THE FEASIBILITY OF REDUCING ENERGY CONSUMPTION BY ALLOWING HIGH-EFFICIENCY VEHICLES TO OPERATE ON HIGH-OCCUPANCY VEHICLE (HOV) LANES

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PREFACE

This work was conducted under a grant from the Oil Overcharge Funds provided by the State of Texas Governor's Energy Office and approved by the U.S. Department of Energy. Austin Research Engineers, a division of Huntingdon Engineering and Environmental Inc. was selected for this study. Engineers who worked on this project included Mr. Stuart W. Hudson, P.E., Dr. Maqbool Khatri, P.E., and Mr. R. Frank Carmichael III, P.E. Mr. Eric D. Moody, P.E. was retained as a subcontractor and consultant on this project. The project was conducted in 1993.

CHAPTER 1
INTRODUCTION

Throughout the 1960's and 1970's, many large urban areas in the United States saw substantial increases in the level of congestion on their respective freeway systems. In an attempt to relieve this congestion, High-Occupancy Vehicle (HOV) lanes, or Special Vehicle Lanes (SVLs) as they are called in this study, were designed and constructed in these urban centers. By forming two and three person carpools, vanpools, or riding a bus, commuters are granted the privilege of using the SVL facility, saving them eight to ten minutes on their daily commute to work.

SVLs are referred to by a number of different names including High-Occupancy Vehicle lanes, busways, carpool lanes, transitways, and commuter lanes. They also encompass a variety of different design techniques, including barrier separated right-of-way, freeway right-of-way, contra and concurrent flow, and various combinations of these techniques. SVLs are currently in use in over 20 metropolitan cities throughout North America and comprise over 300 centerline miles of freeway (*1*).

Although the driving force behind the creation of SVLs was to relieve congestion on existing freeways, they offer other obvious benefits as well. These include:

- Energy conservation through reduced fuel consumption.
- Reduced CO_2 emissions, and thus improved air quality.
- Reduced vehicle miles traveled.
- Lower average travel times.
- Shorter response time for emergency vehicles
- Increased safety.

Through the implementation of innovative design procedures, SVLs have attained a significant success at relieving congestion and increasing the people-moving capacity of freeways. However, their use as a means to promote energy conservation has not been adequately explored. A Transportation Research Information System (TRIS) literature search conducted earlier in this project, did not reveal any documentation directly relating SVL operations and fuel conservation. It is this potential of SVLs that has been investigated in this study.

1.1 ENERGY CONSERVATION

The American public is showing an increase in environmental awareness and the need to conserve natural resources, especially petroleum. In recent years the U.S. Congress has debated numerous pieces of legislation including H.R. 446, the Motor Vehicle Fuel Efficiency Act of 1992. These bills, most of which have failed, would "require new minimum standards for corporate average fuel economy (CAFE) standards." (*4*).

The National Academy of Sciences recently reviewed the current state of research and development in light truck and passenger car fuel economy and the Secretary of Transportation has also been asked to prepare a schedule for increasing the fuel efficiency of all vehicles for the year 2002. Several bills being considered would also double the civil penalties to manufacturers who fail to meet the CAFE standards.

Regardless of the outcome of this legislative activity, environmental activists have made substantial progress in focusing attention on the issue of conserving fuel and reducing air emissions. Forcing car manufacturers to build only high-efficiency vehicles or pay stiff civil penalties would certainly result in more energy efficient vehicles. However, a better approach may be to provide incentives for the driving public to purchase only the most fuel efficient vehicles on the market. This would cause a market response by manufacturers to produce more fuel-efficient cars.

In addition to implementing CAFE standards, there are other ways to encourage people to buy fuel-efficient automobiles. These include raising the gas tax, or charging higher registration fees for the less efficient vehicles. However, these methods would not be very popular with the American public. A better approach would be to provide driving incentives to motorists choosing to purchase high-efficiency vehicles. For example, all motorists with vehicles that get a minimum of 50 mpg could be allowed to operate on the SVLs discussed above. Two single-occupancy vehicles (SOVs) each getting 50 mpg consume less fuel than one double-occupancy vehicle (DOV) getting only 15 mpg. Obviously, in a 50 mile commute, the two SOV's could travel the same distance and consume only two gallons of gasoline, while the DOV would consume 3.33 gallons. Therefore, if two person carpools are allowed to operate on a given SVL for the reasons of fuel conservation, SOV commuters could also be permitted to use the same facility if they are driving highly fuel-efficient vehicles.

Traffic levels on the SVL facility could be monitored. If traffic levels become too high, the required fuel economy rating to operate on the SVL facility could be increased sightly or the number of lanes dedicated to the SVL facility could be increased.

This concept is not entirely new. Motorcycles, a type of SOV, are currently allowed on all SVL facilities across the country (*3*) due to a recent federal referendum. Motorcycles are allowed on the SVL facility not because they relieve congestion, but because they are fuel efficient. If everyone rode a motorcycle to work everyday, fuel consumption attributed to motor vehicles could drop by as much as 60 percent. If motorcycles are allowed to operate on SVL facilities simply because they are fuel-efficient, high-efficiency automobiles would definitely fare to be the next most deserving candidates.

There are also many new technologies being developed that may make policy enforcement on SVL facilities easier. One of the most promising technologies is radio frequency identification, being developed for tracking motor vehicles. A small transponder is mounted on each vehicle and when prompted, emits an electrical signal that contains all vital information about the vehicle. These devices could be required on all SOVs operating on SVLs so the vehicles' authenticity could be checked when entering the SVL facility.

SVLs have been a very useful tool for reducing highway congestion by encouraging carpooling and other mass transit. They may also be a very useful tool for reducing fuel consumption by providing an incentive for commuters to purchase the best fuel-efficient vehicles available.

1.2 BACKGROUND

There have been numerous attempts to reduce fuel consumption through legislative and congressional action. The most significant of these attempts was the U.S. Congress' implementation of the corporate automobile fuel economy (CAFE) act in 1978. This legislation mandated that automobile manufacturers produce car fleets that met certain average minimum fuel economy ratings or pay substantial fines to the U.S. government. This controversial legislation resulted in significant increases in the average automobile fuel economy during the late 1970s and throughout the 1980s. Average automobile fuel economy increased from 14.6 miles per gallon in 1978 to 27.4 miles per gallon in 1986. However, critics have suggested that the increased fuel economy was not the result of the CAFE standards, but rather a direct response to consumer demand for more fuel-efficient cars. As a result of increased fuel prices in the 1970's and early 1980's, consumers were looking for higher fuel economy in their vehicle purchases.

Since 1987, there has been little improvement in the average fleet fuel economy rating. This stabilization of average fuel economy is highly correlated with the stabilizing of fuel prices. The United States Environmental Protection Agency (EPA)'s average fuel economy rating for 1993 vehicles was 28.1 miles per gallon. This is up only by a meager 0.5 miles per gallon over last year's figures. Fuel economy ratings of vehicle fleets will be discussed in more detail later in this report. Nevertheless, the trend in consumer demand suggests that something other than CAFE standards is necessary to encourage consumers to purchase more fuel efficient vehicles.

Many suggestions for improving average vehicle fuel economy have been put forth. These include increasing fuel taxes, and raising CAFE standards to 40 miles per gallon by the year 1996. Both of these mechanisms are in essence taxes placed on consumers. As an alternative to taxes, some sort of incentive (other than avoiding a tax) could be given to consumers for purchasing more fuel-efficient vehicles. These incentives could take several forms. One form may be federal rebates for purchasing selected vehicles. Another may be reduced federal and state taxes for selected fuel-efficient vehicles. Yet another mechanism, in fact the one adopted for this study, focuses on providing vehicle operators of selected fuel-efficient vehicles certain operating privileges on the nations highways. The operating privilege examined in this study is the right to operate on special vehicle lanes located in most of our nation's largest urban centers. By allowing operators of selected fuel-efficient vehicles the privilege of operating on SVLs, those operators would be more inclined to purchase these high-efficiency vehicles. This mechanism does not include any type of tax, but rather creates an incentive through increased privileges for commuters.

To implement such a strategy, many issues were examined in this study. Relative issues examined include:

- Definition of fuel-efficient vehicles
- Capacity vs. usage of selected SVLs
- Distribution of high-efficiency vehicles
- Feasibility of adapting specific SVL designs to allow high-efficiency vehicle operation
- Feasibility of adding lanes (capacity) to existing SVLs
- Policing (enforcement) requirements on SVLs
- Review of EPA procedures for establishing fuel economy ratings
- Review of public perception

Each of these issues has been examined in some detail in this study.

When SVLs were first proposed to alleviate congestion in urban centers, they were highly criticized. In fact, several projects failed due to heavy public criticism of the apparent waste of vital freeway capacity. However, after insistence by the federal government for increased transit activities combined with unrelenting congestion in major urban centers, commuters have come to recognize the benefits of constructing and operating SVLs for car pool and bus traffic.

1.3 HIGH-EFFICIENCY VEHICLES

During the performance of this study it was considered important to develop some sort of criteria for defining high-efficiency vehicles. Since this project started, a considerable amount of information on high-efficiency vehicles has been collected. What is clear at this point, is that there is considerable interest in industry on this specific topic. The next chapter in this report provides detailed information on automobile fuel economy ratings as monitored by the EPA. Also, a brief review is provided of the most fuel-efficient vehicles available on the market during the last 12 years. The last section of Chapter 2 provides recommended methodologies for defining high-efficiency vehicles to meet the objectives of this study.

This criteria must be clearly defined as it will impact consumer choices on vehicle purchases over a period of years. The definitions must be fair to all vehicle owners operating on the entire freeway system.

Many variables must be considered in setting the criteria for a vehicle to be classified as highly fuel-efficient. The potential impact on the SVL is one of the most important factors. Clearly, making the definition so broad that thousands of vehicles automatically qualify would cause substantial congestion on the SVL and obliterate any value of operating on the SVL facility in the first place. Some narrow definition must be developed. This topic is discussed in detail in Chapter 2.

When this study began, the focus was strictly on conventional gas-burning automobiles. However, the extensive literature review performed as a part of this study has revealed some interesting information related to other special vehicles. There appears to be an emergence in the country of two additional primary types of high-efficiency vehicles. These include "electric" vehicles and "ultralight" vehicles. These vehicles types are discussed in subsequent sections.

1.3.1 Electric Vehicles

Electric vehicles are one special type of vehicle that possibly should automatically qualify for the privilege of operating on SVLs. They produce no CO_2 emissions along their path of travel and they would benefit greatly by the protection of barrier-separated SVLs as well as the higher level of service (LOS) typical of SVL facilities. Promoting electric vehicle use would also bring the interest of new research and development in this area.

1.3.2 Ultralight Vehicles

In recent years, there has been considerable technical development in the area of carbon-fiber composite materials. These are the same type of materials that were used to construct the Voyager aircraft, the first plane to fly non-stop around the world. Although carbon-fiber material is considerably more expensive than conventional sheet metal, the fabrication costs for cars constructed with this type of material should be much lower. Use of this material for vehicle fabrication could make it conceivable to achieve fuel economies of over 100 miles per gallon, as the General Motor (GM) prototype did when released in January 1992.

However, for these cars to be economically viable to produce, a fundamental change in consumer demand must occur. Providing an incentive to potential purchasers of this type of vehicle, such as unrestricted use of SVLs nationwide, may provide the initial boost to shift consumer demand. Ultralight and electric vehicles are two types of state-of-the art automobiles that could easily be justified for SVL operation. Because these vehicles are so lightweight, the added safety of the barrier-separated type of SVL is an attractive feature for potential purchasers of these automobiles.

1.4 LITERATURE REVIEW

At the start of this project, a detailed literature review was conducted to determine if any significant work has previously been performed in this area. With respect to transitway operations, no specific research was found that addressed the energy saving potential of transitways. However, there has been a considerable amount of research done on automobile fuel economy.

The Transportation Research Information System (TRIS) database search conducted for this study included the following key words: fuel or energy; efficiency, economy, or consumption; miles per gallon or mpg; transitway; and CAFE. Over 600 publications were initially generated with this comprehensive list of key words. By refining the selection criteria to publications generated since 1982 (last ten years) the list was reduced to slightly over 250 publications. By reviewing the titles for each of these 250, abstracts were acquired for approximately 80 publications. From the list of abstracts, approximately 20 publications were ordered. Numerous other technical references were already available in the project staffs personal library. For a more complete list of the technical references used for this study, please refer to the "REFERENCES" section at the end of this report.

1.5 CLEAN AIR ACT AMENDMENTS OF 1990 (CAAA)

The Clean Air Act Amendment of 1990 (CAAA) set ambitious goals and deadlines for local and state government officials to achieve national air quality goals. This act inevitably requires greater integration of the transportation and air quality planning processes. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) provides the funding necessary to work towards the National Ambient Air Quality Standards (NAAQS) established by the EPA in the CAAA of 1990.

Among the goals of the CAAA is to reduce the number of trips in single-occupancy vehicles (SOVs), including non-work related trips. By reducing the number of SOVs operating on our nation's highways, it is perceived that mobile source CO_2 emissions could be substantially reduced.

Unfortunately, this objective is in direct conflict with the general public's desire to own and operate their own personal vehicles unrestricted by government influence. To reiterate, the objective of this study was to explore the possibility of providing a low cost government incentive for reducing CO_2 emission by creating a consumer demand for the most fuel-efficient vehicles available on the market.

1.6 INTERMODAL SURFACE TRANSPORTATION EFFICIENCY ACT OF 1991

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 provides new opportunities for state and local governments to fund badly needed highway construction and rehabilitation projects. These new funding avenues include public/private partnerships, toll financing in the federal aid program, and the means for levering federal funds with private investment.

Although states first must pass enabling legislation, it is very likely that commuters on the existing federal aid system will see toll plazas installed to fund improvements to those existing systems. There are several advantages to toll financing as they relate to this study. First of all, tolls are a direct charge to.the users for operating on the facility. This toll is typically graduated based on the size and weight of the vehicle. For example, large five axle tractor trailers are typically charged five to ten times the rate charged to passenger vehicles. This is because the large trucks inflict more damage on the pavement surface which reduces the life of the facility and increases maintenance costs. Large tractor trailers also reduce the total vehicle operating capacity of a given freeway, providing another reason to charge them a greater rate.

In summary, toll financing provides a unique method for making a direct charge to the user for the privilege of operating on a given highway facility. Should a given vehicle inflict more damage on the pavement, or reduce the total capacity of the freeway, the toll can be adjusted accordingly.

This ability to graduate the charges to specific vehicle types for operating on a toll facility has several other obvious advantages, one of which relates directly to this study. Major urban centers throughout the United States and the world have two primary problems related to commuter traffic. The first of these is congestion. Congestion is so acute in many areas, that virtual gridlock exists for three to four hours in the morning and in the evening rush periods. This problem is difficult to overcome through conventional capacity expansion. Right-of-way for additional lanes is non-existent or extremely costly. Present traffic growth rates have already surpassed the growth rate of the highway system. Cities are having to develop new strategies for addressing congestion. Government and private employers have been asked to stagger their work hours for employees, thereby reducing the demand place on the system at peak hours. For the most part, these efforts have been voluntary. However, it has become evident that some other types of congestion management techniques must be implemented.

By adjusting toll rates at different times of the day, an incentive or disincentive can be created for operating a vehicle on the facility at that particular time of day. For example, vehicles entering the toll facility before 7:15 a.m. may only be charged $1.00. Vehicles entering between 7:15 a.m. and 8:15 a.m., during the middle of rush hour, could be charged $3.00 for the same operating privilege. After 8:15 a.m. the toll could again be reduced to $1.00.

With the highly automated toll collection facilities available today, this type of graduated charge strategy can be implemented through computer software and hardware.

Similarly, many large urban centers are faced with finding ways to meet the demands of the Clean Air Act. To achieve the goal of cleaner air in urban centers, steps must be taken to reduce automobile fuel consumption and their respective air emissions.

Encouraging SVL activities has been the primary focus of this effort to reduce fuel consumption in the major metropolitan centers. Efforts have also been made to implement more stringent CAFE standards, as discussed earlier. However, by using the highly automated toll collection facilities in urban centers, tolls can also be adjusted based on the fuel consumption of the vehicle operating on the system. The specifics regarding the transportation technology available for automated toll collection are discussed in detail in another section of this report.

In summary, this technology will provide the ability to adjust toll rates based on both the fuel economy rating of a given vehicle and the time of the day that vehicle enters the toll facility. Through this mechanism, commuters would be encouraged to purchase more fuel efficient vehicles and operate those vehicles prior to or just after the peak hour traffic demand. For example, the toll schedule could be set up as shown in Table 1.6.1.

This type of transportation system would provide two full benefits to the community. It would provide an incentive for vehicle operators to commute to work at other than peak hours and to purchase vehicles with higher fuel economy ratings. It would also provide an attractive finance mechanism for badly needed highway improvements as authorized under the 1991 ISTEA. These toll rates can be adjusted by the toll road authorities as circumstances dictate.

1.7 ISSUES RELATED TO FUEL-EFFICIENT VEHICLE OPERATION ON SPECIAL VEHICLE LANES

With the suggestion of allowing fuel-efficient vehicles the privilege of operating on our nation's SVLs, many questions and concerns come to mind. These include:

- How will you establish which cars are highly fuel-efficient?
- What steps should be taken if too many vehicles begin to occupy the SVLs, exceeding the SVL capacity?
- How will you distinguish between approved fuel-efficient vehicles and other vehicles?

This study has attempted to address each of these important issues. Chapter 2, "Defining High-Efficiency Vehicles", addresses the first item. This chapter explains in detail the EPA procedures for establishing fuel economy rating and the range of vehicles with relative high fuel efficiency over the last 12 years.

Table 1.6.1 Toll Schedule Graduated for Time of Operation and Approximate CO_2 Emissions

< =14	$1.00	$1.50	$2.50	$1.50	$2.50	$0.50
15to20	$0.90	$1.40	$2.40	$1.40	$2.40	$0.45
21-25	$0.80	$1.30	$2.30	$1.30	$2.30	$0.40
26-30	$0.70	$1.20	$2.20	$1.20	$2.20	$0.35
31-35	$0.60	$1.10	$2.10	$1.10	$2.10	$0.30
36-40	$0.50	$1.00	$2.00	$1.00	$2.00	$0.25
41-45	$0.40	$1.90	$1.90	$0.90	$1.90	$0.20
46-50	$0.30	$0.80	$1.80	$0.80	$1.80	$0.15
> =51	$0.20	$0.70	$1.70	$0.70	$1.70	$0.10

(1) From midnight to 6:00 am, tolls are low due to no congestion. However, they are still graduated based on fuel approximate CO_2 emissions.
(2) The early morning tolls are set slightly higher reflecting increased demand on the system. The same graduation based approximate CO_2 emissions, remains in affect.
(3) Tolls are increased by $1.00 during the peak rush-hour period of 7:15 am to 8:15 am.
(4) From the end of the AM rush hour till the beginning of the PM rush hour, tolls are reduced.
(5) Tolls for the PM rush hour are similar to the AM rush hours.
(6) Tolls are again reduced for the late evening hours (6:30 pm to Midnight).

Note: The graduation for approximate CO_2 emissions remains in affect for all hours of the day.

An entire chapter is devoted to the issue of SVL capacity vs. usage. Careful planning will have to be performed to ensure that rules are not put in place that cause the average daily traffic on the transitway to even begin to approach the capacity of the SVL. However, an important element of this study is determining which SVLs design types offer the advantage of capacity expansion (i.e., the addition of more lanes). This particular subject is addressed in Chapter 4 of this report.

Enforcement concerns are another issue that should be addressed. A plan must be put in place that provides enforcement officials the ability to distinguish between approved high-efficiency vehicles and other violators of the SVL privileges. Administrative and enforcement concerns of this methodology are addressed in Chapter 5 of this report.

Chapter 6 provides an analytical analysis of the potential fuel savings of allowing high-efficiency vehicles to operate on the SVL facilities.

CHAPTER 2
DEFINING HIGH-EFFICIENCY VEHICLES

2.1 BACKGROUND

An important element of this proposed methodology involves clearly defining which vehicles meet the requirements of being "highly fuel-efficient." In the case of electric vehicles, the problem of establishing minimum specifications is a relatively simple one. If the vehicle is electrically powered and can maintain an established minimum speed, it meets the criteria for SVL operating privileges.

Ultralight vehicles are not so simple. A maximum weight criteria would have to be established for these vehicles. This maximum weight would probably be a function of the number of passenger seats in the vehicle. In other words, an ultralight vehicle that accommodates four people would justify a slightly higher tare weight than a two person vehicle. A study would be required to establish reasonable criteria.

Definitive rules would have to be adopted and distributed to the public well in advance of implementation. This would give commuters time to consider options and alternatives related to their vehicle purchases. Also, automobile manufacturers may need to adjust designs and production estimates based on forecast demand resulting from purchase incentives such as the one proposed in this study.

In defining which conventional vehicles meet the requirements of being "highly fuel-efficient," one must consider: a) the current fleet of fuel-efficient vehicles available to potential purchasers, b) the number of fuel-efficient vehicles currently operating on the network, as well as c) the potential fuel economy ratings of vehicles to be available in the coming years.

In the following sections, the current procedures adopted by the EPA to establish fuel economy ratings are reviewed. A historical perspective is developed on the emergence of the most fuel efficient vehicles since 1980. The final section of this chapter defines selected methodologies that could be adopted for defining high-efficiency vehicles.

2.2 CURRENT EPA PROCEDURES FOR ESTABLISHING FUEL ECONOMY RATINGS

United States Environmental Protection Agency (EPA) has been monitoring new vehicle fuel economy ratings since 1962. The procedures used by the EPA in establishing the fuel economy ratings have remained relatively unchanged over the last 15 years. Each vehicle make and model is tested in the EPA Laboratories under simulated conditions of city and highway driving. The tests are performed under precisely controlled conditions using professional drivers in laboratory conditions on a Dynamometer. Both a cold start condition and a warm start condition are used and the average fuel economy is reported for that particular vehicle. Historically, the laboratory test results have over estimated the actual mileage obtained in the field. To make their laboratory values correlate more closely with actual fuel economy rates, the City estimate is lowered by 10 percent and the Highway estimate is lowered by 22 percent.

The EPA fuel economy values is the most accurate data source available for determining which vehicles are the most fuel efficient. Any other sources considered will be less reliable than the figures provided by the EPA. Therefore, for implementation of this feasibility study, annual EPA estimates of fuel economy ratings are recommended.

2.3 HIGH-EFFICIENCY VEHICLES AVAILABLE FOR 1980 - 1992

Developing criteria for determining which conventional gasoline burning vehicles are "highly fuel-efficient" is a more difficult task. An important aspect of this study was to have a good understanding of the number of high efficiency vehicles that are available on the market today, as well as the number that are currently operating on the roadways. EPA fuel economy data collected over the last 14 years is used in this analysis. By looking back 14 years, we can detect trends in changing fuel economy ratings. Also, since the focus of this study is to consider high efficiency vehicles for operation on urban transitways only, the City miles per gallon estimates are considered.

The information discussed above is summarized in Table 2.1. Clearly, over the last 12 years, the fuel economy rating of the top 5 or 6 commercially available vehicles has been increasing. However, it is interesting to note that there is no one vehicle that significantly exceeds the other models available during any given year. The exception to this may be the 1986 Chevrolet Sprint ER and the Chevrolet Metro XFI.

Since the fuel economy of each of these two vehicles exceeds all other commercially available competitors by 10 percent, they would be the obvious candidate for SVL operating privileges. However, prior to making this decision, a simple market analysis would be required to determine the number of these particular vehicles that may be operating on a given freeway or arterial. If the study reveals that a significant number of these vehicles would immediately qualify for SVL operating privileges, they could not be selected. This may not be the case if non-separated or buffer-separated facilities are readily available and additional SVL capacity is a realistic alternative.

In addition to the electric vehicles and ultralight vehicles discussed in Section 1.3, it is quite possible that the only feasible alternative available for commercially available gasoline-burning vehicles is to set the criteria at some level that is currently not available in vehicles on the market today. This may provide an added incentive to auto makers to produce at least one additional "high-efficiency vehicle". However, in reality, this is not feasible unless steps are taken to significantly increase the potential market. At least with respect to this study, this would only be possible by significantly increasing the total capacity of existing SVL facilities or increasing the number of lane miles of SVL facilities.

TABLE 2.1 SELECTED HIGH-EFFICIENCY VEHICLES FOR THE YEARS 1978 - 1992

MODEL		COMBINED MPG
1978 Vehicles		
Datsun B210		40
Volkswagon Rabbit (Diesel)		45
1982 Vehicles		
Honda Hatchback		41
Isuzu-Imark	M5	41
Volkswagon Jetta	M4	42
	M5	43
Volkswagon Rabbit	M4	45
	M5	43
1986 Vehicles		
Honda Civic Coupe HF		47
Chevrolet Sprint Plus		46
Chevrolet Sprint ER		57
Nissan Sentra		47
Suzuki Force V		46
Volkswagon Golf		41
1990 Vehicles		
Honda Civic CRX HF		46
Geo Metro M5		48
Geo Metro LSI		48
Geo Metro XFI		56
Suzuki Swift M5	1.0 Liter	48
	1.3 Liter	42
1992 Vehicles		
Geo Metro LSI Convertible		44
Geo Metro M5		48
Geo Metro LSi M5		48
Geo Metro XFI		56
Honda Civic M5		45
Honda Civic HB VX		48
Suzuki Swift M5		48

CHAPTER 3
SPECIAL VEHICLE LANE (SVL) DESIGN CHARACTERISTICS CONDUCIVE FOR HIGH-EFFICIENCY VEHICLE OPERATION

Since their conception in the 1970's, SVLs have evolved into a series of unique and diversified transportation engineering systems. This evolutionary process has resulted from both a painstaking engineering process as well as trial and error. Continuous and unrelenting public scrutiny has forced engineers and policy makers to adopt transitway systems to best meet the traveling publics needs in major urban centers.

Although a detailed description of the extremely diversified set of SVL designs is too difficult and beyond the scope of this study, the following sections are aimed at summarizing the state-of-the-art in SVL design and operation. Keep in mind that the focus of this study is to determine which SVL systems will be most adaptable to allow high-efficiency, electric, and ultralight vehicle operation.

No two SVL facilities are completely identical. However, there are certain operating and design characteristics that allow SVLs to be classified into distinct groups. These designs and operational characteristics include barrier separated vs. non-barrier separated, buffer separated, contraflow vs. counterflow operation, freeway right-of-way, and separate right-of-way. Many SVLs are actually a combination of the above features.

3.1 BARRIER-SEPARATED SPECIAL VEHICLE LANES

Barrier separated facilities have the unique characteristic of complete isolation of privileged SVL traffic from the main lane traffic. This characteristic provides an added safety advantage to commuters operating on the SVL. Policing requirements are also less stringent due to the isolated nature of the SVL traffic. The primary disadvantage of these facilities is the limited access nature of the facility. This limited access works to limit ridership to only commuters that enter the freeway system prior to the start of the SVL facility and with a destination past at least the first exit of the SVL. The existence of the barriers also tends to limit expandability of the system to current design width of the SVL. Figure 3.1 shows a typical layout of the barrier separated facility.

One significant advantage of these facilities as they relate to this study is the added protection they provide for SVL commuters. Since high-efficiency and electrical vehicles are extremely light weight compared to their counterparts, their ability to withstand the impacts of larger typical automobiles during a collision is reduced. The added protection of a barrier separated facility is a

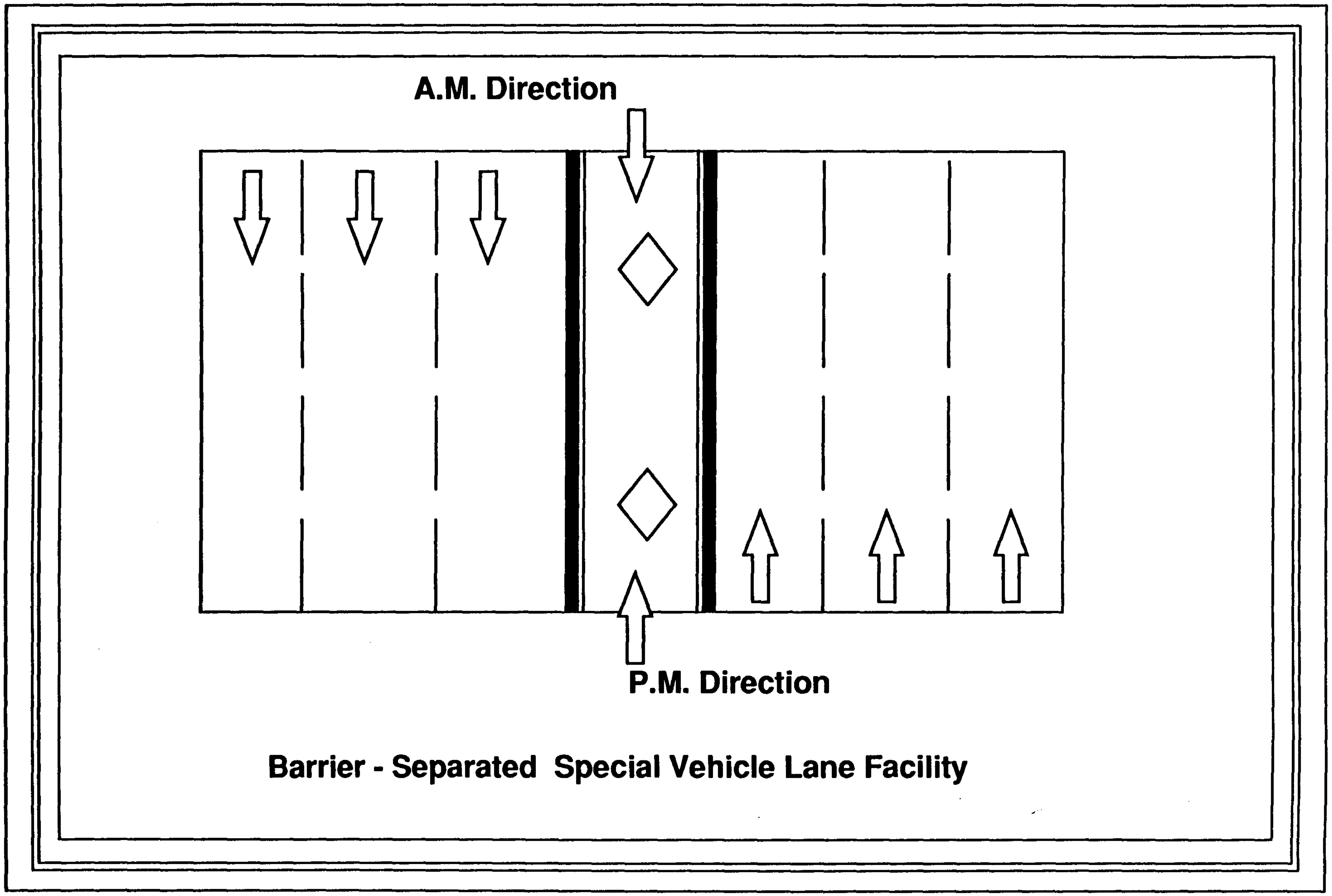

Figure 3.1 Barrier Separated Special Vehicle Lane Facility

significant advantage to those considering the purchase of a new high-efficiency automobile.

3.2 NON-SEPARATED FACILITIES

Non-separated SVLs are usually comprised of the inside lanes of a multi-lane freeway during selected hours of the day. They are typically placed into operation after the existing freeway has been constructed and placed into service, therefore, they typically occupy the existing right-of-way of the freeway. A typical example of a non-separated SVL facility is shown in Figure 3.2.

The primary advantage of this design is ease of access of freeway traffic into and out of the SVL. This provides the added flexibility of SVL operators to enter and exit the SVL at will. This is a significant advantage over the barrier separated SVL.

Since existing freeway right-of-way is typically used for the non-separated facility, the initial costs of these facilities are also minimized. Another significant advantage of these systems is the expandability. In many instances, this may only require the striping and marking of the next adjacent lane. The disadvantages of non-separated facilities include increased cost of policing the SVL and the reduced safety offered to SVL users. Reduced safety is especially acute when the adjacent travel lanes become extremely congested at the peak rush hour, forcing vehicle speeds below 20 miles per hour. If traffic is light in the SVL, vehicle speeds will be typically at their maximum. This significant difference in operating speed between the SVL traffic and the regular lane traffic vehicles poses an increased risk of serious accidents. This is a significant disadvantage when considering light weight, high-efficiency, and electric vehicles for use on SVLs.

3.3 BUFFER SEPARATED TRANSITWAYS

Buffer separated transitways are typically contraflow facilities that operate in a fashion similar to non-separated facilities. The only difference is the existence of a buffer between the transitway lane and the regular traffic lanes. This buffer may consist of a wide separation, typically one meter, between the lanes or a small grade change located between the lanes or a combination of both. Figure 3.3 shows a typical example of a buffer separated SVL.

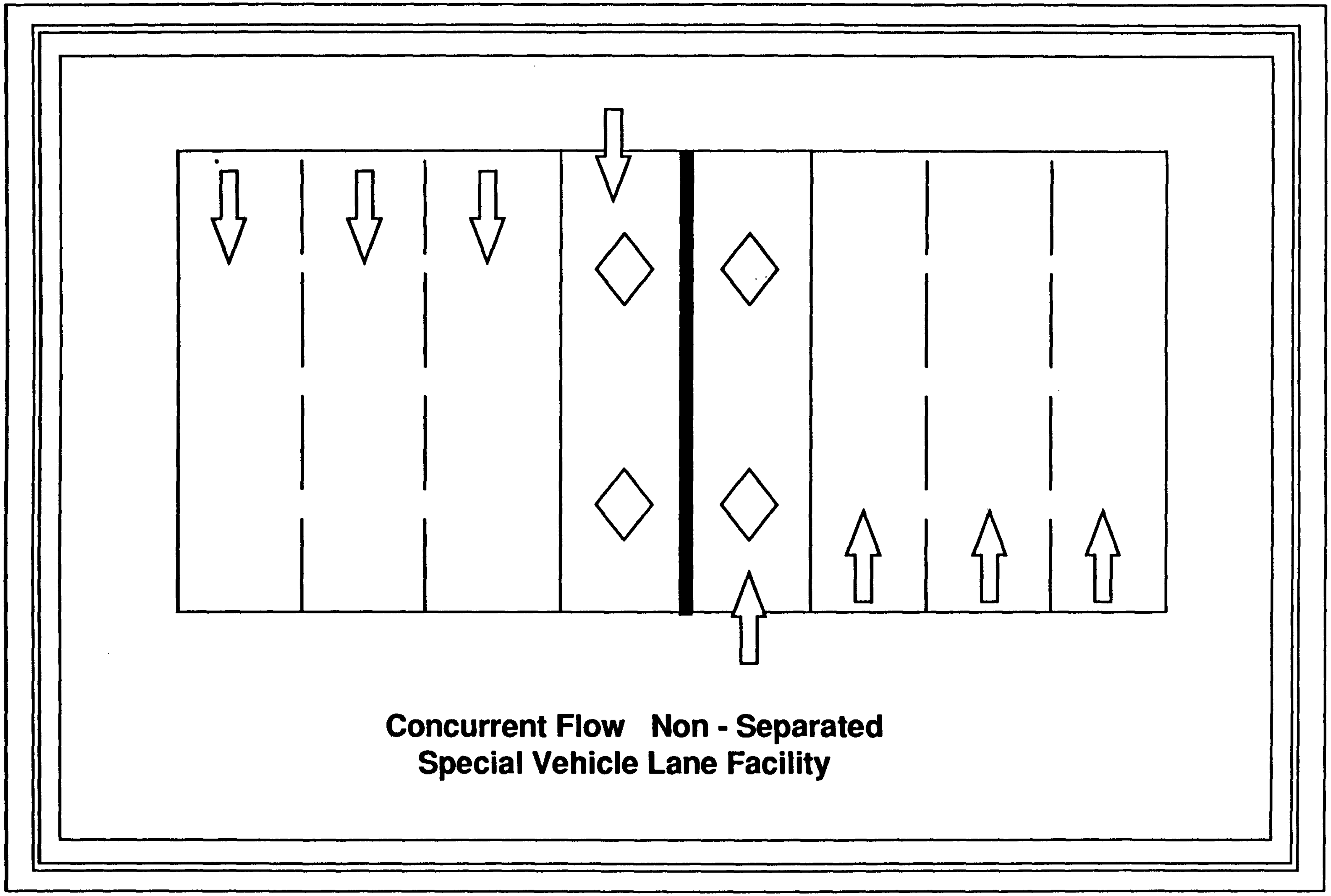

Figure 3.2 Non-Separated Special Vehicle Lane Facility

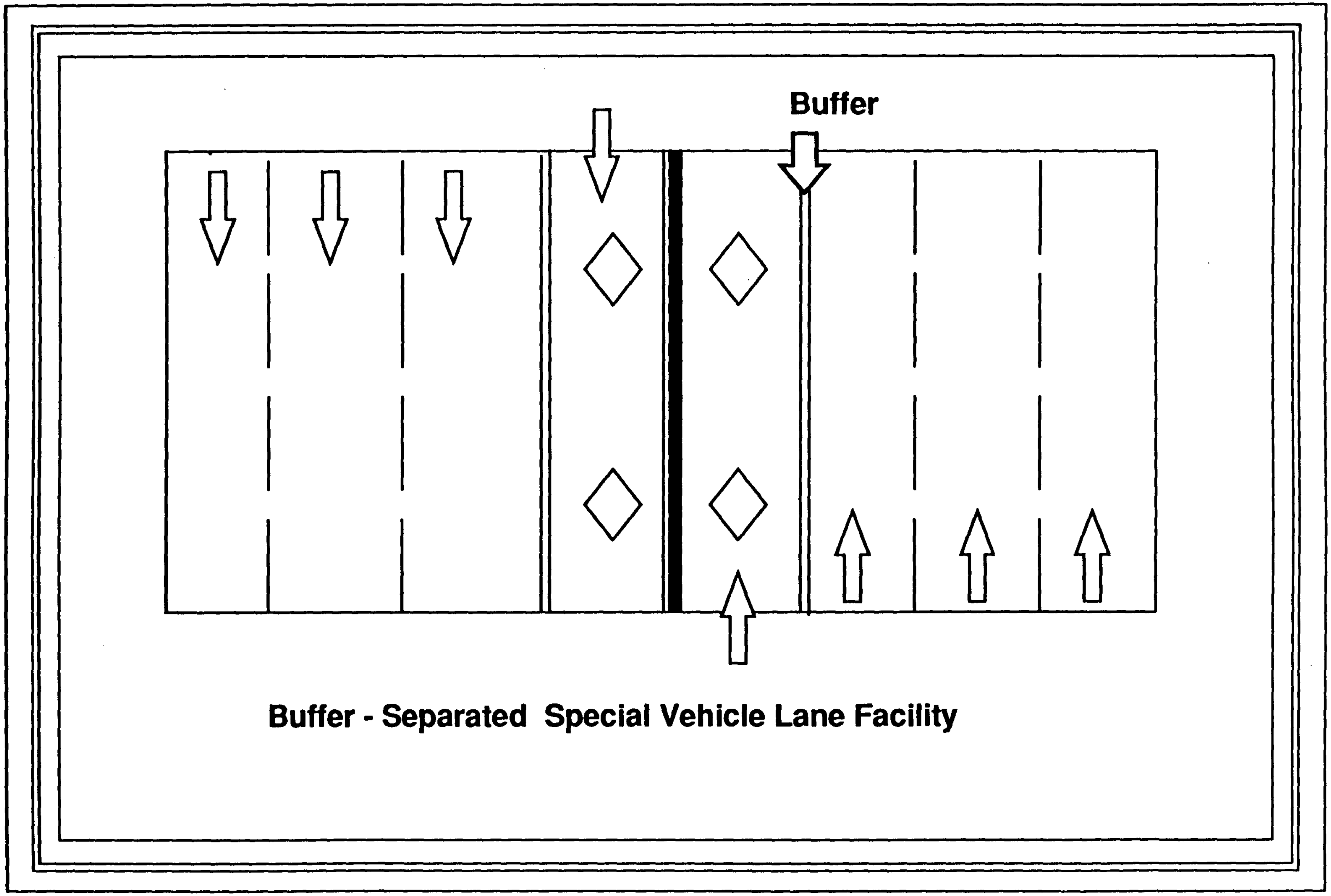

Figure 3.3 Buffer Separated SVL Facility

3.4 CONTRAFLOW AND COUNTERFLOW FACILITIES

Contraflow SVLs are typically defined as non-separated facilities in which SVL traffic flows in the same direction as the adjacent traffic. This characteristic is typical of existing freeways where the inside lane is converted to a limited use transitway.

Counterflow SVL traffic flows in a direction opposite to the adjacent traffic. Figure 3.4 shows the typical operation of a counterflow facility. This type of SVL is typically limited to bus operations. The operation of smaller vehicles would be too dangerous since the SVL traffic is so close to the regular traffic. With respect to high-efficiency vehicles, contraflow facilities are highly preferred over counterflow facilities. Counterflow facilities are unacceptable for high-efficiency vehicle use. One exception to this would be some type of barrier-separated counterflow facility.

3.5 SUMMARY OF TRANSITWAY DESIGN AND OPERATIONAL CHARACTERISTICS

Table 3.1 provides a summary of the key operating characteristics of transitway facilities as well as their advantages and disadvantages for high-efficiency vehicle use.

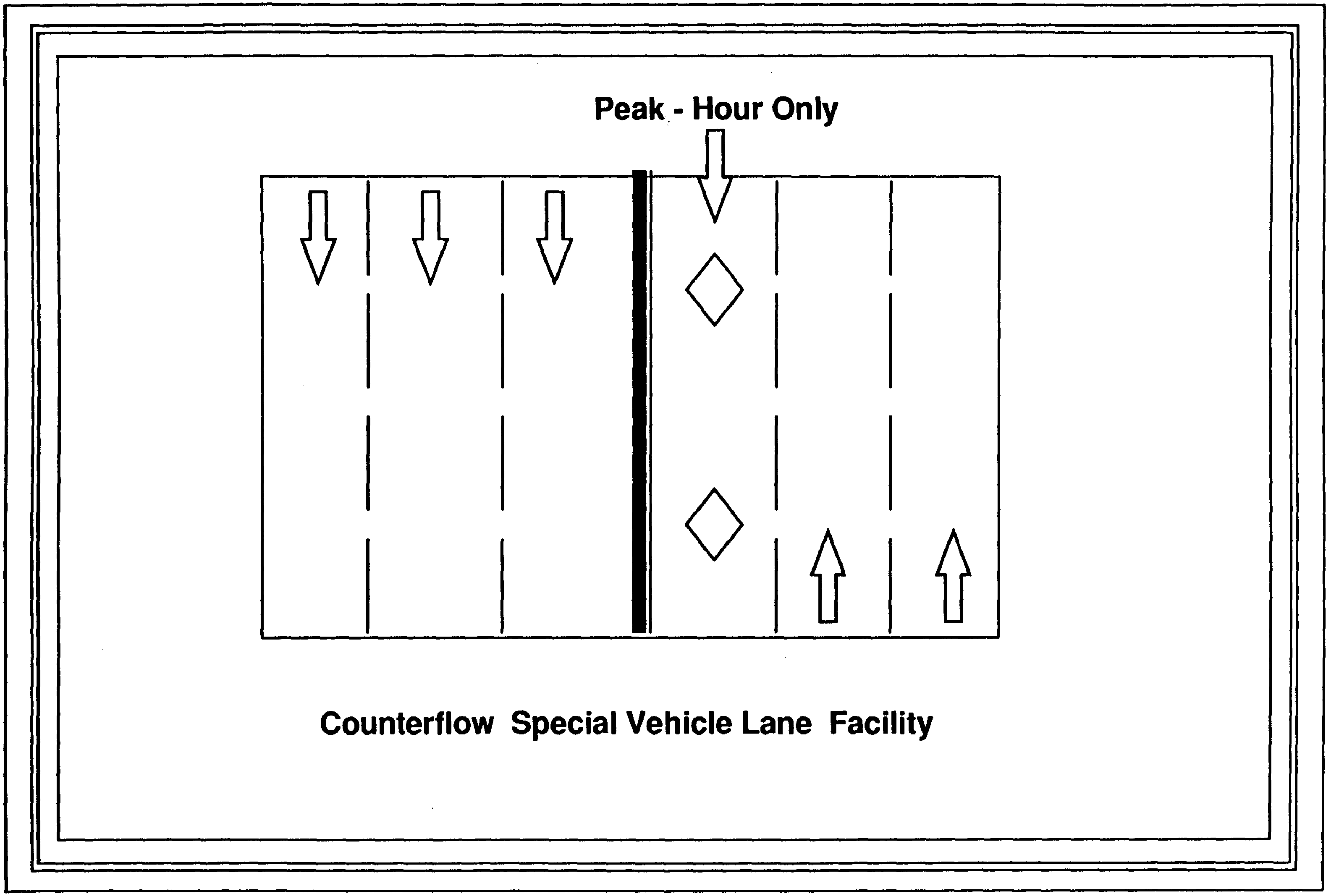

Figure 3.4 Counterflow SVL Facility

Table 3.1 Advantages and Disadvantages of Selected SVL Design Types

Transitway Type	Advantages	Disadvantages
Barrier-Separated Facilities	* Increased safety for transitway vehicles * Increased capacity due to controlled access * Easier to police * Reversible for am and pm rush hours * Ideally suited for high-efficiency vehicle operation	* Limited access to and egress from the facility. * Increased construction cost * Additional R.O.W. required for shoulders in transitway * 5 year lead time for design/construction * May be difficult to add lanes.
Non-Separated Facility	* Ease of access to and egress from transitway * Lower construction costs * Easy to add lanes (expandability) * Short lead time for implementation * Lower operating costs (additional right of way typically not required)	* Reduced capacity due to ease of access * Reduced safety for transitway vehicles * More difficult to police * Not reversible for am and pm rush hours (except for counterflow facilities)
Buffer-Separated Facility	* Increased safety relative to non-separate facility * See advantages for non-separated facility	* See disadvantages for non-separated facility
Contraflow Facilities	* Safer than counterflow facilities * Reduced construction/ operating costs * Accommodate small cars and trucks	* Not reversible for am and pm rush hours * More difficult to police
Counterflow Facilities	* Does not require existing capacity of same direction traffic lanes * Reduced construction costs * Takes advantage of light traffic in opposite travel direction	* Reversible for am and pm rush hours * Reduced safety for transitway vehicles * Increased operating costs * Only available to busses * Not suitable for high-efficiency vehicle operation

CHAPTER 4
SPECIAL VEHICLE LANE CAPACITY

4.1 BACKGROUND

The common argument used by critics of special vehicle lanes (SVLs) is that they are under-utilized and consume valuable freeway capacity that could otherwise be used by all motorists. The argument has merit in some cases, since many SVLs operate at levels significantly less than capacity. As a result, the occupancy requirements for operating in many SVLs has been reduced from "3+" persons to "2+" persons per vehicle. By reducing occupancy requirements, the number of vehicles on the SVLs has been shown to have increased substantially. However, even after lowering occupancy requirements, many SVLs are still operating at 30 to 50 percent below capacity (Ref 15). In only a few cases have SVLs reached capacity under a "2+" occupancy requirement, prompting an increase in the occupancy requirement to "3+" persons. One notable example of this is the Interstate 10, Katy Freeway SVL, in Houston, Texas. This particular freeway had to exclude the use of "2+" person carpools during the peak hour because it had exceeded its capacity. (Ref. 15)

Data on the average daily traffic (ADT) of SVLs is readily available. DOTs often use this data in their efforts to justify funding for policing and expanding SVL facilities. However, information on the ultimate operating capacity of SVLs is not as readily available. The reason for this is that the capacity of SVLs is a function of many variables. These variables include the number of lanes, width of the lanes, egress to and from the SVL, etc. Often the limiting restraint in SVL capacity is the method adopted for discharging the vehicles at the end of the SVL. Bottlenecking often occurs in these areas.

For the purpose of this analysis, the 1985 Highway Capacity Manual was used to estimate ultimate capacity of the SVLs. The estimate of both single and double lane ultimate SVL capacity should be adjusted downward to account for specific variables unique to a given SVL.

4.2 CURRENT CAPACITY OF SELECTED SVLS

Using the assumption stated above for estimating the SVL capacity, the capacity of each SVL in Houston, Texas was estimated. Since the Houston SVLs are all single lane, except at selected locations, the base capacity was easily determined. A similar approach can be used for any SVL being analyzed.

Using the basic concepts of the Highway Capacity Manual to estimate freeway capacity based on the number of lanes, a methodology is developed here for estimating SVL capacity.

Capacity, as defined by the 1985 Highway Capacity Manual, is the "maximum hourly rate at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given period of time under prevailing roadway, traffic and control conditions." This definition of capacity assumes that good weather and pavement conditions exist.

SVLs have unique operating characteristics that make determining the Maximum Service Flow rate difficult. In determining the ultimate capacity of a given SVL, it is important to first understand the concept of *level of service* which is important in the analysis and review of SVLs. The following section briefly describes the levels of service (LOS) A through F taken from the 1985 HCM and presents methodologies that would make these better suit SVL operating conditions.

The primary difference between SVL operations and regular freeways is that SVLs are typically one lane and barrier-separated from the regular lanes. This tends to lower the average traveling speed of SVL vehicles to the speed of the slowest moving vehicle since passing is no longer possible. This lack of maneuverability in the SVL has the effect of shifting the level of service designation for the SVLs upward one level. In other words, flow rate represented by LOS B for a regular freeway correlates with flow rate for LOS A for SVLs. Figure 4.1 describes the shift in LOS due to the operating characteristics of the SVL.

4.3 MAXIMUM SERVICE FLOW RATE FOR SVL

> *"The contrast of high-occupancy vehicles' progressing smoothly while other vehicles are mired in heavy congestion is also intended to act as an inducement to motorists to abandon their car for a bus or carpool.*
>
> *Thus, it is not practical for a lane to operate at or near capacity, or at a poor level of service. To do so would defeat its function and purpose."* (Ref.1985 Highway Capacity Manual)

Keeping this in mind, the ultimate capacity of the SVL was chosen to be between Level of Service B and C as compared to Level of Service D and E for regular freeway traffic. For comparative purposes, this is also shown on Figure 4.1. Shifting the design capacity of the SVL from the transition between LOS

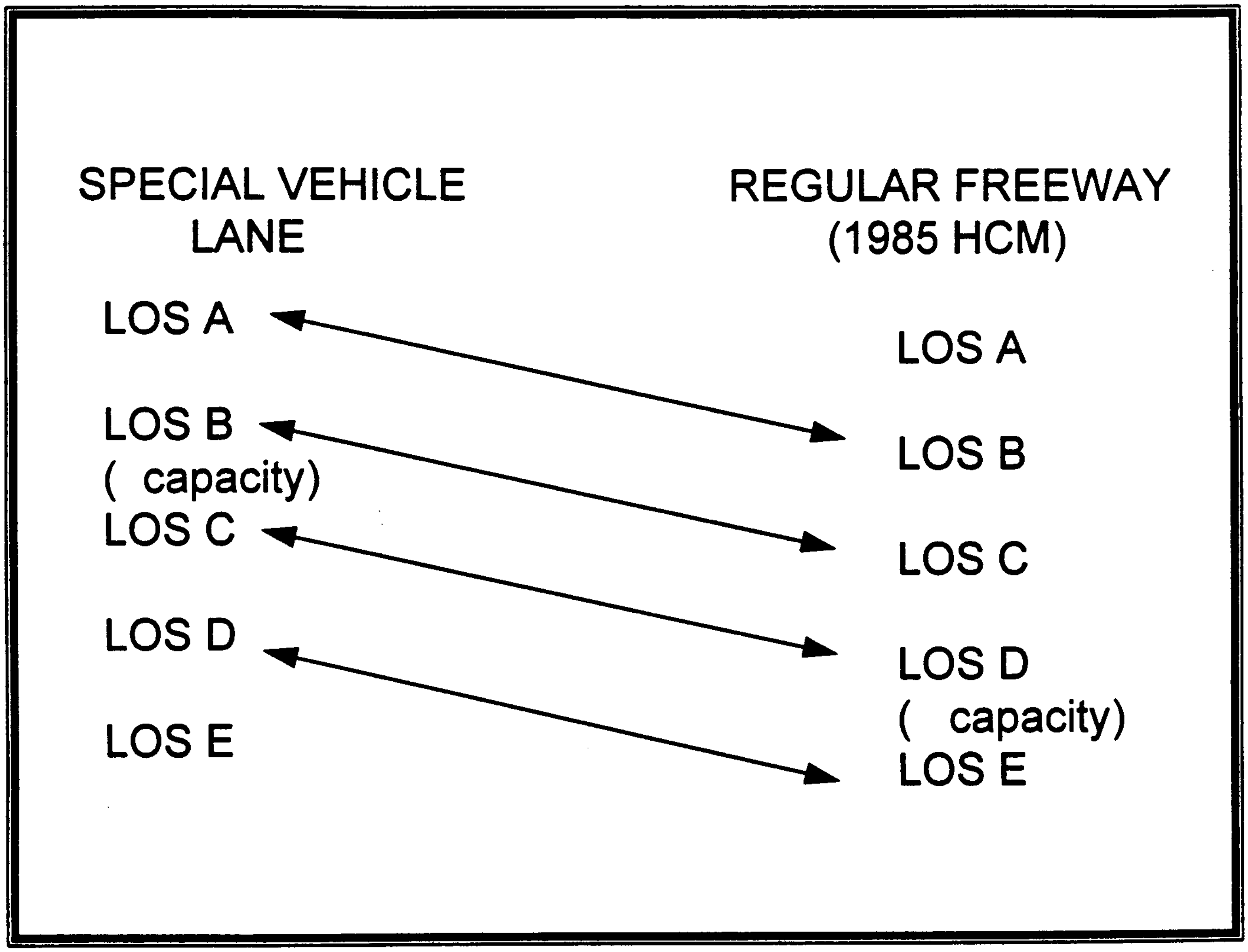

Figure 4.1 LOS for SVLs Based on Service Flow Rate

D and E to the transition point between LOS B and C has a significant impact on the number of vehicles that are granted operating privileges on the SVL.

To estimate the capacity of the SVL, two primary elements of the SVL operational methodology must be analyzed. The first element is the ultimate capacity of the SVL itself under normal operating conditions. The second element that must be investigated is the existence of egression restraints at the terminus of the SVL.

Some of the additional SVL factors that should be considered in determining the Maximum Service Flow rate include access restriction, barrier-separation, single lane operation, percentage of transit busses, and restricted egression. Other significant factors include the lane and shoulder widths.

4.4 BASIC RELATIONSHIPS FOR DETERMINING SVL CAPACITY

As stated previously, an important element of this study is determining exactly what the unused capacity of a given SVL is since this will directly affect the number of high efficiency vehicles that would be allowed to operate on it. The purpose of this chapter is not to determine the ultimate capacity of all SVLs in operation in North America today but rather offer some guidelines for determining the capacity of SVLs.

Therefore, to determine the capacity of the SVL, we begin with the calculation of Maximum Service Flow (MSF) rate (ref. 1985 Highway Capacity Manual).

$$MSF_i = C_i(V/C)_i \qquad (4\text{-}1)$$

where, MSF_i = Maximum Service Flow rate per lane for LOS_i under ideal conditions in passenger cars per hour per lane (pcphpl)

$(V/C)_i$ = maximum volume to capacity ratio associated with LOS_i;

C_j = capacity under ideal conditions for freeway element of designs;

Therefore, in the case of SVLs, the MSF can be calculated as follows:

$$MSF_c = 2000 * 0.70 = 1400 \text{ pcphpl}$$

Note: The V/C ratio of 0.70 corresponds to the transition point between LOS B and LOS C.

This represents the approximate MSF rate of the SVLs under ideal operating conditions. Realistically, however, there are several additional factors that work to limit the MSF to a service flow (SF) rate typical of prevailing SVL and traffic conditions under consideration. These factors act as correction factors to the MSF value as follows:

$$SF_c = MSF_c \, . \, N \, . \, f_w \cdot f_{TV} \cdot f_P \cdot f_{OC}$$

where,

SF_C = Service Flow rate for LOS C under prevailing roadway and traffic conditions for N lanes in one direction in vph;

N = Number of lanes in one direction;

f_W = Factor to adjust for restricted lane widths and/or lateral clearances;

f_{TV} = factor to adjust for the effect of transit vehicles (vans and buses) in the traffic system;

f_P = factor to adjust for the effect of driver population;

f_{OC} = factor to adjust for the operating conditions of the SVL. (Works to increase capacity upwards, especially for barrier separated facilities).

For detailed information on determining values for each of these factors, reference is made to the 1985 Highway Capacity Manual. The following ranges of values are assumed for the subsequent analysis using the computer simulation model described in Chapter 6 of this report.

Lane Widths/Lateral Clearances

Since many SVLs operate under unique right-of-way conditions, it is important to consider the lane widths and lateral clearances for the lanes. In the subsequent analysis, it is assumed that obstacles (bridge piers, light poles, etc) are located within three feet of the travel lanes at selected locations. For 12 foot lane width and obstacles within 3 feet of the travel lane, the 1985 Highway Capacity Manual recommends an adjustment factor of $f_w = 0.98$.

Correction for Transit Vehicles (f_{TV})

Since there are often many transit vehicles, including buses and vanpools operating on SVLs, this is an important factor in determining capacity. For purposes of this analysis, it is assumed that vanpools are equivalent to recreational vehicles in terms of passenger car equivalents (PCEs).

Therefore, in the determination of f_{TV} for the subsequent analysis, it is assumed that vanpools have a PCE of 1.15 and busses have a PCE of 1.50. It is also assumed in the analysis that the range of vanpools in the SVL traffic stream varies from 3 to 4 percent. Likewise for busses, the range is assumed to be 3 to 10 percent of all vehicles. Of course, if different percentages prevail on a given SVL being analyzed, these members would have to be adjusted accordingly. Using the basic equations from the 1985 Highway Capacity Manual, the adjustment factor for transit vehicles can be calculated as follows.

$$f_{TV} = 1 \,/\, [1 + P_{VP}(E_{VP}-1) + P_B(E_B-1)]$$

where, f_{TV} = adjustment factor for combined effects of transit vehicles on the traffic stream;

$E_{VP,B}$ = the passenger car equivalents for vanpools and busses;

P_{VP}, P_B = Proportion of vanpools and busses in the traffic stream;

Therefore, substituting the range of values mentioned above for the factors in this equation yields a range of f_{TV} between 0.93 to 0.98.

Operating Conditions of SVL

The operating conditions of a given SVL may also increase the capacity of the facility. Since access to and egress from SVLs are often restricted to select locations, the amount of weaving and other traffic interactions is reduced. The following is a list of corrections factors for the operating conditions of a given SVL.

Operating Condition	f_{OC}
Non-separated	0.99
Buffer separated	1.02
Barrier separated	1.05
Counter-Flow	(N/A)

Typical Capacity Levels for SVLs

The analysis performed above provides a good indication of the capacity of SVLs selected in Houston, Texas, based on their general operating, traffic, and geometric conditions. Using the adjustment factors described above for lane width and clearance, proportion of transit vehicles, and operating conditions, the service flow rate conditions can be calculated as follows.

$$SF_C = 1400 * 1 * 0.98 * 0.95 * 1.05$$

$$SF_C \approx 1368 \text{ for Barrier Separated Facilities}$$

$$SF_C \approx 1290 \text{ for Non-Separated Facilities}$$

Therefore, for the subsequent analysis of SVLs in the Houston area, a value for maximum service flow rate of 1368 is assumed.

CHAPTER 5
ADMINISTRATIVE AND ENFORCEMENT CONCERNS OF ALLOWING HIGH-EFFICIENCY VEHICLES ACCESS TO SPECIAL VEHICLE LANES

5.1 BACKGROUND OF SVL ENFORCEMENT POLICY

Enforcing SVL operational policy has long been a concern for SVL managers. Much has been learned about the policy enforcement since the first SVL lane was opened on the Shirley Highway in Washington, D.C. in 1969. Most of this knowledge has been gained through a combination of intuition and trial and error.

Many methods have been used in the past by transitway police to enforce operating restrictions. These techniques include manually scanning vehicles from enforcement zones alongside the SVL, shoulder areas, and egress points of the SVL. Video cameras have also been used with limited success to identify violators.

5.2 SPECIFIC ENFORCEMENT CONCERNS REGARDING HIGH-EFFICIENCY VEHICLES

To consider an SVL operating policy that would permit selected high efficiency vehicles to operate on the SVL, raises obvious concerns regarding enforcement. Some techniques would be required to distinguish between high efficiency vehicles (HEVs) and regular vehicles. Existing enforcement measures such as manual observation and vehicle imaging would not suffice.

However, HEVs may even be easier to monitor for operational compliance than carpools. The reason is that with respect to HEVs, the vehicle itself is being monitored, whereas with carpools, it is the number of passengers in the vehicle that is being monitored. This opens up several enforcement options that are not practical for carpool enforcement.

The most obvious of these techniques would be some sort of identification tag, not unlike a vehicle inspection sticker that could be placed in clear view on the windshield or body of each approved HEV. These stickers or tags could be placed on a vehicle to allow easy manual or video inspection of the vehicle. This would preclude any problems with SVL police stopping legally operating HEVs.

Another approach would be to use automatic vehicle identification (AVI) systems to identify qualifying HEVs. This type of system represents a more modified approach to identifying legal HEVs. The use of AVI technology was first proposed by Turnbul during the 1991 national conference on HOV systems held in Seattle, Washington. In her proposal, Turnbul (Ref.12) proposes using electronic tags to identify eligible carpool and van pools to aid in the enforcement of occupancy requirements. She also suggests using the technology for parking facilities where lower rates for HEVs could be offered. The following section takes a closer look at available AVI equipment that may aid in enforcing a policy of allowing selected HEVs the privilege of operating on the SVL.

5.3 REVIEW OF NEW TECHNOLOGY FOR POLICY ENFORCEMENT

5.3.1 Introduction

Recognizing the disadvantages of manual policing techniques in identifying and separating HEV from the other types of traffic on the SVL lanes lead to a search for other techniques that would yield automatic identification of such vehicles. Several different automatic identification technologies are currently in use by various industries.

Until recently, automatic identification of objects was dominated by bar code and optical character recognition (OCR) technologies. Both of these technologies suffer from two basic limitations that would render them unsuitable for automatic identification of HEV. These limitations are: a) relatively short read range and, b) poor readability under harsh environmental conditions.

Recently, however, a new technology, namely, radio frequency identification or RF/ID has emerged which shows considerable promise for use in automatic identification of HEV.

5.3.2 Radio Frequency Identification (Ref.26,27,28)

This relatively new technology, abbreviated RF/ID, is rapidly becoming the system of choice where harsh environments make optical based identification systems impractical. RF/ID is based on use of radio frequency (RF) waves to identify objects. It uses a tag or radio transponder on the object being tracked, the HEV in our case. The tag transmits encoded data over a radio channel and the signal is picked up by an antenna. This signal, which uniquely identifies the object being tracked, is then analyzed and interpreted for proper identification of the object.

RF/ID Basics

A typical RF/ID system consists of five components: transponder (tag), antenna, radio frequency module, reader, and computerized management system. Often times the antenna, the RF module and the reader are jointly referred to as the roadside communications unit (RCU). Figure 5.1 shows a typical schematic of the RF/ID system.

The tag is an electronic programmable field disturbance device. Each tag encodes a unique identification message on the carrier signal broadcast from a system antenna, and reflects the signal back to the antenna for decoding by the system. The antenna is a device used to broadcast and receive RF signals in a range of radio frequency bands.

Radio frequency module is a radio transmitter/receiver controlled by a reader. Upon command from the reader, the radio frequency module generates a radio frequency signal and delivers the signal to the antenna for broadcast. The radio frequency module then receives and demodulates the reflected tag signal returned through the antenna. The demodulated signal is pre-amplified and conditioned before being sent to the reader.

A reader provides the operational link between tagged vehicle and the host computer system. The reader receives a demodulated signal from the RF module, decodes the identification information, validates the identification code, and transmits the code along with any appended information to the host computer system. The reader also performs control operations specified by the user through reader commands.

The host computer system is the control center of an RF/ID system. It receives information from reader, processes the information according to the commands previously programmed, and provides commands for particular functions, such as opening or closing a gate, or alarming management personnel for unauthorized vehicles.

The five components of an RF/ID system work in concert. Each tag is attached to a vehicle and encoded with identification information about that vehicle. The tag is aligned to correspond to the system antenna alignment. As the tagged vehicle approaches an antenna, the antenna broadcasts a radio frequency signal toward it. The tag modifies a portion of the signal and reflects it back to the antenna. This reflected single carries the identification code for the object, the HEV in our case. The antenna transmits the returning signal to the radio frequency module. The module preconditions and amplifies the signal before sending it to

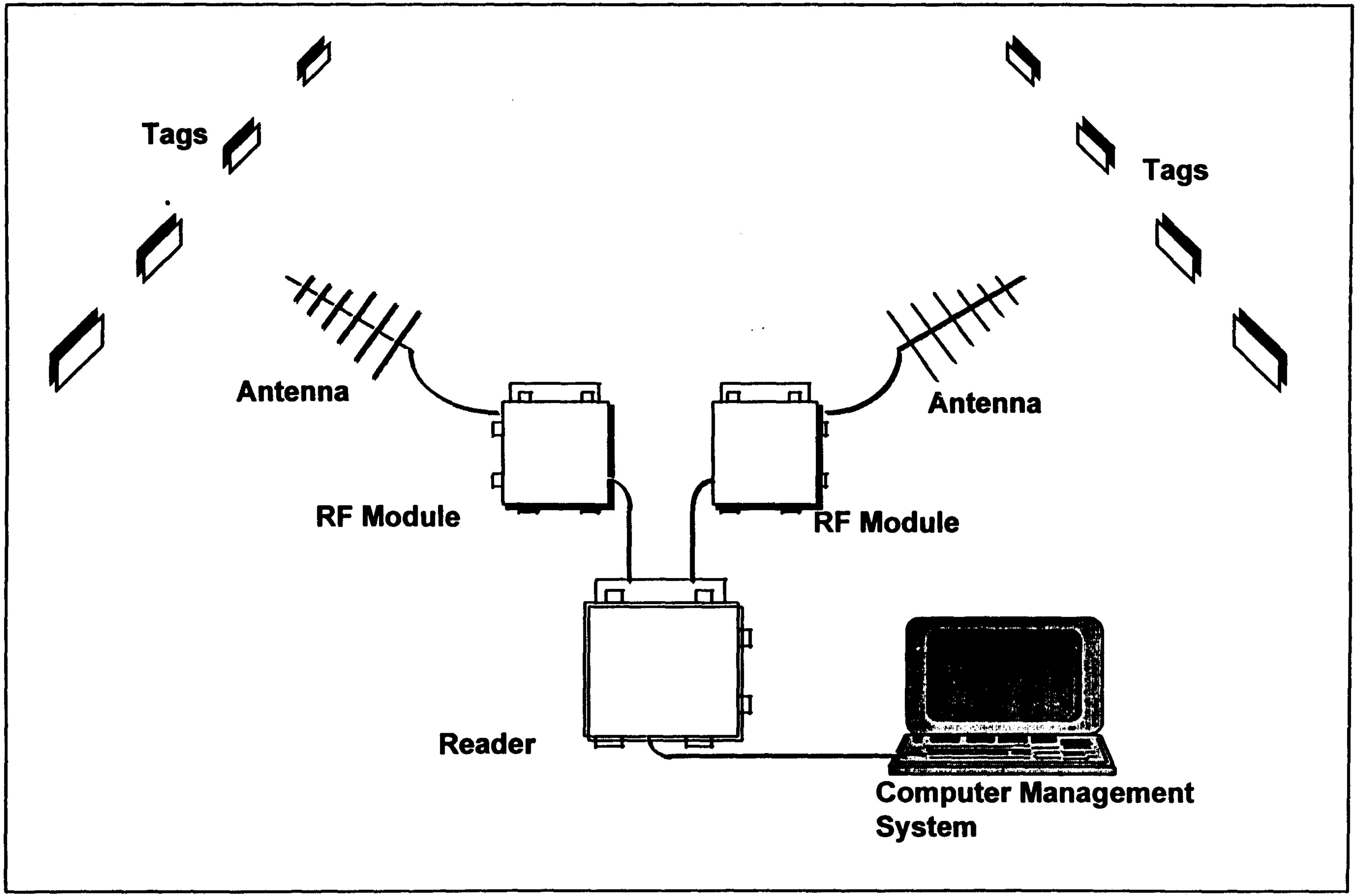

Figure 5.1. Typical Schematic of an RF/ID System

the reader. The reader then decodes the identification code and validates the code based on user-defined criteria. It can also append useful information such as time and date to the code and stores the code in an internal storage buffer and then transmits the code to a host computer for further processing.

Two different classification systems currently exist for classifying RF/ID tags. These include:

1. Read-Only vs. Read-Write Tags
2. Active vs. Passive Tags

Read-Only vs. Read-Write Tags

The read-only tags, as the name suggests, can only respond to the queries made by a reader. There is no way for the user to change the data recorded in a read-only tag. These tags are used only for transmitting a serial number to a computer which then links the identification tag number to the item being identified. Any action required based on the successful identification must then be commanded by the host computer. This is the type of tag most suitable for use in automatic identification of HEVs on the SVL lanes.

Read-write tags allow the user to modify the information they contain. Some read-write tags store hundreds or thousands of characters of information. These devices act as distributed data bases, containing instructions to be implemented by reading stations. Instead of merely transmitting an identification code that a host computer uses to look up a series of instructions for a work center, these tags may contain the instructions themselves.

One example application of read-write RF/ID tags is the vehicle-roadside communication (VRC) system as shown in Figure 5.2. The VRC system can communicate two ways between the tag on a vehicle and the host computer.

The tag used in VRC system contains a user-accessible memory which can store both fixed data and variable data. The fixed data, such as vehicle efficiency ID, is electronically locked during initial programming and cannot be changed except by authorized agents with a security-enabled master programming unit. The variable data, such as date, time, locations, and speeds, can be temporarily stored in the memory and can be retrieved by a radio frequency antenna for the next communication.

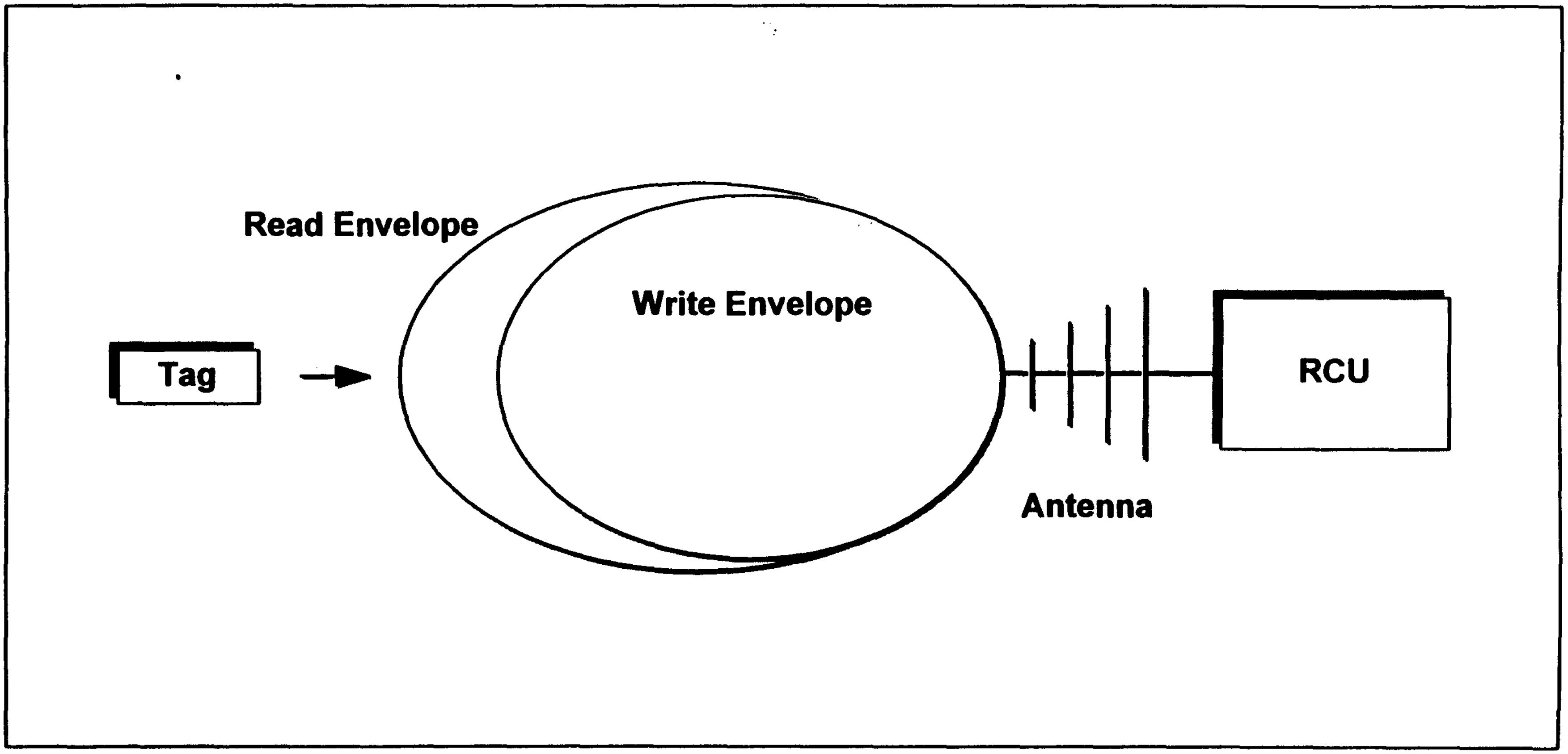

Figure 5.2. Vehicle-Roadside Communication (VRC) Sytem

As a tagged vehicle approaches the roadside communication unit (RCU), a presence detector signals the system to turn on and the unit sends out a signal into the designated area termed the "capture zone". Inside the capture zone, the tag first enters the "read zone", which is as large as the capture zone itself. The radio frequency signal encounters the tag and is returned to the roadside communication unit's antenna, along with the tag's identification and other data encoded in a simple modulation of the original radio frequency signal.

The roadside communication unit decodes and validates the identified tag for use in this system and determines the data to be written back into this tag. Then the RCU begins to transmit the write command, addressed specifically to the tag just read.

As the tag enters the smaller "write zone", and the strength of the radio frequency reaching the tag exceeds a certain threshold, a switch in the tag flips to permit the write transaction. The signal from the RCU is accepted by the tag and the new data is written into the tag's variable memory. To confirm the transaction, the RCU then reads back the ID, along with the new data in the tag, and compares them with the messages it sent. The entire read/write/verify transaction takes only a fraction of a second.

Active vs. Passive Tags

This classification system is based on how an RF/ID tag is powered. Passive tags require no internal power supply to transmit their information, while active tags contain batteries to do their jobs.Because they do not contain batteries, passive tags tend to be slightly better at handling extreme environments, especially high temperatures.

An active tag contains a battery, a small radio receiver and transmitter, and logic and memory chips. A lithium or polycarbon monofluoride battery is used to power the receiver and transmitter circuitry. Manufacturers claim that these batteries will last for 10 years or about 4 to 5 million read/write operations.

Some tags use the battery only to keep the memory active and rectify some of the power in the carrier of the reader to power the logic transceiver. Since these circuits only need to be active when information is being read from the tag, this approach conserves the battery's power without sacrificing performance.

A typical low-frequency (150 Khz or less) active RF/ID system has a range of between 3 and 15 feet. This range is suitable for most of automatic vehicle identification system. AM low-frequency tags are the least expensive but are the most prone to transmission interference.

FM high-frequency systems have a range of 100 to 150 feet and are highly noise-resistant. But these tags are among the most expensive. High-frequency systems are highly directional and can experience "cold spots" or null in the field due to reflection and wave interference.

The other type of tags used in RF/ID system is passive tags. These tags do not contain batteries at all and rely on the power they received from reader's radio frequency carrier to supply all of the tag's power requirements. Compared with active tags, the passive tags do not use relatively expensive batteries. As a result, these tags are less expensive than active tags. However, the passive tags have a much less operation range. A typical passive memory tag can operate up to 18 inches for a low-frequency system, or 30 feet for a high-frequency system.

CHAPTER 6
ENGINEERING ANALYSIS

6.1 OBJECTIVES

The primary objective of the engineering analysis was to develop a computer model that simulates the affect of shifting high-efficiency vehicles (HEVs) to the SVL on the total fuel being consumed by all vehicles operating on a freeway system. The model was developed in a general form so that any SVL system can be modeled. However, some pre-processing is required to determine the ultimate capacity of the SVL as defined in Chapter 4, "Special Vehicle Lane Capacity." The overall objective was to study the feasibility of introducing HEVs into the SVLs thus: a) relieving congestion on the main lanes, b) reducing fuel being consumed by the commuters, and c) providing incentive for the travelling public to purchase high efficiency vehicles.

6.2 ANALYSIS APPROACH

The approach adopted in performing this analysis was to transfer a percentage of the single occupancy main lane vehicles to the SVL as HEVs and determine the impact on the overall fuel consumption. This was done by taking into consideration the difference in the fuel consumption of the HEV and that of regular vehicles. A simulated overall reduction in fuel consumption rating was employed to account for congestion on the SVL as a result of its traffic level reaching capacity. However, this feature of the model was never used in the analysis since it was determined to be impractical for SVLs to approach the capacities of typical freeway lanes.

6.3 ANALYSIS ASSUMPTIONS

The assumptions made in developing the simulation model can be summarized as follows:

1. The average daily traffic (ADT) during the AM rush hour was used to determine capacity. This applies to the SVL capacity as well.

2. HEVs are defined as vehicles having a fuel consumption rating of 60 mpg and above.

Some preliminary investigations were done in order to gather data for the parameters needed for engineering analysis. A summary of the data gathered for Houston SVLs is reported in Table 6.1.

The traffic data and other parameters used in the analysis are reported in Table 6.2.

6.4 ENGINEERING MODEL

The basic flow of the simulation model algorithm can be summarized as follows:

1. Determine the amount of gasoline being consumed by both main lane as well as SVL traffic using their respective fuel economy ratings. This is done using the following equation:

$$\mathit{FUEL\ Consumed} = \frac{\mathit{Distrance\ Traveled}}{mpg}$$

2. Divert a percentage of the main lane traffic as HEVs to the SVL.

3. Determine the gasoline consumed by adjusted main lane vehicles.

4. Determine if the total SVL traffic exceeds the SVL capacity.

   a. If <u>not</u>, compute the gasoline consumed by the SVL traffic using their respective unadjusted fuel economy ratings.
   b. If <u>so</u>, adjust the fuel economy ratings for the SVL vehicles (including HEV) according to the assumed reduction scheme and compute their gasoline consumption using the adjusted mpg values. The mpg reduction factors are determined using the following equation (see Figure 6.1):

$$F_{mpg} = 1.000005P^2{}_{hov}$$

where, F_{mpg} = Mpg Reduction Factor, and
P_{hov} = Percent HEV over and above the SVL capacity.

The adjusted mpg of SVL vehicles can be computed using:

$$\mathit{Adjusted\ mpg} = F_{mpg} * \mathit{Unadjusted\ mpg}$$

Table 6.1. Houston Transitways Data Summary (Ref.29)

Parameter	Transitway				Average
	North	Katy	Gulf	Northwest	
Transitway Length[1], miles	19.7	13.0	15.5	13.5	15.4[2]
Car Pools (Peak Hour Max.)	1,165	983	964	1,465	1,144
Car Pools (Daily)	4,474	6,430	2,831	4,792	4,632
Daily/Peak Hour Ratio	3.84	6.54	2.94	3.27	4.15
Vehicle Trips[3] (Peak Hour Max.)	1,253	1,068	1,013	1,500	1,209
Vehicle Trips (Daily)	4,882	6,783	3,009	4,915	4,897
Daily/Peak Hour Ratio	3.90	6.35	2.97	3.28	4.13

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[1] Inclusive of future extensions.

[2] Considering Eastex Transitway future construction (20.0 miles), the average will become 16.3 miles.

[3] Includes buses and van pools.

5. Determine the total adjusted gasoline consumption and thus the resulting savings. The savings are determined in terms of amount of gasoline saved per day and per year, and the amount of dollars saved per year and as percent of fuel cost before introduction of HEV. The per day numbers are obtained by multiplying the peak hour numbers by a factor of 4 (see Table 6.1 where the daily to peak hour traffic is reported as 4.14 on the average for conditions in Houston). The per year numbers are obtained by multiplying the per day figures by 5*52 = 260 days (5 days/week * 52 weeks/year).

6.5 SAMPLE ANALYSIS

Figure 6.2 shows a sample run of the model. The following parameters, representative of average conditions in Houston (see Table 6.1), were used:

Existing Average Daily Traffic during AM Rush Hour

- Main lanes	7,200
- SVL	1,144

Miles per Gallon

- Main lane vehicles	20
- Existing SVL vehicles	20
- High efficiency vehicles (HEV)	65

Other Data

- Fuel cost per gallon	$1.05
- SVL capacity during AM rush hour	1,368
- Total one-way distance of travel	20 miles

The variables listed above will vary from one SVL facility to the next. However, the user can easily input the variables for the SVL being studied. With the above assumptions, the amount of gasoline being consumed by the existing vehicles before the introduction of HEV into SVL can be computed as follows:

Main lane vehicles = (20/20) * 7,200 =	7,200 gallons
SVL vehicles = (20/20) * 1,144 =	1,144 gallons
Total fuel consumed before introducing HEV	*8,344 gallons*

Table 6.2. Parameters used in the Engineering Analysis

Parameter	Value
Existing Average Daily Traffic (ADT) during AM Rush Hour	
Main Lanes	7,200
SVL	Variable
Fuel Consumption Rating (Miles Per Gallon)	
Main Lane Vehicles	20
Existing SVL Vehicles	20
High Efficiency Vehicles (HEV)	Variable
General Data	
Number of SVLs	Variable
SVL Capacity (ADT during AM Rush Hour)	1,368
One-Way Distance of Travel (Miles)	Variable
Fuel Cost (Per Gallon)	$1.05

The engineering model was written in Microsoft QuickBASIC. It is a straightforward menu-driven program and is very much self explanatory to operate.

Case 1. Total vehicles on SVL approach capacity

In this case, assume that 2.5 percent of the main lane vehicles (i.e., 180 vehicles) are transferred on to the SVL as HEVs. Since the total vehicles on SVL (1,144 + 180 =1,324) does not exceed the peak hour capacity of the SVL (1,368 vehicles), no adjustment to the fuel efficiency of SVL vehicles is needed. With that, the total fuel consumption of the freeway system can be computed as follows:

Adjusted main lane vehicles = 7,200 - 180 = 7,020
Main lane vehicles consumption = (20/20) * 7,020 = 7,020 gallons
Existing SVL vehicles consumption = (20/20) * 1,144 = 1,144 gallons
Gasoline consumed by HEV = (20/65) * 180 = 55 gallons
Total fuel consumed after introducing HEV 8,219 gallons

The amount of gasoline saved during peak hour and per day is thus computed as:

Gasoline saved during peak hour = 8,344 - 8,219 = 125 gallons
*Gasoline saved per day = 4 * 125 500 gallons*

Assuming 52 * 5 = 260 working days per year, the yearly savings are:

*Gasoline saved per year = 500 * 260 130,000 gallons*

With the assumed cost of fuel of $1.05 per gallon, the yearly savings for moving 2.5 percent of main lane vehicles as HEV to the SVL can be computed as:

*Yearly gasoline cost savings = 1.05 * 130,000 = $136,500*
*Percent Savings = (125/8,344) * 100= 1.5 percent*

Case 2. Total vehicles on SVL exceed capacity

When this study was first proposed, it was theorized that it would be permissable to allow substantially large numbers of HEVs to operate on the SVL. As a result, the engineering model was designed to simulate decreased fuel consumption of vehicles operating on the SVL when the capacity of the SVL had been exceeded. During the course of conducting this study, it was discovered that SVLs are intended to operate at levels substantially below capacity in order to entice commuters to opt for the increased time efficiency of the SVL. As a result, the sample analysis that follows is unrealistic. However, it is included here for informational purposes.

In this case, assume that 4.0 percent of the main lane vehicles (i.e., 288 vehicles) are transferred to the SVL as HEVs. Since the total vehicles on the SVL (1,144 + 288 = 1,432) now exceeds the capacity of the SVL (1,368 vehicles), an adjustment to the economy of each SVL vehicle is required to account for congestion. Using equation (6-2), the mpg adjustment factor can be computed as:

Vehicles over SVL capacity = (1,432-1,368) / 1,368 = 4.7 percent
Mpg reduction factor = 1 - 0.0005 $(4.7)^2$ = 0.989

With that, the amount of gasoline being consumed under the new scenario can then be computed as follows:

Adjusted main vehicles = 6,912

Main lane vehicles consumption = (20/20) * 6,912 = 6,912 gallons
Existing SVL vehicles consumption =
20/(20*0.999) * 1,144 = 1,145 gallons
Gasoline consumed by HEV = 20/(65*0.999) * 288 = 89 gallons
Total fuel consumed after introducing HEV 8,146 gallons

The amount of gasoline saved during peak hour per day is thus computed as:

Gasoline saved during peak hour = 8,344 - 8,146 = 198 gallons
*Gasoline saved per day = 4 * 198 = 792 gallons*

Assuming 52 * 5 = 260 working days per year, the yearly savings are:

*Gasoline saved per year = 792 * 260 = 205,920 gallons*

With the assumed cost of fuel of $1.05 per gallon, the yearly savings for moving 4 percent of main lane vehicles as HEV on to the SVL can be computed as:

Yearly gasoline cost savings = 1.05 * 205,920 = $216,216
*Percent Savings = (198/8,344) * 100 = 2.4 percent*

6.6 SENSITIVITY ANALYSIS

A sensitivity analysis was performed to better understand the impact of selected variables on the results of the model. The following key variables were analyzed:

1. Fuel economy rating (mpg) of the HEV

2. Existing traffic on the SVL (before transferring HEV)
3. Average trip distance by all vehicles
4. Capacity of SVL

Figures 6.3 through 6.6 show the effect of the above factors on the saving in fuel consumption. The savings are reported both: a) as a percent of the fuel cost before introducing HEV into the SVL, and b) as total gallons of fuel saved per year. The following observations are made:

1. The amount, and hence the percent, of savings in fuel consumed increase linearly with an increase in the number of vehicles transferred to the SVL as HEV. As formulated, the savings start to decline as the capacity of SVL is exceeded and eventually a reversal is observed.
2. Higher overall savings are observed for HEV with higher mpg ratings.
3. Lesser savings are realized as the existing traffic on the SVLs is increased with a much quicker reversal in the trend, as expected.
4. The distance travelled has a significant effect on the total gallons saved although not affecting the percent cost saved.
5. Higher savings are realized as the capacity of the SVL is increased.

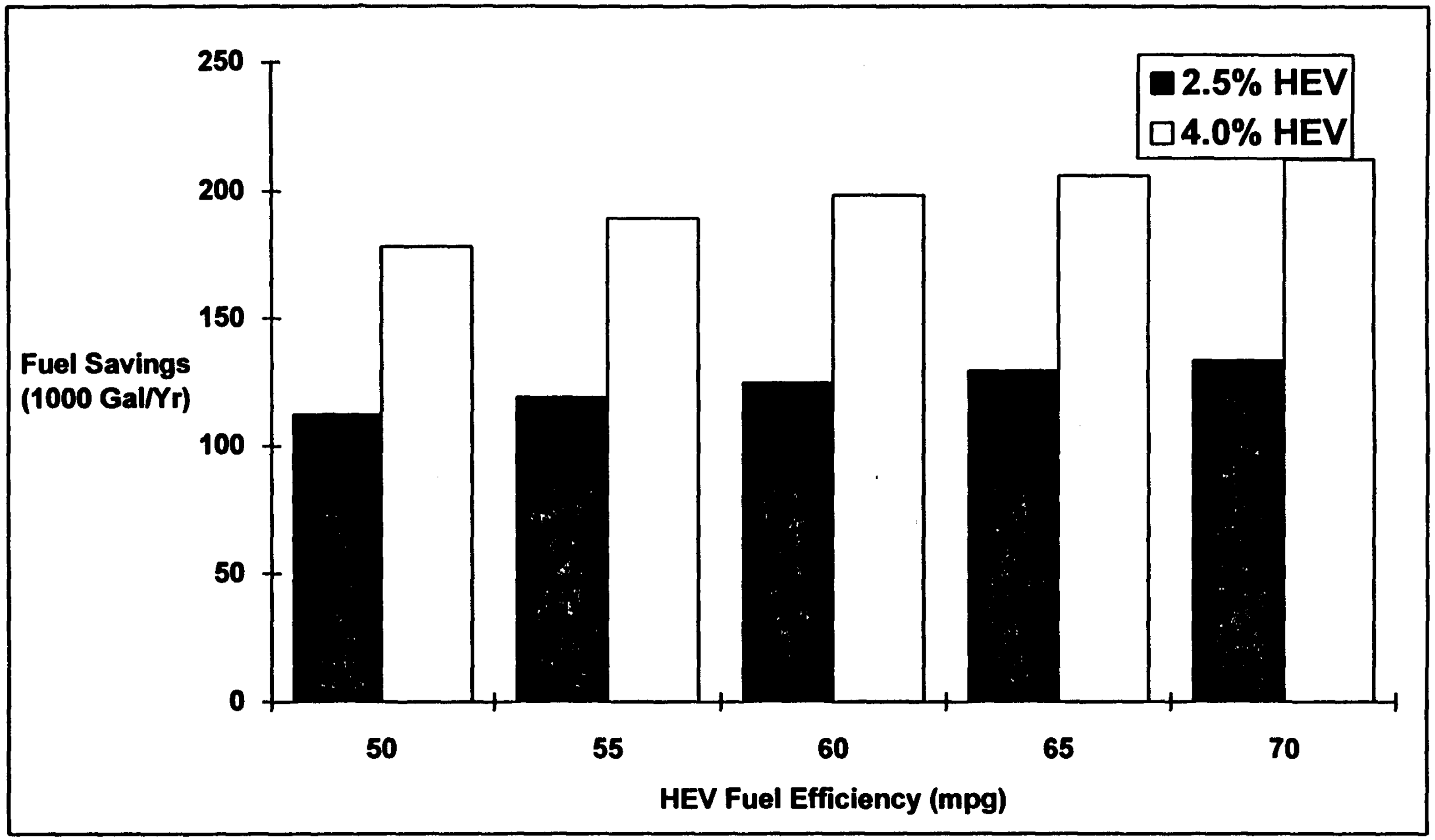

Figure 6.3. Effect of HEV Fuel Efficiency

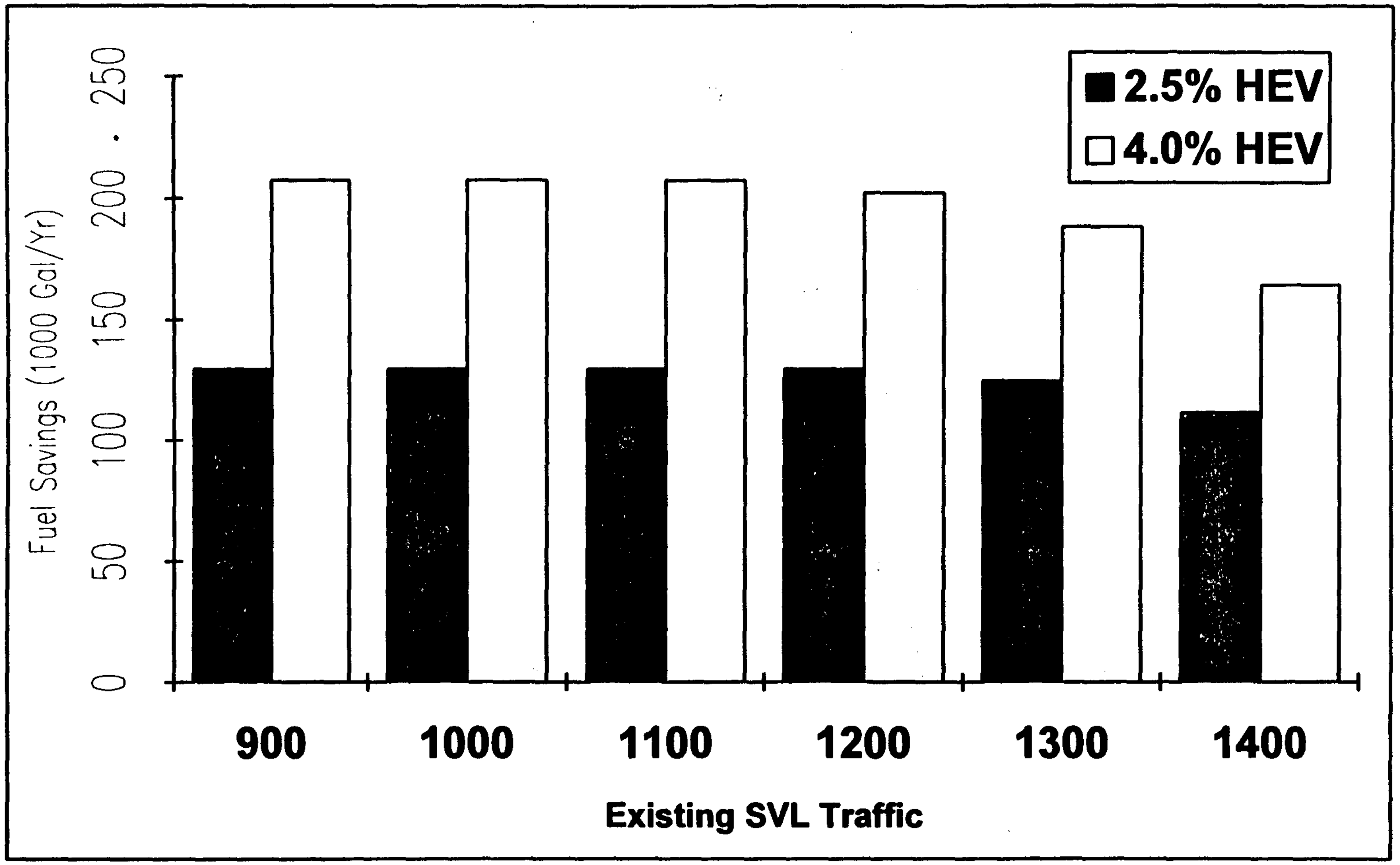

Figure 6.4. Effect of Existing SVL Traffic

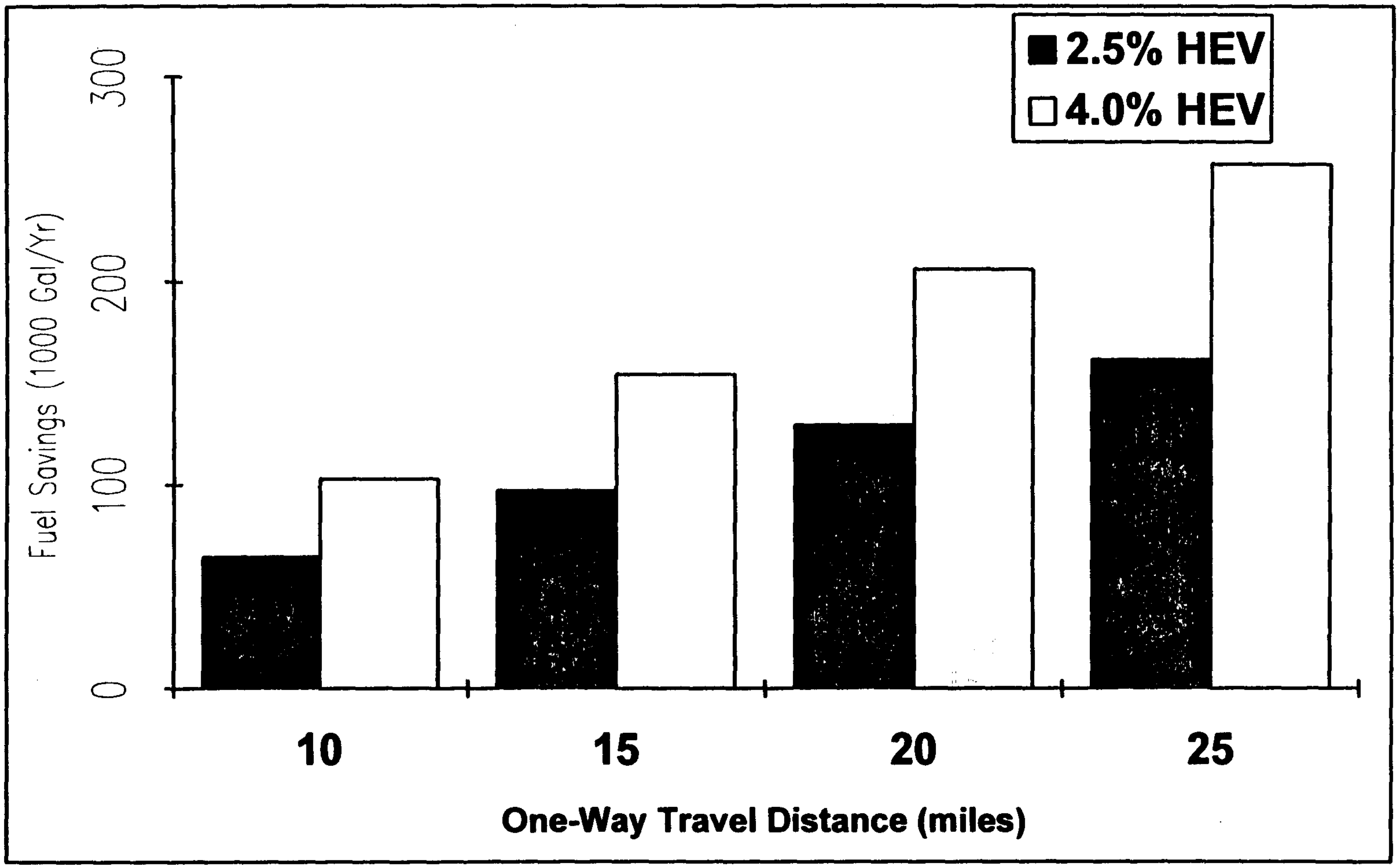

Figure 6.5. Effect of Travel Distance

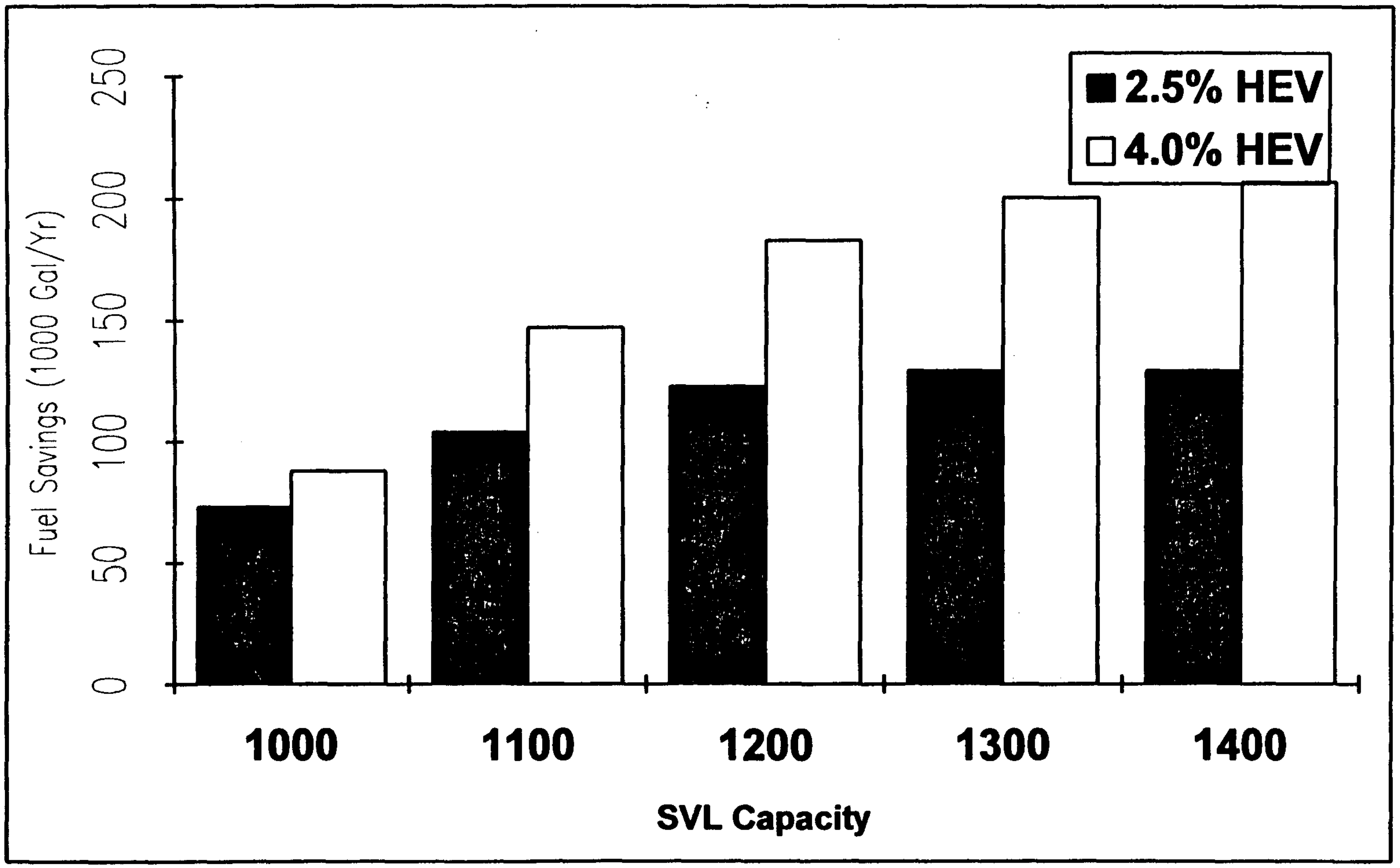

Figure 6.6. Effect of SVL Capacity

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

A considerable amount of knowledge related to operational characteristics of SVLs was gained as a result of this study. SVLs are often referred to as HOV lanes, bus lanes, or transitways. There are presently 49 separate SVL facilities making up 380 miles of freeway in over 22 cities throughout the United States (Turnbul, Ref.12). By the year 2000 the number of SVL lane miles is expected to increase to over 1000.

The general consensus has been that despite some obvious shortfalls, SVL facilities have been successful at reducing congestion on major urban freeways by providing a transit alternative to commuters that offers the distinct advantage of reduced travel times. In essence, the driving force behind adoption of SVLs has been reduced congestion on major urban freeways throughout the U.S. Nevertheless, these SVL facilities offer several additional benefits as well. Fuel consumption, and thus CO_2 emissions, are reduced due to the reduced VMT, shorter response time for emergency vehicles, and increased safety. However, these benefits are considered extraneous and very little justification for SVLs has been placed on any benefit other than reducing congestion.

This study attempts to address an area of research regarding the use of SVLs as a tool for conserving energy. Although historically, energy conservation has been a significantly lower priority than reducing congestion, in recent years there has been an increase in environmental awareness of air quality in the large urban areas. The result has been increased pressure to reduce CO_2 emissions through reduced vehicle emissions..

One alternative for doing so is to allow either high efficiency vehicles, ultralight vehicles, or electric vehicles the privilege of operating on SVL facilities.

7.1 POTENTIAL ENERGY SAVINGS

The results of the analysis conducted in this study confirm that over 600,000 gallons of gasoline per year could be saved in the Houston area alone using only the existing SVLs. This figure is increased substantially when you consider adding additional lanes to the existing SVLs. Although consideration of construction and operational costs of adding additional lanes was beyond the scope of this study, the analysis of fuel consumption suggested an energy savings of over 5,000,000 gallons annually, by adding one additional lane to each SVL facility in the Houston network.

Since the cost of adding an additional lane to each barrier separated SVL in Houston would be substantial, the feasibility of such an approach is not clearly understood. However, an additional service lane can be added on non-separated facilities at much lower costs, since construction techniques are typically simpler. Unfortunately, the advantage of barrier separation, which is an attractive SVL characteristic to electric and ultralight vehicles, is not available in the non-separated facilities. Buffer separated facilities may be a suitable compromise for HOV, ultralight, and electric vehicle operations. Buffers provide an added element of protection to the vehicles operating in the SVL without the substantial cost associated with the barrier construction.

7.2 POLICY STATEMENT FOR IMPLEMENTATION

The following is a brief statement regarding potential implementation of the results obtained during this study. It is perceived that the implementation recommendations contained in this statement are reasonable and could be implemented with little or no risk to the state.

Like in the case of motorcycles, SVL operating privileges should be immediately granted to electric vehicles and ultralight vehicles statewide. Presently there is a substantial amount of unused capacity on SVLs throughout Texas that could accommodate these vehicles and their use would work to achieve the goal of reducing CO_2 emissions in the metropolitan areas. The number of qualified vehicles should be limited should the capacity of SVLs be reached. Qualified electric and ultralight vehicles should be given an identification sticker that identifies them as such. This sticker will allow for easy identification of approved vehicles and will work to reduce enforcement costs.

A research study should immediately be conducted to investigate the feasibility of adding additional lanes to existing SVLs and identifying additional freeways that may be conducive to non-separated, or buffer separated facilities that would add the capacity necessary to accommodate all designated high efficiency vehicles (HEVs).

7.3 RECOMMENDATIONS FOR FOLLOW-UP RESEARCH

Creating a "special" operating privilege for carpools and transit vehicles on major urban freeways has been a moderately successful tool for reducing congestion. These "special" privileges should be investigated further to determine if they should be used to either: 1) reduce CO_2 emissions, or 2) reduce fuel consumption. Although historically, these items have not been given much consideration in the policy making process, there are a number of signs that suggest that this is going to change. Therefore, a more in depth feasibility study similar to the one proposed herein is justified.

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