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THE IMPACT OF THE NE PACIFIC STREET HOV FACILITY

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16. Abstract

Arterial High-Occupancy-Vehicle (HOV) Lanes are used infrequently because of lack of space for lane conversion, problems with access to abutting property, and construction difficulty near intersections. However, Arterial HOV lanes can be a practical method of addressing arterial capacity issues in face of environmental and fiscal constraints in roadway system development. In Seattle, HOV lanes already exist in the Central Business District (CBD), Aurora Avenue (SR 99) and Lake City Way (SR 522). Because congestion was a major problem in the south and east corridors of the University District in Seattle. a NE Pacific Street HOV Lane was built and has been in operation since September 1991. The present study is the after study of the NE Pacific Street HOV lane, based on an earlier study in 1992.

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CHAPTER 1

ARTERIAL HOV FACILITIES

INTRODUCTION

Arterial High-Occupancy-Vehicle (HOV) Lanes, while not a new development, are infrequently used because the differences between an arterial and a highway dictate extra considerations prior to implementation. One major difference is the lack of space to add a lane in arterial environments as opposed to the highway where there is usually a shoulder available for conversion. Other differences that distinguish arterial HOV lanes from highway HOV lanes are the necessity to provide access to abutting property and the turning movements associated with accommodating this access. Having to deal with intersections are major concerns also. Additionally, the difference in speed between the priority lane and the general traffic lanes can affect the perceptions of concurrent-flow traffic and those motorists traveling in the opposite direction who are attempting to turn.

Arterial HOV lane use on arterials is undergoing careful investigation in urbanized areas, such as the Metropolitan Seattle area, where increased road capacity is a primary concern. HOV lanes are a practical method of addressing capacity issues, especially when environmental and fiscal constraints are factors in roadway system development. The capacity term used here is defined in terms of people-moving capacity versus the traditional concept of vehicle-moving capacity. It is possible to apply the theoretical premise that has been used for highways as a basis for the implementation of arterial HOV lanes, but the differences must be considered as well.

In the Central Business District (CBD), priority lanes are primarily dedicated for bus usage only, while non-CBD areas accommodate carpools more often. The percentage of buses in an area is a major factor to consider when trying to determine the capacity of downtown streets. If the number of buses traveling in a lane can be reduced, the vehicular capacity and the overall running speed can be improved. Bus percentage is one of the factors involved in determining capacity in the Highway Capacity Manual calculations that reduces the vehicular capacity of the lane.

SEATTLE ARTERIAL HOV LANES

In Seattle, HOV lanes already exist in the CBD as well as in the northern portion of the city. HOV lanes exist on Aurora Avenue (SR 99) and Lake City Way (SR 522). Three priority lanes exist downtown on 2nd, 4th , and 5th Avenues, but they are designated for bus use only. The 5th Avenue priority lane is a contra-flow lane for bus use throughout the day, while the 2nd and 4th Avenue priority lanes are used during the AM and PM peak periods from 6:00 - 9:00 AM and 3:00 - 6:00 PM.

METRO INVOLVEMENT

On November 3, 1988, the Council of the Municipality of Metropolitan Seattle (METRO) approved the University District Program Action Plan which called for the construction of the Northeast Pacific Street High-Occupancy Vehicle Lane [1]. In the Agreement between METRO and the City of Seattle [2], it states that "the construction of an eastbound high-occupancy vehicle lane on Northeast Pacific Street would increase the efficiency of said thoroughfare, reduce transit operating costs, and provide incentives for the greater use of buses, carpools, and other rideshare vehicles." This lane is the major Metro-funded element in the University District Transportation Program (UDTP). The total cost of the HOV project, including construction, construction management, and inspection was estimated to be $2,228,000.

PROBLEM STATEMENT

Congestion is a major problem in the south and east corridors of the University District. In particular, the intersection of Montlake Boulevard and NE Pacific Street is one where there is a high level of delay for motorists. Because of the constraints of no new bridges being built nor expansion of the Montlake Bridge, there is difficulty in obtaining more traffic capacity for this area. To compound this problem, the Montlake Bridge is a drawbridge that increases delay time for motorists when it opens to serve the boat traffic which uses the Lake Union Ship Canal. The restriction for the bridge does not allow for bridge openings from 3:30 PM to 6:30 PM, and this is obviously done to reduce the adverse impacts that would be associated with the heaviest volumes and densities with a roadway that is not passable.

To provide the potential for greater person-movement capacity in the southeast corridor of the University area, an HOV lane has been built on NE Pacific Street, and it has been in operation since September 1991. The before study of NE Pacific Street has been done and it includes an extensive data collection effort as well as simulation modeling. With the completion of the after study of this project, a better understanding of the arterial HOV lane concept should be gained.

PROJECT BACKGROUND

In the thesis by John E. Davis - "The Study of the Planned NE Pacific Street HOV Facility" [3] - the first part of a Before-and-After research project has been performed with a study that forecasts the impacts of the facility. The study is part of an overall HOV incentives research project at the University of Washington with Dr. Nancy Nihan of the Department of Civil Engineering as the principal investigator. This HOV lane, which is approximately a 1/4 mile in length, serves as a queue bypass with an advanced-green phase at the intersection of NE Pacific and Montlake Boulevard for the priority lane. An after study is needed to evaluate the arterial HOV lane, and this is it.

Since the University of Washington is planning to expand its facilities, there is concern about greater demand being placed on the transportation system. How does an area grow without adding additional vehicular traffic to the area? This would suggest the need of a systematic means of inducing more people to share the ride in a motorized vehicle or investigate the walking or bicycling modes. If the University exceeds a certain traffic limit which has been imposed by the City of Seattle, it will have to pay a percentage of the costs of any improvements on the system. With this in mind, greater utilization of the traffic system with regard to movement of people rather than vehicles is a primary motivation for wanting to implement an HOV lane.

Another issue at hand is that of the use of *UPASS* [4]. *UPASS* is a transportation management program developed by the University of Washington in conjunction with METRO to provide University students, faculty, and staff incentives for riding the bus and carpooling. It includes daily discounted parking passes, preferential parking for carpoolers, reduced fares for bus riders and a host of other Transportation Demand Management (TDM) strategies that assist in providing people transportation options. The issue of the presence of the *U-PASS* raises concern in that it will be a contributing factor along with the HOV lane in attracting motorists to carpool and take the bus versus being able to attribute success/failure to the HOV lane alone.

Objectives of HOV Facilities

The overall objective of HOV facilities is to facilitate a more efficient transportation system by increasing the person-carrying capability. That is the goal for this corridor of the University District, whether it be by carpool, vanpool, or transit. Modal shift is a major objective of the HOV facility also.

The location of NE Pacific Street and the surrounding network is shown below in Figure 1.

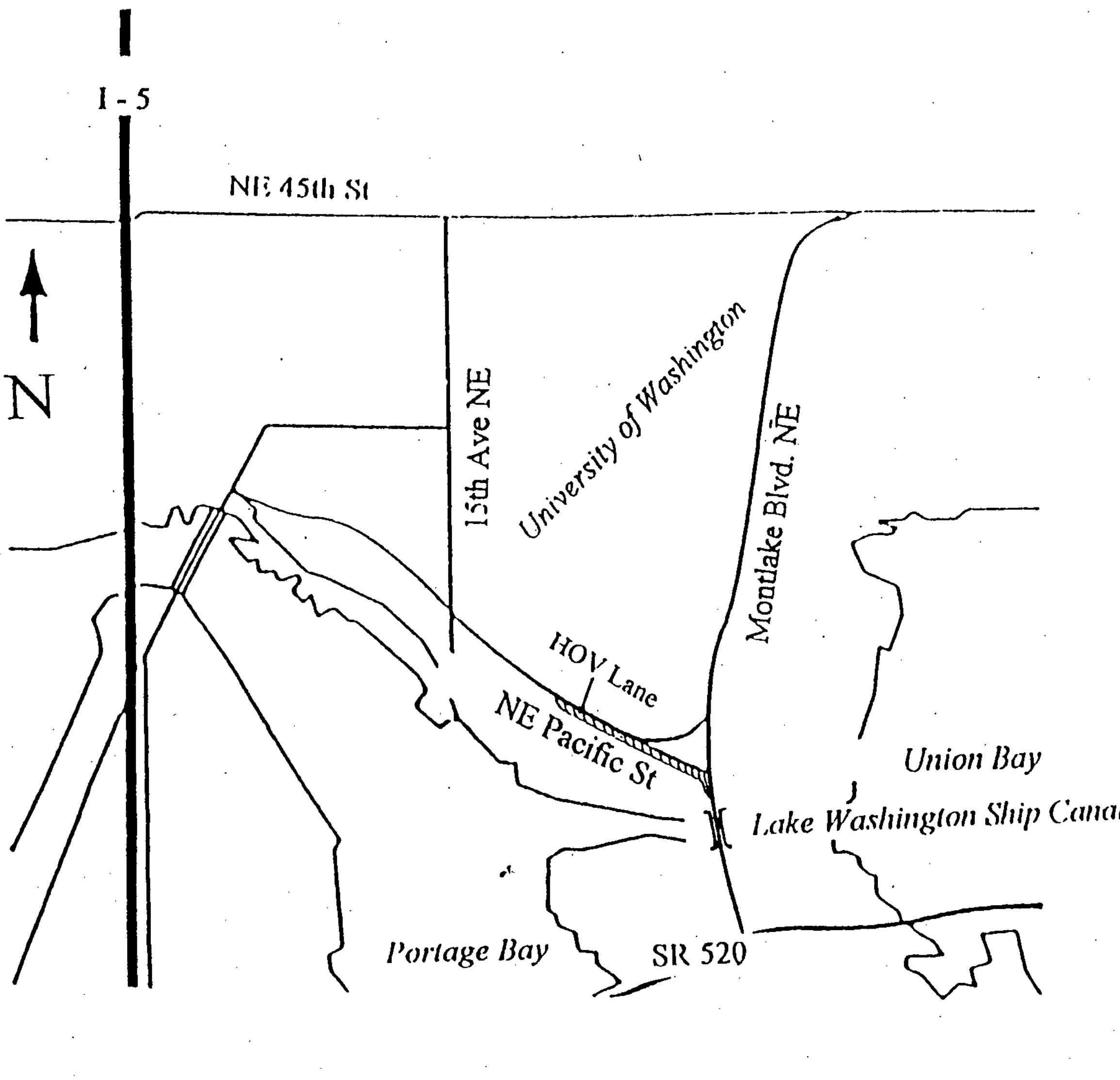


Figure 1: Roadway Network in the University District

DEVELOPMENT OF FOLLOWING CHAPTERS

The following chapters provide the findings of the literature review, data collection, and statistical analysis involved in this project. The literature review is found in Chapter 2. The literature review is designed to build upon the Davis study [3] and investigate recent studies of concerns such as development strategies, safety, enforcement, planning/design, applications, environmental issues, and the societal outlook. Replicating the data collection method was of vital importance in regard to time and locations to obtain a true comparison for evaluation. The data collection method of timing as well as locations are described in Chapter 3. Data was collected during the Spring Quarter 1992 by a team of civil engineering students from the University of Washington on NE Pacific Street and Montlake Boulevard. Chapter 4 provides the results of the study along with the statistical tests of the various hypotheses. This is the core of the study. From this section, the hope is that there is evidence, although maybe not the strongest, of a successful program of implementation through a rigorous Before & After Study. The project's outcome is important because it will provide the opportunity of sharing an arterial HOV experience for other potential sites since Seattle is continuing to expand its HOV lane system. Integration of arterial lanes into the extensive freeway HOV lane system will provide greater system continuity. Finally, Chapter 5 provides the conclusion of the study as well as recommendations.

CHAPTER 2

STATE OF THE ART LITERATURE REVIEW

INTRODUCTION

Congestion is a major concern facing most of the urban areas in this country. Creating more capacity by adding another general purpose lane is not the only answer any more because of the lack of funds or because of constraints due to the topography or development in areas. One popular method of addressing the congestion problem is that of High-Occupancy-Vehicle (HOV) Lanes. The idea is not a new one, but it is a major issue for areas trying to reduce congestion, especially with terms given in the Intermodal Surface Transportation Efficiency Act (ISTEA) that states that if a new build project is to be allocated funding, it must include the capacity to be a more efficient people-mover. Theoretically, HOV lanes provide better efficiency for the roadway in terms of people-moving capability due the higher average vehicle occupancies. Presumably, this will yield lower volumes of traffic, but this is not always the case with HOV lanes by themselves. Supporting facilities such as Park & Rides and TDM policies have to be in place along with a well-informed public audience -- the ones who will utilize the facility. Ultimately, the extent to which the HOV lane is a viable solution in tackling the congestion problem will depend on how well the lane is used and how well that it is used as intended.

In terms of HOV facilities, there is a wide variation in the types of facilities that can be found. Although there is a plethora of information available on freeway HOV facilities, it is just the opposite for the arterial HOV facilities. The goals of the two different types of facilities are very similar as well as the measures of objectives and the theoretical nature of the two. From this viewpoint, the nature of the findings of the literature will be treated similarly with adjustments as needed for the different types of roadways. In this review of the literature, information will be included about the various issues that play a role in making HOV lanes work effectively and safely as well as their future applications as portions of improvements to the transportation network.

HOV LANE BACKGROUND & DEVELOPMENT

The state of Washington is one of the leaders in the country in HOV lane development, and there is a plan for an extensive HOV system [5]. Most of this development is occurring in the Metropolitan Seattle area. Although, most of the HOV lanes in this area are on the freeways, there are a few arterial segments that already exist. An effective HOV system will link key arterial segments into the freeway HOV lanes. Determining these segments is integral for optimal use of HOV lanes.

HOV Lanes...Why?

Christiansen [6] investigated six areas in the United States committed to an extensive system of HOV facilities and noted several reasons found as a basis for utilization of HOV lanes. They are noted below.

- Low risk and affordable
- Low operation cost/passenger
- Relatively quick implementation time that can be staged.
- Serve wide variety of trip patterns
- Compatibility with the Intelligent Vehicle Highway System(IVHS) program
- Compatibility with the New Clean Air Act
- Reduction in energy consumption.

- General public support.
- Recognition in the National Transportation Policy

Along with these issues, they also have a wide variety of funding sources. They also provide flexibility in their usage. An example of the HOV facility flexibility is in Seattle where they have plans to convert the bus tunnel to Light Rail Transit in the future [7].

It is one thing to want to build an HOV project, and yet another to build a successful project. In the study by Turnbull and Christiansen [8], successful projects were studied around the country to determine what makes a successful HOV project. Their study took the project from the decision-making process through the implementation process. From their study, the following characteristics were found to be significant:

Decision-Making Process

- Corridor and areawide traffic congestion and growth in travel demand
- Lack of fixed-guide way transit plan for the corridor
- Planned or scheduled highway improvements
- Project champion or champions in positions of authority
- Legislative direction and agency policy support

Implementation Process

- Lead agency
- Interagency cooperation
- Joint funding
- Flexibility and adaptability
- Support of federal agencies

The study suggests a framework for those places that would like to work with the HOV idea, and maybe suggests how to improve other planned projects that are going nowhere. It also suggests that teamwork is necessary to accomplish an effective project.

ARTERIAL HOV APPLICATIONS

The best way to determine whether HOV lanes will be successful or not is to put them into operation. HOV applications provide information on what works and what does not although each situation is unique. The Batz study [9] is the most comprehensive view of arterial HOV facilities in the United States. Turnbull [10, 11] provides a description of the different types of HOV facilities in North America and internationally. They vary from peak hour/period operation to 24-hour operation and from exclusive right-of-way to non-separated facilities. In general, applications provide ideas for others who may want to implement a facility, although there will have to be modifications that suit their location best.

Applications of arterial HOVs and HOV treatments have been investigated by examining HOV/priority lane use throughout the world. This will lend an idea of what is going on technique-wise in regard to implementing the arterial HOV lane. Also, it will provide a means of looking at new technology if available. Reserved bus lanes exist world-wide and have been used in densely populated urban cores. They have also been implemented outside of the CBD in recent years. Because of these lower densities, carpools and vanpools have been utilized in some situations.

Arterial HOV treatments can be grouped by various characteristics. The groupings are as follows [12].

- Separated, non-separated
- Unidirectional, reversible
- Contra-flow, concurrent flow
- Median lane, curb lane
- Buses only, buses and carpools/vanpools
- Spot-application
- Peak period, 24 hour
- Signal progression, signal preemption; and
- Queue by-passes

For bus operations, Davis[3] notes Levinson's [13] proposal of the following suggested criteria for a successful arterial HOV curb lane.

- 30 to 40 buses per hour
- 1200 to 1600 passengers per hour
- potential time savings of 1-1/2 to 5 minutes per mile; and
- at least two other lanes still available for other traffic.

Improving bus reliability has seemed to be a major goal with arterial HOV efforts, and transit agencies should take advantage of this finding if they want to improve their service. With the above suggested criteria, the HOV lane will definitely be perceived as being used, and that is important when it comes to the public's response to HOV treatments.

Some applications with their travel time savings are provided in Table 1. indicating what has occurred at various locations in the United States [14].

The range of length varies from 2.0 miles to 9.9 miles, while the travel time savings ranges from 0.02 to 1.4 minutes/mile.

Table 1. Arterial HOV Applications of Travel Time Savings

Project	City	Length (mi)	TTSavings (min/mile)
NW 7th Avenue	Miami	9.9	0.65
South Dixie Hwy	Miami	5.5	1.3
Harry Hines Boulevard	Dallas	2.0	0.40
Fort Worth Avenue	Dallas	2.0	0.02
York Road	Baltimore	6.5	0.05
Kalanianaole	Honolulu	2.5	1.3
Arlington Boulevard	Arlington	4.5	1.1
Wilson Boulevard	Arlington	3.5	1.4

Applications of arterials vary and are usually site-specific in that it is difficult to have the same conditions in different locations. Politics are different also, and that can frequently come into play as well as the attitude that the public has about HOV lanes. Travel time savings is usually the main benefit sought after in HOV lane implementation, although other objectives benefit as well.

Various cities throughout the United States and abroad have arterial HOV lanes. Sometimes they are accompanied by special signalization, whether it be pre-emption techniques or advanced phasing. More arterial HOV projects are planned for the near future. Studies include the following cities: Minneapolis, MN; Denver, CO; Los Angeles, CA; Chicago, IL;

Bremerton, WA; and Seattle, WA in the United States. Auckland, New Zealand is included as a representative of non - North American cities.

Minneapolis

An example of contra-flow HOV lane usage on arterials can be found in Minneapolis [15]. The reason for even coming up with this type of usage was due to an increased demand of transit vehicles on downtown streets. It was also a necessity in handling the growing need for use of transit to meet the capacity constraints of the existing roadways and ease congestion. One-way street pairs were tried initially, but that did not work. The next thought was to explore one way reversible flow transit lanes on Marquette Ave and Second Street. With this idea, safety issues for pedestrians and driveways came into play. A temporary set-up was demonstrated initially by using traffic signals, signing, and painted islands along with barricades/drums rather than a concrete raised island. The operation was a success, and then it was made permanent. They received Federal Aid Urban Funds and local funds in the amount of $770,000, and they built a permanent concrete island to separate the bus traffic from the automobiles along with the signing and signals that were needed. During the peak period, Marquette Ave alone was carrying over 120 buses per hour. Some adjustments had to be made in the system, and now these two streets only carry express routes while Nicolette Mall, a retail street in downtown Minneapolis carries the local routes. The local route buses currently using the bus lanes and the express buses currently using the bus lanes will be terminated at both the south and the north end of downtown with users transferred to an alternative-fueled Nicollet Mall Shuttle vehicle. The shuttle will operate on a 45 second or 90 second headway carrying patrons along the Nicollete Mall for distribution to the various businesses and offices along the route. This is similar to a condition in Denver in their successful 16th St. Mall. Due to the success, Hennepin Ave has also was constructed with reversible flow lanes.

Regular hours allow the use of these lanes to taxis and delivery trucks. Emergency vehicles are allowed to use the facility during any time except peak periods. Carpools and vanpools are not allowed to use this excess capacity during the peak period.

The transportation management plan for I-394 between downtown Minneapolis and I-494 to the west is to create parking garages for HOV users to encourage transit, carpool, and vanpool from home to the workplace [15]. The reverse flow lanes on the freeway are called "Sane lanes." The garages will be connected to the downtown core by overhead skyways, as well as by the MTC dime zone bus operation. The transit operations will operate at street level as well as the freeway level. A major incentive for HOV use is a parking rate of $10 a month for HOV users, while the parking rate is $80 a month for SOVs. Development is also being encouraged around these parking garages. They reported $200 million of development as of the time of this article. This is a good example of integrating the transportation system to work jointly.

Denver

This example is yet another of transit use in the CBD. This is the primary use of arterial HOV applications in the city. At least, transit seems to get the most benefits from HOV lane utilization. The example is the Lincoln-Broadway bus lane corridor [16].

The Lincoln-Broadway bus lane corridor is 2.3 miles in length. Broadway operates in the SB direction in a five-lane configuration, with curb parking on both sides of the street. Lincoln operates in the northbound direction with a four-lane section south of Speer Blvd., 1.7 miles long, and a five-lane section north of it. North of Speer, on Lincoln, there is curb parking on both sides of the street, while south of Speer, curb parking is on the east side during off-peak periods. North of Speer, the bus lane is the second from the right lane. On Broadway, the bus lane is on the right side adjacent to the parked cars.

Enforcement is controlled by the City of Denver and the court system. Violators are those who:

1) drive for several blocks in the lane
2) use the lane as a queue by-pass, or those who drive a few blocks with right turn signal on
3) leave a car parked in the lane during the restricted period.

Because of this area being a residential area, there is resistance by residents to enforcing the 7AM rule. Parking is allowed from 6 PM to 7 AM. Of course this is another issue that has to be addressed when dealing with arterial streets.

Transit trips through the Lincoln-Broadway corridor have been two minutes faster than the auto trip, and the length of the lane is 2.3 miles. This provides a 0.87 minute/mile savings ratio. Transit person trips have increased by 22% since 1974. Since 1985, employment in the Central Business District has decreased by 15%. Transit operations have improved in terms of more reliability, more consistency, and more predictability. They operate inbound and outbound in the PM peak with the ability to have the same bus return and carry a second or even a third trip.

Chicago

In Chicago, they were looking at the implementation of traffic signal pre-emption and HOV lanes. The overall project is called "Operation Green Light" (OGL), and it is a system of planned demonstration projects [17]. The project was still in the developmental stage in Northeastern Illinois at the time of this report in 1990. These are, however, two important elements of an evolving comprehensive plan they have come up with to control the growth of congestion.

To promote these OGL transit goals, the Illinois Department of Transportation (IDOT) has set aside $75 million in its five-year program to implement capital projects that emphasize innovative approaches to enhance transit ridership. OGL is a plan to identify and combat the urban congestion problem from a localized traffic operational problem by obtaining participation from private and public sectors - the developers, municipalities, transit, and the highway. The plan was created in winter of 88/89 through the effort of the IDOT, the Illinois State Toll Highway Authority, the Regional Transit Authority, the Chicago Area Transportation Study and the NE Illinois Planning Commission. It complements their 2010 Transportation System Development Plan which identifies needs of major highway/transit expansion needs during the next 20 years.

One pre-emption system that they define is an application of the emergency system that uses strobe lights to trigger a green signal as the vehicle approaches the light. A great deal of cycle time is lost in this method if overused by the transit vehicles. This is something that a city may use if they can place constraints on the controller system in terms of transit usage.

Another pre-emption technology that is defined is one that utilizes detector loops in the pavement that are activated by programmable transponders on moving vehicles [17]. Traffic engineers find this system very familiar due to the extensive use of detector loops in most areas. Use of induction loops can provide precise control of the location and programming of the pre-emption signals. Each intersection can be set to provide different responses to requests for pre-emption, depending on existing conditions at that location at that time of day.

A system using transponders has the ability to receive and send messages and has computerized control with considerable storage capacity. A bus can be programmed with its schedule for the day. As it reacts with the intersection's controller, the bus can calculate its on-time performance and limit the pre-emption signals to those times when the bus is behind schedule. This enables traffic engineers to know more precisely when the system is being used. In this situation, the buses that are late get signal priority, while others that are on time or ahead of schedule flow as the signals dictate. These buses are equipped with transponders.

Certain corridors were chosen to perform tests with pre-emption without rigorous criteria, but because transit operators were having difficulty operating efficiently in traffic. One location that was chosen was the Cermak Road Corridor which is a major arterial having an ADT volume of 25,000 and intersecting streets with varying volumes from 5,000 to 35,000 daily. The corridor is located in three suburban communities and is lined with retail activity in a combination of strip shopping and shopping centers. One CTA route and two Pace routes run along the corridor, and 3 other Pace routes intersect the corridor. They approximate equipping 25 buses with transponders.

South Michigan/119th Street Corridor has a total of 20 signalized intersections and street volumes are 12,000 daily with intersecting street volumes varying from 1500 to 20,000 daily. This route is also served by Pace and CTA buses, and they estimate needing 47 transponders on buses.

They will measure success with terms of schedule adherence, before/after travel times and speeds, perceptions of motorists, passengers and bus operators, impacts on intersecting streets, ridership and reliability of equipment.

Chicago is a city that has a different existing situation than many of the cities trying to implement HOV lanes in that they built rail transit into the median of some of their freeways. There are currently three expressways to downtown Chicago that have rapid rail transit in their medians. They do not want to disturb the rideshare of the transit users, but would like to alter the SOV usage. This is a sensitive issue here that should be treated with care. Treatments that are being considered are those of special access at train stations, by-pass lanes at bottlenecks, and lanes to bypass queues at ramp metering signals that will promote transit usage and ridesharing activities while not threatening rail transit ridership. Other suggestions are priority parking for HOV users and possibly HOV bypass at tollbooths. There are concurrent and contra-flow bus lanes already existing downtown and these will be maintained and expanded as necessary. They are also looking at the possibility of using light-rail.

Los Angeles

In Los Angeles, an OPTICOM system, has been employed for a demonstration project - the Ventura Boulevard Bus Priority Traffic Signal Pre-emption Demonstration Project [18]. It covers a ten mile stretch of Ventura Boulevard in the San Fernando Valley of the City of Los Angeles. Average Daily Traffic (ADT) ranges from 35,000 to 50,000. There were average travel time savings of 4.2% and a decrease in delay of 21.6%. There were mechanical problems with emitters and detectors though, and this is a problem that will occur with new hardware. HOV bypasses at ramp-metering locations were included also

Bremerton, WA

In Bremerton, a low priority system exists for buses using a TRACONEX signal system [19]. Kitsap Transit obtained funds from the Federal Aid for Urban Systems funding to purchase hardware for the controllers and for their buses. The TRACONEX system will be used throughout the city. This will be a different setting than most other cities in that Bremerton only has a population of approximately 35,000, but this could be comparable to studying various corridors in larger cities.

The City of Bremerton placed constraints on the system since the disruption of the signalization pattern could have very detrimental effects if the transit vehicles were allowed to change the signal at any time. The buses are equipped with a low-priority signal, and only one of these vehicles per cycle will be allowed to proceed through an intersection with the prioritization. Once a vehicle has gone through the intersection, a full cycle will have to take place before another vehicle can be processed. Another restriction is that a high-priority vehicle will cancel the possibility for a low-priority vehicle to use that cycle. One other restriction that the City of Bremerton has made in the contract with the Transit Agency is the possibility of canceling out the processing of low-priority vehicles during the peak period that occurs between 4:30 and 5:30 PM.

Seattle

Three arterial HOV facilities do exist on SR 99, SR522, and NE Pacific Street. SR 99 is a radial arterial that extends from the Seattle City limits northbound 1.5 miles through a suburban business district with varying levels of commercial and residential development [20]. It has a 3+ carpool requirement and it operates 24 hours a day. Along SR 522, there is a northbound lane that extends for 0.92 miles and a southbound lane that is 3.27 miles long. These sections along SR522 are open to buses only and operate during their respective peak flow periods. NE Pacific Street's HOV facility has been open since September 1991, and it serves as a queue-jump facility open to 3+ carpools, vanpools, and buses. The facility is open 24 hours a day to the eligible vehicles.

There are also preferential lanes in the CBD of Seattle. Three priority lanes exist downtown on 2nd, 4th , and 5th Avenues, but they are designated for bus use only. The 5th Avenue priority lane is a contra-flow lane for bus use throughout the day, while the 2nd and 4th Avenue priority lanes are used during the AM and PM peak periods from 6:00 - 9:00 AM and 3:00 - 6:00 PM.

International Facilities

In Turnbull's study [11] of international HOV facilities, arterial HOV applications were found in 75 cities around the world, and they ranged from guided busways to short queue-jumps on local streets. Most of the international HOV facilities are designed for transit usage only, however, there is an HOV facility in Auckland that is singled out due to the carpool eligibility. There are exclusive and non-exclusive facilities that are separated and non-separated, which are operated either in the peak period operation or 24 hour periods like many of the roadways in North America. For the non-physically separated lanes, the most commonly used priority measure is signal-preemption. In Yokohama, Japan, they have exclusive bus lanes that have computer-controlled location devices as well as priority traffic signalization. In general, the more advanced technologies involved were found in Europe and Japan. The information provided from this study gives positive support for the potential of the arterial HOV lanes in that they can work by themselves with priority measures or they can act as links to other major roadways in a HOV system.

Auckland, New Zealand

On Onewa Road in Auckland, an HOV facility is open to carpools and buses. It is called the Onewa priority scheme [11]. The 0.7 mile facility roadway is a two-lane uni-directional facility operating in the AM peak period from 7:00 AM til 8:30 AM, and it has been in operation since 1982. As of the last report in 1989, there were 1680 vehicles and 4070 passengers using the HOV lane on average during the morning period of operation. To help make this work more effectively, parking has been restricted on certain parts of the roadway.

ENFORCEMENT

Enforcement plays a valuable role in HOV operation. Policies without enforcement are useless, and this is an issue for HOV lane usage. Knowing that someone is out there observing the movement of one's vehicle is a strong incentive to obey the rules. The enforcement studies provide possible concerns for the development of arterial HOVs mostly from an emphasis of keeping violation rates at a minimum giving the perception that the lane will be used for its intended purpose. This section takes a view at the different means of enforcing correct HOV lane utilization.

Without enforcement, the violation rate for the HOV lane has a propensity to be higher. Billheimer [21] provides results from a study investigating different HOV lanes in Southern and Northern California. The lowest rates were found on those roadways with constant enforcement, while the highest rates were those where there was rare enforcement. The rates ranged from 1% to 31.5%. Fuhs [22] provided rates from all over the country, and he found the same types of results in regard to rates and the amount of enforcement. Fuhs did note that facilities separated from general traffic lanes had lower violation rates associated with them. In Boston, a 1% violation rate was obtained with asphaltic curb separating the HOV lane along with constant enforcement. One item to note was little variation in violation rates during different periods of the day when there was 24-hour HOV lane usage. Christiansen and Morris [23] noticed this also in their evaluation of the Houston system. Fuhs [22] also includes enforcement methods, enforcement costs, fines, etc., for HOV facilities across the country.

Factors that attributed to violations in the HOV lane were primarily from engineering design, enforcement procedures, and public attitudes according to Billheimer [21]. Having the ability to design enforcement areas into the facility was a major help. In Seattle, there were lower violation rates associated with the routes where there was refuge area adjacent to the lane [24]. Different methods of enforcing in terms of "chasing" the violators were studied as well as the effect that it had on disrupting traffic. In San Diego

[25], strong enforcement was used initially to curtail violations, and it produced 6% - 7% violation rates. Christiansen and Morris [23] found more accurate use as time went on. In California [22], a $271 fine for illegal use exists. In the Metropolitan Seattle area, the implementation of the *HERO* program helped produce a 33% decrease in violations [26].

MONITORING

Monitoring the HOV lane provides the capability of determining what is happening within the lane through consistent observances. This is important to arterial HOV lanes in terms of noting person movement and in determining violation/compliance rates. The State of Washington has a good monitoring system [26], and methods used here as well as those used in other areas in the United States are represented in this review.

Monitoring can exist on a short-term or long-term basis, and the reasons for monitoring vary. Short-term monitoring usually exists to investigate the HOV lane for a short period after the implementation to note whether the operation is going as planned. This usually occurs for monitoring accident problems, violation rates, or volumes. Virginia, California, and Texas were three states found to have long-term monitoring [26].

Methods of monitoring vary from the use of closed-circuit television as used by the Washington State Department of Transportation (WSDOT) for scanning roads for incidents to the use of video cameras by the California Department of Transportation (Caltrans). The *HERO* program allows motorists to report HOV lane violators in the Metropolitan Seattle area [26]. WSDOT has an auto occupancy monitoring program also [27]. Billheimer's study [28] investigated the use of video-camera in support for on-line enforcement, remote ticketing, and performance monitoring.

TRANSPORTATION DEMAND MANAGEMENT(TDM)

Transportation Demand Management focuses on the behavioral portion of the transportation system in increasing the efficiency. The HOV concept is about efficiency in terms of greater average vehicle occupancies that really place more people and fewer vehicles in the system. TDM strategies focus on incentives and disincentives that tempt the commuter to change their work trip mode from the SOV to the HOV whether it be carpool or transit.

Incentives/Disincentives

This is a major issue to address in terms of trying to influence people from taking their single-occupancy-vehicles and into a more efficient mode of movement of persons. Pratt [29] defines incentives as those inducements that make the alternative more attractive, while the disincentives make solo driving less attractive. Sixty percent (60%) of the bus passengers have all or part of their bus fares paid by their employer according to the Houston HOV System report done by Christiansen and Morris [23]. Brownstone and Golob [30] found preferential parking, rideshare cost subsidies, a guaranteed ride home program, and HOV lanes as significant employee-provided incentives . Beroldo [31] found flex-time to be one issue that was negative toward carpooling. Disincentives were higher parking costs for SOV's versus discounted rates or no costs for those in HOV's.

Kuzmyak and Schreffler [32] evaluated various TDM programs around the country. They found vehicle reduction rates for trips that varied from 5.5% to 47.9%. At the University of Washington in Seattle, the *U-Pass* [33] program was implemented and it has resulted in reducing SOV usage, raising transit ridership and raising HOV usage.

Parking is a critical element when concerned changing people's travel behavior. Ulberg [34] states that "parking policies probably represent one of the most critical elements available to change our current transportation system." Higher parking costs and limited availability will cause people to look into their options more closely before getting into their SOV.

AIR POLLUTION(ENVIRONMENTAL FACTORS)

Environmental impacts is a major issue when it comes to transportation projects. The Clean Air Act requires for cities that are not meeting federal air quality standards to develop pollution control strategies and to bring their areas into compliance with these standards or fines will be placed on the cities. Seattle is one of these cities. Studies included in this review have shown that HOV alternatives provide significant air quality benefits. Arterial HOV lanes will help mitigate these impacts within the roadway system when used in strategic locations.

Congested vehicular traffic is a major producer of air pollution. One of the worst characteristics of congestion is that it creates stop-and-go traffic and this allows emissions to concentrate. It was determined that HOV lanes produce a desirable effect in the reduction of carbon monoxide (CO) [6]. In Houston [23] and San Diego [25], studies have shown lower levels of pollutants contaminating the air in corridors with HOV lanes than if there had been no HOV lanes in place. The Metropolitan Washington, D.C./Northern Virginia area has found a reduction in emissions as well [35]. In the Metropolitan Transportation Commission's study [36] of the San Francisco Bay area, the modeling of their planned HOV system indicates emission reductions in air pollution also. In another study done in California [37], software was developed that determined air pollution impacts by investigating the "Level of Service" and the"Traffic Assignment" approaches.

PLANNING/DESIGN

The planning and design phases of the HOV facilities are very important, especially for arterial HOV lanes. Effective planning should include marketing strategies that "sell" the rideshare idea or using the public transportation system. The design does not just include the plan views for the facility, but it should account for comprehensive signing that informs the driver of what is happening in this preferential lane. Fuhs [38] provides a comprehensive view of the planning, design, and implementation phases.

Planning

Planning allows for thought of what should occur, when it should occur, and it provides thoughtful insight into the most productive means of getting the project implemented. Marketing plays a major role in the HOV lane planning process, and Stamm [39] notes many reasons to include it. Providing people with the proper information and correctly conveying it makes marketing necessary to "sell" the HOV lane to the public and for them to use it.

Design

The design of the HOV lane is just as important as the design of regular lanes because safety is of the utmost importance for motorists. For the highway applications and the arterial applications, often the change is just retrofitting the existing roadways by restriping and signing to provide notice of the new HOV lane [40]. Awkward geometric design for the facility could pose problems for the HOV as well as the adjacent general traffic lane if the facility is not separated; hence, the HOV lane should adhere to standard design principles. Hawkins [41] calls for a unique symbol as well as a unique name for all HOV lanes. Setting standards for the HOV lane will help clarify the lane's intent, and the MUTCD seems to be the appropriate place for the standards to be set for the signing portion of the design.

EVALUATION

The evaluation phase is important to the project as a means of measuring how well the arterial HOV lane is being utilized. Without evaluation, the project can not be judged as to whether it is working as intended or not. Evaluation techniques and measures of effectiveness are investigated in this portion of the review. Objectives need to defined for the evaluation. Christiansen [6] provides three principal objectives for the HOV system development as 1) increased average persons/vehicle; 2) preserved person-movement capacity of the roadway; and 3) enhanced bus transit operations. Primary measures of effectiveness are listed below.

1) travel time savings (time unit)
2) modal shift (% of transit, carpools, vanpools, SOVs)
3) person throughput (persons/unit time)
4) transit improvement (reliability, ridership change)
5) Fuel cost savings (dollars)
6) Violation rates
7) Accident rates

Lomax [42] devised a method of evaluating HOV projects in terms of corridor mobility. This is estimated by using the *Speed of Person-Volume* (SPV) and *Person Movement Index* equations. From these equations, a *Corridor Mobility Index* (CMI) is determined. If the HOV lane value is greater than one, it is an effective project. Christiansen, Henks, and Turnbull [43] devised a procedure for evaluation of effectiveness.

ALTERNATIVES ANALYSIS

Alternatives that include HOV lanes have proven to be the best alternative in terms of reducing air pollutants, being cost-effective, and needing the least amount of time to implement. Alternatives analysis enables making the best choice for the transportation system by putting the alternatives through a rigorous screening that will determine a best alternative or a selection of best alternatives that complement the system. One study done in California presents a methodology that assesses potential HOV sites by running them through an analysis that is based on sixteen criteria, operational issues, and evaluation in FREQ10PL [44].

INTELLIGENT VEHICLE HIGHWAY SYSTEM (IVHS)

Intelligent Vehicle Highway Systems is an exciting issue in transportation, and HOV facilities are an excellent place to demonstrate some of these technological techniques in the roadway system. The four general categories of IVHS given by Turnbull [45] are those of advanced traffic management systems (ATMS), advanced traveler information systems (ATIS), advanced vehicle control systems (AVCS), and commercial vehicle operations (CVO). ATMS, ATIS, and AVCS are now known as APTS (advanced public transportation systems). ATMS is focused on surveillance and monitoring for detection, communication, and operations, while ATIS is focused on providing in-vehicle information and pre-trip information to the people who are making traveling decisions. AVCS is focused on the control and guidance of vehicles, and CVO is more concerned with the use of heavier trucks, but there could be applications to buses.

Two of the more common types of usage of applications of IVHS technologies in the ATMS are the automobile vehicle identification (AVI) and automobile vehicle location (AVL) systems. AVI uses electronic "tags" that are attached to the vehicle and detected by a receiver. AVL is useful in that vehicles can be tracked in the system. This will allow for real-time information for delays, travel status, and other operational characteristics. AVI is in present use on the I-495 contraflow HOV lane in New York City as it is used to detect buses for electronic fare collection at the toll plaza. By enabling this technology to be used, buses do not have to stop at the toll plaza. As far as AVL applications are concerned, there are current uses in Ann Arbor, San Antonio, and Baltimore in the United States, while Ottawa has an AVL system that provides real-time information to current riders and potential customers. On I-15 in San Diego, Caltrans is testing collision warning and collision detection devices during the times that the lanes are closed.

OPERATIONS

This is the portion of the review that looks at the operator's standards for the facility. In this section, operational issues are addressed that may help in determining how to operate the arterial HOV lane. Issues such as 2+, 3+, 4+, bus & vanpools only are decisions to be made. Whether to allow motorcycles to use the facility is an operations decision. Whether the roadway is to be reversible, concurrent flow, or contraflow is an operations issue. Traffic flow is what is important, and the traffic operations team has to decide on what is best for the overall system. Peak-period only operation versus 24-hour operation is also discussed.These are the types of items that are discussed in this portion of the review. Houston did it successfully in their peak morning period without problems, and it could be implemented here [46]. The Houston lanes work inbound from 4 AM to 1 PM and are reversed for outbound traffic from 2 PM to 10 PM. According to Roper, 2, 3, or 4+ definitions will work for HOV lanes with the proper use of signing and communication systems [47]. Jon Williams of the Metropolitan Washington Council of Governments questions whether the 2+ idea is "just a means of moving cars around instead of increasing auto occupancies [35]." Policies for transportation demand management have to be invoked, so that the system can work more efficiently in terms of mitigating congestion and enhancing mobility. HOV lanes alone do not solve the problem, but support facilities and enforceable policies are the keys toward making a multi-modal system work well.

SAFETY

Safety for those driving and pedestrians is of paramount importance and issues concerning this are addressed in this part of the review. For arterial HOV lanes, there are many safety issues to address, and these have to be met before anything else is done. This will include issues such as access management, turning vehicles, pedestrian crossings, appropriate signing, and intersection movements. Ultimately, the idea is to minimize accidents.

The TRANSPO group [14] provides some good suggestions for the State Route 99 project in Seattle. Suggestions include such meaures as consolidating driveways, improving striping delineations, and placing diamonds on the HOV lane with greater frequency especially in front of major driveways. Hawkins [41] calls for more standard marking and signing that would be uniform throughout the country, and for it to be updated in the MUTCD.

MODELING

Modeling is an issue when it comes to being able to simulate the expected conditions of the HOV influence. Good modeling techniques of arterial HOV lanes assists in obtaining a prediction of what may happen when the lane is implemented. For modeling purposes of HOV lanes, the Davis study [3] provides reference to models such as FREQ6PL, CORFLO, and NETSIM. Davis actually used Traf-Netsim for modeling NE Pacific. There were also references to equilibrium models such as the ones developed by Sheffi and Mannering & Hamed. Sketch-planning models were referenced as well. The major software programs that are most efficiently used to model HOV lanes on arterials as well as freeways. As far as trying to model signals along with bus priority or special signal operations such as actuated signal TRAF-NETSIM and NETSIM are very powerful tools currently. The project in Boston on the Central Artery/Third Harbor Tunnel project uses an updated part of the UTPS modeling program called UROAD, which has a sequencing fearture that allows for a more effective analysis of the HOV lane's effect on the roadways [48].

SUMMARY

In summarizing the HOV literature, there are many issues that have to addressed. Applications of other HOV facilities seem to be the most useful in terms of adopting a framework for the development for a new system. Although there is not much literature specifically on the arterial HOV, there is information available on the freeway HOV and general issues that link the two. The key is not to just place the HOV lane out there and hope that the public uses it, but to devise an overall comprehensive plan to make the project a beneficial one for all concerned. That includes the designer, the operator, and the public.

Issues addressed in this review covered everything from enforcement to modeling. Studies of enforcement and violations were covered to indicate how to successfully control the usage of the facility. Enforcement techniques were provided as well as characteristics of violation patterns, which may alert the operator to possible problems. Issues such as incentives covered the spectrum to show how TDM comes into play and how you can induce modal shift. Design is always important, and there were concerns addressed on how to convert existing right-of-way or construct a new HOV facility. The design aspects included the issue of proper marking and signing. This ultimately, provides safety. Other issues that were discussed were those of evaluation of products. Without an evaluation, how do you determine whether the project was worthwhile. Suggested procedures were stated as well as what type of data to collect and how to collect it. Even the impacts on the environment were discussed, especially on providing better air quality with HOV systems. It all comes into play when trying to make the effort a worthwhile one. Planning is the key to making it work successfully, and this review is a comprehensive investigation of the needs for the plan of the HOV facility from start to finish.

CHAPTER 3

RESEARCH DESIGN

INTRODUCTION

Collecting and analyzing data was essential to this project for the purpose of facilitating a thorough Before and After Study of the NE Pacific HOV lane addition to the road network in the University District. The literature review was the other major portion of this project. It served as the complement to the review done by Davis [3].

OBJECTIVE

The objective of this After Study was to collect and analyze data for the study area after implementation of the lane and to compare the Before data with the After data as well as compare with the HOV simulation prediction.

AFTER STUDY

In consideration of the objective, the study examined the effects of the implementation of the HOV treatment that serves as a queue bypass on NE Pacific Street in the southeast direction going toward the NE Pacific Street/Montlake Boulevard Intersection. The first part of this study was to perform a literature review on HOV lanes and accompanying issues. Data collection was the second portion of the project. Next there was the analysis stage, and finally the production of the overall written product. To determine the effects, the study investigated certain measures that were obtained from field data by going through a rigorous statistical comparison of the data. Data measures included:

1) Person movement

Person volume (persons/hour)

2) Transit reliability and ridership

schedule adherence (minutes)

ridership (person volumes)

3) Travel times

general vehicles, carpools, bus (seconds)

general lanes vs. HOV lane (seconds)

4) Modal split

% in general vehicles (1 or 2 passengers), carpools (3+), buses

5) Queue lengths

length of vehicular queueing at the turn of the traffic light from red to green

6) Volume

5-minute volumes of traffic determined as vehicles passed a certain point

7) HOV Violation Rates

Rate of non-eligible vehicles traveling in the HOV lane

Data collection was the key to providing the necessary variables for analysis. To measure the efficiency of the corridor, the study was geared toward determining whether the HOV lane had generated a higher proportion of person volume passing through the study area. This was done through field observation by recording vehicle occupancies and volumes of traffic. Improvements in transit operation were investigated through field observation by monitoring adherence to schedule and ridership counts. Postcard surveys were passed out to motorists in vehicles stopped at the traffic light at the intersection of Montlake and Pacific. Travel time savings were measured through field observation by using lap-top computers to enter the license plate of the vehicle as it passed the entrance and exit points of the study. Measurements for modal shift were taken from the occupancy data collected. The occupancy levels provided numbers to compare with previous numbers to allow for evaluation. Evaluation of the survey information provided characteristics of the motorists traveling through this study area. Queue lengths and volume data provided support for the travel time argument as well as more values for comparison.

The data that were obtained in the After Study were compared with those of the Before Study. The role of the *U-Pass,* an incentives program developed by METRO and the University of Washington, was investigated also because of the impact it had on the use of the transportation system in the area. Data that were collected were travel times, queue lengths, volumes, and vehicle occupancies. The times when the Montlake Bridge opened were noted also.

Tremendous delay was already occurring in the southeast corridor during the peak period, and trying to determine one reason for it would not have been appropriate because of the comprehensive nature of factors taking place. The HOV lane has an advanced green phase that allows it the "jump" on the general traffic lanes on NE Pacific Street. An initial thought was to distribute this "lost" green time throughout the approaches on the intersection, but it was decided to just take this green time from Pacific Street. This would isolate the delay to Pacific Street and not allow an adverse effect on Montlake. If there was such an interest in promoting the HOV treatment, the incentive and disincentive should be placed on the same approach for the overall good of the system. With many pre-emptive systems, the delay is usually encumbered by the cross street. For Pacific Street, 35 seconds are dedicated to green time. Out of this, 0 to 8 seconds are dedicated to the HOV lane and the time that is actually given is determined by the presence of vehicles by the loop detectors.

BEFORE STUDY DATA

For an accurate comparison of two studies, same types of situations have to be compared. It was important for the After-Study that the typical traffic conditions during the afternoon peak period be resolved. One phenomenon that occurs is that of the Montlake drawbridge openings. At this point, vehicles are at a stand still.

Determining what to do about the times when the drawbridge was open and the time period after that when the traffic returns to "normal" flow was the first issue to resolve. In the Before Study, Davis did a regression analysis, and it provides a significant variable denoting fifteen minutes as the time period that it takes for the traffic to return to prior operating conditions. The reason that this was done is that there was found to be a tremendous difference in the data gathered on days when the bridge opened and when it did not. To use all the data available, there had to be something in common. Finding "uninterrupted" data was the result. This is the time of non-bridge opening effects. This was used in the After Data collection and analysis also.

Resolution of Before Data

One major hurdle to overcome was that of determining what to use for the Before Data for comparison sake. Within the collection of data for Pacific Street and Montlake, there was data that included Friday as well as the more typical collection data that comes from Tuesday through Thursday. The initial motivation was to try to combine the data so as to have one number that best resembled the condition of each measure whether it be travel time, volume, queue length, or occupancy. This proved to be unsuccessful as the data was significantly different when tested. The middle-of-the-week collection days provided numbers that varied quite drastically for the travel times and queue lengths. The travel times varied by over 200 seconds and the queue lengths by approximately 70 vehicles. The Friday data set yielded higher numbers than the higher of the two data sets obtained for the middle-of-the-week. The final resolution was to just compare the data separately.

Resolution of TRANSYT-7F Simulation

The mean travel times used for the TRANSYT-7F simulation run by Chen [49] in his work done on NE Pacific were much lower than the average stated in the Before Study by Davis [3]. It was important to resolve how this number was obtained since it is needed for comparing the simulated value with the actual field data study on how the HOV facility impacts NE Pacific Street. The results of the initial data collection effort was used for modeling purposes because it indicated the most representative situation of how the system operated with the signal timing and queue back-ups that would be created due solely to the intersection. The problem of the spillover from the SR 520 EB on-ramp onto Montlake Boulevard is a factor in the PM peak period, due to the inability of the TRANSYT 7-F modeling to simulate the back up that occurred downstream.

Analysis and Comparison

As for the analysis, the After Study evaluated the HOV treatment from the raw data obtained during the data collection period in the Spring Quarter of 1992. A comparison of the Before Study's simulation outcome with this information will provide a determination of how well HOV use on arterials can be predicted. Traf-Netsim was the model used initially for the simulation, but it could not model every part of the system exactly. Therefore, to provide another comparison, the same data was placed into the Transyt-7F model.

HYPOTHESIS TESTING

For the determination of significant differences between the before and the after data, hypothesis testing was necessary. Setting up the hypothesis in terms of a null hypothesis and an alternative hypothesis provides the means for stating whether there will be a significant difference. The numerical quantity on which this is based is the *test - statistic.* For the purpose of this project, the formula for calculating the test - statistic is shown below.

$$z = \frac{(X_1 - X_2)}{\sqrt{\sigma_1 2 / n_1 + \sigma_2 2 / n_2}}$$

For this project, the significance is shown to be at 95% and 99% confidence levels according to the resulting test-statistic. The one-tailed test was used since the objective was to show whether conditions improved by showing a reduction in travel time, volumes of vehicles, queue lengths, and an increase in vehicle occupancy.

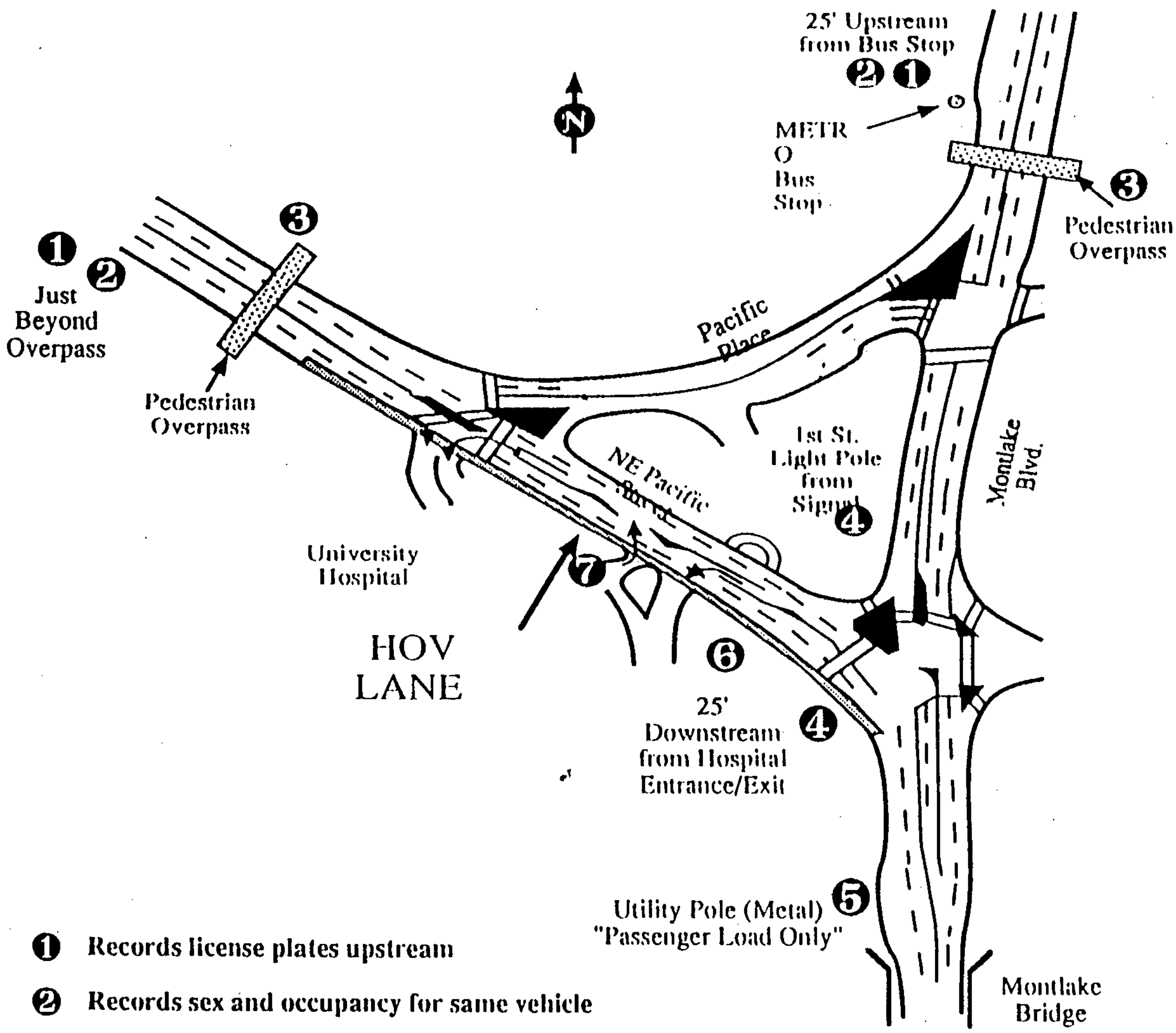
In analyzing the travel times of the buses, the study also investigated the standard deviation to determine whether there is greater consistency in the amount of time that it takes to go through the study location. More reliability is an important issue when speaking of creating an attraction for higher numbers of bus riders.

Data Collection Procedure

During the Spring Quarter of 1992, data was collected by a team of seven civil engineering students on NE Pacific Street and on Montlake Boulevard. The data that was obtained was that of travel times, queue lengths, average vehicle occupancies, vehicular volumes, and headways. Transit adherence to the schedule was noted also for the bus stop in front of the University Hospital. Another assignment was to measure the violation rate in the HOV lane. As a last assignment to the team, a travel survey was passed out to drivers of vehicles and to passengers waiting for the bus.

Tuesday afternoons were the scheduled days for the data collection, and Thursdays were planned as alternatives for collection in case of rain on Tuesday. The data collection period began on April 7, 1992. There was a orientation day with the laptops and the locations held on April 2, 1992.

The seven different data collection assignments are described below. Their locations are shown in Figure 2 for the various stations along Montlake and NE Pacific.



❶ Records license plates upstream

❷ Records sex and occupancy for same vehicle

❸ Records length of queue at start of each green phase (may need binoculars)

❹ Records Volumes of vehicles passing a specific point

❺ Records license plates at downstream end

❻ Records lincense plates of vehicles in the HOV lane

❼ Records departure time of bus from University Hospital bus stop

Figure 2. Locations for Data Collection

ASSIGNMENT 1

- To record license plates of vehicles at the upstream collection points.

  This would provide the entry time into the study of for the travel time data.

ASSIGNMENT 2

- To record occupancy of the vehicle and sex of the driver

  This person was located next to the upstream license plate collector so that the plates and times would correspond for the purpose of being able to identify travel times associated with the different types of vehicles.

ASSIGNMENT 3

- To record length of queue at the start of each green phase

  The queue refers to the number of vehicles along the roadway traveling downstream eastbound on NE Pacific or southbound on Montlake. This length was recorded at the change of the signal light from red to green. The queue consisted of a continuous link of vehicles. For reference in accounting for the vehicles, light poles on the side of the street were used. The end of the queue was defined in terms of the last light pole and the number of vehicles extending beyond the light pole. If the two were averaged and the number was entered.

ASSIGNMENT 4

- To record volumes of vehicles passing a specific point

The program allowed for the classification of vehicles, and that was used, as well as for general counts to obtain 5-minute volume counts. In terms of classifying the vehicles, the following system was used.

1) auto in general lanes (1 or 2 occupants)
2) HOV (3+)
3) bus

The exact time that a vehicle passed the specific point was when the classification was entered. The specific point was determined for each roadway.

ASSIGNMENT 5

- To record the license plate of the vehicle at the downstream collection point

ASSIGNMENT 6

- To record license plates of vehicles in the HOV lane.

  This was done to get the number of vehicles using the lane as well as the violation rates.

ASSIGNMENT 7

- To record times when the bus leaves the bus bay.

  This was done to get an account of the schedule adherence.

SURVEY DATA

The surveys were distributed in the same manner as done in the Before study[3] with 850 surveys being passed out on each Montlake and NE Pacific to motorists while they were waiting for the light to change. Safety was of the highest importance, and the team was provided with orange safety vests and hard-hats. This was done on May 12, 1992.

Summary

The research design was instrumental in facilitating the task of determining data collection needs and location as well as time. Being able to duplicate the methodology followed by Davis [3] correctly was important so that the only concern was the data that was collected. The primary aspects of this research are those of "after" data collection, comparison with before data and simulation, data analysis, and evaluation. The complement to the literature review done in the Before Study was also key to completing the overall work begun.

CHAPTER 4

RESULTS AND INTERPRETATION

During the Spring of 1992, a data collection effort was undertaken for the After Study of the Southeast corridor of the University District on NE Pacific Street and Montlake Boulevard. The data were collected during a six week period. Two weeks were dedicated to collecting data on Montlake Boulevard, and three weeks were dedicated to NE Pacific, while the last week was dedicated to distribution of surveys. The data collected included travel times, volumes, queue lengths, vehicle occupancy, transit departure times, and HOV lane violations. To collect the data, laptop computers were used with traffic data collection software developed by WSDOT and TransNow. The team of collectors varied from six to seven depending on the day, but all the necessary stations were covered as needed for the specific roadway.

TRAVEL TIMES

NE Pacific Street

Travel time savings is constantly touted as the major benefit in studies in investigating the effectiveness of an HOV facility. Many other factors come in to play, but travel time savings is a measure that commuters find as tangible evidence for getting out of their SOV and into a High-Occupancy Vehicle, whether it be carpool, vanpool, or bus. For the 0.51 mile stretch of roadway used as the study area, the data obtained on travel times for NE Pacific Street for the After Study are found in the following table along with the numbers for comparison from the Before Study and the Simulation model.

Table 2. NE Pacific Street Travel Times(seconds)

	Mode		
Study Period	Auto	Carpool	Bus
Before Data (4/11/90)	378.7 (275.3)	378.7 (275.3)	477.7 (364.6)
Before Data (4/18/90)	130.6 (88.8)	130.6 (88.8)	204.2 (40.5)
Existing System Simulation	175.8	175.8	266.4
HOV Simulation	167.7	151.9*	244.8*
After Data(Combined Days 4/7/92 & 5/7/92)	154.7 (99.8)	128.0* (62.5)	170.5* (51.5)

* Refers to Vehicle being in HOV lane
() Numbers in parentheses refer to standard deviation

From the data above, one can see two very different days of travel time data from the Before Study. The first day has very high travel times, while the second day yields low travel times in comparison. The existing system simulation numbers were chosen as representative numbers for NE Pacific Street based on a sample of data of 20 vehicles from the initial stages of the Davis [3] data collection. They were used to calibrate the simulation model. In a meeting with Davis and Ho Chuan Chen, it was noted that the judgment for choosing the sample as representative was based on what they had seen during field observations. The simulation numbers that are provided in the table above are a model representation of what would happen just with the introduction of the HOV lane. The After Study data shows improvements as the simulation suggested.

Comparison Study

For the determination of the significant difference of the means between the Before and the After studies, hypothesis testing is employed. Setting up the hypothesis in terms of a null hypothesis and an alternative hypothesis provides the basis for stating whether there will be a significant difference. The numerical quantity on which this is based is the z - *statistic*. The method of calculating this is stated in the Research Design. For this project, the 95% and 99% confidence levels were used to show significance. The one-tailed test is used since the objective was to indicate whether conditions improved by showing a reduction in travel time in the After data. The hypotheses are set up as follows.

$$Ho: \mu = \mu o$$

This is the case when the averages show no significant difference or the means are the same.

$$H1: \mu < \mu_o \text{ or } H1: \mu > \mu_o$$

This is the case when the means have a significant difference, and they were tested for either according to the variable being investigated.

The test statistics are found in Table 3.

In the case of the *Before* data, there were distinct days of data collection that varied quite drastically in terms of the length of time it took to traverse the study area. For the *After Study*, the sampling had travel times with means that were not significantly different, so these two days were combined. From this, the comparisons were made.

Table 3. Significant Testing of Travel Time Scenarios on NE Pacific Street

Scenario	Test Statistic	Significance
Before (4/11/90) vs After(4/7/92 & 5/5/92)	6.9258	$p < 0.01$
Before (4/18/92) vs After(4/7/92 & 5/5/92)	**-2.527**	$p < 0.01$
Before (4/11/90) vs After(Buses(4/7/92 & 5/5/92))	3.565	$p < 0.01$
Before (4/18/90) vs After(Buses 4/7/92 & 5/5/92)	3.236	$p < 0.01$
After General vs HOV Lane	1.730	$p < 0.01$

When analyzing the general traffic travel times and the bus travel times for the Before and After study periods, different results occur in significance testing, but for different reasons. For the general traffic travel times, the tests show that there are significant differences in the two Before days as compared to the After travel times for general traffic. The first day of the Before study indicates a significantly higher travel time, while the second day indicates a significantly lower travel time. For the *bus travel times*, the most outstanding issue to note is that the travel times for the After study are significantly lower in comparison to each day of the Before Study. For the second day of study in the Before study, it seems to be an ideal day for traffic flow through the study area, yet the buses aren't moving through the corridor quicker than in the After study. For the After study, the buses have the

the privilege of traveling in the HOV lane through the NE Pacific Street/Montlake Boulevard intersection.

For *carpool* comparison, the best studies compare carpools to the movement of vehicles in the general traffic lanes in the After study and then comparing the difference that the simulation predicts for the addition of the HOV lane. The reason for comparing both scenarios is to show a distinction in movement of vehicles in the HOV lane and general lanes with the HOV lane present and then determine how accurately the simulation modeling predicts. The carpool travel time in the HOV lane for the After study is significantly less than that of the general lane traffic as indicated in the table. In the simulation, the general traffic reduction is determined to be reduced by 8 seconds, while the actual result obtained from the data shows a reduction of 21 seconds from the existing simulation. The actual rate in minutes per mile for the general traffic is 5.13. The carpool rate in minutes per mile is 4.26. The criteria usually used as successful for a freeway segment is a reduction of at least 1 minute per mile, while 0.87 is the rate for this segment.

Study of Standard Deviation

To gain a better perspective of the travel time situation, a study of the standard deviation was investigated. The results of this effort are found in Table 4.

Table 4. Standard Deviation Comparisons for Travel Time on NE Pacific

Scenario	Test Statistic	Significance
Before General(4/11/90) vs After(4/7/92 & 5/5/92)	5.4167	p < 0.01
Before General(4/18/90) vs After(4/7/92 & 5/5/92)	-0.6437	Insignificant
After Carpool vs After General	2.4589	p < 0.01
Before Bus(4/11/90) vs After Bus(4/7/92 & 5/5/92)	3.6331	p < 0.01
Before Bus(4/18/90) vs After Bus(4/7/92 & 5/5/92)	-1.0623	Insignificant

Table 4 reveals a significant difference at the 99% confidence level except for the comparison of the second day of the Before data with the After data for the general and the buses where the difference is insignificant. This supports the idea that one the reliability for those traveling in it is better. The desire is to produce a system that flows better, and the shifting of vehicles into the HOV lane can help facilitate this. An incentive to shift modes to the HOV would be knowing that one could travel through a corridor in less time and with greater reliability. These results suggest that this can be achieved.

Montlake Boulevard

For Montlake, there is a drastic change in the travel times in that they have been lowered on the average by over 100 seconds as indicated by the data in the table on the following page. This change is truly a coup because the major hope was to not adversely affect Montlake traffic. There was concern over the values being so low, but on both of the days the travel times were consistently lower in the latter part of the data collection period (4:00 - 4:45 PM). The queues and the volumes also were reduced according to the data. Lower vehicle volumes, queue lengths, and the *U-PASS* are the apparent reasons for better flow.

Table 5. Travel Times for Montlake Boulevard

	Mode		
Study Period	Auto	Carpool	Bus
Before Data	180.3	180.3	277
Existing Simulation	181.2	181.2	258
After Data	80.8	80.8	105.9
After HOV Simulation	181.4	181.4	258.0

From the above table, the simulation indicates that the situation really should not change with the introduction of the HOV lane on NE Pacific Street.

Table 6. Significance Testing of Montlake Travel Times

Scenario	Test Statistic	Significance
Before General(5/2/90) vs After(4/14/92 & 4/28/92)	19.271	$p < 0.01$
Before Buses(5/2/90) vs After(4/14/92 & 4/28/92)	1.953	$p < 0.05$

The large test-statistic is representative of the drastic drop in travel time for the general traffic data collected for the After Study.

VOLUMES

NE Pacific

In terms of volume of traffic, there was no significant increase found on NE Pacific, although the mean value of the After data is a little higher than that for the Before Data. The actual number of buses did increase, but this was due to the greater demand being served because of greater transit usage. The volume of other traffic increased insignificantly.

Table 7. Pacific Volumes

	5-Minute Volumes
Study Period	
Before	**55.4**
After	**57.2**

Table 8. Significance Testing of Pacific Volumes

	Test Statistic	Significance
Scenario		
Before(4/11 & 4/18/90 vs After(4/7 & 5/5/92)	-0.823	Insignificant

Montlake

The vehicle volumes on Montlake have gone down. In trying to understand the dynamics of what was going on according to the data, the best resolution comes with there being a lower density involved, and the data suggesting flows on the non-congested side of the flow-density curve. There was more traffic moving through on Montlake in the prior study, but it was passing the "counting" point at a slower rate. Now, the vehicles are moving at a higher rate of speed going through the study zone.

Table 9. Montlake Volumes

	5-Minute Volumes
Study Period	
Before	**72.8**
After	**59**

The numbers suggest that there is a possibly significant change in the data from the two collection periods, and the test statistic shows that they are significantly different at the 99% confidence interval.

Table 10. Significance Testing of Montlake Volumes

	Test Statistic	Significance
Scenario		
Before(5/2/90) vs After(4/14 & 4/28/92)	3.812	$p < 0.01$

QUEUE LENGTHS

NE Pacific

Queue lengths are measures of how delay will be distributed. In the case of this study, there is tremendous fluctuation in the data with there being data representing a very bad day and an ideal day for traffic flow. During the

Before study [3], Davis does comment seeing queues that backed all the way to 15th Street at times, but they never approximated that during the After Study. This did not even occur during times of bridge openings during the After Study. The After Study data does show less variability with the range of average queues in the general lane being between 13 and 21 vehicles.

Table 11. Average Pacific Queues (# of vehicles)

	General Lane Queue	HOV Lane Queue
Before Day 1(4/11/90)	72.8	NA
Before Day 2 (4/18/90)	8.73	NA
After Day 1(4/7/92)	13.5	1.38
After Day 2 (4/21/92)	16.3	1.20
After Day 3 (5/5/92)	20.5	1.61

The two tables show how the two distinct days of data are affecting the study. The first day indicates a poor day for traffic flow, while the other represents a good day for traffic movement with low queues and travel times. For either case, they are significantly different at the 99% confidence level than the After data as can be seen from Table 12.

Table 12. Significance Testing of Pacific Queues

Scenario	Test Statistic	Significance
Before Day 1(4/11/90) vs After(4/7/92)	6.73	$p < 0.01$
Before Day 1 vs After(4/21/92)	6.44	$p < 0.01$
Before Day 1 vs After(5/5/92)	6.00	$p < 0.01$
Before Day 2(4/18/92) vs After(4/7 /92)	-3.72	$p < 0.01$
Before Day 2 vs After(4/21/92)	-6.26	$p < 0.01$
Before Day 2 vs After(5/5 /92)	-8.96	$p < 0.01$

It is important to note that the queueing in the *HOV lane* has not become a problem. As can be seen from the average data, there are not many vehicles queued, and from the chart on the following page, there usually are 0-2 vehicles present in the queued lane. There have been up to six vehicles queued in the lane. This is significant to note because there is no queueing problem yet.

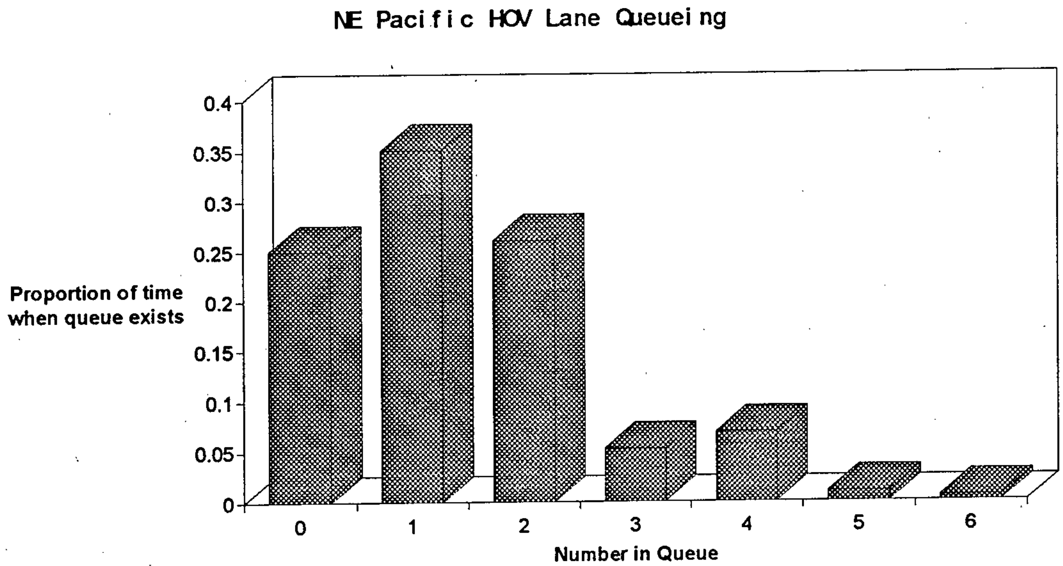


Figure 3. HOV Lane Queues

Montlake

The queue lengths on Montlake were drastically reduced. This corresponds to the lower travel times that were found on Montlake.

Table 13. Average Montlake Queues (# of vehicles)

	Queues
Before(5/2/90)	111.1
After(4/14/92 & 4/28/92)	21.3

The Before and After queues are tremendously different as is every thing else associated with Montlake from the two studies. The table above indicates the disparity in the two means, and the table below demonstrates the significant difference.

Table 14. Significance Testing of Montlake Queues

Scenario	Test Statistic	Significance
Before(5/2/90) vs After(4/14 & 4/28/92)	8.626	$p < 0.01$

VEHICLE OCCUPANCY

NE Pacific

The average vehicle occupancy (AVO) showed no change for Pacific Street as the occupancy remained at 1.33 persons per vehicle. The original number was believed to be high at first, but a study done by DKS & Associates [50] turned up numbers very similar to these. Their discovery indicated that the AVO indicated no measurable changes for vehicles traveling eastbound on NE Pacific Street, and the AVO that they found was 1.33 from planning studies. The overall occupancies in buses has decreased with a drop from the *27.3 passengers* per bus to approximately *23.9 passengers*. This is understandable. Once when out trying to get occupancy counts for bus, two buses that were running the same route were observed in the bus bay at the same time. The first bus picked up almost all the passengers, and the second bus only had two. Service has increased also with a greater supply of buses. Overall occupancies have not increased for general vehicles, but

that may be due to shift of persons from vehicles in the general lanes to buses in the HOV lane. It is indicative of a general equilibrium situation where a good situation has been set up with the introduction of the U-Pass, more bus service, and the HOV lane. In Houston [46], their HOV situation indicated that the carpooling situation gets better as time goes along. This evaluation was done six months after implementation.

Table 15. Pacific AVO

	Average Vehicle Occupancy
Time Period	
Before	**1.33**
After	**1.33**

The test-statistic table is not shown since it is zero due to no change at all.

Montlake

The average vehicle occupancy actually showed a decrease on Montlake falling from 1.32 to 1.26. This proves to be a significant change at the 99% confidence level as indicated in Table 17. This phenomenon seems to be most interesting in that there is preferential parking and reduced rates available in the Montlake parking lot. The one thing that may help explain this is that there is greater transit ridership in the University District with the *U-Pass* in effect, and this may have taken carpoolers from automobiles on Montlake and put them on buses on NE Pacific.

Table 16. Montlake AVO

	Average Vehicle Occupancy
Time Period	
Before	**1.32**
After	**1.26**

Table 17. Montlake Significance Testing of AVO

	Test Statistic	Significance
Scenario		
Before vs After(4/14 & 4/28/92)	-2.363	$p < 0.01$

TRANSIT DEPARTURE TIMES

Although there is no comparison from the Before study, there data were collected to provide an investigation of schedule adherence. A chart has been created that shows all the bus routes that use the University Hospital bus bay and their average deviation from their schedule. This may provide some comparison for other areas if METRO wishes to use it or provide other data for further study of this facility.

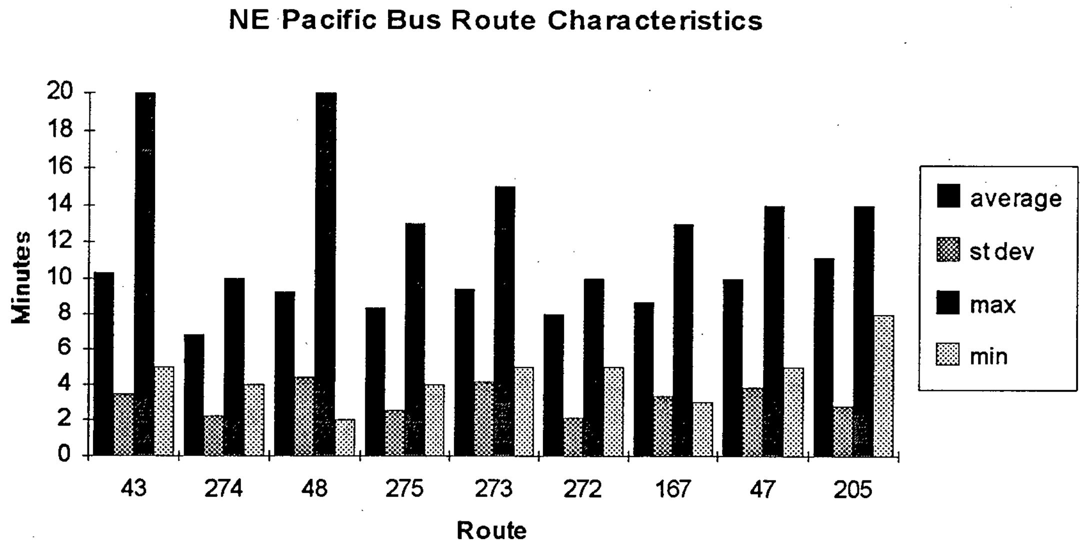


Figure 4. NE Pacific Bus Traveling Characteristics

In Figure 4, each route is shown as well as the amount of time it takes for each to arrive at the University Hospital stop from their last location.

HOV LANE VIOLATIONS

The utilization of the HOV lane as it is intended is definitely a major concern. If there are large numbers of HOV lane violators, it is possible that the public would request that the lanes be accessible to all vehicles. The violation rate for the lane turned out to be 34%. This is out of a total of 285 vehicles that used the lane from observations done in the After Study. Since an HOV lane does not exist this number can not be compared, but it does provide the operator of the system with some possible concerns.

One problem that may need addressing is the lack of signing or "good signing." One sign exists that states the definition of 3+, but its placement does not make it easily visible. There are inconsistencies within the system in that there are some locations where the definition is 2+ for eligible usage for most of the HOV lanes, but this only occurs on the freeways. Nevertheless, many may think that all HOV lanes are 2+. If it were so, it would lower the violation rate, but it may also disturb the integrity of the lane in its performance in terms of travel time savings.

Person Movement

Person movement through the corridor is important in determining how efficient the HOV lane is versus the general lane. Out of the average person movement of 1412 people per hour on NE Pacific street, the HOV lane accounts for 41.9% of the person movement. Table 18 shows the person movement by mode. The average occupancy for 3+ vehicles was 3.4 persons, while the average occupancy used for the buses was 23.9. These numbers were used based on the data collection.

Table 18. Person Movement

Mode	Persons/Hour	Modal Split Percentage
SOV	507	35.9
Two Occupant	260	18.4
3+ in General Lanes	54	3.8
3+ in HOV lane	41	2.9
Bus in HOV lane	550	39.0

What Is Happening?

Introducing the new lane provides two effective lanes of flow versus one in the peak hour when the buses were mixed in the general lane for the Before Study. There was no bus bay and there is a stop within the study zone in front of the University Hospital. Now, the buses have their own lane with a bus bay allowing the carpools and vanpools that flow through the lane without delay due to a bus stopping. Without a high level of other vehicular traffic, the task of getting back into the traffic stream is not as difficult.

The greatest impact so far is that the bus times have decreased significantly on NE Pacific, and that is due to the introduction of the HOV lane, and with the majority of the vehicles that use the lane being buses, it may be considered a bus lane. In addition to that, the variance has been lowered and is significantly lowered. Although there is no comparison of schedule adherence in the Before Study, the variance decrease indicates that there should be more consistency with the bus departing at or very near the time that it is scheduled.

Travel Survey on NE Pacific Street and Montlake Boulevard

On Tuesday, May 12, 1992, a mail-back postcard survey was conducted on NE Pacific Street and Montlake Boulevard at the Intersection of the two roadways. The postcards were handed out to motorists by the team of data collectors while the motorists were stopped for their respective red lights. These postcards had the postage prepaid and a return address on them already for the motorists. On the other side was the survey that was used. 850 cards were passed out on Pacific Street and Montlake Boulevard. In Figure 5, the survey instrument used for the travel survey is represented.

Survey Objectives

For the survey, the overall goal was to acquire knowledge about the users of the two roadways being investigated in this study. As was the case with the original survey used in the Before Study, the objectives were similar

TRAFFIC SURVEY

1. Origin of this Trip (Neighborhood or Street Address) — 1. [ ][ ][ ][ ][ ]

____

______________________ Zip Code ________

2. Destination of Trip (Neighborhood or Street Address) — 2. [ ][ ][ ][ ][ ]

____

______________________ Zip Code ________

3. Please indicate the number of people in your vehicle on this trip (Please include driver) ________ — 3. [ ][ ]

4. Exact time of departure ____________ — 4. [ ][ ][ ][ ]

5. Exact time of arrival ____________ — 5. [ ][ ][ ][ ]

6. Please indicate the purpose of trip (check one) — 6. [ ]

   [ ] Work [ ] Shopping [ ] School
   [ ] Social / Recreation [ ] Other

7. Your age [ ] 16-25 [ ] 26-35 [ ] 36-45 [ ] 46-55 [ ] 56-65 [ ] > 65 — 7. [ ]

8. Sex [ ] Male [ ] Female — 8. [ ]

9. Household income [ ] 0-15,000 [ ] 15,001-30,000 [ ] 30,000-45,000 [ ] 45,001-60,000 [ ] >60,000 — 9. [ ]

10. For me driving alone is (check one) — 10. [ ]
   [ ] Always better than the Carpool
   [ ] Usually better than the Carpool
   [ ] Sometimes better than the Carpool
   [ ] Seldom better than the Carpool
   [ ] Never better than the Carpool

11. For me driving alone is (check one) — 11. [ ]
   [ ] Always better than the Bus
   [ ] Usually better than the Bus
   [ ] Sometimes better than the Bus
   [ ] Seldom better than the Bus
   [ ] Never better than the Bus

Comments:______________________________

____

____

____

Figure 5. Travel Survey

except now the data was to be used as a means of comparison with the results from the prior study [3]. There were eleven questions on the survey. The questions ranged from origin/destination, arrival/departure data to more motorist oriented characteristics such as age, sex, income. Other questions included such items as trip purpose and vehicle occupancy. The final two questions were asked as a means of obtaining attitudes of driving alone versus taking a carpool or the bus.

Results from the Surveys

The return rate for the surveys was 26.4% for those on NE Pacific and 28.7% for those on Montlake Boulevard with 224 and 244 postcards being returned respectively. Some postcards were returned with questions that were left unanswered, but that was to be expected. The answered questions from the surveys were coded and then analyzed.

When the initial survey was conceived, attention was focused heavily on the attitudes about carpools and buses. Questions 10 and 11 focus on this explicitly. The results from the survey are found in Table 19.

Table 19. Results from Questions 10 & 11 from Pacific and Montlake Respondents

Location	**# OBS**	**Q10 Mean**	**Q10 S.D.**	**# OBS**	**Q11 Mean**	**Q11 S.D.**
Pacific	214	2.27	1.38	214	1.99	1.16
Montlake	231	2.02	1.22	231	1.84	0.99

These answers were coded 1 - 5 with 1 representing the "always'" response and 5 representing the "never" response. Since these answers are coded, the interpretation of the results for the respondents on Pacific to questions 10 and 11 would be that driving alone ranks just higher than "usually better than the carpool" and driving alone ranks below "usually better than the bus." For Montlake, the results are similar with the carpool attitude ranking higher than "usually" and the bus attitude ranking less than "usually." The results of this portion follows the logic in that there is greater bus service on Pacific and an HOV lane there as well. This would support those who would potentially use the carpool or bus.

General Motorist Information

To obtain a better perspective of the profile of the typical type of person traversing these roadways, the general background data was also analyzed. The information that is presented is that of age, sex, and income. This is provided in Table 20.

Table 20. Motorist Characteristics from Survey

Location	# OBS	Age	# OBS	Male/Fem	# OBS	Income
Pacific	221	3.13	222	45.5%/55.5%	217	3.47
Montlake	244	3.30	244	47.5%/52.5%	226	3.49

These answers are coded the same as the ones done earlier. For the age bracket, the code ranges from 1 to 6 with the 1 being coded as the lowest bracket. The income is coded on a 1 to 5 bracket. Brackets 3 and 4 from the age category are 36-45 and 46-55. For the income bracketing, the codes of 3 and 4 refer to the 30-45K and 45,001-60K range. As for the percentage of male versus female drivers, there is is a slightly higher proportion of female drivers on both roadways.

Trip Purpose, Origin/Destination

For this portion of the discussion, the focus turns toward trip purpose and the Origin/Destination of the motorists that traversed the Pacific Street and Montlake Boulevard roadways. This discussion is best investigated by looking at the percentages of types of trips and those that have origins or destinations in the University District. Below is data gathered from the surveys.

For trip purpose, the greatest percentage of the trips are work oriented for both NE Pacific and Montlake Boulevard respondents with 53.57% and 42.62% respectively. School trips account for 11.61% and 11.48% respectively for Pacific and Montlake. This is interesting to note since the University of Washington is a major attractor/generator for the University District.

In terms of origin/destination, the University District seems to be the major player. In terms of origin, 58.04% of the trips for Pacific and 64.58% of the trips on Montlake. The highest percentage of Pacific traffic destinations are the area from South of the Montlake Bridge to the Capitol Hill District. This is the *98112* zip code. Oddly though, the second highest destination is the University District. This is peculiar since the traffic is supposedly headed south of the bridge. The same holds for the Montlake respondents. Seemingly, on some of the surveys, the respondents turned the origin/destination around. Some definitely thought of their initial trip of the day when they placed the time of arrival and departure in the AM hours.

Surveys Overall

The most noteworthy items to mention are those of the trips being mostly work-related during the peak period in the PM. With a heavy student population, the average age of the motorists was expected to be lower, but the average age was in the 40s. The heaviest concentrated area of travel for the motorists was to the Montlake/Capitol Hill section and following that there was no concentration to a specific area. Approximately 21% of respondents from Montlake and Pacific were were going Eastbound across the SR 520 Bridge.

Results of the Implementation of The U-Pass

The *U-Pass* has made a definite impact on the commuting tendency of those with origins or destinations as the University of Washington. For that reason, providing data about those using the program is necessary in conjunction with the field data collected. This gives further support to the use of a TDM program along with an HOV lane.

The Gilmore Research Group [33] performed a telephone survey of students, faculty, and staff of the University of Washington to determine levels of use, awareness, and satisfaction of the *U-Pass* Program. The following items are some of their findings.

- In 1992, 45% of the UW population usually commuted by HOV, which is an increase from 35% in 1991.
- 27% of the UW population who usually commuted by driving alone in 1991 commuted by HOV in 1992
- 92% of the U-Pass holders are at least "somewhat satisfied" with it, and only 3% are not satisfied with the service.

- For the majority of the persons interviewed, the cost benefits are noted as the favorite features.
- At least 74% of those interviewed reported having seen or read the U-Pass User's Guide. The Transit Guide and the Walking/Bicycling Guide has been seen by less than half.

From the *U-Pass* Annual Report [4], there is SOV permit decrease, increased transit ridership, and increased carpool permits. The SOV permit decrease is 17%, while the carpool permit increase is 21%. The transit ridership shows a 20% increase. Overall, the U-Pass program is definitely doing what it was created to do.

Volumes According to Various Study Locations around the Campus

The traffic volume counts that the University of Washington does are conducted in conjunction with the City of Seattle to provide the data for measuring if the objectives are being accomplished according to the 1983 Agreement [51] between the University of Washington and the City of Seattle. For support of the data collected in this After Study, the traffic exiting the various count locations of the campus in the PM Peak Period of 3 - 6 is has been studied [52]. The overall peak period of volumes traveling from the campus are as shown in Table 21. Table 22 provides data about specific locations.

Table 21. PM Peak Period Traffic Volumes Traveling from Campus

Year	PM Traffic Volumes
1990	8979
1991	8205
1992	8246

Table 22. Average Weekday Traffic from the Various Count Locations

Year	Main Campus	South Campus	Stadium Lots E-11/E-12	Montlake Lots E-1/E-5	West Campus	Total
1990	16,165	5,110	1,853	4,758	1,680	29,556
1991	16,496	5,015	1,809	3,559	1,279	28,158
1992	16,279	4,314	1,911	3,633	1,161	27,298

The overall traffic volumes have decreased from 1990 to 1992 for the traffic leaving from the campus locations as well as the Average Weekday Traffic. For the traffic leaving the campus during the 3 - 6 PM peak period, there is a small increase from 1991 to 1992. The data gathered from the After study indicates a decrease in traffic from the data 1990 data collection in the Before data. Prime candidates for entering Montlake are the vehicles that park in Montlake lots E-1 and E-5. There has been a steady reduction in vehicles since 1990. The south campus and west campus parking lots have shown a steady reduction also, and these are candidates for traveling on NE Pacific. From the main campus, there has been a slight increase. The overall picture is that the University of Washington has done its part to mitigate adverse transportation effects.

Summary

In summary, the NE Pacific Street HOV lane and the U-Pass have made a favorable impact on the network in the southeeastern portion of the University District. The travel times for buses are lower than the Before data and the carpool travel times are lower than the general lane travel time. The volumes are a little higher, but not significantly. From the data in this study, the travel times, queues, and volumes are lower. The *U-Pass* results indicate higher transit ridership and greater carpool permits. The cordon counts around the University of Washington campus indicate decreased traffic coming from the campus during the PM peak period. Together, the *U-Pass* program and the HOV lane are making a positive impact.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

In the Seattle Metropolitan area, there is interest in the implementation of arterial HOV lanes and treatments such as pre-emption systems. Arterial HOV lane use has varied from bus-only facilities to queue-jumpers, as is the case on NE Pacific Street. The major problem that exists is that there is very little arterial HOV lane documentation in the literature. This is a project where the intent is to add to the knowledge base of what happens before and after an arterial HOV facility improvement has been implemented. The documentation on HOV lanes on freeways is healthy with projects in the literature from one coast to the other such as Boston's Southeast Expressway Project, Northern Virginia's/Washington D.C.'s Shirley Busway, Houston's Transitways, Southern California's representatives in San Diego & Los Angeles, and projects in the Bay Area. Of course Seattle has provided its citizens with HOV lanes on various portions of I-5, I-405, I-90, and SR 520. Although these are freeways, they have the basic underlying premise of providing greater person-movement efficiency. There are arterial HOV lanes in urban areas around the United States as well as internationally that exist with dedication to bus use primarily. Most of the arterial facilities are dedicated to buses only, but there are those that allow 3+ carpools and vanpools as well. The facilities in the CBD of Seattle are dedicated to buses only, while the NE Pacific Street, SR 99, and SR 522 arterial facilities permit the carpools and vanpools. Obtaining more knowledge on HOV improvements on signalized arterials is still necessary so that better planning and design can be done to make the overall transportation system more effective.

For this project, the impacts of the NE Pacific Street HOV Lane were analyzed. This should help METRO and other agencies concerned about person movement obtain better insight from an operations perspective on how to plan and implement an HOV lane. Even though the results are from a specific type of treatment (a queue-jumper), the information is valuable in terms of how people responded to the presence of the HOV lane and the corresponding TDM strategies. The use of loops to provide the advanced-green time to vehicles in a lane can be of use to those trying to understand the phenomena of how one lane's early movement pattern may affect other planned and potential sites that are contemplating using the HOV lane as an alternative to an existing or predicted problem.

Impacts of the NE Pacific Street HOV Facility

The NE Pacific Street HOV lane project has been a successful one in terms of accomplishing a reduction in travel time for buses and for carpoolers in this corridor. The bus travel time through the study area has been the most outstanding item to note. With the second day of data collection in the Before Study [3], the travel time for general vehicles, the queue lengths, and the volumes provide a seemingly ideal situation in terms of traffic movement. Even with this, the mean bus travel time on NE Pacific indicates improvement for the After Study. The mean travel time for the bus was 170.5 seconds versus 204 seconds for the Before data. Carpools in the HOV lane had a significant advantage over general traffic also with an average of 128 seconds versus 155 seconds as they traversed through the study section. The travel time that was most representative of the Before data for the vehicles traveling in the general lanes was 175 seconds. Having data collected before implementation allows for the recognition of differences made in the system.

This queue-jumper facility does show positive results in that is has accomplished much of what was intended. In the Agreement [2] between the City of Seattle and METRO, the addition of the HOV lane was to increase the efficiency of the roadway, reduce transit operating costs, and provide incentives for greater use of buses, carpools, and other rideshare vehicles. This has happened on NE Pacific Street. While it is difficult to distinguish what the HOV lane did by itself, it is a positive story in terms of accomplishing these objectives when coupled with the U-Pass. When improvements are made in one area, there usually is an area that is adversely impacted. This has not been the case with the introduction of the HOV lane in this corridor in that the general traffic has been improved also. The *success* that has been involved with this project is listed below.

- Bus travel times are down and reliability is up
- General traffic travel times are down
- Carpools in HOV lane have a travel times savings of 0.87 minutes/mile in this corridor vs. general traffic
- HOV lane moves 41.9% of the people in approximately 5% of vehicles where there are two general purpose lanes available
- Advanced-green phasing for HOV lane is a signalization technique worth investigating

It follows intuitive thought in that removal of vehicles from the lane would improve traffic flow, although green time was taken from the general traffic lanes and given to the HOV lane for its advanced green time. The HOV lane has a loop detector noting the presence of a vehicle, and the time allotted for advance movement for vehicles in this lane ranges from zero seconds (no vehicle present) to eight seconds. After eight seconds, the general traffic automatically gets a green light. This case is a first in the literature where a car (Vs bus) has the ability to control the signal for the arterial HOV lane. OPTICOM systems exist where a bus has a strobe that emits a signal to the controller to pre-empt the timing within the cycle.

Of significant importance is the potential application of these queue-jump facilities to other portions of the transportation system. With the intention of creating an extensive system of HOV lanes on the highway system, these queue jumpers could provide excellent entrance lanes to the highway system. With more arterial HOV facilities of a longer variety, there could be more efficient usage of other portions of our roadway system for vehicular flow. Ultimately, these should be used in strategic locations to work toward diminishing the congestion problems throughout the system.

From the literature review, the major goal found for HOV projects was that of increasing the overall efficiency of the transportation system. The major benefit is travel time savings. This facility fit in the range of travel time savings (0.02 to 1.4 minutes/mile) as indicated by Table 1 on page 13 with the 0.87 minutes/mile. This does not quite meet the suggested criteria of 1.5 minutes to 5 minute potential savings per mile.

Most of the models that have examined efficiency have been noted on the freeway system, but the arterials may have an impact on the overall system also if the system is integrated. Better efficiency would also promote a mode shift from the SOV. We have seen that in this project. The integration of the *U-Pass* into the program with its strong bus program definitely had an influence on influencing bus ridership. Carpool and vanpool usage have increased also.

The travel survey did point out some interesting items. The majority of the trips into the District were work trips, and the people had an average household income in the $40-50K bracket. The average age was in the mid-forties. The destinations were primarily to the Montlake/Capitol Hill area as well as to the east via SR 520. The other destinations were very scattered. Many people commented on possibly using transit if there were more direct routes. Many of those on the East side of Lake Washington said they would use transit if there were more frequent service. Having to transfer to another route disturbed respondents also.

External Transfer of Results

Like most HOV situations, there are site specific situations. This one is truly one that is unique with its constraints. The waterways and the Montlake Bridge restrain this situation tremendously. The location is in the University District, where the University is the major attractor and generator of traffic. Additionally, the arterial HOV lane acts as a queue-jumper. There is also good transit service already available in this area.

However, these should not be viewed as constraints. Where there is good transit service availability in an area, it should be viewed as a possible target area for an HOV lane. If there is a capacity issue being threatened because of a heavy supply of buses, this is an ideal place to make a change in a system. Buses have a stop-and-go nature because of the service they render. Providing them with a priority lane is good for the system. It takes the bus out of an otherwise flowing lane and puts them in their own lane.

Transit bays are helpful also in keeping the lane moving as a bus has to stop. Otherwise, they are still blocking traffic. Stops and then traffic lights double the impact of movement on an arterial. Giving them a priority lane is good for the whole system. Some worry that if a bus gets into a bay, it will have difficulty getting back into the stream of traffic. The concern is minimized with an adjacent HOV lane in that gaps should be prevalent because of the low volume. Ultimately, the volume should not be so low in that it is difficult for general traffic motorists or other onlookers to recognize the utilization of the lane. The volume should be lower than the general traffic lane so as to be able to maintain the movement that gives it an advantage over the general lane(s). This is another reason to have good transit service in place so that there is a noted presence of High-Occupancy-Vehicles. Every one sees the bus.

The Metropolitan Seattle area is looking into various corridors where arterial HOV lanes may be effective. Taking issues such as transit service existing, bus bays, and possibly an advanced green/detector operated system versus a pre-emption system into account are really concerns to consider when planning or designing the optimal arterial HOV lane for each unique location. Taking time to model it with good data is also of paramount importance for an effective simulation and after-implementation analysis and evaluation.

Methodological Recommendations

The whole project (Before & After) was a reinforcement of techniques already existing. The use of Traf-Netsim and TRANSYT-7F for modeling proved to be challenging, but they assist in simulating the existing system and producing a forecast with the HOV addition. Traf-Netsim especially has the capabilities of modeling small, arterial projects effectively. Data gathering is of vital importance also as a means of breaking down the barrier of the unknown about arterial HOV lanes. The use of lap-top computers in the field helped tremendously in the ability to synchronize times among computers for better travel time accuracy. It also helps in coordinating occupancy counts with vehicles if a study wishes to identify travel times with certain types of vehicles. Good monitoring after the implementation of the HOV lane is helpful also in determining patterns. Hopefully, the methodology used in this project is one that provides a framework for others.

Marketing the system plays a major role in how the public perceives it. This is why agencies should be willing to take these projects to public relations specialists or professional marketing people who can make the public feel included and enthused about the project. Getting people to use it as well as accept its presence is also important. Getting people to use them as they were intended is important also. As is seen here in this study, the HOV violation rate is very high. When the HOV lane is present and people see violators using it, it makes the other motorists either think of doing it also or possibly think of asking why is the lane dedicated to car-pools/buses only when it should be a general lane.

Suggestions for Further Research

The reason for this project is a suggestion for further research in that there is a paucity of information existing on Before & After Studies on arterial HOV lanes. This project is not a full-fledged HOV lane, but it does have the same types of issues with which to contend, but on a shorter scale. Traffic signals are present. Abutting driveways are present. Turning movements into and from the lane are present.

For further research, there should be follow-up data taken to determine whether there are any gains being made in the modal shift for the study site. Volume counts as well as travel times should be investigated again. Even various simulations of different modal considerations with the lane already present may provide some other opportunities for Transportation Demand Management Programs. Accident studies should be conducted also to determine whether there are any adverse impacts due to the introduction of the HOV lane. Expanding already existing transit markets may also be a good consideration to gain even greater utilization out of the transit system.

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