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16. Abstract

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SOUTHWEST REGION UNIVERSITY TRANSPORTATION CENTER

An Evaluation of Energy Conservation Measures Utilized by Public Transit Systems: A Case Study in Texas

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PREFACE

This text was designed to study the energy consumption of selected transit entities by analyzing the type of energy characteristics expended by local transit systems. The findings of this research delineate the mechanisms which can provide significant fuel savings.

Successful completion of this document is due to the direction, guidance and counsel of Dr. Naomi W. Lede´. Her supervision is gratefully appreciated. In addition, much gratitude goes to several staff members of the Center for Transportation Training and Research who made major contributions to this document. Theresa Logan assisted with wordprocessing, and Damita Roberts helped with the construction of charts. Chanta Lee provided technical services on editing, setup and wordprocessing. Professor Carol Lewis assisted with the final review, editing and comments on the final draft. Also, funding for the initial tasks were provided by the Texas Department of Energy from the Texas Oil Overcharge Funds.

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ABSTRACT

The primary focus of this study was to emphasize transit system energy characteristics by examining the vehicle characteristics, right-of-way characteristics and the operational aspects of the services. The objectives of this study were to become familiar with types of energy expended by local transit systems, understand the characteristics and side effects of the energy types, become familiar with vehicle and right-of-way characteristics, analyze the operational aspects to the systems, and develop an energy consumption model to determine the variance in energy consumption. The project has several phases which, to some extent, may be performed concurrently including planning, instrument development and calibration, and data base development. The project also includes the creation of energy consumption models that can be used to predict the energy needs and consumption levels of transit systems. Independent variables were identified from other studies on energy consumption/conservation and selected urban transportation agencies were surveyed.

EXECUTIVE SUMMARY

Due to the increasing concerns about energy conservation, many public transit systems have taken measures to decrease their energy consumption. There have been many private organizations and federal government agencies implementing energy conservation measures, however, efforts at the local level, as related to public transportation, have been less evident and poorly coordinated. Continuous research was needed to evaluate transit system energy characteristics in order to identify fuel efficient solutions to local transportation problems.

The major purpose of this study was to analyze the energy consumption of selected transit systems. This study has provided information and insight into the energy consumption in Texas and discussion on how this consumption contributes to the total energy problem. The research objectives focus on (1) analyzing the type of energy characteristics expended by local transit systems, (2) identifying fuel efficient solutions to local transportation problems, and (3) developing a conceptual model or procedure, that can be utilized by public transit systems.

The basis of this research study was reliance upon a survey relating to energy conservation sent to several agency maintenance supervisors, planning supervisors, and driver training supervisors. A total of twenty (20) survey questionnaires were distributed to cities in Texas with a population of 50,000 or more. The targeted agencies were selected because of the diversity of their fleets, differing climatic conditions, and differences in population size and social economic structure of their clientele.

The data received from these agencies were analyzed and incorporated into a conceptual model that can be used by urban mass transit agencies to enhance the identification of fuel efficient solutions to local transportation problems. The analysis included an examination of each variable in a multivariate analysis to determine the independent impact of each of the variables on the energy consumption of the transit systems included in the study. To measure the quantitative attributes of the survey data a three-step analysis was used: Pearson Product-Moment Correlation Coefficients determining the magnitude and direction of relationship between energy conservation (dependent variable) and the factors influencing fuel efficiencies (independent variables) and between each independent variable, beta weights comparing the impact and relative importance of the independent variables on change in energy use, and the multiple regression, determining the relationship between energy consumption and the independent variables.

Some of the findings of this research study showed transit management improvements and driver's training programs which improve maintenance procedures can provide significant fuel savings. It is recommended that several guidelines for policy be formed to develop a strategy that improves maintenance of the entire vehicle, trains drivers in proper handling of the vehicle, and rewards achievement in safe driving.

Chapter 1

INTRODUCTION

Background

At the end of World War II, oil, for the most part, was relatively inexpensive. Since 1973, however, there has been almost a 600 percent increase in the price of petroleum. Additionally, there have been projections that the future cost of oil will increase another 200 percent by the year 2000 (Coyle, et. al., 1990).

The dwindling supply of petroleum and escalation in prices, coupled with the fact that the urban transportation sector has been a large consumer of petroleum, has prompted the federal government to promote energy conservation in the urban transportation sector by encouraging passenger traffic to shift to more fuel efficient modes (Talley, 1983; Coyle, et. al., 1990). The Congressional Budget Office (CBO) 1977 and 1979 has also publicized the results of several studies that demonstrated the potential savings of petroleum associated with different modes of urban transportation.

Transportation scholars have also analyzed the energy consumption of transportation systems. Such analyses include studies concerning energy use during peak hours (Boyce, et. al., 1978), the energy conservation potential of public transportation (Stunz and Hirst, 1975), and energy impacts of improved urban transit systems (Wagner, 1982). This scholarly interest and concern about energy consumption and urban transportation lends credence to the notion that energy is the key factor that has shaped, and will continue to shape, urban transportation movement and mobility. However, one of the most important factors determining unit energy consumption for transporting passengers along a given route is the vehicle occupancy (Vuchic, 1981). The automobile, which is one of the major contributors to highway and urban congestion, is also one of the least fuel efficient form of transportation on a per passenger basis (Coyle, et.

al., 1990). Increasing transit ridership is therefore extremely effective in reducing energy consumption and enhancing mobility. As a result, many urban policy motives have been to discourage automobile transportation while promoting alternative transit modes, modes that generally have a considerable lower consumption of energy per unit because of their high average occupancies. Buses and light-rail connector systems, for example, have received much attention from transportation planners at all levels of the transportation industry (Boyd, et. al., 1976; Smith, 1973).

In sum, the government has promoted petroleum energy conservation while placing particular emphasis on the transportation sector which accounts for over half of our petroleum energy consumption (Boyd, Asher, and Welzler, 1976). The emphasis of the government's promotional effort is primarily focused on four basic approaches: improving the energy efficiency of transportation vehicles, shifting passenger and freight traffic to more fuel efficient modes, developing alternative fuels and reducing travel through consolidation (Talley, 1983; Coyle, et. al., 1990).

In dealing with buses and light rail connector systems, important questions that need to be addressed by transit agencies pertain to the comparative energy efficiency of these transportation modes and models. Despite the inherent relative advantage transit systems have over the private automobile, they consume large quantities of energy. Transit agencies, therefore, must be concerned with achieving the maximum possible energy efficiency in their operations. In several countries, and particularly in the United States, the energy efficiency of public transportation systems was neglected throughout the 1950s and the 1960s (Vuchic, 1981). Hence, ways to enhance the energy efficiency of the existing systems either in the short term by changing operations, or over the long term by changing the rolling stock and design of the infrastructure may have been excluded from many urban transportation programs.

Research Objectives and Methodology

The purpose of this study is to analyze the energy consumption of selected Texas Transit Systems in an effort to identify fuel efficient solutions to local transportation problems. Although, there are a number of factors that influence energy consumption by a transit system, these factors can be classified into three general categories: vehicle characteristics, right-of way characteristics, and the operational aspects of the service (see Table 1). Even though the first two categories cannot be significantly changed in the short term, there is a need to examine them during this study. This study investigated these factors and developed a conceptual model that can be used by urban mass transit departments to identify fuel efficient solutions to local transportation problems.

The specific objectives of this research are to: (1) become familiar with the types of energy expended by local transit systems, (2) understand the characteristics of the energy types, (3) understand the side effects of using the identified type, (4) become familiar with vehicle and right-way characteristics, (5) analyze the operational aspects of the systems, and (6) develop an energy consumption model to determine the variance in energy consumption. In sum, this study consists of three phases. Phase I comprised planning, instrument development and calibration, and data collection. Phase II involved development of the data base. Phase III consisted of data analyses and the creation of energy consumption models that are used to predict the energy needs and consumption levels of transit systems.

Table 1

Factors That Influence the Energy Consumption of a Transit System

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Vehicle Characteristics of the Transit Systems

Vehicle Characteristic Types
- -propulsion
- -control
- -guidance system

Design Features
- -specific weight of the vehicle
- -seating/standing ratio
- -capacity
- -air conditioning
- -other

Dynamic Performance
- -acceleration rate
- -maximum speed
- -method of braking

Type of Motor Control and Transmission
- -fleet vehicles (speed governors)
- -vehicle transmissions (automatic or gear driven)
- -horse power of the engines

Right-of-Way Characteristics of the Transit Systems

Technological features
- -guidance and support
- -alignment
- -route profile and grades of the transit systems

Operational Aspects of the Transit Systems

- -scheduling characteristics (such as turn backs, dead heads, etc.)
- -traffic conditions for each for each mode (Those modes operating on surface streets with mixed traffic and those modes that are physically separated by curbs, barriers, etc., from other traffic, but with grade crossings for vehicles and pedestrians light-rail transit)
- -station spacings and stopping policy (demand or all-stop)
- -local, accelerated, or express service alternatives
- -operating characteristics for those modes with fully separated rights-of-way.

Statement of the Problem

Energy, which is of vital importance to our nation's economy, has been a subject of considerable interest since the Arab oil embargo of the 70's (Alberts, 1983; Barker, 1979; Colpitts, 1983; Erlbaum, 1977). The nation's major energy source is petroleum. However, petroleum resources are somewhat limited, and any significant increase in consumption will lead to a substantial depletion of resources by the early part of the next century. Some scholars have suggested that the United States' domestic production of petroleum might have reached its zenith in 1974 (Holdren in Murdoch, 1975). As a result, the government has promoted petroleum energy conservation, placing particular emphasis on the transportation sector, which accounts for over half of our consumption (Boyd, Asher, and Welzler, 1976).

As previously stated, this emphasis has focused for the most part, on four basic approaches: improving the energy efficiency of transportation vehicles, shifting passenger and freight traffic to more fuel efficient modes, developing alternative fuels, and reducing and consolidating travel (Talley, 1983). This latter approach can also be used for energy conservation measures utilized by mass transit systems. Carpooling, vanpooling, and other forms of transportation operating on the principle of passenger consolidation to alleviate congestion are also more energy efficient (Coyle, et. al., 1990).

Even though there have been many private organizations and federal government agencies implementing energy conservation measures, the efforts at the local level, as related to public transportation, have been less evident and poorly coordinated. Continuous research is needed to evaluate transit system energy characteristics in order to identify fuel efficient solutions to local transportation problems. The end could result in a solution which gives a more concise definition/evaluation of transit system energy characteristics, thus facilitating the possible alleviation of some transportation problems.

Chapter 2

REVIEW OF RELATED LITERATURE

This chapter provides a comprehensive review of the state-of-the art literature related to issues pertaining to energy. As such, an in-depth study of the analysis of energy conservation utilized by public transit systems is warranted. Because of the difficulties associated with finding a sufficiently broad range of empirical results, most investigators adopted the strategy of examining the issues and problems associated with energy consumption and/or utilization that have previously been explored by preceding scholars.

For convenience, this analysis will be discussed in two sections. The first section deals with the general concerns that affect urban areas in terms of urban travel and transportation requirements. The purpose for the division of the sections is to demonstrate the range of indicator measures utilized in each study and to identify the nature of the differences in modeling techniques among the studies. The second section provides an analysis of the factors influencing fuel efficiency in the transit system. It presents the serious issues that must be analyzed and assessed for the purpose of presenting future recommendations to assist in decisions concerning energy consumption and levels.

General

The transportation sector in the United States accounts for more than 25 percent of the nation's total energy consumption and approximately 53 percent of the total petroleum that is expended. Additionally, petroleum is the energy source of 96 percent of all U.S. transportation activities, with highway transportation accounting for more than 83 percent of the consumption (Talley, 1983).

Hee (1975) and Campbell (1980) indicated that a method for reducing fuel consumption by highway vehicles might lie in shifting traffic modes from energy intensive to energy efficient and by increasing the load factors of existing transportation systems. The reduction in trip distances should be an objective when reducing energy consumption. The need for this objective was confirmed by Keyes (1980) when he proposed that if a savings of 20% to 25% was achieved by transit users, higher total fuel savings could be achieved.

Peskin Lance (1977) elucidated some key policy issues regarding energy consumption in urban mass transportation by developing a mathematical model to simulate alternative proposed transportation energy conservation policies, exploring a broad range of policy changes concerning urban growth, developing/exploring transportation networks, analyzing the results in order to formulate practical guidelines when developing policies regarding transportation.

The objective of Kwang Sik Kim's study (1983) was to analyze the physical separation between residences and workplaces, the travel distances for urban passengers, and the role transportation energy consumption plays in urban mass transportation. This was approached by using a transportation simulation model, and testing a spatial statistics package, designing and simulating a number of experimental areas for travel measures, and by analyzing these measures to test the main hypothesis of the study.

The main hypothesis of Clark Wilson's study (1975) was to define what is called the "final" phase of an energy-consumption model. The energy-consumption model which was developed used the mean and variance of the trip length distribution as inputs and produced a measure of the energy required for journey-to-work travel. In general, energy intensiveness and average trip-lengths decline with increasing propensity to take short trips. That implies that urban area transit was important with respect to longer trips like home-to-work, which suggested that differences in the locations to home and work-places had the greatest effect on differences in total transportation energy intensiveness.

Dale Keyes (1980) indicated that the consumer has to adopt a variety of strategies - fewer trips, carpooling, mass transit, more fuel-efficient cars, change of place of residence, and change of place of employment. The average trip length of the journey to work was sensitive to the separation of jobs and homes, which suggested that the more compact urban areas were most energy efficient. On the other hand, there was a lack of the empirical evidence to justify this assumption and, in fact, the empirical studies were mixed (Keyes, 1980). Experiments indicated that an important factor in determining the length of trips to work was the similarity between population and employment distributions. To conserve energy, certain changes in urban areas were most desirable to balance population and employment distributions. The average commuting distance can be reduced if the new residents were located at central locations, where jobs were concentrated in the Central Business District (CBD). Once new employment was distributed evenly in an area of high population decentralization, the same result was achieved. Also, more energy-efficient modes were encouraged where there were either residential facilities or employment opportunities, and also in areas where there was the accessibility to and the availability of transit lines.

The model Keyes designed was to provide a test for the effect of gasoline consumption on urban patterns using the following variables: total metropolitan area population, proportion of the metropolitan area population living in high density census tracts (10,000 persons or more per square mile), variation in population density within the metropolitan area, and proportion of jobs in the metropolitan area located in the CBD. Data were taken from the Bureau of the Census and other sources. The model indicated a strong relationship between each of the variables and gasoline consumption, which induced an energy-efficient, small and compact city, with high-density neighborhoods and a relatively dense distribution of jobs and residences. The quantitative effect of urban development on energy consumption was calculated by considering a simultaneous shift in the magnitude of each development variable of one standard deviation. These estimates of Keyes' studies agreed with another empirical study conducted by the Urban Institute (Washington, D.C.) in which it was discovered that households in high-density neighborhoods near the urban core of small cities had the lowest auto travel miles, and those with low-density neighborhoods on the periphery of large urban areas had the highest. Energy conservation methods selected by an individual depended on his or her present economic status, pattern of travel, and the location of the individual's residence. Of these three, changing residential location yielded the highest transaction-cost benefits. The fuel-scarce city generally had small populations, which resulted from moving from suburban, low-density neighborhoods to high-density residential area closer to the CBD.

In conclusion, Keyes suggested that in the next decades development in the metropolitan fringe would continue, as well as a modest amount of central-city renewal. Furthermore, employment growth would occur in suburban areas, while employment levels in central cities would remain stable and the location of employment growth would play a major role in the distribution of residential development in the future.

Factors Influencing Fuel Efficiency

Although, there are a number of factors that influence the energy consumption of a transit system, they can be classified into three general categories: vehicle characteristics and maintenance strategies, right-of-way characteristics, and the operational aspects of the service (Department of Transportation, 1984; Vuchic, 1981). While the first two categories cannot be significantly changed in the short run, there is still a need to examine them during this study.

Vehicle Characteristics and Maintenance Strategies

Air-Streamlining. Studies have revealed that the type of propulsion, control, vehicle weight, seating/standing ratio, capacity, amenities such as air conditioning, acceleration rates, maximum speeds, braking methods, the use of speed governors, type of transmission and the horsepower of the engines all contributed to fuel consumption (Vuchic, 1981). Additionally, studies have shown that aerodynamically designed vehicles have higher miles per gallon (MPG) ratings than those whose design has not made use of air-streamlining concepts (Department of Transportation, 1984). For mass transit vehicles traveling along city streets at low speeds, air resistance is not a significant factor. But those vehicles traveling at higher speeds along the arteries on the outer fringes of the city will experience geometrical increases in air resistance. In fact, at speeds in excess of 60 MPH, air resistance is the single greatest factor impacting MPG (Department of Transportation, 1984). Thus, as transit systems provide more and more freeway and suburban service, efficient aerodynamic designs to overcome air resistance become more important. Specific design enhancements mentioned in studies include sloped windshields, rounded corners, and smooth vehicle sides (Department of Transportation, 1984). This study will evaluate the extent to which transit agencies consider these air-streamlining features when procuring fleet vehicles.

Temperature-sensitive fans. Another vehicle design feature that has received attention as a technique to enhance fuel efficiency is the temperature-sensitive fan. Engine fans require significant power ranging from 10 to 40 horsepower and, as a result, a significant amount of horsepower is diverted from bus propulsion. Therefore, conventional fans place two strains on fuel efficiency: more fuel to be powered and the need for a larger engine to turn both the fan and to propel the vehicle (Department of Transportation, 1984). Conversely, temperature sensitive fans are activated only when engine temperatures reach a certain level and function as needed to reduce engine temperature to acceptable levels. One study reported that truckers who switched to temperature sensitive fans not only saved fuel, but were also able to use smaller, more fuel-efficient engines Department of Transportation, 1984). As a result, fuel savings that averaged 5.5 percent were reported (Department of Transportation, 1984). Mass transit agencies, used the savings from the deployment of the fans to order more new buses with temperature sensitive fans. For example, if coaches ran the fans 50 percent of the time, fuel savings could range between 2 and 3 percent, or as much as $300 per coach per year. Additionally, the amount of noise pollution would also be reduced (Department of Transportation, 1984).

Turbo charged engines. Turbo charged engines also represent a major advancement for diesel engines. By propelling more air into the combustion process, ignition efficiency is increased and more horsepower is generated than with a conventional diesel engine of the same size. The environment also benefits from the use of turbo charged engines in that fuel is burned more cleanly resulting in less air pollution (Department of Transportation, 1984).

Vehicle weight. The amount of fuel that is needed to power a vehicle increases with the weight of the load. In fact, vehicle weight and occupancy weight are one of the biggest drains on the fuel efficiency of transit vehicles operating in intermittent traffic (Vuchic, 1981). Tests, for example, showed that a weight reduction of 1,000 pounds could improve MPG by 2 percent (Department of Transportation, 1981).

Air conditioning systems. As stated above, air conditioning is a major factor in fuel consumption. For example, studies estimate that the use of the air conditioning system will reduce fuel efficiency anywhere from .5 to 1 MPG (Department of Transportation, 1984). The use of air conditioners, however, is almost a necessity during the hot summer months in low attitude climates. Thus, the identification of alternative ways to cool bus interiors would be fitting. One alternative tested by several transit agencies is the use of evaporate cooling systems. The Denver RTD, for example, has retrofitted several of their coaches with a high powered ventilation unit and new evaporative cooling equipment, and as a result, has been able to reduce coach temperatures by as much as 25 degrees Fahrenheit and reduce the maintenance expense associated with air conditioning systems. Fuel savings to date, however, have not been determined (Department of Transportation, 1984).

Vehicle tune-ups. A well tuned vehicle engine burns fuel more efficiently, resulting in higher miles per gallon, a reduction in smoke emissions, and increased power for the vehicle. According to industry estimates, a well tuned vehicle engine can average up to 4 percent more MPGs than poorly tuned vehicle engine (Department of Transportation, 1984). Thus, an important part of an effective maintenance program is to have regularly scheduled engine tune-ups for the fleet; this includes regularly scheduled tune-ups that also pay attention to the idling speed of the vehicle. If a vehicle's idle speed is set too high, it will waste considerable amounts of fuel.

Tire pressure. Another important factor to consider and include as a part of routine maintenance is tire pressure. Friction between tires and the road surface can reduce the vehicle's MPG. The manufacturer's recommended tire pressure minimizes friction while optimizing MPG. Thus, underflated tires can cause a significant decline in fuel efficiency because the increased friction that occurs as tire pressure declines requires that the bus engine work harder to move the vehicle along the road; work that translates into decreased fuel efficiency and lower MPGs.

Air filters. It is common knowledge within maintenance circles that air filters prevent dirt particles from entering the engine while allowing air to enter and mix with the fuel. Thus, if an air filter is still in use after it is too dirty to allow sufficient air flow, fuel will be wasted. Some transit systems have used manometers to test whether the air filter is allowing sufficient air to enter cylinders--a necessity for the efficient burning of fuel. As a result, filters are regularly changed resulting in some fuel savings.

Engine rebuilding programs. Several transit systems have implemented aggressive engine rebuilding programs in an effort to improve fuel efficiency and increase the number of miles between breakdowns. Maintenance managers have reported that the average bus runs satisfactorily for 250,000 to 300,000 miles, after which performance significantly deteriorates, fuel efficiency declines, and maintenance problems escalate (Department of Transportation, 1984). To address these problems, several transit agencies have implemented major engine rebuilding programs that have resulted in dramatic improvements in vehicle performance and significant increases in coach MPG (Department of Transportation, 1984).

Fuel injectors. Fuel injectors eliminate the necessity for a carburetor by metering the flow of fuel into the engine and injecting it directly into the cylinder. Thus, an inappropriate sized fuel injector can waste fuel. For example, if the injector openings are too large, then the engine will be fed more fuel than it can handle efficiently while the vehicle is accelerating. On the other hand, openings that are too small will detract from the power of the vehicle and increase the time necessary to move out of the lower, less fuel efficient gears. However, the size of the injector is dependent upon the use of the coach. That is, highway service vehicles should be fitted with injectors having smaller openings while inner-city buses should be fitted with injectors having larger openings. The reason for this is that the inner city vehicles use the lower gears more and, thus, need more fuel to be injected while moving through the gears.

Radial tires. The Department of Transportation recommends using radial tires as a way to reduce the friction between tires and the road, and thus increasing fuel efficiency. However, because of their design, radial tires are structurally weaker than those on bias-ply tires. Vuchic (1981) suggests that as a result, radial tires may not have as much longevity on city streets because of the constant rubbing against city curbs.

Thermostats. Fuel burns more efficiently in warmer engines than in cold ones because oil moves more freely which provides less resistance and friction. Thus, the more complete combustion of fuel in a warmer engine means more BTU's from each gallon of fuel. Most transit agency vehicles are equipped with thermostats that activate at 170 or 180 degrees Fahrenheit. Some agencies, however, have experimented with thermostats that accept engine temperatures up to 190 degrees Fahrenheit before activating the cooling system. These high temperatures should improve vehicle MPG (Department of Transportation, 1984).

Throttle-delay valves. When a driver fully depresses the accelerator while pulling out of a stop, more fuel is supplied to the engine than it can handle. The result is wasted fuel and excessive exhaust smoke. To address these problems, most of the newer transit vehicles are equipped with a throttle-delay valve or some other device restricting the amount of fuel than can be injected into the engine during the first few seconds of acceleration. Thus, even if the accelerator is pushed to the floor, a corresponding amount of fuel will not be released. Some transit agencies in an effort to increase the power of a bus pulling out of a stop have disengaged the throttle delays that are a part of the newer vehicles. While there may be a very slight increase in the vehicle's power, there is also an increase in exhaust and wasted fuel. Thus, throttle-delay valves can enhance the fuel efficiency of transit fleets. In sum, there are several ways that public transit vehicles could be designed, equipped and maintained that would enhance fuel efficiency; air streamline designs, temperature sensitive fans, turbo charged engines, evaporative cooling systems, periodic engine tune-ups coupled with an aggressive engine rebuilding program, systematic tire pressure and air filter inspections, the use of appropriate sized fuel injectors, radial tires, and throttle-delay valves.

Right-of-Way Characteristics

Drivers who avoid unnecessary braking and accelerations will achieve enhanced fuel efficiency for their transit agencies. While much of this responsibility does rest with the vehicle operators, a transit system can also increase fleet MPG by implementing planning strategies that will increase average bus speeds. For example, exclusive bus lanes on highways and major arterial, bus only curb side lanes and one-way streets in the central business district, peak hour turning and curb side parking restrictions for automobiles in downtown areas, and bus activated traffic control systems are ways that a transit agency can make the operator's job easier (Department of Transportation, 1984). Additionally, each of these strategies provides multiple benefits including improved traffic flow for automobiles as well as for the transit fleet and savings in vehicle operating time as well as in fuel.

Operational Characteristics

Many energy conservation specialists assert that vehicle operators, through their driving practices, provide a source of fuel savings. Estimates of the potential fuel savings from energy efficient driving practices range as high as 20 percent (Department of Transportation, 1984). Therefore, transit systems should make fuel efficient driving one of the key components of their fuel conservation program. To be successful, however, such a program requires rigorous training, regular motivation, driver participation when establishing goals and objectives, personal incentives and recognition for conservation efforts by the drivers. Some factors that should be stressed during the training sessions include idling techniques, smooth starts and stops, defensive driving, adherence to posted speed limits, easing up on the gas pedal when traveling downhill, and turning off air conditioning systems when scaling steep hills.

Idling practices. Idling buses are major fuel wasters. Of course it is necessary to idle vehicles when they are first started in the morning, but three to five minutes is usually enough to build up pressure levels. But while idling, a coach gets zero miles per gallon and a coach will warm up faster if it is moving. Additionally, tires that are warmed are more pliable and thus provide less resistance to the road. However, tires can only be warmed up when in motion. Many drivers also believe they should idle engines during layovers to keep them warm, but tests show that an idling engine actually cools faster than one that has been turned off (Department of Transportation, 1984). As a rule, it also requires less fuel to restart an engine than it does to keep the engine running for one minute. Thus, drivers with lay overs in excess of three minutes should turn off their engines. In addition, transit agencies should implement procedures to curtail the unnecessary idling that occurs at many transit agency garages.

Smooth starts and stops. Operators who stop sharply and gun the engine when pulling out of a stop are costing a transit system money while wasting fuel. Smooth starts and stops will reduce brake wear while saving fuel money. When pulling out of a stop, drivers should accelerate briskly but steadily. Gunning the bus will waste fuel, as well as create hesitant or timid starts.

Defensive driving. While defensive driving is primarily seen as a safety measure, drivers who drive defensively can spot potential problems and improve fuel efficiency by eliminating the need to make sudden stops and acceleration. Because drivers can slow down in anticipation of potential problems, they can maintain steady speeds which contribute to better MPG (Department of Transportation, 1984).

Other Conservation Alternatives

Alternative fuels. Since the 1974 oil embargo, which was accompanied by substantial price increases, alternative sources of energy began to receive increased national attention (Moulton and Sefer, 1984). While a significant amount of research has been done on the production and use of alternative fuels, there are several problems that should be resolved before adopting them to be used in transit fleet vehicles (Booz, Allen & Hamilton, 1981). The resources most apt to be commercialized in the coming years are methanol and fuels derived from shale oil - including gaseous fuels, alcohols, vegetable oils, synthetic fuels and diesel blends (Moulton and Sefer, 1984). However, the use of diesel No. 2 over diesel No. 1 received much support during the eighties. Until recently most transit systems have opted to use Diesel No. 1 because it is lighter and has a cleaner cost. As a result many systems have converted to the No. 2 diesel which typically cost less. In addition to price savings, No. 2 diesel has a high BTU content per gallon, which exceeds the BTU of the No. 1 diesel by about 7 percent, thus changing from No. 1 to No. 2 increases MPG by 1 to 3 percent. The higher BTU content of No. 2 diesel may also make it possible to switch to smaller sized fuel injectors, as another fuel saving initiative (Department of Transportation, 1984).

Fueling practices. Although standard fuel nozzles contain an automatic shut off valve, some maintenance personnel bypass it completely because they consider the premature shutoff during fueling operations to be an inconvenience. However, because high pressure fuel hoses can pump up to 60 gallons of fuel per minute, tanks are often overfilled and fuel is spilled. As a result, one study estimated that transit vehicles could lose almost 38 gallons per year based on 300 fuelings per year (Department of Transportation, 1984). Thus, it would be more cost effective not to bypass shut off valves or to use drybreak nozzles which are intended to eliminate the premature shutoff problem.

Fleet segregation. Based on some of the fuel efficient innovations discussed previously, such as the use of radial tires and various injector sizes, it may be more cost effective for transit agencies to segregate their fleets by function. That is separating those that will be used consistently in highway service from those used in the inner city. Thus, one last factor to consider when evaluating the fuel conservation practices of transit agencies is the extent of fleet segregation by function.

Climatic conditions. Many transit agencies in areas that experience humid conditions, such as Houston, Texas, may not adopt several of the initiatives discussed. As a result many systems have converted to the No. 2 diesel which typically costs less. In addition to price savings, No. 2 diesel has a higher BTU content per gallon, which exceeds the BTU of the No. 1 diesel by about 7 percent, thus changing from No. 1 to No. 2 increases MPG by 1 to 3 percent. The higher BTU content of No. 2 diesel may also make it possible to switch to smaller sized fuel injectors, another fuel saving initiative (Department of Transportation, 1984).

Chapter 3

DESIGN OF THE STUDY

Statement of the Problem

Petroleum is the nation's major energy source. Our supply, however, is severely limited, with any significant increase in consumption leading to a substantial depletion of resources by the early part of the century. As previously stated in Chapter 2, some scholars have contended that domestic petroleum production has reached its zenith here in the U.S. in 1974 (Holdren in Mudoch, 1975). Thus, the government has promoted petroleum energy conservation, while placing particular emphasis on the transportation sector, which accounted for over half of total domestic fuel energy consumption. This emphasis has focused, for the most part, on four basic approaches: improving the energy efficiency of transportation vehicles, shifting passenger and freight traffic to more fuel efficient modes, developing alternative fuels, and reducing and consolidating travel (Talley, 1983). This latter approach can also be used to enhance mobility in the urban sector. Carpooling, vanpooling, and other forms of transportation operating on the principle of passenger consolidation to alleviate congestion, for example, are also more energy efficient (Coyle, et. al., 1990).

Organizations and agencies on the federal and local levels have initiated measures to address the need for energy conservation as related to public transportation. On the other hand, entities within transportation have omitted this environmental concern. Further research is needed to evaluate transit system energy characteristics in an effort to identify fuel efficient solutions to local transportation problems.

Research Objectives

This research study will analyze the energy consumption of selected transit systems. The primary focus emphasizes transit system energy characteristics, right-of-way characteristics and the operational aspects of the services. The objectives of this research are to:

1. Analyze the type of energy characteristics expended by local transit systems.
2. Identify fuel efficient solutions to local transportation problems.
3. Develop a conceptual model or procedure, that can be utilized by public transit systems.

Research Procedure

This research study was based on a survey relating to energy conservation sent to agency maintenance supervisors, planning supervisors, and driver training supervisors. There were twenty (20) survey questionnaires distributed to cities in Texas with a population of 50,000 or more. These agencies were selected because of the diversity of their fleets, differing climatic conditions, and differences in the population size and social economic structure of their clientele. Agency maintenance supervisors, planning supervisors, and driver training supervisors were administered by a questionnaire in an effort to obtain data pertinent to the variables discussed above. The survey questions were established based on the research study objectives. A copy of the questionnaire can be found in Appendix A.

The data developed from these agencies were analyzed and incorporated into a conceptual model that can be used by urban mass transit agencies to enhance the identification of fuel efficient solutions to local transportation problems. The analysis included an examination of each variable in a multivariate analysis to determine the independent impact of each of the variables on the energy consumption of the transit systems included in the study. This analysis included several steps. First, Pearson Product-Moment Correlation Coefficients were calculated to determine the magnitude and direction of relationship between the dependent and independent variables and between each independent variable. Second, beta weights were calculated to compare the impact and relative importance of the independent variables on change in energy use. Third, multiple regression was used to determine the amount of relationship between energy consumption and the independent variables.

At the onset of this study, three general hypothesis were formulated which were developed and tested during the study. The theories are as follows:

HO_1 There is a positive relationship between vehicle characteristics and fuel consumption

HO_2 There is a positive relationship between right-of-way characteristic and fuel consumption

HO_3 There is a positive relationship between operational characteristics and fuel consumption

In addition to the substantiation of several of the theoretical bases used to support the approach used in this study, the model used to determine the amount of variance in energy consumption was based upon changes in the various independent variables. Additionally, the model was used as a predictive tool to assist in decisions concerning energy consumption and levels. For the purpose of this study, the model that was used for a testing tool was as follows:

$$EC=VC_1+VC_2+...+VC_n+RW_1+RW_2+...RW_n+0_1\ 0_2+...+0_n$$

Where as:

EC	=	Energy Consumption
$VC_{1,2,n}$	=	Vehicle Characteristics
$RW_{1,2,n}$	=	Right-of-Way Characteristics
$0_{1,2,n}$	=	Operational Characteristics

CHAPTER 4

ANALYSIS AND INTERPRETATION OF THE DATA

GENERAL

The approaches used to achieve the goals and objectives involved an assessment of the state-of-the-art and a descriptive survey distributed to those Texas cities that have a population in excess of 50,000 people and a public transit system (see Table 2). The sample size consisted of twenty-two (22) transit agencies selected to participate in the survey. These agencies were selected from cities in Texas that are members of the American Public Transit Authority (APTA). Selection was based on the diversity of their fleets, differing climatic condition, and differences in the population size and socio-economic structure of their clientele. The survey contained questions pertaining to energy conservation measures utilized by urban public transit systems, the characteristics of the energy types used by agencies, the side effects of the energy types, the vehicle and right-of-way characteristics of the transit systems, and the operational characteristics of the systems. Twenty-two (22) survey questionnaires were distributed to agency maintenance supervisors, planning supervisors, and driver training supervisors. A total of twelve (12) surveys were completed and returned according to their respective categories. The response rate was fifty-four point five percent (54.5 %), somewhat lower than expected. The surveys are divided into six sections, including vehicle improvements, maintenance and equipment strategies, operations strategies, right-of-way characteristics, other strategies and a comparative analysis of each city in Texas which are all factors that influence the energy consumption of a transit system. Chart 1 in the Appendix B illustrates the percentage distribution of public transit systems using vehicle improvements. Chart 2 outlines the maintenance and equipment strategies of a public transit system. Chart 3 and 4 suggest operations strategies that public transit systems could express in the reduction of fuel efficiency.

Chart 5 identifies the right-of-way characteristics scenario prior to improving savings in vehicle operating time in consuming fuel. In Appendix B, Charts 6 and 7 reveal the strategic location used by the respondents to reduce fuel.

Table 2

CITIES OF TEXAS
N=12

CITIES	POPULATION	FLEET
Austin	604,621	177
Corpus Christi	280,000	68
Dallas	1,300,000	652
El Paso	600,000	122
Fort Worth	500,000	148
Houston	4,000,000	1,028
Laredo	120,000	31
Lubbock	180,000	37
McAllen	661,370	40
Port Arthur	63,200	10
San Antonio	1,055,000	531
Waco	125,000	15

The examination of the factors that influences energy consumption will be discussed interchangeably from the perspective of correlation matrices analysis. These factors are complex ways to reduce fuel consumption in transit agencies revenue fleets, where as, some are complex and require time to implement, and others may require a decision/simple changes. Using the energy consumption model as instrumented can save a large amount of money, at the time, reduce tremendous amount of fuel in the public transit systems. In Appendix C, Tables 11, 12, 13, 14, and 15 show the analysis of the relationship between the factors and energy consumption. The correlation coefficients measured the relationship between the dependent (which are the factors influence energy consumption) and independent (energy consumption) variables. The above tables reveal a moderate positive association between the complex ways (dependent variables such as vehicle improvements and maintenance/equipment strategies) and energy consumption (independent variables) which has an average score of .30 -.49. The right-of-way characteristics, operation strategies and other strategies are factors that need only a decision to be made or some simple changes to take place resulting a substantial positive association (average between .50 - .69 factor).

Beta weights were use to determine the relative importance of the factors influencing energy consumption. The actual magnitude of the coefficients depend on the units in which the variables were measured. It was important to make regression coefficients somewhat more comparable for this research.

Multiple regression determines the importance of each variable towards energy consumption (whether vehicle improvements are more important in energy consumption versus right-of-way characteristics). According to the significant factors analysis below, the result shows a very strong positive association between right-of-way characteristics and vehicle improvements to energy consumption.

Significant Factors Analysis

Vehicle Improvements	.11
Maintenance and Equipment Strategies	.02
Operations Strategies	.00
Right-of-Way Characteristic	.74
Other Strategies	.51

An abbreviated discussion of the major findings of each outlined factor that influences the energy consumption effort is described in the remainder of this chapter. Specific recommendation guidelines for policy will be included in Chapter 5 found in the next chapter of this study. Priorities were based on both the vehicle and driver needs.

Major Findings

Vehicle Improvements

According to survey results in Table 3, sixty-six point seven percent (66.7%) of the respondents revealed that they believed that the use of air-streamling has lower miles per gallon (MPG) ratings. The uses of sloped windshields, rounded corners, and smooth vehicle sides have been shown to be more important in overcoming air resistance which is one of the single greatest factors impacting miles per gallon in the transit systems. Temperature-sensitive fans were consistently used among the transit agencies vehicles as a design feature to enhance fuel efficiency since the fans are activated only when the engine temperatures reach a certain level and function as needed to reduce engine temperature to acceptable levels. Turbo charged engines represent a major upgrade from diesel engines-not only in saving fuel but in consideration for the environment (less air pollution).

In the reducing of the vehicle weight, responses showed that the respondents did not feel it was a significant factor in fuel efficiency, despite the fact that the amount of fuel that is needed to power a vehicle increases with the weight of the load. One of the biggest drains on the fuel efficiency of transit vehicles operating in stop and go traffic is based upon the vehicle weight and occupancy weight. The reduction of the vehicle weight could improve MPG percentage.

According to the respondents, evaporative-cooling technology is a major factor in decreasing fuel consumption, depending on serveral factors: diversity of the fleets, differing climatic conditions, differences in the population size, and differences in the socio-economic structure of the clientele. The results showed that the use of the air conditioning system will reduce fuel efficiency.

Table 3

Vehicle Improvements
N=12

Category	%	Austin	Corpus Christi	Dallas	El Paso	Fort Worth	Houston	Laredo	McAllen	Port Arthur	San Antonio	Waco
Air-Streamlining	83.3	--	•	•	•	--	--	•	--	•	•	•
Sloped windshields	50.0	--	•	•	•	--	--	--	--	--	•	•
Rounded corners	66.7	--	•	•	•	--	--	--	--	--	•	•
Smooth vehicle sides	83.3	•	•	•	•	--	•	--	--	•	•	•
Temperature-sensitive fans	75.0	--	•	•	•	•	•	•	--	--	•	•
Turbocharged engines	75.0	•	•	•	•	•	•	•	--	•	•	•
Reduced vehicle weight	8.3	•	•	•	•	•	•	•	•	•	•	•
Evaporative-cooling technology	33.3	•	--	•	--	•	--	--	--	--	--	•

Legend:

- • = Yes
- -- = No

Maintenance and Equipment Strategies

The responses indicated that the vehicles scheduled for regular tune-ups burn fuel more efficiently, thus resulting in higher miles per gallon. Because of a reduction in smoke emissions, power is increased for the vehicle. One hundred percent (100%) of the respondents stated they have a tune-up scheduled regularly either by a mileage based tune-up or a performance based tune-up. Daily tire-pressure checks and maintenance responses were highly positive and proved to be a significant factor in reducing friction between tires and the road surface and, consequently, lowering the vehicle miles per gallon. Manometer air filter checks and scheduled engine rebuilds showed a sixty-six point seven percent (66.7%) effective score from the transit agencies. The respondents percentage for the fuel injectors were very low. Radial tires had a fifty percent (50%) score of respondents who felt they were a significant factor increasing fuel efficiency, even though they may not have as much longevity on city streets because of the constant rubbing against city curbs. High-temperature thermostats, high-pressure radiator caps, throttle delays and speed governors rated above the fifty percent (50%) percentile score by the agencies on responses of being a significant factor which would enhance fuel efficiency (see Table 4).

Operations Strategies

Table 5 highlights the distribution of responses relevant to the implementation of initial driver's training, periodic driver's training and driver's incentive awards for safe driving.

Table 6 shows a breakdown of the alternative fuels perceived to be most likely to decrease fuel efficiency by respondents. As indicated in Table 6, liquid petroleum gas has a very low percentage response of being the choice of fuel mostly used in the transit systems. Over 83 percent of the public transit systems responding to the survey indicated that they were experimenting with alternative fuels.

Table 4

Maintenance and Equipment Strategies N=12

Category	%	Austin	Corpus Christi	Dallas	El Paso	Fort Worth	Houston	Laredo	Lubbock	McAllen	Port Arthur	San Antonio	Waco
Regularly scheduled tune-up program mileage based tune-up performance based tune-up	100	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Daily tire-pressure checks and maintenance	83.3	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y
Manometer air-filter checks	66.7	Y	Y	Y	N	Y	Y	Y	N	N	N	Y	Y
Scheduled engine rebuilds	66.7	Y	Y	Y	N	Y	Y	Y	N	N	N	Y	Y
Fuel injectors based on vehicle routing	25.0	N	N	N	N	Y	Y	Y	N	N	N	N	N
Radial tires	50.0	N	Y	Y	N	Y	Y	N	N	Y	Y	N	N
Higher-temperature thermostats	58.3	Y	Y	Y	Y	N	N	Y	N	Y	N	Y	N
High-pressure radiator caps	58.3	N	Y	Y	Y	N	Y	N	N	Y	Y	N	Y
Throttle delays	83.3	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y	Y
Speed governors	66.7	Y	N	N	Y	N	Y	Y	Y	N	Y	Y	Y

Legend:

Y = Yes
N = No

Table 5

Operations Strategies - 1
N=12

Category	%	Austin	Corpus Christi	Dallas	El Paso	Fort Worth	Houston	Laredo	Lubbock	McAllen	Port Arthur	San Antonio	Waco
Initial driver's training Reduced idling during lay overs and at garages Smooth starts and stops Defensive driving Adherence to speed limit Downhill crossing Turning air conditioning off on uphill grades	100	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Periodic driver's training Reduced idling during lay overs and at garages Smooth starts and stops Defensive driving Adherence to speed limits Downhill crossing Turning air conditioning off on uphill grades	100	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Driver incentive awards for safe driving	83.3	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y

Legend:

Y = Yes
N = No

Table 6

Operations Strategies - 2
N=12

Category	%	Austin	Corpus Christi	Dallas	El Paso	Fort Worth	Houston	Laredo	Lubbock	McAllen	Port Arthur	San Antonio	Waco
Alternative Fuel	83.3	Y	Y	N	Y	Y	Y	Y	N	Y	Y	Y	Y
Liquid Petroleum	16.7	Y	N	N	N	N	N	N	N	N	N	Y	N
Diesel #1	50.0	Y	N	N	N	Y	N	Y	N	Y	Y	N	Y
Diesel #2	25.0	N	N	N	Y	N	Y	N	N	N	Y	N	N
Other	33.3	Y	Y	N	N	Y	Y	N	N	N	N	N	N
Automatic Shut-off valves	66.7	Y	Y	Y	N	Y	Y	Y	N	N	N	Y	Y
Drybreak nozzles	33.3	N	N	Y	Y	Y	N	N	N	N	N	N	N

Legend:

Y=Yes
N=No

Right-of-Way Characteristics

Table 7, shows an average of fifty percent (50%) or more of the surveyed respondents identifying express service, traffic signal coordination and modernization, special parking restrictions and right turn on red as ways that the tranist agency can make the operator's job easier. They can improve the traffic flow for automobiles transit fleets and improve savings in vehicle operating time fuel consumption. Reversible lanes category had a 16.7% unfavorable response as preferred factor in helping reduce fuel.

Table 7
Right-of-Way Characteristics
N=12

Category	%	Austin	Corpus Christi	Dallas	El Paso	Fort Worth	Houston	Laredo	Lubbock	McAllen	Port Arthur	San Antonio	Waco
Bus only lanes	33.3	N	N	Y	N	Y	Y	N	N	N	N	Y	N
Express service	41.7	Y	N	Y	Y	Y	N	N	N	N	N	Y	N
Traffic signal coordination and modernization	50.0	Y	N	Y	Y	Y	N	N	N	N	Y	Y	N
Special parking restrictions	66.7	Y	Y	Y	Y	N	N	N	Y	N	Y	Y	Y
One-way streets	33.3	Y	N	N	Y	N	N	N	Y	N	N	N	Y
Reversible lanes	16.7	N	N	N	Y	N	Y	N	N	N	N	N	N
Right turn on red	75.0	Y	Y	Y	Y	N	Y	N	Y	N	Y	Y	Y
Traffic channelization	25.0	Y	N	N	N	N	Y	N	N	N	Y	N	N

Legend:

Y = Yes
N = No

Other Strategies

Table 8 and 9 show other strategies and/or methods used by respondents to reduce fuel consumption. The study revealed that the strategic location of air hose and pressure guages throughout the garages had responses of seventy-five percent (75%). Also, it shows an eight point three percent (8.3%) favorability response.

Table 8
Other Strategies
N=12

Category	%	Austin	Corpus Christi	Dallas	El Paso	Fort Worth	Houston	Laredo	Lubbock	McAllen	Port Arthur	San Antonio	Waco
Segregated fleet by type of service	83.3	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y
Active participation of drivers and maintenance in consumption efficiency programs	41.7	N	Y	Y	N	N	Y	N	N	N	Y	N	Y
Strategic location of air hose and pressure guages throughout the garages	75.0	Y	Y	Y	Y	N	Y	Y	N	N	Y	Y	Y
Posting of fuel efficiency goals and objectives	8.3	N	N	N	N	N	N	N	Y	N	N	N	N

Legend:

Y = Yes
N = No

Table 9

A Matrix of Other Energy Conservation
Strategies Used by Public Transit Systems N=12

Category	%	Austin	Corpus Christi	Dallas	El Paso	Fort Worth	Houston	Laredo	Lubbock	McAllen	Port Arthur	San Antonio	Waco
Air conditioning	100	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Automatic transmission	100	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Tire maintenance contract	83.3	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y

Legend:

Y = Yes
N = No

Comparative Analysis of Public Transit Systems in Texas

A comparative analysis of public transit systems throughout the State of Texas is shown in Table 10. This table indicates that McAllen, Texas, has the lowest average vehicle capacity score of 20, whereas Lubbock, Texas (60) ranks the highest. The number of trips per day in Houston (8,358) ranks highest over all the other cities in Texas. Number of miles per day or per month demonstrates the travel pattern in the different public transit systems' fleets. Average miles per gallon per vehicle shows a mode of 4.5 among the cities in Texas. The most popular fuel injector size used in the transit agencies systems is the 7E60. The average engine size used is 6V92. Average vehicle weight ranged from 4,200 pounds to 39,500 pounds. The fuel consumption average shows the amount of fuel used by the transit agencies for per vehicles/passengers. The fleet size indicated the amount of vehicles used by the public transit systems. Each day the amount of fuel consumed for each passenger is an average of .6 gallons or more.

Table 10
Comparative Analysis of Public Transit Systems in Texas N=12

CITIES	Averge Vehicle Capacity	# of Trips da/mo	# of Miles da/mo	Average MPG per vehicle/pounds	Fuel Injector Size	Average Engine Size	Average Vehicle Weight pounds	Fuel Consumption average gallons da/mo	Fleet Size	Fuel Consumption per vehicle gallons da/mo	Fuel Consumption per passenger gallons da/mo
		(1.)	(2.)	(3.)				(4.)	(5.)		(6.)
Austin	35	1,644 50,000	19.552 594,696	3.5	9F70	6V92	20,000	6,152.9 187,151	177	35/1,057	1/30
Corpus Christi	36	583 17,732.9	6.575 200.000	4.4	9G60	6V92	32,000	1,518.9 46,200	68	22/679	.6/18.9
Dallas	46	6,795 206,681.3	75,686.6 2,302,134	3.25	9H85 7G65 9G75 7E760N	565 Cubic Inches	27,000	18,904.1 575,000	652	29/882	.6/19
El Paso	41	826 25,124.2	14,425 438,760.4	3.7	7E60	8V71	36,000	3,945.2 120,000	122	32.3/983.6	.8/24
Fort Worth	41	1,374 41,792.5	15,618 475,047.5	4.03	C-60	692 Diesel	30,000	3,879.5 118,000	148	26/797	.6/19.4
Houston	45	8,358 254,222.5	134,510 4,091,345	3.25	7G65 9T70 9F80 7G75	6V92	26,000	29,753.4 905,000	1,028	28.9/880	.6/19.5
Laredo	41	547 16,637.9	2,850 86,687.5	3.0	7G70	6V92	39,500	947.2 28,812	31	30.6/929.4	.7/22.7
Lubbock	60	267 8,121.3	3,000 91,250	3.7	7E60	6V71	36,000	920.5 28,000	37	25/756.7	.4/12.6
McAllen	20	461.9 14,049.5	1,992 60,414	3.2	7G65	6V92	4,200	65.8 2,000	40	1.6/50	.1/2.5
Port Arthur	25	60 1,825	1,097 33,367.08	6.8	7G65 5A50	6V92T 6V53T	23,000	161.1 4,900	10	16/490	.1/21
San Antonio	39	5,700 173,375	59,215.46 1,801,153	3.78	7E60	6V71	24,680	13,150.7 40,000	531	24.7/753	.6/19.3
Waco	31	129 3,923.8	1,173 35,679	4.8	C-50	6V53	35,000	243.3 7,400	15	16.2/493	.5/15.9

LEGEND

(1) # of Trips = (days x 365/12 = month; months; months x 12/365 = days;
(2) # of Miles = (days = months x 12/365;months = days x 365/12;
(3) Average MPG Per Vehicle = # of miles x 365/12/monthly fuel consumption average
(4) Fuel Consumption Average = (daily) = monthly fuel total x 12/365;
(5) Fuel Consumption Per Vehicle = fuel consumption average/diesel size;
(6) Fuel Consumption Per Passenger = fuel consumption per vehicle/ average vehicle weight.

Summary of Findings

The public transit agencies are becoming increasingly aware of the need to conserve energy. This section of the report provided an analysis of the public transit systems' fleets in the State of Texas because of the population size and the fleet size of the operation. The results of the tables show that transit management improvements such as improving maintenance procedures can provide significant fuel savings. The load factor, and fuel injector size also play a large part in fuel efficiency. Clearly, maintenance upkeep that directly affects the transit system is much more effective in saving energy than is the right-of-way characteristics designed to shift the vehicles to energy-efficient alternatives.

Chapter 5

SUMMARY OF IMPLICATIONS AND RECOMMENDATION

The results of this research study are based on the collection of data from a survey of agency maintenance supervisors, planning supervisors, and driver training supervisors. An analysis of the results indicated that most of the participants in the survey gave very positive responses to maintenance upkeep of the vehicles and driver training programs. Both areas mentioned above are very crucial in saving fuel in the public transit systems. Fleet owners and operators have always been careful in controlling fuel, but now more than ever they must tighten their belts. Marginal operators are headed for trouble, but if action is taken to save fuel, well-managed fleets can continue to be profitable. Therefore, it is safe to say that the combination of the vehicle characteristics plus the right-of-way characteristics and the operational aspects of the services will give transit agencies their reduction in energy consumption.

Policy Implications and Recommendation Guidelines

There are several things fleet operators can do to reduce the amount of fuel consumed and to cut the cost and generally thereby reducing operating costs. The results of this study suggest several guidelines for policy. Suggestions include the need to improve maintenance of the entire vehicle, train drivers in proper handling of the vehicle, and reward achievement in safe driving.

Improve Maintenance

Transit agencies should use the equipment manufacturer's recommendation to tune engines for economy, concentrating on such things as fuel system adjustments and timing. Regularly, the air, oil, and fuel filters should be changed because restricted air cleaners increase fuel consumption and decrease engine efficiency. Any engine fault that adversely effects fuel combustion also has an adverse effect on fuel consumption. The condition of the engine can decrease fuel consumption if the engine is well maintained.

An engine diagnostic equipment machine can provide a quick check of engine operating efficiency. When it is used regularly at lube and oil changes for a period of time, it can point out engines which need either shorter or longer tune-up intervals for optimum efficiency. A rigid tune-up schedule, without regard for variables like the driver, operating conditions, and individual engine differences can be very wasteful both in over- and under-maintenance. Careful attention to the trend in fuel mileage can also serve as an alert for a vehicle tune-up.

With the assistance of a lubricant supplier, consideration should be given to adjusting oil drain intervals to account for both manufacturer's recommendations and actual operating conditions. Both oil and labor are saved when drain intervals are optimized. Also there should be a review of the types of engine oil stocked and some consideration made to the savings possible by changing to an oil suitable for mixed fleet service.

Besides the engine tune-ups, there are other factors that should be taken into consideration. Underinflated tires increase rolling resistance and waste fuel, in addition to reducing tire life. Fuel and oil leaks, even small ones, can be costly if allowed to continue without correction. Poorly adjusted brakes, and wheels which are out of alignment also contribute to higher fuel consumption and operating costs. Dirty air cleaners and automatic chokes which do not shut off completely, both waste fuel. Also, faulty diesel injectors can shorten engine life and increase fuel consumption.

Train and Reward Drivers

Some fleet operators tend to forget that drivers are people before they are drivers. Drivers who are trained to do a better job and are rewarded when they do it, can save huge amounts of money for their fleets. They will care more about their jobs if they know management cares about them. Training clinic are on a way for management to show they care.

If operating and maintenance costs for the vehicles assigned to the driver begin to get out of hand, and no mechanical cause is apparent, the driver can expect to be called in for a refresher course.

Drivers should not only be encouraged to report mechanical problems with their vehicles, they should see that management cares enough to take action and correct the problems. The ways drivers can save fuel are as follows:

(1) Ratio factors such as weight, frontal area and drag can be adjusted by observing the speed limit depending on vehicle configuration.

(2) Avoid fast acceleration and hard braking. Maintain a steady setting for maximum economy. Smooth driving is the essence of a professional operator.

(3) Do not idle the engine at route stops. No fuel is used if an engine is not running.

(4) Shift gears at the proper engine speed. Rejuvenating beyond the shift point and lugging the engine are both wasteful and can shorten engine life.

(5) Forecast conditions ahead and begin to react sooner. For instance, fuel can be saved if the driver slows down enough when approaching a red light. This will allow the light to change before the driver reaches the intersection. A single down-shift to pick up speed saves both time and fuel compared to a dead stop an shifting up through the gears.

Finally, it seems quite certain that fleets will experience problems of fuel and lubricant availability in the public transit systems. However, it is good business to improve maintenance procedures, train and sensitize drivers about the need for future fuel efficiency requirements.

APPENDICES

Appendix A

Questionnaire

QUESTIONNAIRE

CTTR is conducting an independent research in conjunction with the Center for Transportation Training and Research Department at Texas Southern University concerning energy conservation models currently in use. Please, spend a few minutes to answer the following questions. Thank you for your cooperation.

Please circle **ANY** of the following strategies (measures) that your agency or organization has implemented as part of a transit fleet energy-saving effort.

A. Vehicle Improvements: Please circle all that apply to your department.

1. Air-streamlining
    a. Sloped windshields
    b. Rounded corners
    c. Smooth vehicle sides
    d. Other (Please specify)
2. Temperature-sensitive fans
3. Turbocharged engines
4. Reduced vehicle weight
5. Evaporative-cooling technology

B. Maintenance and Equipment Strategies: (Circle all responses that apply

1. Regularly scheduled tune-up program (If yes, is your program:)

    Please circle one.
    a. Mileage based
    b. Performance based
2. Daily tire-pressure checks and maintenance
3. Manometer air-filter checks

4. Scheduled engine rebuilds. If yes, at what point do you consider rebuilding engines.
5. Fuel injectors based on vehicle routing (i.e., highway and inner-city routes).
6. Radial tires
7. Higher-temperature thermostats (i.e., those that activate at 190 degrees).
8. High-pressure radiator caps
9. Throttle delays
10. Speed governors

C. Operations Strategies: (Please circle all that apply.)

1. Initial driver's training
    a. Reduced idling during lay over and at garages
    b. Smooth starts and stops
    c. Defensive driving
    d. Adherence to speed limits
    e. Downhill coasting
    f. Turning air conditioning off on uphill grades
2. Periodic driver's training. (Please circle all that apply)
    a. Reduced idling during lay overs and at garages
    b. Smooth starts and stops
    c. Defensive driving
    d. Adherence to speed limits
    e. Downhill coasting
    f. Turning air conditioning off on uphill grades.
3. Driver incentive awards for safe driving? (Please circle if apply)
4. Alternative fuel. (Please circle if apply)
    a. Liquid Petroleum. Cetane Rating

b. Diesel #1. Cetane Rating

c. Diesel #2. Cetane Rating

d. Other Cetane Rating

5. Automatic shutoff valves.

6. Daybreak nozzles

D. Right-of-way Characteristics: (Please circle all that apply)

1. Bus only lanes
2. Express service
3. Traffic signal coordination and modernization
4. Special parking restrictions
5. One-way streets
6. Reversible lanes
7. Right turn on red
8. Traffic channelization
9. Other

E. Other Strategies: (Please circle all that apply)

1. Segregated fleet by type of service
2. Active participation of drivers and maintenance in consumption efficiency programs
3. Strategic location of air hoses and pressure gauges throughout the garages
4. Posting of fuel efficiency goals and objectives
5. Other

Please circle, that which pertains to your agency or organization:

a. Air conditioning

b. Automatic transmission

c. Tire maintenance contract

Please circle, those which pertain to your agency or organization:

a. Averse vehicle capacity

b. Number of trips per day

c. Number of miles per day

d. Average MPG per vehicle mile

e. Fuel injector size

f. Average engine size

g. Average vehicle weight

h. Monthly fuel consumption

i. Fleet size

Please comment on any factors that you consider to be important in a public transit fuel consumption program.

Appendix B

Percent Distribution of Public Transit Systems

Chart 1

Percent Distribution of Public Transit Systems Using Vehicle Improvements N-12

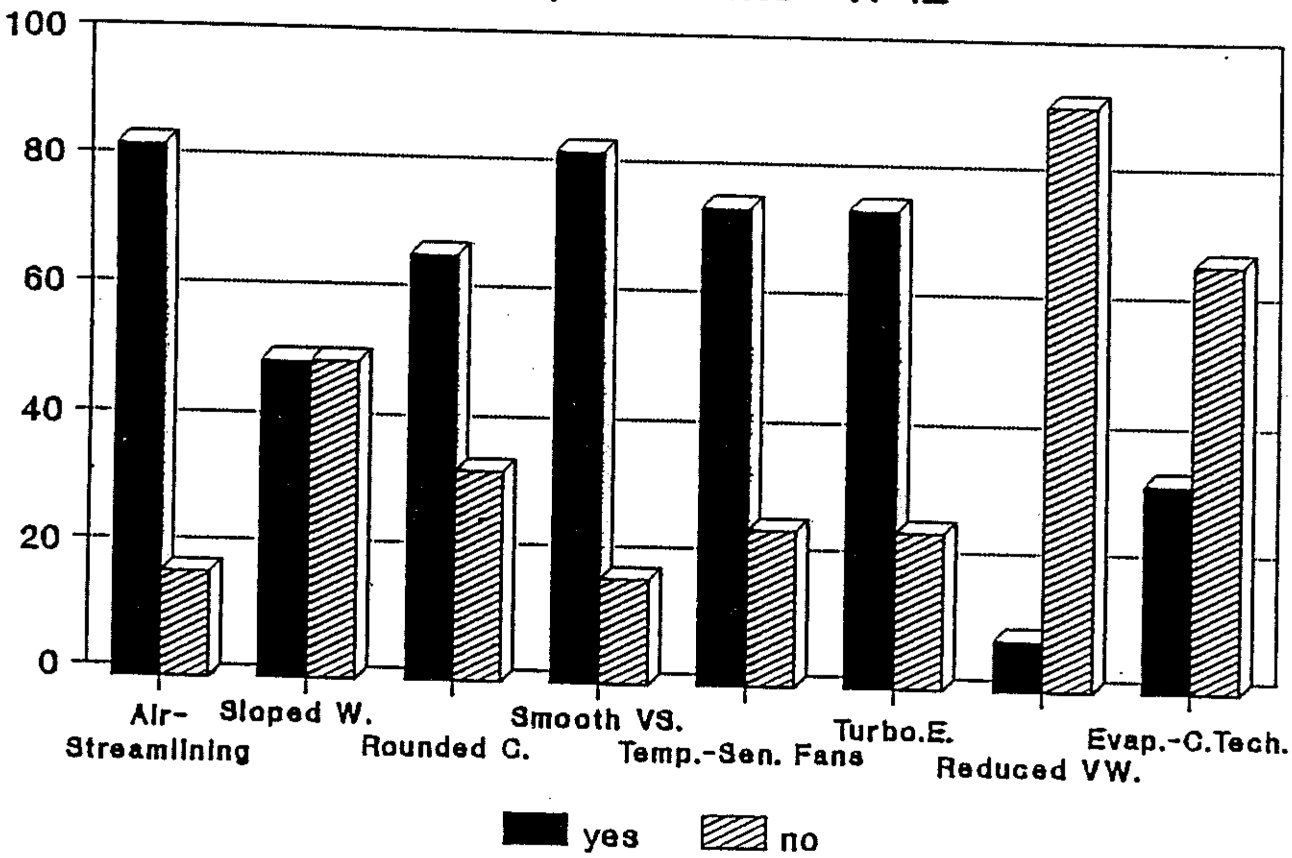


Chart 2

Percent Distribution of Public Transit Systems Using Maintenance and Equipment Strategies N=12

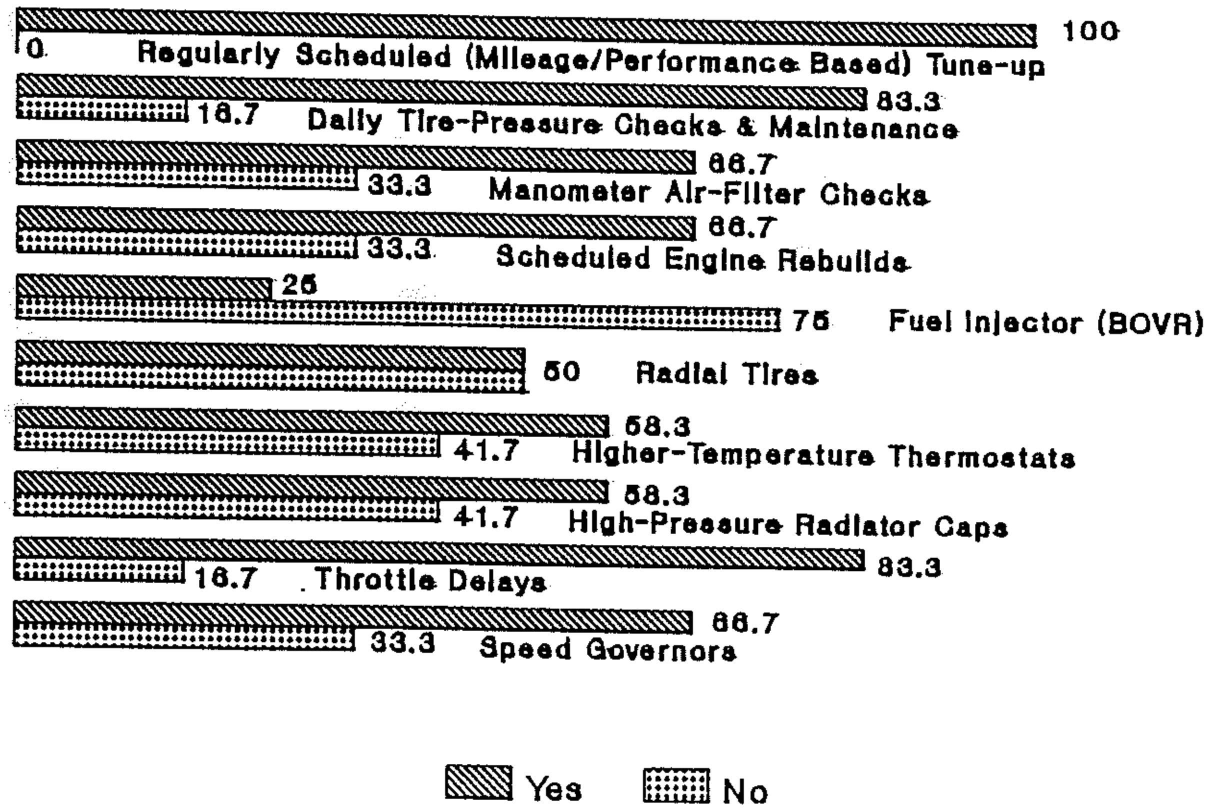
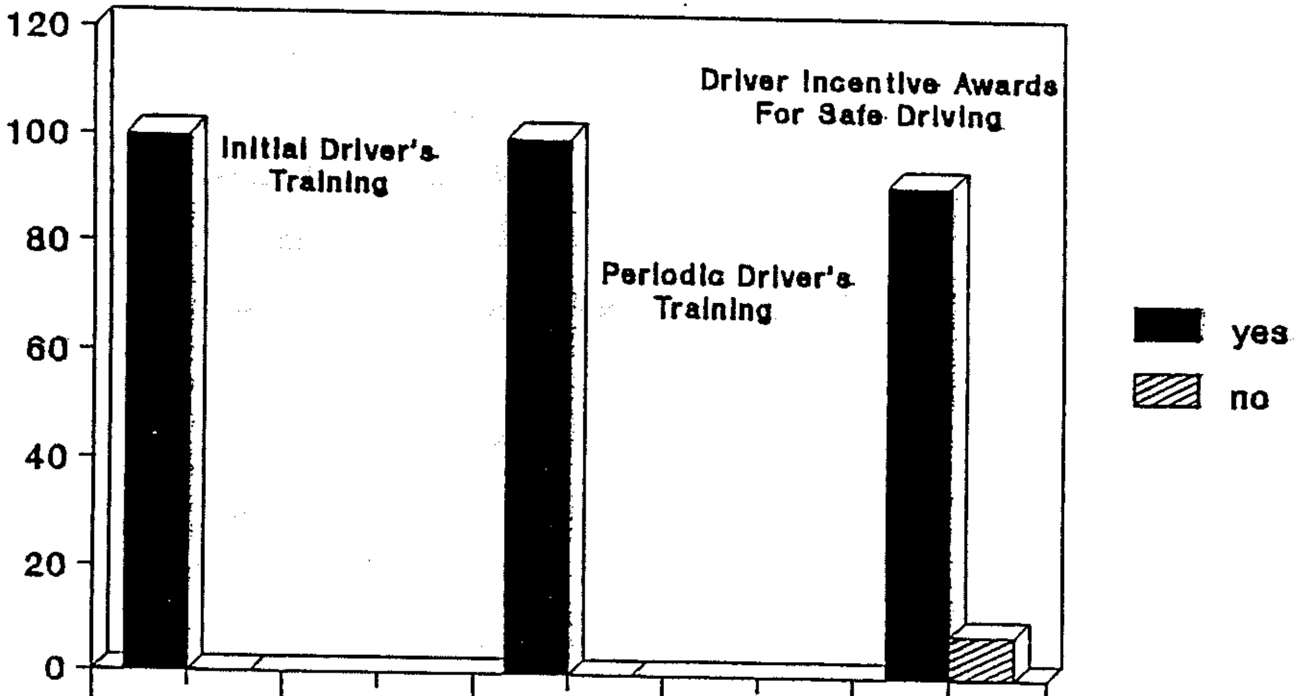


Chart 3

Percent Distribution of Public Transit Systems Using Operations Strategies N=12



yes	100		100		91.7
no	0		0		8.3

Chart 4

Percent Distribution of Public Transit Systems Using Operations Strategies N=12

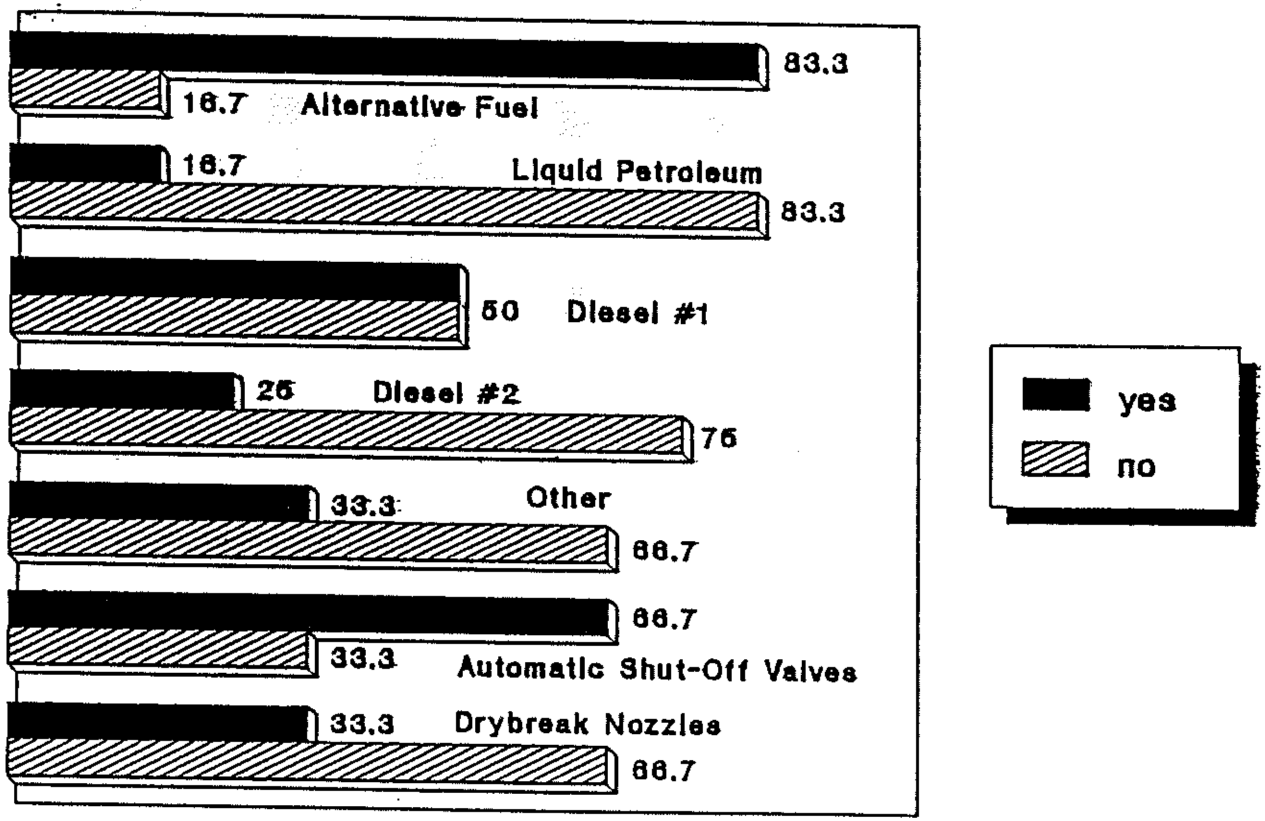


Chart 5

Percent Distribution of Public Transit Systems Using Right-of-Way Characteristics N=12

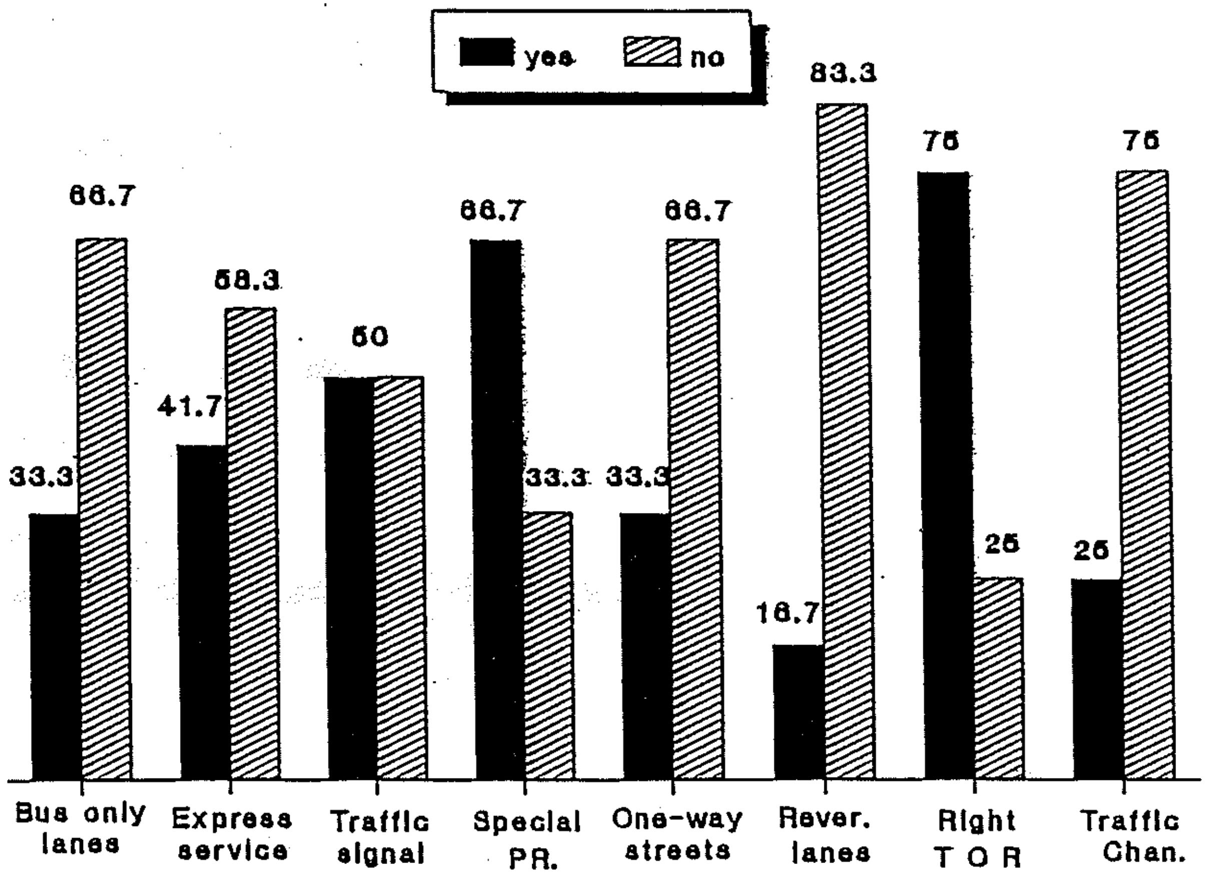


Chart 6

Percent Distribution of Public Transit Systems Using Other Strategies N=12

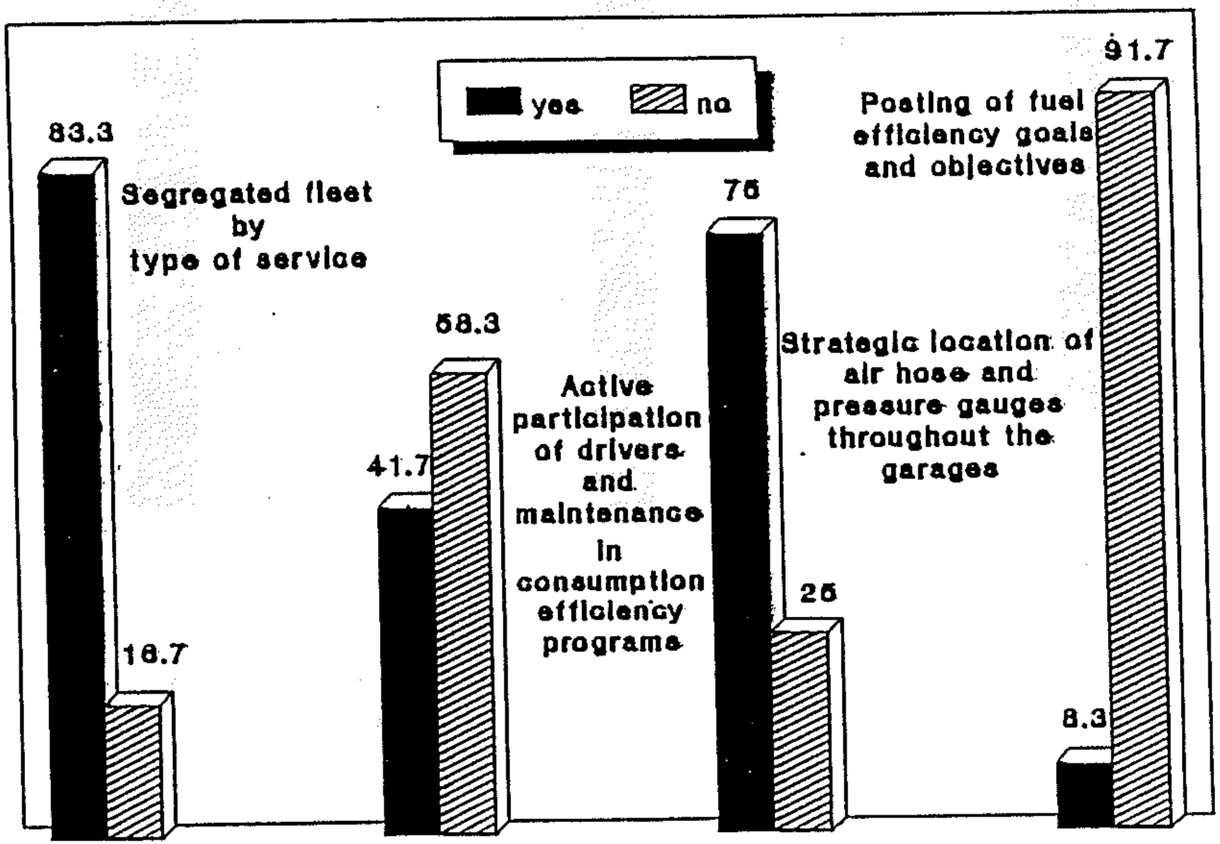
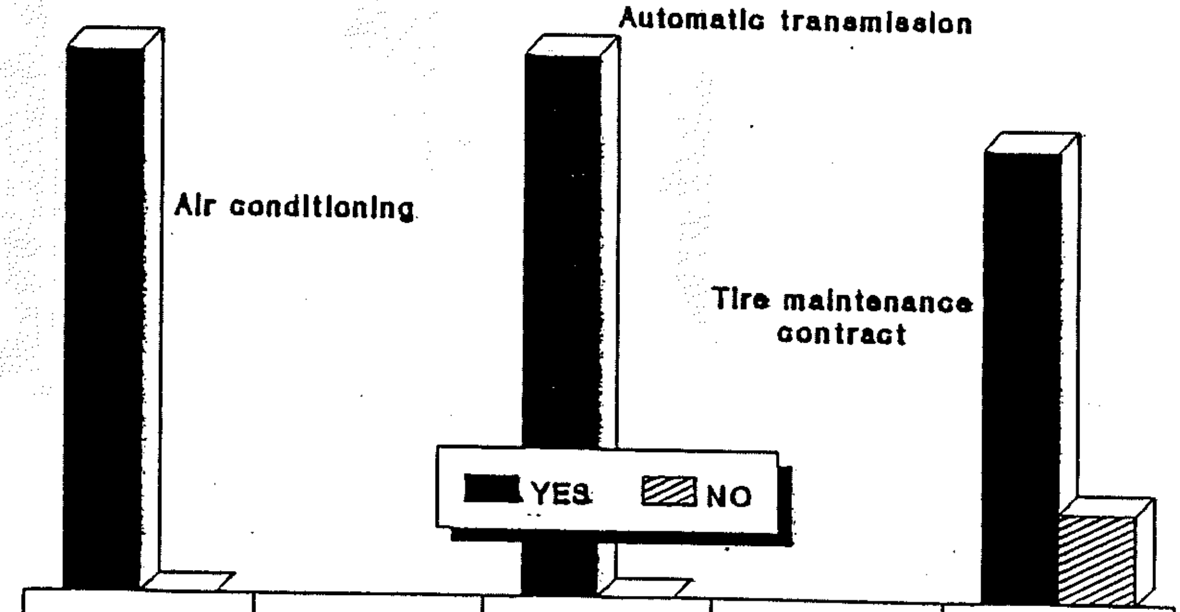


Chart 7

Percent Distribution of Public Transit Systems Using Other Energy Conservation Strategies N=12



	Air conditioning		Automatic transmission		Tire maintenance contract
YES	100		100		83.3
NO	0		0		16.7

Appendix C

The Correlation Coefficient Matrices

Table 11

The Correlation Coefficients Matrix
Vehicle Improvements

Categories	Sloped windshields	Rounded corners	Smooth vehicles sides	Temperature-sensitive fans	Turbocharged engines	Reduced vehicle weight	Evaporative-cooling technology
Sloped windshields	.0000 P=.500	.7071 P=.005	.5774 P=.025	.0000 P=.500	.1925 P=.275	.3015 P=.170	.3536 P=.130
Rounded corners	.7071 P=.005	.0000 P=.500	.8165 P=.001	.1581 P=.312	.0000 P=.500	.2132 P=.253	.2500 P=.217
Smooth vehicle sides	.5774 P=.025	.8165 P=.001	.0000 P=.500	.2582 P=.209	.1111 P=.366	.4082 P=.094	.1741 P=.294
Temperature-sensitive fans	.0000 P=.500	.1581 P=.312	.2582 P=.209	.0000 P=.500	.7746 P=.002	.1348 P=.338	.3162 P=.158
Turbocharged engines	.1925 P=.275	.0000 P=.500	.1111 P=366	.7746 P=.002	.0000 P=.500	.1741 P=.294	.4082 P=.094
Reduced vehicle weight	.3015 P=.170	.2132 P=.253	.1741 P=.294	.1348 P=.338	.1741 P=.294	.0000 P=.500	.4264 P=.083
Evaporative-cooling technology	.3536 P=.130	.2500 P=.217	.4082 P=.094	.3162 P=.158	.4082 P=.094	.4264 P=.083	.0000 P=.500

Table 12

The Correlation Coeffiecients Matrix
Maintenance Equipment Strategies

Categories	Mileage based	Performance based	Daily tire-pressure checks/maintenance	Manometer air-filter checks	Scheduled engine rebuilds	Fuel injectors	Radial tires	Higher-temp thermostats	High pressure radiator caps	Throttle delays	Speed governors
Mileage based	.0000 P=.500	.3333 P=.145	.1741 P=.294	.0000 P=.500	.4082 P=.094	.3333 P=.145	.1925 P=.275	.0976 P=.381	.2928 P=.178	.4436 P=.074	.2928 P=.178
Performance based	.3333 P=.145	.0000 P=.500	.1741 P=.294	.0000 P=.500	.0000 P=.500	.1111 P=.366	.1925 P=.275	.4880 P=.054	.2928 P=.178	.1901 P=.277	.0976 P=.381
Daily tire-pressure checks/ maintenance	.1741 P=.294	.1741 P=.294	.0000 P=.500	.2132 P=.253	.2132 P=.253	.5222 P=.041	.3015 P=.170	.3568 P=.127	.3568 P=.127	.1655 P=.304	.3568 P=.127
Manometer air-filter checks	.0000 P=.500	.0000 P=.500	.2132 P=.253	.0000 P=.500	.6250 P=.015	.4082 P=.094	.0000 P=.500	.1195 P=.356	.2390 P=.227	.0776 P=.405	.2390 P=.227
Scheduled engine rebuilds	.4082 P=.094	.0000 P=.500	.2132 P=.253	.6250 P=.015	.0000 P=.500	.4082 P=.094	.2390 P=.227	.2390 P=.227	.1195 P=.356	.3105 P=.163	.1195 P=.356
Fuel injectors based on vehicle routing	.3333 P=.145	.1111 P=.366	.5222 P=.041	.4082 P=.094	.4082 P=.094	.0000 P=.500	.1925 P=.275	.2928 P=.178	.2928 P=.178	.3169 P=.158	.0976 P=.381
Radial tires	.1925 P=.275	.1925 P=.275	.3015 P=.170	.0000 P=.500	.2390 P=.227	.1925 P=.275	.0000 P=.500	.1690 P=.300	.5071 P=.046	.3293 P=.148	.5071 P=.046
High temperature thermostats	.0976 P=.381	.4880 P=.054	.3568 P=.127	.2928 P=.178	.2390 P=.227	.2928 P=.178	.1690 P=.300	.0000 P=.500	.0286 P=.465	.4638 P=.064	.3714 P=.117
High pressure radiator caps	.2928 P=.178	.2928 P=.178	.3568 P=.127	.2398 P=.178	.1195 P=.3560	.2928 P=.178	.5071 P=.046	.0286 P=.465	.0000 P=.500	.2412 P=.225	.0286 P=.465
Throttle delays	.4436 P=.074	.1901 P=.277	.1655 P=.304	.0776 P=405	.3105 P=.163	.3169 P=.158	.3293 P=.148	.4638 P=.064	.2412 P=.225	.0000 P=.500	.6494 P=.011
Speed governors	.2928 P=.178	.0976 P=.381	.3568 P=.127	.2390 P=.227	.1195 P=.356	.0976 P=.381	.5076 P=.046	.3714 P=.117	.0286 P=.465	.6494 P=.011	.0000 P=.500

Table 13

The Correlation Coefficients Matrix
Operating Strategies

Categories	Initial Driver's Training	Periodic Driver's Training	Automatic shut off valves	Drybreak Nozzles
Initial Driver's Training	.0000 P = .500	1.0000 P = .000	-.2132 P = .000	.2132 P = .253
Periodic Driver's Training	1.0000 P =.000	.0000 P = .500	-.2132 P = .000	.2132 P = .253
Automatic shut off valves	-. 2132 P = .000	.2132 P = .253	.0000 P = .500	.5000 P = .049
Drybreak Nozzles	.2132 P =.253	.2132 P = .253	.5000 P = .049	.0000 P = .500

Table 14

The Correlation Coefficients Matrix
Right-of-Way Characteristics

Categories	Bus Only Lanes	Express Service	Traffic Signal Coordination and Modernization	Special Parking Restrictions	One-way Streets	Reversible Lanes	Right Turn on Red	Traffic Channelization
Bus Only Lanes	.0000 P=.500	.7071 P=.005	.3536 P=.130	-.2500 P=.217	-.5000 P=.049	.1581 P=.312	.0000 P=.500	.0000 P=.500
Express Service	.7071 P=.005	.0000 P=.500	.6667 P=.009	.0000 P=.500	.0000 P=.500	.4472 P=.072	.1925 P=.275	.1925 P=.275
Traffic Signal Coordination and Modernization	.3536 P=.130	.6667 P=.009	.0000 P=.500	.3536 P=.130	.0000 P=.500	.1925 P=.275	.1925 P=.275	.1925 P=.275
Special Parking Restrictions	-.2500 P=.217	.0000 P=.500	.3536 P=.130	.0000 P=.500	.5000 P=.049	-.1581 P=.312	.8165 P=.001	.0000 P=.500
One-way Streets	-.5000 P=.049	.0000 P=.500	.0000 P=.500	.5000 P=.049	.0000 P=.500	.1581 P=.312	.4082 P=.094	.0000 P=.500
Reversible Lanes	.1581 P=.312	.4472 P=.072	.0000 P=.500	-.1581 P=.312	.1581 P=.312	.0000 P=.500	.2582 P=.209	.2582 P=.209
Right Turn on Red	.0000 P=.500	.1925 P=.275	.1925 P=.275	.8165 P=.001	.4082 P=.094	.2582 P=.209	.0000 P=.500	.3333 P=.145
Traffic Channelization	.0000 P=.500	.1925 P=.275	.1925 P=.275	.0000 P=.500	.0000 P=.500	.2582 P=.209	.3333 P=.145	.0000 P=.500

Table 15

The Correlation Coefficients Matrix
Other Strategies

Categories	Segregated Fleet by type of service	Active participation of drivers and maintenance in consumption efficiency programs	Strategic location of air hoses and pressure gauges throughout the garages	Posting of fuel efficiency goals and objectives
Segregated Fleet by type of service	.0000 P=.5000	.2390 P=.227	.0000 P=.500	.2132 P=.253
Active participation of drivers and maintenance in consumption efficiency programs	.2390 P=.227	.0000 P=.5000	.4880 P=.054	.2548 P=.212
Strategic location of air hoses and pressure gauges throughout the garages	.0000 P=.5000	.4880 P=.054	.0000 P=.5000	.5222 P=.041
Strategic location of air hoses and pressure gauges throughout the garages	.2132 P=.253	.2548 P=.212	.5222 P=.041	.0000 P=.5000

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