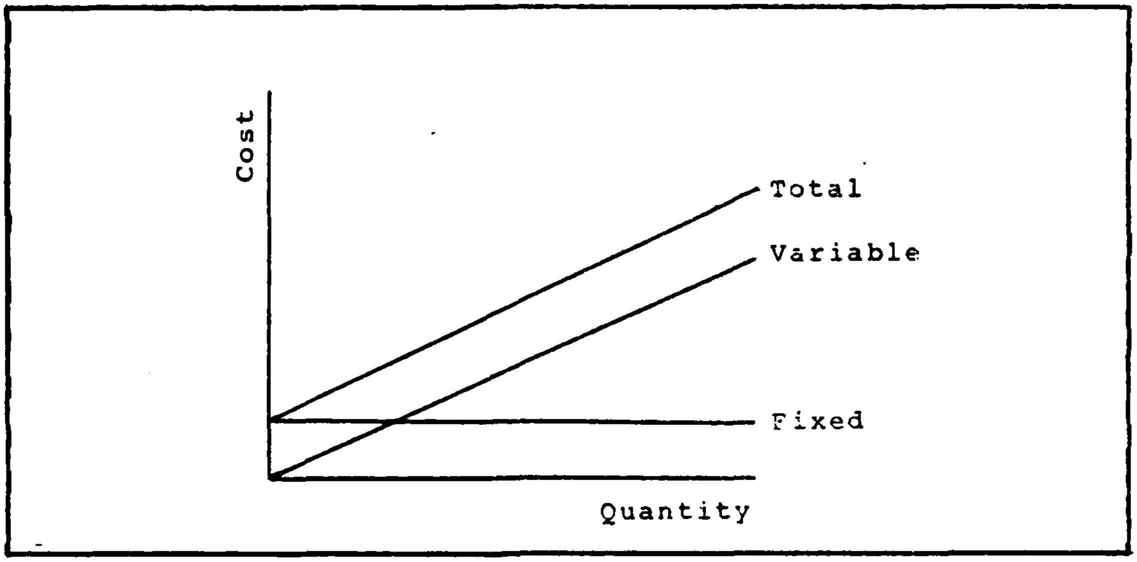

Figure 3.1 Cost Quantity Relationships.

relevant range over which these costs remain fixed depends on the number of vehicles the infrastructure is capable of supporting before additional support facilities must be added. This depends largely upon the size of the fleet and the usage rate of the vehicles. Larger fleets and higher usage rates require more refueling and additional support facilities. In actuality these costs are semi-fixed, increasing in a stepwise fashion as the number of vehicles exceed the capacity of the supporting infrastructure. These costs will be described futher when the cost of each alternative is addressed. Variable investment costs include vehicle procurement, conversion kit procurement, and salvage value. These costs are nonrecurring. Procurement costs are assumed to be incurred in year one and salvage costs in the final year of the life cycle.

Vehicle procurement costs are represented by the average purchase price of vehicles purchased by the General Services Administration for the Navy. They are listed in the Automotive Commodity Center Monthly Customer Agency Report which is a cumulative listing of vehicles purchased by vehicle type for the Federal government. Purchase prices by vehicle code are listed in the Transportation Equipment Descriptive Reference File Listing. For vehicles utilizing natural gas, the procurement cost is the cost of the vehicle plus the cost of the conversion kit necessary to convert to CNG. Procurement costs for EV's represent the average purchase prices of vehicles that will meet mission requirements and were obtained from EV manufacturers.

2. Operating Costs

Operating costs consist of annual fuel costs and are determined by the price of fuel, vehicle efficiency, and annual miles traveled. The price of fuel is measured in dollars per gallon or kilowatt hour and vehicle efficiency is measured in gallons per mile or kilowatt hours per mile.

3. Maintenance Costs

Maintenance costs consist of preventive and corrective maintenance performed on the engine and drive train. Included are all maintenance costs reported on the Operating Budget/Expense report which includes the cost of oil, spark plugs, filters, and replacement parts and components. They also include maintenance contracted to outside activities. Maintenance costs for CNG are a reduced percentage of the costs incurred for gasoline vehicles. The percentage factor is the savings in maintenance claimed by CNG manufacturers and users. Maintenance costs for EV's are computed separately and are a funtion of annual miles. They also include the pericdic replacement of battery packs for EV's.

Maintenance costs are difficult to measure because accounting procedures do not allow for distinguishing preventive from corrective maintenance. Maintenance data for CNG and electric vehicles is inconclusive because record keeping is inconsistent and incomplete, and manufacturers are inclined to advertise the best case as opposed to average maintenance costs. There is a good deal of uncertainty associated with maintenance costs but the difference between alternatives is sufficient to warrant their consideration.

If an alternative is not included in the final solution the fixed costs would be zero and a discontinuity would exist at the origin for the fixed and total cost curves.

B. LIFE CYCLE COST

Life cycle costing is based on the economic life of the vehicle. The economic life extends through the period during which the vehicle is capable of performing its assigned mission. Annual mileage and preventive maintenance weigh heavily in determining the useful life of the power train. Environmental factors may cause the body to deteriorate before the engine does. Delays in programming and acquiring replacements may require a command to maintain a vehicle well beyond the point where it makes prudent sense to do so [Ref. 29].

Activities report annually to their Transportation Equipment Management Center (TEMC) the projected mileage of each vehicle over the next three years. Using life expectancy criteria in NAVFAC P300 Appendix C, the TEMC's determine how many vehicles will require replacement and program that number into the procurement cycle. Public works personnel determine which vehicles to dispose of when new replacements are received. Age and mileage expectancies for sedans and trucks under one ton are 6 years or 72,000 miles. In addition to the age or mileage criteria, a vehicle is eligible for replacement when the cost of repair exceeds 50 percent of the present wholesale value of the vehicle as determined from computational factors provided in NAVFAC P300, Appendix C. With a two year planning, programming, and budget cycle and an additional year for GSA to purchase, receive, and deliver vehicles, an additional three years may elapse before a vehicle is finally replaced.[1] For this analysis the life cycle was based on a ten year economic life, an arbitrary but suitable period. This also corresponds to the life expectancy of EV's claimed by EV manufacturers.

C. DISCOUNT RATE

Present value techniques are used to discount future cash flows to present value. DODINST 7041.3 recommends a discount rate of 10 percent in comparative cost studies of general purpose real properties. This rate incorporates interest cost, investment opportunities foregone, and a 2 to 3 percent inflation stabilizer. Constant 1982 dollars were used in this analysis. Table VII contains uniform continuous flow discount factors for single year and cumulative uniform flows at 10 percent.

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[1]Interview with Mr Bob Ashby, General Services Administration, San Francisco, California, 11 January 1983.

TABLE VII
Discount Factors at 10 percent

Project Year	Present Value of $1 Single Amount	Present Value of $1 Cumulative Uniform Series
1	.954	.954
2	.867	1.821
3	.788	2.609
4	.717	3.326
5	.652	3.977
6	.592	4.570
7	.538	5.108
8	.489	5.597
9	.445	6.042
10	.405	6.447
11	.368	6.815
12	.334	7.149
13	.304	7.453
14	.276	7.729
15	.251	7.980

Source: Department of Defense Instruction 7041.3, 18 October 1972.

D. GASOLINE

1. Investment Costs

Fixed investment costs for gasoline-powered vehicles consist of underground storage tanks, fuel pumps, and distribution system. These are treated as sunk costs and not considered in the analysis.

Variable investment costs consist of the purchase price of the vehicle less its salvage value. The FACSO RPT SYM/NC 11200/F825 AE02 provided the current unit purchase price of vehicles by equipment code and family designator. The average purchase price of the seventy two vehicles at NPS was determined from the unit price and frequency of occurrence for each equipment code. A weighted average purchase price of $7,600 was determined.

The salvage value of a vehicle is dependent on its age, mileage, condition, type, inflation, and consumer demand. Historically, the General Services Administration has recovered 25 percent of the purchase price of sedans and 30 percent of two wheel drive light trucks after approximately 72,000 miles. This figure applies to all Federal agencies in California, Arizona, and Nevada. The Defense Property Disposal Office at Fort Ord, California is recovering 25 percent of acquisition costs on Army sedans and light trucks after approximately seven years or 100,000 miles. The Defense Property Disposal Office at Naval Air Station, Alameda, California estimated the average salvage value of sedans and light trucks after ten years and 60,000 miles at ten percent of acquisition cost. These characteristics correspond to the projected age and usage rate of the vehicles used in this analysis, therefore, ten percent was used as the salvage value.

2. Operating Costs

Annual fuel costs equal the annual gallons of gasoline consumed multiplied by the price per gallon. Annual fuel consumption is the product of the average annual miles and the average fuel efficiency of the fleet.

The average annual miles for the NPS fleet was obtained from the Equipment Usage Record 12ND NPS 11240/1 (2/77). Fuel efficiency was obtained from the Operating Budget/Expense Report by dividing the annual miles by the annual gallons of fuel consumed for each cost account code. The average annual miles for the seventy two vehicles was 5,928 and the average fuel efficiency was 14 miles per gallon or .071 gallons per mile.

The price of gasoline was obtained from the November gasoline bill. The State of California refunds the state gasoline tax of seven cents per gallon for gasoline consumed on Federal installations. The percentage of on-base use was obtained from the Monthly Gas Sheets and averaged 20 percent for the vehicles in the study. The price of $1.196 was obtained by taking a weighted average of the price paid before and after taxes were removed.

3. Maintenance Costs

Preventive maintenance is performed at regular intervals based either on mileage or on a specified time period. Preventive maintenance is predictable over the life of the vehicle, increasing only as the price of material and labor increase. Corrective maintenance is unscheduled , at or near zero during the warranty period and increasing over the life of the vehicle as components begin to fail. Total maintenance costs would expect to increase as the vehicle ages.

Unfortunately standard government accounting procedures do not identify preventive and corrective maintenance. Records at the activity level and data accumulated by the General Services Administration only reflect total maintenance costs, number of vehicles, and number of miles traveled. A reasonable assumption is that the average age of a fleet, particularly a large fleet, remains fairly constant as new vehicles are added and old vehicles salvaged. Total fleet maintenance costs, therefore, can be expected to be fairly constant.

Annual maintenance cost per mile for NPS was derived from the Operating Budget/Expense Report. Total maintenance cost and total mileage for the cost account codes under consideration were summed and divided to obtain a cost per mile figure. This was done for fiscal years 1978 through 1982. The unadjusted automotive maintenance repair index for all urban consumers was used to inflate prior year costs per mile to 1982 dollars. The adjusted figures were averaged to obtain a cost per mile of $0.032.

4. Cost Model

The total LCC procuring, operating, and maintaining one gasoline-powered vehicle is:

$$TC_U = P_V + PV_i(Mi \times ((P_{GAS} \times \eta) + M)) - PV(S) \qquad (3.1)$$

Where:

- TC_U = Total unit life cycle cost.
- P_V = Variable Procurement cost.
- P_{GAS} = Price of gasoline.
- Mi = Average annual miles.
- M = Maintenance cost per mile.
- S = Salvage value.
- PV_i = Present value factor for equal annual cash flows for i years. i equals the number of years per life cycle.
- PV = Pesent value factor for a single cash flow in the final year of the life cycle.
- η = Vehicle efficiency in gallons per mile.

The total LCC for procuring, operating, and maintaining a fleet of gasoline-powered vehicles is:

$$TC_F = n(TC_U) \tag{3.2}$$

Where:

TC_F = Total fleet life cycle costs.

n = number of vehicles in the fleet.

For NPS, the net present value of the total LCC for one vehicle was $11,760. The net present value for a fleet of 72 vehicles was $846,720.

E. COMPRESSED NATURAL GAS

There were a number of CNG systems available with different operating characteristics and prices. Having a service representative in close proximity to the vehicle fleet and the cost of sending personnel to the distributor for training would favor conducting business with a local company. Dual Fuel Systems, Inc. of Culver City, California was the only distributor in California and quoted lower prices than the next closest distributor in Colorado. Unless otherwise noted, their data were used in the analysis.

1. Investment Costs

Fixed investment costs consist of the compressor or compressors, cascade system, refueling nozzles, installation and training. The cost of the compressor, cascade system, and nozzles was $39,000. The compressor was capable of supplying 45 gallons of CNG per hour or 270 gallons in a six hour day. For the vehicles in this study a complete refueling required 5 gallons. The maximum capacity of the compressor was nine vehicles per hour or 54 vehicles per day assuming six hours of continuous operations. One compressor was considered adequate for the NPS. Additional compressors would cost an additional $23,000 each.

The cost to install the system and connect the compressor to a source of electricity and natural gas was estimated at $5,000 by the Colorado distributor.

Training was considered a one time cost. Training was provided by the manufacturer free of charge, however the activity would have to pay for travel, per diem, and rental car. Training costs, based on sending two employees to Culver City, California for two weeks were $3,100. The total fixed investment costs were $47,100.

Variable investment costs consist of vehicle procurement, conversion kit procurement, and salvage costs. The vehicle procurement and salvage were the same as those for gasoline ICE vehicles. The conversion kits cost $1,175 per vehicle. The useful life of the kits, the gas cylinders in particular, extend beyond the useful life of the vehicle and may be transfered from one vehicle to the next as vehicles are salvaged but their exact life cycle is not documented, and for the purpose of this analysis, was assumed to be the same as that of the vehicle. The total variable investment costs were $8,775.

2. Operating Costs

Operating costs are a function of the number of miles driven on CNG and on gasoline, the prices of CNG and gasoline, and the efficiency of the vehicle on each fuel. Additional costs are incurred to operate the compressor. It was assumed that a vehicle would operate on CNG until the supply of CNG was exhausted and then switch to gasoline for the remainder of the day. A vehicle with two CNG cylinders containing five gallons of CNG and averaging 14 mpg could travel 70 miles per day or 16,800 annual miles. Annual mileage at or below 16,800 would be costed using CNG and annual mileage above 16,800 would be costed using gasoline. The average annual mileage at NPS was below this limit so the total cost reflects CNG use only. In actuality, the daily usage rate is not uniform. Some vehicles would travel beyond the range of CNG necessitating the use of gasoline.

The price of $0.48 per therm for natural gas was obtained from the most recent gas bill from Pacific Gas and Electric. A therm is equivalent to one gallon. The cost to operate the compressor was quoted at nine cents per gallon and added to the cost of natural gas. Vehicle efficiency was assumed to be the same as that for gasoline-powered vehicles.

The State of California requires an annual operating permit for each vehicle operating on natural gas. The permit fee was $36.

3. Maintenance Costs

Maintenance costs are best measured as a percentage savings over maintenance costs incurred by a gasoline-powered vehicle. The most tangible savings are reductions in the maintenance intervals for oil, filters, and spark plugs. However, car warranties may dictate specific maintenance intervals preventing these saving. Savings resulting from less engine wear may be realized because of fewer carbon deposits but are less quantifiable. The maximum benefit would be obtained from a vehicle that had been operating exclusively on CNG. This vehicle would require fewer engine repairs and have a longer service life because it would not have been subjected to carbon deposits from gasoline use.[1]

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[1]Interview with Mr. James McCord, Compressed Natural Gas (CNG) Vehicle Equipment Company, Ft. Collins, Colorado, 13 December 1982.

A survey of automotive parts sales and auto repairs and service conducted in 1972 indicated that spark plugs, filters, and grease and oil comprised eleven percent of the market. Parts sales directly related to the engine comprised 44.34 percent of the market [Ref. 30]. Expenditures on gasoline-powered vehicles for engine related repairs and services that would be affected by CNG were 39.5 percent of total repair and service costs. A General Services Administration study reported a 37 percent savings in engine-related maintenance.

Five CNG users were surveyed by telephone to determine actual savings. Their combined fleet size was approximately 300 vehicles, the average fleet size was 60 vehicles, and the average time in service was two years. Two users had not extended their service intervals due to car warranties. Three reported savings as a result of extended service intervals. The Boeing Company in Seattle, Washington reported a 30 percent savings in maintenance costs. Vehicle service life had been extended from 80,000 - 90,000 miles to 100,000 - 125,000 miles although this was due in part to the depressed economy. The majority stated that maintenance costs were clearly reduced if service intervals were extended but more data were needed before they could quantify the savings.

While CNG systems manufacturers claim 50-60 percent savings in mantenance costs, market research and user experience would indicate it is considerably less. The actual savings in maintenance would depend on the age and usage rate of the fleet and a priori estimates would be very subjective. Uncertainty in these estimates can be evaluated by using sensitivity analysis. An optimistic estimate for NPS would be a 37 percent reduction in the 39.5 percent of maintenance costs or approximately a 15 percent savings factor.

4. Cost Model

The total LCC for procuring, operating, and maintaining one vehicle converted to CNG is:

$$TC_U = P_V + \qquad (3.3)$$

$$PV_i((Mi_{CNG} \times n \times P_{CNG} + Mi_{GAS} \times n \times P_{GAS}) +$$

$$(Mi_{CNG} + Mi_{GAS})(1-s)(M) +$$

$$OP) - PV(S)$$

Where:

TC_U = Total unit life cycle cost.
P_V = Variable Procurement cost.
P_{GAS} = Price of gasoline.
P_{CNG} = Price of compressed natural gas.
Mi_{CNG} = Average annual miles traveled on CNG.
Mi_{GAS} = Average annual miles traveled on gasoline.
M = Maintenance cost per mile.
s = Maintenance cost savings factor.
S = Salvage value.
OP = Annual operating permit fee.
PV_i = Present value factor for equal annual cash flows for i years.
PV = Pesent value factor for a single cash flow in the final year of the life cycle.
n = Vehicle efficiency in gallons per mile.

The total LCC for procuring, operating, and maintaining a fleet of CNG-powered vehicles is equal to the fixed investment cost plus the variable cost multiplied by the number of vehicles.

$$TC_F = P_F + n(TC_U) \qquad (3.4)$$

Where:

TC_F = Total fleet life cycle cost.

P_F = Fixed procurement cost.

n = Number of vehicles in the fleet.

For NPS, the net present value of the total LCC for one vehicle is $11,284. The net present value for a fleet of 72 vehicles is $859,692.

F. ELECTRIC VEHICLES

Electric vehicle manufacturers are few and their numbers are dwindling. There exists a wide divergence in cost data lending little value to an industry average. One manufacturer was chosen on the basis of current availability of vehicles and the lowest procurement cost.

Battronic Truck Corporation of Boyertown, Pennsylvania manufactures two minivans and one pickup truck that could replace low performance sedans and trucks. Performance data and characteristics are displayed in Table V and Table VI. Costs used in the following analysis pertain to these vehicles.

1. Investment Costs

All three vehicles of Battronic Truck Corporation had purchase prices of $15,950. The purchase price included a two module, 112 volt, industrial-type battery, and an on-board charger.

The salvage value after ten years was quoted by the sales representative at six percent of the acquisition cost. This was derived from the current market value of the lead, copper, and iron scrap in the vehicle.

2. Operating Costs

Operating costs were quoted at 1.5 kilowatt-hours per mile based on data collected from EV users for both winter and summer driving. This is a conservative figure relative to data collected on other types of EV's of similar weight, and should be easily attainable.

The price of one kilowatt-hour paid by NPS was $0.0706. The average annual mileage of vehicles determined to be low performance was 4097.

3. Maintenance Costs

The simplicity of the electric motor relative to the ICE should result in lower maintenance costs. Sixty-two percent of maintenance costs for conventional cars arise in the engine and its fuel, ignition, cooling, and exhaust systems. Maintenance costs for EV's were estimated at 38 percent of the maintenance costs for ICE vehicles. The reduction to 38 percent reflects the elimination of most of the parts and labor required by the ICE, whereas the electric motor and controller require little or no service during the life of the vehicle [Ref. 31]. However, additional maintenance costs are incurred that are unique to EV's.

The major expense is associated with the labor involved with battery charging and maintenance [Ref. 32]. This is supported by maintenance data collected by the U.S. Postal Service. Data collected from the Department of Energy's Electric and Hybrid Vehicle Demonstration Project show that about 75 percent of the maintenance on EV's is battery-related preventive maintenance: watering cells, cleaning terminals, and tightening connections, and consumes about 1-1/2 hours every two weeks per vehicle. Battery replacement is a major recurring expense.

The battery used by Battronic Truck Corporation was guaranteed for 750 cycles. One cycle per day, 240 days per year, would provide a useful life of three years. Batteries would require replacement in years four and seven of the life cycle. Replacement price for the battery pack was $4,800. The scrap value, based on a current market price of lead of $0.22 per pound. was $506. This was treated as a reduction of the battery replacement cost.

Material and labor maintenance costs were quoted by Battronic Truck Corporation at $0.08 per mile.

4. Cost Model

The total LCC for procuring, operating, and maintaining one EV is:

$$TC_U = P_V + PV_i(Mi \times (n \times P_{Kwh} + M)) + PVa(B) - PV(S) \quad (3.5)$$

Where:

TC_U = Total unit life cycle cost.
P_V = Variable Procurement cost.
P_{Kwh} = Price of electricity.
Mi = Average annual miles of traveled by EV's.
M = Maintenance cost.
S = Salvage value.
PV_i = Present value factor for equal annual cash flows for i years.
PVa = Present value factor for the year in which battery replacement occurs.
B = Battery replacement cost less salvage value.
PV = Pesent value factor for a single cash flow in the final year of the life cycle.
n = Vehicle efficiency in kilowatt-hours per mile.

The total LCC for procuring, operating, and maintaining a fleet of EV's is:

$$TC_F = n(TC_U) \quad (3.6)$$

Where:

TC_F = Total fleet life cycle costs.
n = number of vehicles in the fleet.

For NPS, the net present value of the total life cycle cost for one electric vehicle is $25,863. The net present value for a fleet of 35 vehicles, the maximum number vehicles determined to be suitable for replacement with low performance vehicles, is $905,205, compared to $411,600 for thirty-five gasoline-powered vehicles.

IV. LINEAR PROGRAMMING

A. THE NATURE OF THE LINEAR PROGRAMMING PROBLEM

Linear programming is a mathematical tool for determining the optimal allocation of an organization's limited resources among competing demands. It is characterized by a linear objective function prefixed by profit or loss coefficients. The objective function is either maximized or minimized subject to linear constraints which define the area of feasible solutions. As with all decision models, it is an aid to the decision maker and is not intended to be the sole basis for a decision.

The simplex method is an iterative process for solving a linear programming problem. The search begins at the origin where a test for optimality determines if the value of the objective function can be increased (for maximization problems) by moving to an adjacent corner point of the feasible area. The process continues until no further improvement is possible.

Computer software is available for solving the linear program. An International Mathematical and Statistical Library (IMSL) routine was used in this analysis.

1. General Characteristics and Terminology

A linear programming problem is composed of:

Decision variables: The variables whose value is unknown. The variables represent the projects or alternatives and the value is the quantity included in the final solution. They are usually designated by X1,X2,...etc.

Profit or Cost Coefficients: The coefficients of the variables in the objective function. They express the rate at which the value of the objective function increases or decreases as one unit is added or removed from the final solution.

Objective function: A mathematical expression showing the linear relationship between the decision variables and a single goal or objective which is either minimized when the decision variables are prefixed by cost coefficients, or maximized when the decision variables are prefixed by profit coefficients. The objective function is a measurement of effectiveness of goal attainment. The value of the objective funtion is represented by the variable z.

Constraints: The constraints represent the limited availability of resources or specify the minimum project requirement in the final solution. They limit the maximum or minimum value of the objective function. Constraints may be expressed as linear equalities or inequalities. Constraints consist of input-output coefficients written on the left-hand side of the equation and capacities written on the right.

Input-output coefficients: The coefficients prefix the decision variables and express the rate at which a resource is utilized or depleted as one unit of a decision variable is added or deleted from the final solution.

Capacities: The availability of various resources expressed as an upper limit, lower limit, or inequality.

Nonnegativity: Only nonnegative values of the decision variables are allowed in the final solution.

2. Assumptions with Linear Programming

Certainty: All data associated with linear programming is known with certainty. Sensitivity analysis provides some leeway in dealing with the certainty assumption.

Linearity: The unit costs and input-output coefficients change linearly with volume. They are unaffected by changes in quantities produced or purchased.

Nonnegativity: All decision variables are required to take nonnegative values.

Additivity: The total utilization of a resource is determined by summing that portion of the resource consumed by each alternative.

Divisibility: The decision variables are continuous, that is, they can take any fractional value. In this problem fractional values are infeasible but it will be assumed that rounding to the nearest whole value will not alter the optimality of the final solution.

Independence: Complete independence exists among alternatives and resources.

3. A Product Mix Example

A simple product mix problem will be used to illustrate linear programming. Two products, A and B, with profit contributions of $25 and $30 respectively, must compete for three limited resources. Eighty hours of labor time and ninety hours of machine time are available each week. The manufacturer is unable to market more than seven units of product A each week. Product A consumes 8 hours of labor and product B 10 hours. Product A consumes 13 hours of machine time while product B consumes 6. The constraints, written as linear functions, are:

Labor hours $8A + 10B \leq 80$

Machine time $13A + 6B \leq 90$

Marketing $1A + 0B \leq 7$

Solving for the variables A and B in each equation yields the A and B intercepts. The constraints are plotted

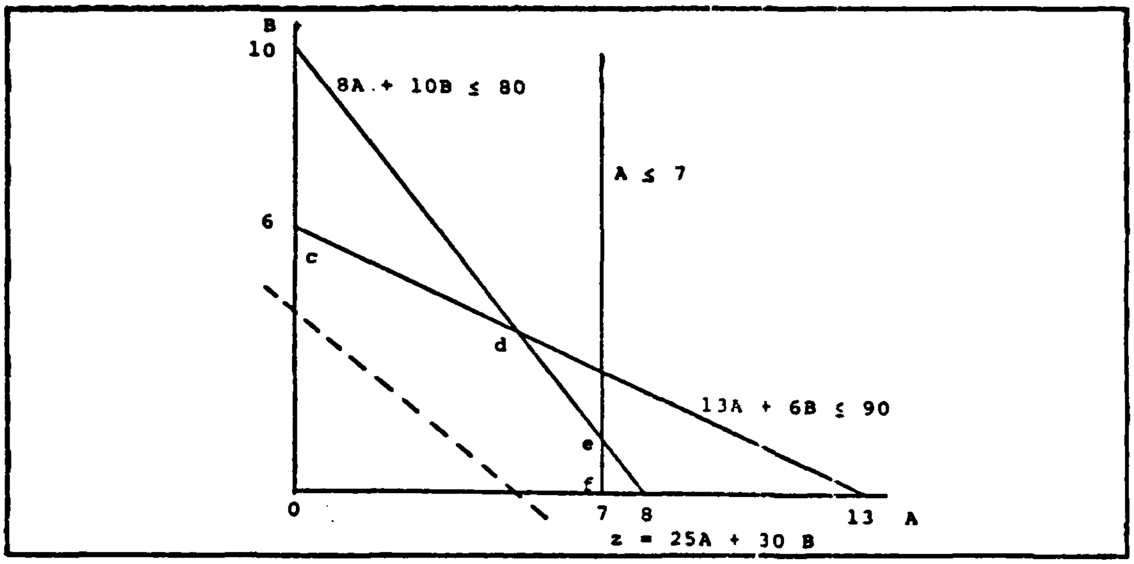


Figure 4.1 The Product Mix Problem.

graphically in Figure 4.1. The area bounded by O-C-D-E-F defines the feasible area in which the optimal solution may be found.

The objective is to maximize profit which is represented by the variable z. The objective function is:

Maximize $z = 25A + 30B$

The slope of the objective function is an isoprofit line. Starting at the origin the value of z is increased by moving the isoprofit line away from the origin until it intersects the point on the boundary of the feasible area where profits cannot be increased without exceeding one or more constraints.

Three dimensional problems require considerable effort to solve graphically. With four or more variables it is impossible. Linear programming uses an iterative process to analytically evaluate all corner points defining the feasible region and test for optimality.

4. Capital Budgeting

A widely used heuristic method for allocating a limited capital budget is the net present value method proposed by J. H. Lorie and L. J. Savage in 1955. A firm is tasked with investing a fixed amount of capital in a number of possible projects with known cash flows. The cost of capital is assumed to be known and independent of investment decisions. Cash flows are discounted to present value and projects are ranked in decreasing order of net-present-value-to-cost ratios. Projects are selected from the top of the list until the available capital is exhausted.

A project with a high net-present-value-to-cost ratio may be of such magnitude that it excludes the possibility of selecting multiple smaller projects that may result in a larger net present value for the firm. This method fails to consider capital limitations in investment periods beyond the present except through a trial and error analysis of combinations of projects. It also does not consider any surplus capital that could be utilized for additional projects.

H. Martin Weingartner, in 1962, cast the Lorie-Savage problem in a linear program. The present value of each alternative is evaluated in a linear function. Although integer programming methods may be used to deal rigorously with the indivisibility of investment projects, the excessive computation time produces only slight improvements over the linear program approximation. The capital requirements of each alternative and the capital constraint for each year of the project are also represented by linear functions. The objective is to choose the alternative or alternatives that maximize the net present value without violating any budget constraints up to a specified horizon. Restricting the upper value of each project in the final solution to unity ensures that only one of any project is included in the final solution. Projects with a value of one are selected [Ref. 33].

John J. Clark, et al, formulated a set of heuristic decision rules for accomodating fractional values. If the value of the project was between 0.80 and 1.00, the firm would probably seek additional funding for the project. A value between 0.30 and 0.80 may warrant a joint venture with another firm. If the value was 0.30 or less the project would probably be rejected [Ref. 34].

B. THE FLEET MIX PROBLEM

The fleet mix problem has characteristics of the product mix and capital budgeting examples. A mixture of high and low performance vehicles can fulfill the mission requirements of an activity, but operating budgets and capital requirements must also be considered. The technique of selecting the fuel type with the lowest net present value of costs may not always be the optimal solution because; (1) the fuel type with the lowest total cost may not be feasible for high performance vehicles, (2) a fuel type may result in lower operating and maintenance costs but the investment and conversion costs may exceed procurement budgets, and (3) combining two fuel types may result in a net present value of costs greater than that of operating solely on gasoline due to the fixed investment cost which must be added to the total variable cost.

The mission requirements of an activity dictate the number of high or low performance vehicles that can be in the final solution. The Equipment Usage Record indicates vehicles with annual usage rates and daily operating ranges that exceed the limit for low performance vehicles established in Chapter II. A listing of vehicles on-board can be used to identify vehicles with load capacity requirements that exceed the limit established for low performance vehicles. The fleet managers must make a subjective decision based on mission assignments as to how minimum acceptable speeds affect vehicle classification. For example, a requirement for extended highway use would preclude asignments as low performance vehicles. Of the 72 vehicles at the Naval Postgraduate School, 11 vehicles had annual usage rates over 11,800 miles, 26 vehicles had minimum load capacities over 1400 pounds, therefore 37 vehicles were classified as high performance. The remaining 35 vehicles were classified as low performance. An analysis of individual vehicle requirements and classification based on speed or highway use was not considered.

The problem is formulated to take into account an activity's Operations and Maintenance (O&M,N) and Other Procurement, Navy (OP,N) budgets. At a minimum, OP,N is an estimate of the amount the General Services Administration has budgeted for gasoline-powered vehicle procurement. Procurement dollars for vehicle conversion to CNG need not originate from within an activity if external procurement dollars are available. In this problem, however, it is not required, or even desired, to consume all of the available capital.

The decision variables represent the number of vehicles of each fuel type and are defined as follows:

X_1 = Gasoline-Powered Vehicles
X_2 = CNG-Powered Vehicles
X_3 = Electric Vehicles

The coefficient (c) of each decision variable expresses the total variable unit cost of procuring, operating , and maintaining one vehicle of each fuel type. These values are obtained from equations 3.1, 3.3, and 3.5 respectively. The value of the objective function, z, represents the total variable LCC of procuring, operating, and maintaining the fleet. The fixed costs must be added to the value of z to arrive at the total fleet LCC. The goal is to minimize the value of z.

The cost coefficients in the first constraint are the unit variable purchase costs and variable investment costs (CNG conversion kits) for each alternative. The right-hand side is an estimate of the OP,N amounts budgeted for vehicle procurement and additional OP,N amounts planned for investment/conversion. The procurement budgets are treated as one appropriation account; however, an activity would not be able to transfer funds from one appropriations account to another.

The cost coefficients in the second constraint are the unit O&M costs for each alternative derived from equations 3.1, 3.2, and 3.3. The right-hand side is the O&M dollars budgeted for vehicle operations and maintenance in the first year.

The cost coefficients in the third constraint are the unit present value of annual O&M costs less the salvage value. The right-hand side is the present value of an activity's budgeted O&M costs for the fleet. The computation of annual and budgeted O&M costs and budget constraints for NPS are contained in Appendix A.

The fourth constraint limits the number of low performance vehicles in the final solution, low performance vehicles being previously defined as electric vehicles. The coefficient for low performance alternatives is one. The right-hand side is the maximum number of low performance vehicles allowed by an activity.

The fifth constraint provides the user with the option of specifying the number of vehicles that an activity desires to remain gasoline-powered, for example, emergency vehicles or Admiral's sedans.

The sixth constraint specifies the fleet size. The coefficient for each alternative is one and the right-hand side is equal to the fleet size.

The problem written as linear equations is:

Minimize $z = c_1X_1 + c_2X_2 + c_3X_3$

Subject to:

$$b_{11}X_1 + b_{12}X_2 + b_{13}X_3 \leq b_1$$

$$b_{21}X_1 + b_{22}X_2 + b_{23}X_3 \leq b_2$$

$$b_{31}X_1 + b_{32}X_2 + b_{33}X_3 \leq b_3$$

$$b_{43}X_3 \leq b_4$$

$$b_{51}X_1 \geq b_5$$

$$b_{61}X_1 + b_{62}X_2 + b_{63}X_3 = b_6$$

Constraints written as inequalities may not be fully utilized in the final solution. A constraint of the form "less than or equal to" may have an unused capacity which is represented by a slack variable (S) that is either positive or zero. A constraint of the form "greater than or equal to" may exceed the minimum capacity which is represented by a surplus variable (S) that is either positive or zero. To ensure surplus variables remain positive, an artificial variable (A) is added to the equation. This variable does not have any physical meaning and is assigned a penalty value of M to prevent it from entering the final solution. M is the largest value that the computer can hold. Artificial variables are also required in equality constraints to maintain the identity. Slack, surplus, and artificial variables are included in the objective function.

A solution to a system of linear equations requires that the number of variables equal the number of equations. If there are more variables than equations, there are an infinite number of solutions. If there are fewer variables than equations, a solution would exist only if there was degeneracy, i.e., when three or more equations intersect at the optimal solution. To overcome this problem some of the variables are set to zero. The variables in the final solution are called basic variables and may have positive or zero values. The number of basic variables is equal to the number of constraints. Variables not in the final solution are called nonbasic.

To solve the linear program with the computer the problem was rewritten as a maximization problem in standard form and artifical variables introduced. To change to a maximization problem the objective function was multiplied by -1 and the variable for the objective function was changed from z to w, where, $z = -w$. The problem is now written as:

Maximize w =

$$-c_1X_1 - c_2X_2 - c_3X_3 + 0S_1 + 0S_2 + 0S_3 + 0S_4 - 0S_5 - MA_1 - MA_2$$

Subject to:

$$b_{11}X_1 + b_{12}X_2 + b_{13}X_3 + S_1 \leq b_1$$

$$b_{21}X_1 + b_{22}X_2 + b_{23}X_3 + S_2 \leq b_2$$

$$b_{31}X_1 + b_{32}X_2 + b_{33}X_3 + S_3 \leq b_3$$

$$b_{43}X_3 + S_4 \leq b_4$$

$$b_{51}X_1 - S_5 + A_1 \leq b_5$$

$$b_{61}X_1 + b_{62}X_2 + b_{63}X_3 + A_2 \leq b_6$$

To facilitate solving, either manually or by computer, the problem is written in a tableau. The variables are written accross the top and only the coefficients are displayed in the main body. The coefficients of the objective funtion are written below the constraints in the row designated Cj. The Zj row is the summation of the product of the basic variable coefficients and the corresponding elements of the main body. For example, Zj for column X1 is: 0(8293) + 0(3468) + 0(0) - M(1) - M(1) = -2M. It shows the amount by which the objective funtion decreases as one more unit of the variable is added. (The amount by which total cost increases). The Cj-Zj, or evaluator row, shows the net impact on the value of the objective function by adding one unit of a non-basic variable to the basis. The basic variables and their coefficiants are written on the left-side of the tableau. Table VIII illustrates the problem written in tableau form. The coefficients are those computed for NPS and are derived in Appendix A. The value of the right-hand side of the fifth constraint was arbitrarily set equal to two for illustrative purposes. The final tableau for the problem is displayed in Table IX.

TABLE VIII

Vehicle Mix Tableau

Basic Variable	Coeff.	Quantity	X_1	X_2	X_3	S_1	S_2	S_3	S_4	S_5	A_1	A_2
S_1	0	631800	7600	8775	15950	1	0	0	0	0	0	0
S_2	0	49902	693	437	762	0	1	0	0	0	0	0
S_3	0	271816	3468	2073	9152	0	0	1	0	0	0	0
S_4	0	35	0	0	1	0	0	0	1	0	0	0
A_1	-M	2	1	0	0	0	0	0	0	-1	1	0
A_2	-M	72	1	1	1	0	0	0	0	0	0	1
		Cj	-11760	-11284	-25863	0	0	0	0	0	-M	-M
		Zj	-2M	-M	-M	0	0	0	0	M	-M	-M
		Cj-Zj	-11760 +2M	-11284 +M	-25863 +M	0	0	0	0	-M	0	0

TABLE IX

Final Tableau

Basic Variable	Coeff.	Quantity	X_1	X_2	X_3	S_1	S_2	S_3	S_4	S_5	A_1	A_2
S_1	0	2350	0	0	7175	1	0	0	0	-1175	1175	-8775
S_2	0	17926	0	0	325	0	1	0	0	356	-256	-437
S_3	0	119770	0	0	7079	0	0	1	0	1395	-1395	-2073
S_4	0	35	0	0	1	0	0	0	1	0	0	0
X_1	-11760	2	1	0	0	0	0	0	0	-1	1	0
X_2	-11284	70	0	1	1	0	0	0	0	1	-1	1
		Cj	-11760	-11284	-25863	0	0	0	0	0	-M	-M
		Zj	-11760	-11284	-11284	0	0	0	0	476	-476	-11284
		Cj-Zj	0	0	-14579	0	0	0	0	-476	476 -M	11284 -M

The values of basic variables are read from the quantity column. Non-basic variables are equal to zero. The value of w is computed by substituting the values for X1, X2, and X3 into the objective function. The final solution is:

$X_1 = 2$	$S_1 = 2{,}350$	$S_4 = 35$	$z = 813{,}400$
$X_2 = 70$	$S_2 = 17{,}929$	$S_3 = 0$	
$X_3 = 0$	$S_3 = 119{,}770$	$w = -813{,}400$	

The fleet would be composed of two gasoline-powered vehicles, seventy CNG-powered vehicles, and zero EV's. The OP,N and O&M savings over budgeted O&M in year one would be $2,350 and $17,926 respectively. The present value of the savings in O&M for years two through ten would be $119,770. Thirty-five vehicles previously classified as low-performance still employ a high-performance alternative. Based on usage rate and load capacity, these vehicles could be replaced by EV's without mission impairment. The requirement for a fleet size of seventy-two vehicles has been satisfied.

The total fleet variable cost is $813,400. Adding the $47,100 fixed cost for the CNG infrastructure, as developed in Section E(1) of Chapter III, brings the total life cycle cost to $860,500. This exceeds the total life cycle cost for gasoline-powered vehicles by $13,780 derived in Chapter III. Using the criterion established in Chapter I, the decision would be to continue operating with gasoline-powered vehicles.

C. SENSITIVITY ANALYSIS

The analysis proceeds under the assumption that an activity is willing to make the initial fixed cost investment and configure the fleet in accordance with the final solution. This assumption is based on an acceptable payback period which will be addressed in a subsequent section.

The evaluator row (Cj-Zj) shows the net impact on total life cycle cost of bringing one unit of a non-basic variable into the solution. Adding one EV (X3), which necessitates the removal of one CNG vehicle (X2) to satisfy the equality constraint, will increase LCC by $14,579. A requirement for each additional gasoline-powered vehicle (S4) will increase total costs by $476.

The ratios of substitution indicate the tradeoffs that occur when a non-basic variable becomes a basic variable. The ratios are contained in the body of the tableau under the non-basic variable of interest. Adding one EV will decrease the first year's savings in OP,N by $7,175 , O&M by $325, and the the present value of subsequent year's savings in O&M by $7,079. This will also decrease the low performance vehicle surplus by one, have no impact on the number of gasoline-powered vehicles in the final solution, and decrease the number of CNG-powered vehicles by one.

Increasing the requirement for gasoline-powered vehicles will reduce OP,N expenditures in the first year by $1,175, but decreaseO&M savings by $256. Savings in years two through ten will decrease by $1,395. This will have no impact on the low performance vehicle surplus and will reduce the number of CNG vehicles by one.

Of greater interest is the range of values that the coefficients of the decision variables may assume without changing the composition of the basis. This range is composed of an upper and lower limit. As long as a coefficient is within this range the current optimal solution will remain unchanged. Should the coefficient go above or below these limits there will be a change in the basis and optimal solution. The simplex approach distinguishes between the analysis of basis and non-basic variables.

Analysis of Basic Variables (B): The analysis of variable x1 will be used as an example.

Step 1. Copy the Cj-Zj row of the optimal solution.

Step 2. Copy the X1 row below the Cj-Zj row.

Step 3. Divide the Cj-Zj row by the X1 row for each non-basic variable.

	B	B	NB	B	B	B	NB
Cj-Zj	0	0	-14579	0	0	0	-476
X1	1	0	0	0	0	0	-1
$\frac{Cj-Zj}{X1}$	--	--	∞	--	--	--	476

The smallest positive number (476 in this example) tells by how much the coefficient of X1 can be increased before the solution is changed. The smallest negative number (absolute value) indicates by how much the coefficient can be decreased without changing the solution. The smallest negative value in this example is infinity. The range of values is, therefore,

$$-11760 - \infty < c_1 < -11760 + 476$$

or

$$-\infty < c_1 < -11284.$$

The total variable LCC would have to decrease to $11,284 before the composition of the fleet would be composed of gasoline-powered vehicles only. An increase in the total variable LCC would have no effect on fleet composition.

Repeating the same analysis for variable X2, the range of values is

$$-11760 < c_2 < 0.$$

The total variable LCC could increase to $11,760 before the composition of the fleet would change to gasoline-powered vehicles only.

Analysis of non-basic variables: In order for a non-basic variable to enter the final solution, its coefficient will have to change from its present value (Cj) to C'j, where

$$C'j > Zj.$$

For an EV to enter the final solution, its LCC would have to decrease to a minimum of -11284.

Knowing the range of values that the coefficients may assume without changing the final solution, the user can then examine the determinants to evaluate their sensitvity, or determine the changes required before an alternative becomes cost effective.

D. ANALYSIS OF THE DETERMINANTS OF TOTAL LIFE CYCLE COST

1. Gasoline

Since acquisition cost and salvage value are the same for gasoline and CNG, changes in relative LCC's would have to be a result of changes in operations and maintenance. The price of gasoline is the most likely determinant to change. To reduce LCC to $11,284, life cycle operating costs would have to decrease from $3,243 to $2,767 (Equation 3.1). To achieve this reduction the price of gasoline would have to fall to $1.019 per gallon, a likely occurence with today's oil glut and price instability.

If maintenance cost savings with CNG were predicted to be 50 percent instead of the 37 percent used in this analysis, LCC for gasoline-powered vehicles would have to drop from $11,766 to $11,239. To achieve this reduction, the price of gasoline would have to fall to $1.003 per gallon.

2. Compressed Natural Gas

With a bill pending in Congress to deregulate the natural gas industry, the price of natural gas is most likely to change. To increase variable LCC from $11,284 to 11,760, life cycle operating cost would have to increase from $1,547 to $2,023 (equation 3.2), which equates to an increase in the price of natural gas form $0.57 to $0.75 per gallon, or, approximately $7.50 per 1000 cubic feet. This would be a 31 percent increase over the current price.

Maintenance cost savings with CNG are uncertain but the total LCC is relatively insensitive to changes in the saving factor. The current LCC is based on a conservative estimate of 37 percent savings in engine-related maintenance. An optimistic estimate of 50 percent would decrease LCC by $45 to $11,239 or 0.4 percent.

The cost per conversion kit can increase to $1,551 or 40 percent before LCC reaches $11,760.

3. Electric Vehicles

Acquisition cost is the single largest determinant of total LCC for EV's. Acquisition cost is likely to remain high until consumer demand induces larger scale production and lower unit cost. An increase in demand is likely to be the result of increased cost in operating gasoline-powered vehicles and shortages in gasoline supplies.

Battery replacement and maintenance costs are the second largest determinant. Projected lead-acid battery performance in 1985 is 1000 deep cycles and an energy density of 46 Wh/Kg. Together they might multiply the range of EV's nearly fivefold and cut battery depreciation in half. (Hamilton 31).

Evaluating hypothetical scenarios, if an EV purchase price was reduced by approximately one half to $8,000, and the useful life of batteries was extended to five years, the total LCC would be $15,320. This is still $3,560 greater than gasoline-powered vehicles. If the price of gasoline were to increase to $2.00 per gallon, total LCC for gasoline-powered vehicles would increase to $13,944, still less than an EV.

Comparing an EV with a ten year life cycle, $8,000 purchase price, and five year battery replacement cycle, to a gasoline-powered vehicle with a seven year life cycle and a gasoline price of $2.00 per gallon, the annualized LCC for an EV over the ten year cycle is $1,532. The annualized LCC for a gasoline-powered vehicle over seven years is $1,567, slightly greater than on EV.

E. PAYBACK PERIOD ANALYSIS

A decision to incur investment costs to achieve savings in O&M would be based on an acceptable payback period. Approval authority is dependent on the investment value of the project. Energy Conservation Improvement Projects (ECIP) that require approval by major claimants are generally approved if the payback period is three years or less.

An alternate approach to sensitivity analysis is to determine the impact of various determinants on the savings in O&M. Since the high LCC of EV's place them out of the picture for the near future, the analysis will focus on gasoline and CNG. Determinants with the greatest potential for affecting savings in O&M are the difference in the prices of gasoline and natural gas, fleet size, and average annual miles. Savings in maintenance costs resulting from conversion to CNG have little impact on the difference in O&M.

A large divergence in the price of gasoline over the price of CNG will result in greater O&M savings and a shorter payback period. Average annual miles is likely to remain constant for any one activity; however, an activity may be interested in the impact of varying the number of vehicles converted. The analyst must keep in mind the effect average annual miles and the number of vehicles converted have on the required numbers of compressors, cascade systems, and the resulting investment cost.

Derived from equations 3.1 and 3.3, the equation for O&M savings is:

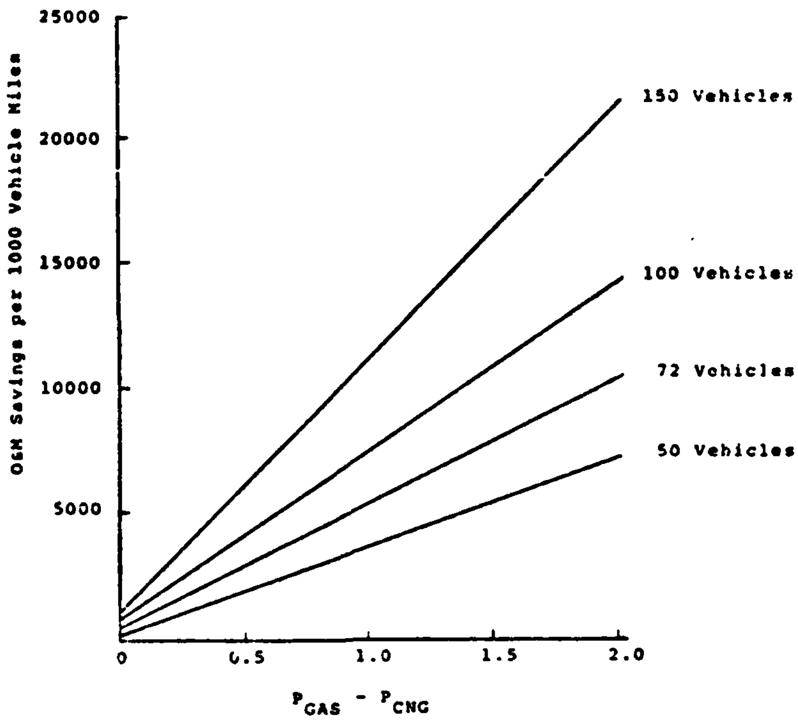
$$\Delta O\&M = n \times Mi((\eta(P_{GAS} - P_{CNG}) + M - (1-s)(M)) + n \times OP \quad (4.1)$$

Where:

- P_{GAS} = Price of gasoline.
- P_{CNG} = Price of compressed natural gas.
- M = Maintenance cost per mile.
- s = Maintenance cost savings factor.
- Mi = Average annual miles.
- OP = Annual operating permit fee.
- n = Number of vehicles.
- η = Vehicle efficiency in gallons per mile.

With the exception of annual operating permits which vary according to the number of vehicles, O&M savings is a function of the price difference between gasoline and natural gas, average annual miles, and the number of vehicles. Figure 4.2 depicts fleet savings in O&M per 1000 average annual miles per vehicle as a function of the price of gasoline minus the price of CNG for various fleet sizes. The savings is computed by multiplying the value obtained from the abscissa by the average annual miles per vehicle divided by 1000. This value must be reduced by the annual operating permit fee multiplied by the number of vehicles.

For the 72 vehicles at NPS averaging 5928 annual miles, and the current prices of gasoline and natural gas of $1.196 and $0.57 per gallon, respectively, the savings in O&M is



Source: Text.
Note: Savings must be reduced by the operating permit fee multiplied by the fleet size.

Figure 4.2 Gasoline and Natural Gas Prices vs. O&M Savings.

$18,432. With a $131,700 initial investment for the compressor, cascade, and conversion kits, the payback would be approximately seven years.

To achieve a three year payback period, annual savings in O&M would have to be $43,900. Setting O&M in equation 4.1 equal to $43,900, holding annual miles and number of vehicles constant, and solving for PGAS - PCNG, the price difference would have to be at least $1.46 per gallon.

To achieve a three year payback using the Navy-wide average miles per vehicle/year of 7900, and average mile per gallon of 13.5 [Ref. 35], 143 vehicles would have to be converted. This is based on the requirement for two compressors and a target annual O&M savings of $51,600.

F. SUMMARY

The linear program was designed for maximum flexibility. Cost coefficients and right-hand side values may be changed to reflect changing prices and fleet characteristics of any activity.

The linear programming solution to the above scenario calls for a fleet mix of two gasoline-powered vehicles and seventy CNG-powered vehicles. (A result of the arbitrary requirement for two gasoline-powered vehicles in the final solution.) The total variable cost is $813,400. Added to this is the fixed investment cost of $47,100 for a compressor and distribution system for a total LCC of $860,500. Compared to the LCC of $846,720 for gasoline-powered vehicles, and in light of the decision criterion of lowest LCC established in Chapter I, the final decision should be to continue operating gasoline-powered vehicles.

The final decision rests with the treatment of fixed costs. While the total LCC with CNG is $13,780 greater than that of gasoline, annual O&M is $18,432 less. Depending on the prices of gasoline and natural gas, annual miles, and fleet size, savings in O&M may be of such magnitude to justify incurring the investment cost associated with CNG. For NPS to recover the $131,700 investment in three years, annual O&M savings would have to be $43,900. To achieve this, the price difference between gasoline and CNG would have to be $1.46 per gallon.

V. SUMMARY AND CONCLUSIONS

The purpose of this thesis was to provide fleet managers with a consolidated source of information and decision models for evaluating the potential for using alternative fuels. Advantages and disadvantages of compressed natural gas (CNG), alcohol, and electric vehicles were presented and a determination made as to their suitability as replacements for gasoline-powered vehicles.

The gasoline-powered vehicle served as a baseline against which other alternatives were compared. To accomodate the different performance characteristics associated with each alternative, measures of effectiveness were established reflecting these differences and served to distinguish between high and low performance alternatives. These measures were: range, usage rate, speed, load capacity, and fuel availability. The minimum level of effectiveness for high performance alternatives was set to preclude replacing a gasoline-powered vehicle with an alternative that degraded its ability to perform its mission.

The analysis was conducted in 1982 dollars and alternatives were evaluated based on their current state-of-the-art technology. The decision criterion was based on the minimizing total life cycle cost (LCC) of procuring, operating, and maintaining a fleet of vehicles.

Seventy-two vehicles at the Naval Postgraduate School (NPS) served as a sample population for comparing total LCC. The population consisted of sedans, station wagons, and light trucks with gross vehicle ratings of one ton or less. The total LCC for procuring, operating, and maintaining this fleet was $846,720.

Compressed natural gas (CNG), when used as a dual fuel with gasoline, satisfied the minimum levels of effectiveness for high performance alternatives. The primary advantage is its lower price per gallon and its plentiful supply, although with natural gas deregulation, future gas prices are uncertain. Because CNG burns cleaner than gasoline, maintenance intervals may be extended and exhaust emissions reduced. Fuel efficiency may be increased because of better cold starting capabilities. CNG's lower specific gravity relative to air and the narrow range of air/fuel ratios that will support combustion make it a safer fuel than gasoline.

Adding two gas cylinders to a vehicle adds about 250 pounds and occupies up to 7 cubic feet. The additional weight reduces acceleration from 25 to 40 percent and fuel economy by 5 to 10 percent.

The high initial investment cost is the major disadvantage to CNG. Conversion to CNG requires compressors, storage and distribution systems, and vehicle conversion kits. The amount of savings in O&M is dependent on the price difference of gasoline and natural gas, the vehicle usage rate, and the number of vehicles converted. Using November 1982 fuel prices and Navy-wide average annual miles and fuel efficiency data for fiscal year 1981, 143 vehicles would have to be converted to achieve a three year payback.

The investment cost to convert seventy-two vehicles at NPS is $131,700. The total LCC to procure, operate, and maintain seventy-two vehicles would be $459,692, or $12,972 more than gasoline, however, annual O&M cost would be reduced by $18,432. To achieve a three year payback the price difference between gasoline and natural gas would have to be at least $1.46 per gallon.

Interest in alcohol (methanol and ethanol) has stemmed from a need to reduce the nation's dependence on foreign oil. Currently, this interest has ebbed as a result of today's oil glut. Alcohol poses technical problems with vehicle performance, distribution and handling, and compatability with materials. These problems are not insurmountable and are likely to be solved with further research. The advantage with alcohol is that delivery, storage, and dispensing systems would not be substantially different than gasoline system. However, alcohol for motor vehicle use is not currently produced in sufficient quantities to be considered as a viable alternative to gasoline.

Electric vehicles have shorter ranges, slower cruising speeds, and lighter load capacity than gasoline-powered vehicles yet they are still capable of fulfilling some missions currently performed by gasoline-powered vehicles. They are ideally suited for short-range delivery or utility vehicles with missions characterized by low speeds and multiple stops.

The analysis focused on EV's with commercial applications. The EV's manufactured by Battronic Truck Corporation were used in the analysis based on current availability, lowest procurement cost of the five manufacturers surveyed, and suitability for replacing gasoline-powered vehicles without mission impairment. Acquisition and battery replacement costs remain the biggest deterrent to EV use. Acquisition cost for the EV's manufactured by Battronic Truck Corporation was $15,950, equiped with on-board chargers. The battery pack had a useful life of three years and a repacement cost of $4,800.

Operating cost may be lower for specific applications and when compared to inefficient ICE vehicles. Energy consumption is minimal when the driving pattern is characterized by frequent stops, coasting, and deceleration which do not consume energy. Regenerative braking increases the range and reduces the operating cost. Annual O&M cost per vehicle was $69 greater than that of gasoline.

The simplicity of the electric motor should result in lower maintenance cost; however, failure rates are currently high owing to the lack of maturity in the EV industry. A lack of trained personnel for maintenance and difficulties obtaining replacement parts have been cited as disadvantages by EV users.

The LCC for one EV was $25,863. Thirty-five vehicles at NPS were determined to be suitable for replacement by EV's. The LCC for a fleet of thirty-five EV's and thirty-seven gasoline-powered vehicles was $1,340,325, or $493,605 greater than a gasoline-powered fleet.

The linear programming model was effective in analyzing the variable cost components of each alternative. It provided a means for assessing the impact of substituting one alternative for another on total variable cost and O&M budgets.

For illustrative purposes, a constraint calling for a minimum of two gasoline-powered vehicles was imposed leading to a solution that specified a fleet mix of two gasoline-powered vehicles and seventy CNG-powered vehicles. The variable LCC was $813,400 and, after adding fixed costs, the total LCC was $860,500. The first year savings in O&M and OP,N would be $20,279, and subsequent savings in O&M would be $119,770.

The linear program produced the range of LCC values over which the fleet mix solution remained valid, from which the sensitivity of LCC determinants could be analyzed. Gasoline prices could decrease to $1.019 per gallon, or, natural gas prices could increase to $0.75 per gallon without changing the fleet mix. The final solution was relatively insensitive to maintenance cost savings with CNG.

The final fleet mix decision depended on the treatment of fixed costs. Adding the fixed costs to the variable costs obtained from the linear program changes the solution from a mix of CNG and gasoline to gasoline-powered vehicles only.

While the LCC for CNG is $13,780 greater than that of gasoline, annual O&M is $18,432 less. The decision may be governed by the time it takes to recover fixed costs. For NPS, the payback period is approximately seven years. To achieve a three year payback period the price difference between gasoline and natural gas would have to be $1.49 per gallon.

APPENDIX A

COMPUTATION OF ANNUAL AND BUDGETED CASH FLOWS

A. COMPUTATION OF ANNUAL CASH FLOWS

Cash flows in year one are the unit procurement costs and the operating and maintenance costs for each alternative derived from equations 3.1, 3.2, and 3.3. Cash flows in year two through nine are the annual operating and maintenance costs in 1982 dollars. For EV's in years four and seven, the operating and maintenance costs are net of battery replacement costs of $4,800 in procurement less $506 in salvage value. Cash flows in the final year are net of vehicle salvage value.

The OP,N and O&M in the first and second constraint of the linear program are the first year cash flows. The O&M in the third budget constraint are the cash flows in years two through ten discounted to present value using a 10 percent discount rate.

B. COMPUTATION OF BUDGETED CASH FLOWS

The practice for budgeting O&M in the Public Works Department of the Naval Postgraduate School is to budget the current year's O&M adjusted for inflation and increased by any extraordinary items. The budgeted O&M for each year is the amount required to operate and maintain 72 gasoline-powered vehicles computed from equation 3.1, and considered to be the minimum amount that can be budgeted each year. The procurement budget is the average unit purchase price of gasoline-powered vehicles, plus additional OP,N available for investment and conversion. In this problem, sufficient OP,N was programmed to include the cost of CNG conversion kits. Table X shows cash flows by year for each alternative and the budgeted O&M and OP,N.

TABLE X

Annual Cash Flows

Year	Gas	CNG	EV's	Budgeted
1 (OP,N)	7,600	8,775	15,950	631,800
1 (O&M)	693	437	762	49,905
2	693	437	762	49,905
3	693	437	762	49,905
4	693	437	5,056	49,905
5	693	437	762	49,905
6	693	437	762	49,905
7	693	437	5,056	49,905
8	693	437	762	49,905
9	693	437	762	49,905
10	(67)	(323)	(195)	49,905

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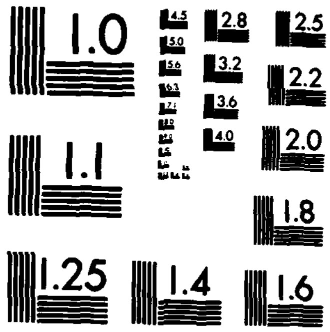

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