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HOV IMPROVEMENTS ON SIGNALIZED ARTERIALS IN THE SEATTLE AREA

VOLUME III:
N.E. 85th HOV STUDY

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16. ABSTRACT

This paper will discuss the problems that are inherent with adding a higher speed HOV lane to an arterial with its unlimited access points. Investigation of current literature will show that although freeway HOV applications have been researched and understood to an adequate degree, almost no data of any kind is available to predict the effectiveness of an arterial HOV project. Further, it will be proposed that not only does the research not exist, but that the "measures of effectiveness" to evaluate existing arterial HOV lanes are severely lacking.

In addition to the literature search, a motorist survey was handed out to collect data describing commute trip behavior. Questions about trip origin, destination, and purpose were asked to determine what residential and commercial zones were being served by NE 85th/Redmond Way, and for what purpose. The questionnaire also requested information on the duration of the trip and the occupancy of the vehicle. This data was used as input for a mathematical model to predict the volumes on the facility one year after the implementation of an HOV lane. Since the model was based on past freeway applications across the nation, the threats to validity that causes were also presented. The final questions on the survey concerned the motorists' own prediction about how likely they were to carpool and what they thought were some of the problems preventing them. These views were compared with the results from the model. The predictions and resulting effectiveness of the project were evaluated versus the stated objectives of the Eastside Transportation Program (ETP) policy statement.

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HOV IMPROVEMENTS ON SIGNALIZED ARTERIALS IN SEATTLE AREA

VOLUME III: N.E. 85th HOV STUDY

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In addition to the literature search, a motorist survey was handed out to collect data describing commute trip behavior. Questions about trip origin, destination, and purpose were asked to determine what residential and commercial zones were being served by N.E. 85th/Redmond Way, and for what purpose. The questionnaire also requested information on the duration of the trip and the occupancy of the vehicle. This data was used as input for a mathematical model to predict the volumes on the facility one year after the implementation of an HOV lane. The fact that the model was based on past freeway applications across the nation, and the threats to validity that causes, will also be presented. The final questions on the survey concerned the motorists' own prediction about how likely they were to carpool and what they thought were some of the problems preventing them. These views will be compared with the results from the model. The predictions and resulting effectiveness of the project will be evaluated versus the stated objectives of the ETP policy statement.

DISCLAIMER

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SUMMARY

The Eastside Transportation Program (ETP), a cooperative planning effort of government agencies involved with transportation issues east of Lake Washington, has recommended an integrated system of arterial HOV improvements linking Eastside activity centers to the regional HOV system. N.E. 85th St./Redmond Way (SR 908) from Interstate 405 in Kirkland to Willows Road in Redmond was identified as one of the highest priority arterials that could be improved by the implementation of an HOV system.

This report discusses the problems that are inherent in adding a higher speed HOV lane to an arterial with unlimited access points. An investigation of current literature showed that although freeway HOV applications have been adequately researched and understood, almost no data are available to predict the effectiveness of an arterial HOV project. Further, not only does the research not exist, but the "measures of effectiveness" for evaluating existing arterial HOV lanes are severely lacking.

In addition to the literature search, a motorist survey was conducted to collect data describing commuter behavior. Questions about trip origin, destination, and purpose were asked to determine the residential and commercial zones that N.E. 85th St./Redmond Way was serving, and the purposes for those trips. The questionnaire also requested information on the duration of the trip and the occupancy of the vehicle. These data were used as input for a mathematical model to predict the volumes in that area one year after the implementation of an HOV lane. The validity concerns caused by the fact that this model was based on past freeway applications across the nation were explored. The final questions on the survey concerned the motorists' own predictions about how likely they were to carpool, and some of the issues preventing them from carpooling. These commuters' views were compared with the results obtained from the model.

The predictions and resulting effectiveness of the project were then evaluated and compared with the objectives of the ETP policy statement.

INTRODUCTION

The Eastside Transportation Program (ETP), is a cooperative planning effort of state, regional, and local agencies involved with transportation issues in the section of King County immediately east of Lake Washington. One of the ETP's recommended policies is entitled "Transit and Ridesharing Facilities and Services." Under this title the following phrase appears: "Support and actively work toward an integrated system of arterial HOV improvements linking Eastside activity centers to the regional HOV system, in order to provide time advantages for HOV's over Single Occupant Vehicles (SOV's) in congested corridors and locations." Of these arterial HOV applications, one of the highest ranked facilities is N.E. 85th St. from Kirkland to Redmond. (This route goes by several names: N.E. 85th, Redmond Way, and State Route 908, but for this report, N.E. 85th will be used to refer to the entire study section.

This report will investigate the characteristics of N.E. 85th, the need for implementing an integrated system of arterial HOV improvements, and the problems that are associated with such an implementation. To test the probable success of an HOV lane, data were taken from field observations and from a motorist survey. These data were used as input for a mathematical model based on past national applications. The results will be noted, and their coherence with the ETP intent will be discussed.

The Federal Highway Administration's 1983 National Personal Transportation study noted that the largest increases in traffic volumes in the last 20 years have been in intra-suburb and suburb to suburb trips (2). What has made this such a problem for both motorists and traffic engineers is that the suburbs usually do not have the existing roadway infrastructure to allow driver choice when the primary routes become congested. Typically, the growth of the suburbs has been accelerated by access to radial or circumferential freeways. Like a sewer system, the freeway acts as the trunk line and accepts all the flow from the immediate area, with the local arterials feeding the collected traffic to it as quickly as possible. Because of this drainage basin design, with all roads leading to the same corridor, efficient parallel routes are few, and those that do exist are poorly connected by surface streets. Different routes simply allow motorists to access the freeway a mile or two further downstream.

In the last 15 years, high occupancy vehicle (HOV) lanes have been implemented on freeways. However, these lanes have not provided much relief to travel in the suburbs for two major reasons. First, the most congested freeways are still the radial ones, and these were the first to receive upgrading with HOV lanes. Second, because of the design of roadway systems in the suburbs, and the continuing movement of companies and residences toward the edge of developed areas, the major portion of a commuter's trip may not be on the freeway. In the suburbs, motorists are spending more and more time trying to travel on crowded arterials through one overburdened traffic signal after another.

Upgrading the capacity of the major arterials is almost impossible because of the cost of right-of-way. The ubiquitous strip development along the arterials shows that land with easy access is valuable, despite how congested that access is. With demand exceeding capacity on an almost continuous basis, and the cost of added capacity exceeding available funds (besides, perhaps not being in the best interest of the community), planners and designers in suburban areas are following the path that highway engineers made a decade ago, that is, they are now considering the implementation of HOV lanes on surface arterials.

STATE OF THE ART - "SUBURBAN ARTERIAL HOV LANES"

DEFINITION OF TYPE

The Highway Capacity Manual defines urban and suburban arterials as "signalized streets that primarily serve through traffic and provide access to abutting properties as a secondary function." (11) It places arterials, as a functional element, "between collector and downtown streets on one side and multi-lane suburban highways and rural roads on the other side." The most important defining factors are signal spacing and intensity of roadside development. Rural roads and suburban highways have signal spacing of over two miles, while signal spacing for arterials is less than two miles. Signalization on downtown streets also may not be as dense as on arterials, but the major difference is their access function. The main function of downtown streets and collector streets is to provide more access to abutting properties than arterials do. However, with the tremendous growth in suburban development, especially along the arterials, the property access function of the suburban arterial is closer to that of the downtown street.

Suburban arterials are typically lined with nothing but retail and office development, though often the business areas are not clearly defined. They may end suddenly and residential areas may appear, or there may be a gradual change, or worse, from a traffic perspective, the different types of developments may be intermixed in an unorganized pattern. All of this makes defining of a suburban arterial and subsequent problem solving very difficult.

Trip generation is another difficult factor to define. Because suburban routes run through large residential areas and are bordered by a growing number of service businesses, and because the percentage of non-work trips originating from both home and work are increasing, there is no longer a clear peak traffic period. As soon as the morning commute is over, service, business, and shopping trips begin.

These types of trips continue all day and merge with the evening commute, after which time the social recreation trips become predominant.

The last point to discuss regarding suburban arterials is the effect the local system design has on the routine flow of traffic. If the arterial parallels a suburban freeway, tolerable volumes may become gridlock situations on days when there is an incident on the freeway, as motorists seek alternate routes. The number, size, and spacing of feeder streets also produces individual problems to solve for each roadway, as does the direction of flow onto and out of these side streets. Large turning movements create the need for double turning bays and special signal phases.

Arterials, especially suburban arterials, are much more complex and varied than freeways, and there are many more aspects that must be considered when HOV lanes are involved. Arterials are where Americans live. People travel on the freeway to get from one town to another town, but travel on arterials to work, school, the mall, the gas station, the restaurant, and cultural activities. Almost every trip utilizes arterials, and almost every service is available on them. They contain the few suburban bus routes, and provide access to a growing number of pedestrians and bicyclists. Much needs to be considered when major changes affecting arterials are contemplated.

EXISTING APPLICATIONS

Seattle is one of the few cities in the United States to have implemented a restricted HOV lane on a non-CBD arterial (and they have three of them). Two of the three are on SR 522, or Lake City Way, which is a radial arterial connecting a freeway to the suburbs. The northbound lane is 0.92 miles (1.5 km) long and the southbound lane is 3.27 miles (5.5 km) long. At the time of this report, both of these sections were restricted to buses only and operated only during their respective peak flows. SR 99, or Aurora Ave., is also radial, but extends from the

CBD to the city limits. Its HOV lane goes through what could be called a suburban business district, basically a strip development along the arterial. This HOV lane is only northbound, 1.5 miles (2.5 km) long, open to three or more person (3+) carpools and transit, and operates 24 hours a day. All three sections have operated since the early 1980s.

Long range plans from groups like the Puget Sound Council of Governments (PSCOG) and the ETP, which would extend the HOV network to all freeways and many of the main arterials in the area, have stimulated both Snohomish and King County to actively pursue HOV lane implementation. In most cases, the arterials are overburdened two- or four-lane facilities that link bedroom communities and freeways. When major improvements are deemed necessary, transportation designers are supposed to make a full investigation of the possibility of adding HOV lanes. Because there is so little background knowledge of this kind of application, agencies are proceeding ahead, uninformed, with many questions regarding how the priority lane should look and operate, where it should begin and end, how it will interact with the adjoining land uses, and how the purchase of the necessary right-of-way will be funded. Ironically, the funding issue is one of the main proponents for large-scale arterial HOV projects. The state of Washington has set aside a portion of the gas tax revenues to be used for city and county projects on a discretionary basis. This fund, administered by the Transportation Improvement Board (TIB), gives precedence to those projects that include transit improvements and involve more than one jurisdiction. An HOV lane on an arterial that goes through the county and one or more small cities is highly ranked on the discretionary list.

Nationwide, few if any suburban arterial HOV lanes are mentioned in available literature. Studies of HOV applications in the U.S. by ITE in 1985 and the Texas Transportation Institute (TTI) in 1990 address only those HOV applications on freeways or separate rights-of-way. The only reports that investigated arterial

HOV treatments to any degree were by Batz in 1986 (6) and Nihan and Davis in 1990 (14). However, of the 95 arterial applications listed by Batz, the majority were for some type of CBD bus lane, and only eight were on facilities that could be considered suburban. Of those eight, three were for buses only, one was a queue jumper, and two were on the two routes in Seattle. Even the Nihan-Davis report, which was a state-of-the-art survey, was unable to identify anything definitive regarding standard arterial HOV treatment; they concluded only a "cautious generalization." This lack of experience with and information about arterial HOV treatments is in direct contrast to the interest shown in arterials at the Transportation Research Board's 1991 National HOV Conference held in Seattle. Many attendees informally expressed a desire to know more about the feasibility and possibilities of arterial HOV treatments.

Not surprisingly, by far the most extensive study done on the possibilities of adding a full-use HOV lane (carpools and transit) to a suburban arterial was done in Seattle. The draft report of the Highway 99 High Occupancy Vehicle Study, funded by METRO, and performed by the TRANSPO Group, Inc., (5) is a proposal for just such an inter-agency project envisioned by the TIB. This 15-mile (25 km) project involves four cities (Seattle, Edmonds, Lynnwood, and Everett), two counties (King and Snohomish), two transit agencies (Seattle Metro and Community Transit), and the Washington State Department of Transportation.

The study is a classic example of multi-criteria evaluation, where three different alternatives are rated on nine quantifiable criteria. TRANSPO's three alternatives were as follows:

(1) Full-length HOV lanes in both directions;

(2) Short sections of HOV lanes, usually less than four miles, in the most congested areas; and,

(3) Spot improvements, such as HOV turn lanes, queue jumpers, and

signal prioritization.

The criteria used to judge the alternatives were as follows:

(1) Corridor travel time savings,

(2) Person throughput,

(3) Level of service and delay,

(4) Traffic safety/accident potential,

(5) Transit stop location and operation,

(6) Community acceptance,

(7) Policy support,

(8) Operational flexibility, and

(9) Costs and funding sources.

Actually, only the first criterion, corridor travel time savings, seemed to be of much importance. The realistic alternatives (criteria four through eight) were also highly ranked. Person throughput, an important factor, was defined at a certain predetermined level in all of the alternatives. Time savings, which had to meet "the generally-accepted travel time advantage threshold of one minute per mile," and costs and funding sources, finally were judged the most important alternatives.

Because relative travel times were so important in the deciding matrix, it was surprising to note some of the unrealistic assumptions made which affected this variable. Constant demand was used, assuming no increases in volumes due to the increase in capacity. The vehicles that moved to the HOV lanes decreased the general purpose traffic. This, in turn, reduced the travel time for these lanes, making them more attractive. Yet there was no assumption of additional traffic diverted from other parallel routes. This tremendous relief to the general purpose traffic that the HOV lane addition would bring was never considered within the realistic scope of an HOV lane's purpose.

The report was in draft form when it was reviewed and has many obstacles, including the fact that its results have to be accepted by at least nine separate agencies before it is deemed an acceptable effort.

PROBLEMS TO OVERCOME

When the application of HOV lanes on arterial streets is mentioned, the question of safety is almost always brought up. Unlike freeway priority lanes, which are generally placed on the inside lane, priority lanes on arterials are usually envisioned on the outside. This is because HOV lanes must serve local bus routes, and the cost and logistical problems of moving the stops to the center of the roadway are prohibitive. The result of having outside, or right hand, HOV lanes is that free-flow traffic, i.e., carpools traveling in uncongested conditions, are sandwiched between the slow lane of the general purpose traffic and pedestrians along the shoulder or sidewalk. In addition, entering and exiting traffic from property adjacent to the arterials must cross this higher speed lane to complete their maneuvers.

Most of these concerns are derived from engineering judgement and common sense, as there is little documentation of safety hazards. Of the 95 arterials listed by Batz, nine were suspended because of poor enforcement or low utilization (7). Only two arterials mentioned referenced safety as a problem. On one of those, an attempt was made to use a center left turn lane during peak hours, but it was closed due to accidents. The only report dealing strictly with arterial HOV safety that the researchers could find was on the Seattle arterial HOV lanes by Larry Senn of WSDOT (15). He found no increase in accidents on the two SR 522 HOV lanes, which are peak hour and transit only. However, on the 24-hour, full-use HOV lane on SR 99, he found that the accident rate was 428 percent greater than on a comparable adjacent section with no HOV lane. The accidents "are almost all related to opposing left turns across the HOV lane and lane changes into the HOV lane." This is concrete support of the popular belief about potential problems with arterial HOVs. The next step, obviously, is to find solutions to the safety problem. Senn's recommendations are to restrict access and to increase the visibility of the HOV lane by adding more painted diamonds and more visible dividing striping and buttons.

As mentioned before, an arterial is not as isolated as a freeway, and so the community is more easily affected by changes made to arterials. Therefore, there are many other problems, though not always as life-threatening as the above problems, that must be addressed before an HOV lane can work on an arterial. Access, from both the edge of the roadway and across the center line, is probably the most important and most difficult concern. Its significance is realized in the comparison of accidents on the two Seattle arterials. Most of the HOV lane on SR 522 has few driveways and/or median divider curbs which greatly reduce the turning traffic across the HOV lane. On SR 99, on the other hand, there is not only a two-way left turn lane traversing the entire length, but there is practically unrestricted access from the abutting properties. There is no curb and gutter, and only some raised curb marking driveways. Several lots have car access along the entire length of their frontage. This amount of access not only creates an accident hazard, but also slows the priority vehicles down by making them negotiate all crossing traffic.

This access problem is difficult to solve because its scope is far beyond the usual traffic engineering solutions. Buttons and paint can only do so much. Reducing the number of curb openings is critical, but few, if any, agencies have the power to regulate access without actually purchasing it at a very high cost. Even if the money is available, this process accomplishes little when the development is a series of small lots with limited parking. Usually, just two or three small businesses share the same access point and the reduction in incidents is not substantial. Pre-planning to allow access only at the sides and back of the lots is necessary to allow crossing and turning movements to be made from signalized side streets. However, as is often the case with suburban arterials, no side streets exist until after the first strip development is in place. In this case, only a long and aggressive campaign of redirected land use can help. The commercial buildings, which normally face the arterial and a parking lot, need to be placed toward the front of the lot and have access provided from the rear, turning their focus 180 degrees.

The most enigmatic problem for HOV lanes, and for arterial lanes to a greater degree, is probably the slowing and blocking effect that buses produce in these lanes. This is a critical problem because bus traffic is one of the main reasons for the lane's existence, but also one of the biggest deterrents for carpools using it. Research of arterial HOVs has yet to show how motorists actually overcome this problem with buses, whether they go around and re-enter the restricted lane immediately, or continue in the general purpose lane until a distinct advantage can again be gained. A very limited study by Rubstello found that only 23 percent of carpools that entered the SR 99 carpool lane at the beginning, were still in it a mile and a half later (8). Whether this was due to bus traffic, vehicles turning out of the corridor, or because no time advantage was gained, was not clear.

The only realistic way to limit the slowing and blocking effect buses produce is to provide widened pullouts at each bus stop. One problem with this is that transit operators do not like exiting the traffic stream because of the difficulty of reentering. The lower volume of the HOV lane should make this easier, but the higher speeds of the vehicles negate most of the benefit. Perhaps the most restrictive obstacle to implementing widened pullouts is the extra right-of-way required. The extra width required to add an HOV lane can often be made from the existing corridor by using shoulders, planter strips, or several feet of a parking lot. Taking another 14 to 20 feet for a bus bay could be prohibitive.

Another problem with arterial HOV applications, and one that changes with each individual route, entails the type and length of trip that is made on the arterial, and the arrangement of the alignment as a parallel or feeder route. SR 99, for example (see Figure 1), is a 20-mile (33 km) long radial arterial, but it is paralleled only two miles (3 km) to the east by the major north-south freeway in the area. Therefore, even though many of the vehicles are making long commutes, they may only be on SR 99 until they reach a cross street that takes them to Interstate 5. Therefore, the researchers believe HOV lanes should only be placed where the vehicles using the route can spend the majority of their trip on an HOV facility, either along the arterial or connected to one on the freeway.

Another unique challenge of each arterial is the turning traffic volumes. The bulk of the traffic on SR 99, because the Interstate 5 freeway is so close to the east side originates west of the roadway. In northbound traffic, on the p.m. commute, most vehicles exit to the left, which is west. An HOV lane on the right creates the problem of having to merge to the left when the time to exit approaches, and that merging has to be done in the vicinity of the signal where most of the congestion exists. Knowing the Origin-Destination matrix of the traffic on a corridor allows one to know how much through traffic can be assisted by an HOV lane.

As the bicycle and pedestrian lobbyists become more vocal, situating high-speed traffic in the right lane becomes increasingly difficult. Bicyclists have already spoken against coordinated signals and right turn lanes because they raise the the motorized traffic speed. The pedestrian advocates, including landscape architects and designers who are planning to make the cityscape and suburb-scape more livable, also prefer slower traffic to enhance the walking experience. Whereas an HOV lane may reduce the number of cars on a roadway, the widened pavement and higher speeds makes pedestrian activity less pleasant and more dangerous. Pedestrian and cycling facilities must be clearly planned as a separate part of the widened facility; they can no longer share the areas left over by the cars.

As noted in the Highway 99 HOV Study, one of the biggest problems with arterial decisions is that because of their length, they usually run through more than just one jurisdiction. They may go through a state highway or a county road, as well as a main street, to several towns. People in the outlying communities use the route to get into the city or across the metropolitan area as fast as possible. Conversely, the citizens of the communities it goes through want the traffic's speed reduced to make the areas safer for children, pedestrians, and crossing traffic. The two viewpoints are in direct opposition to one another and a decision on where and if to implement higher-speed high occupancy lanes is a difficult one.

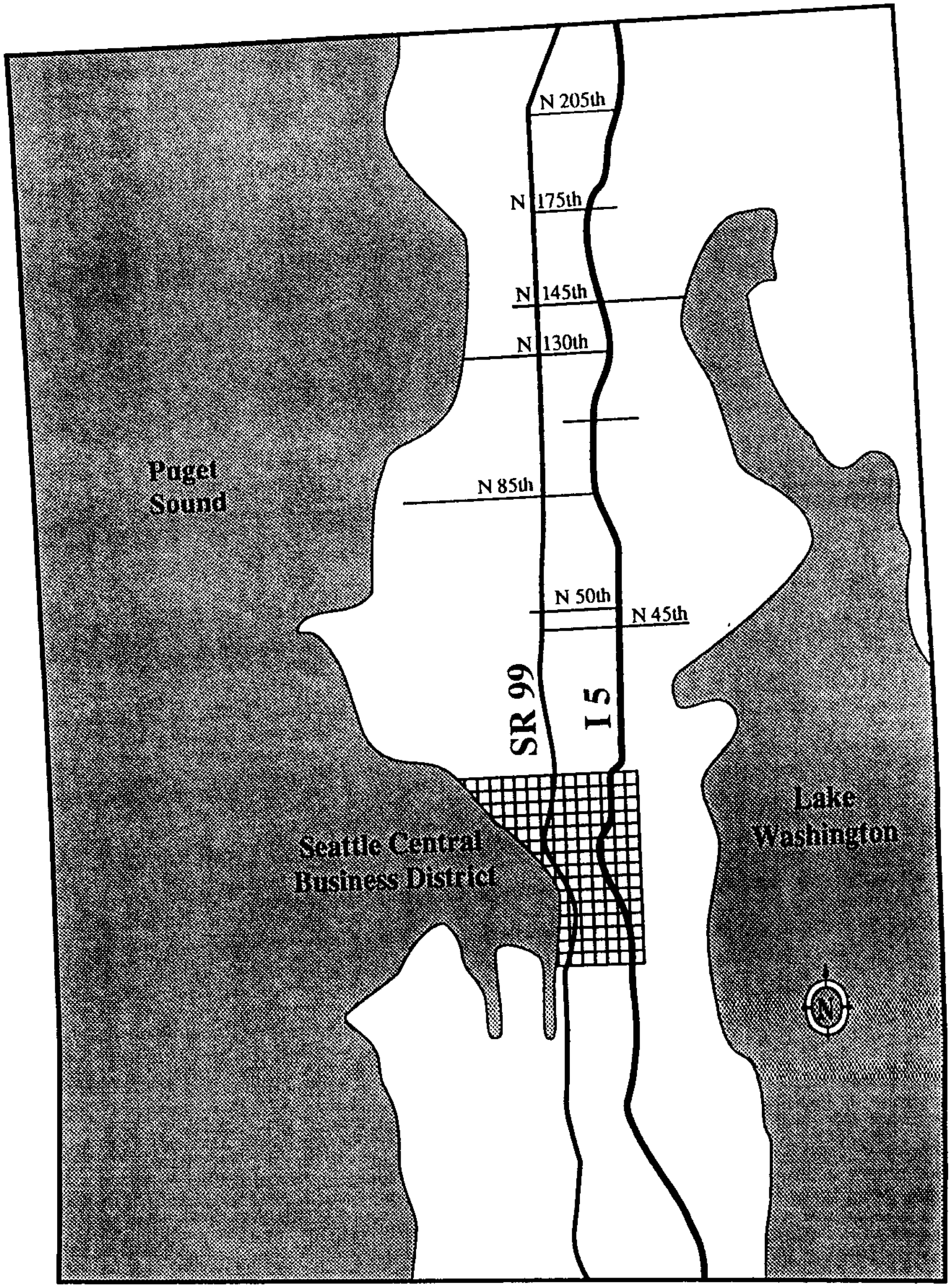

Figure 1. SR 99 Location in Metropolitan Seattle

SPECIFICS OF N.E. 85TH EXISTING CONDITION

The specific conditions that exist for each arterial can be unique. Location, traffic patterns, freeway access, parallel routes, bus service, signal spacing, and business and residential density are only some of the factors that can influence the effectiveness of an arterial HOV lane. This chapter will address these important descriptive elements of the study area on N.E. 85th.

LOCATION IN METRO AREA

Figure 2 shows the location of the N.E. 85th corridor in the Seattle metropolitan area. It runs east-west between Kirkland and Redmond on the east side of Lake Washington. Its interchange with Interstate 405, the western terminus of the study area, is approximately 11 miles (18 km) from downtown Seattle by freeway. From the I-405 interchange, in Kirkland, N.E. 85th runs east and south to Redmond. The eastern boundary of the study section is Willows Road, so that the entire study section is 2.4 miles (4 km).

Its location makes N.E. 85th an intra-suburban arterial that more often serves commuters going to other suburban destinations than to downtown Seattle. Another important factor about this general location is the auto orientation of the suburban population. The researchers cannot say whether the people of the suburbs preferred using their cars and so built an environment to suit their desires, or if previous land development dictated that plight. However, whatever the cause, the Kirkland-Redmond area is a typical American suburban bedroom community, with large residential areas free of the congestion associated with services. Services are only available along the major arterials and in a few community and regional shopping malls.

LOCATION OF HOUSING AND JOBS

Another characteristic of the Kirkland-Redmond area that is typical of modern suburbs is the growth in the number of high-tech companies that are locating there. (Figure 4 shows the locations of computer and technology-based employment in the Redmond area.) These jobs at the eastern end of the study area create a traffic flow that is greater than the more traditional, "inbound," or western flow. Westbound traffic is headed for employment in Kirkland and Bothell, and to a lesser extent, Seattle and Everett. Residential housing is located all around N.E. 85th. Kirkland, west of I-405, contains a mix of single family residences, apartments, and condominiums. East of the freeway, in the areas near 85th, housing is almost exclusively single family units. The Redmond section of the arterial is bordered, for the most part, by large apartment complexes set back from the roadway.

In addition to being near housing, N.E. 85th is the closest east-west arterial to the north end of Lake Sammamish providing one of the few ways to travel west from the large residential development there to east of the lake.

TRAFFIC PATTERNS AND VOLUMES

The balance in the commute flows along N.E. 85th is reflected in traffic counts taken by the cities of Kirkland and Redmond. The Kirkland count, shown in Table 1, is from near the intersection of 124th N.E., and the Redmond numbers are from 140th N.E. (The Redmond values include an average of the vehicles lost and gained because of the number of turning movements at the intersection.)

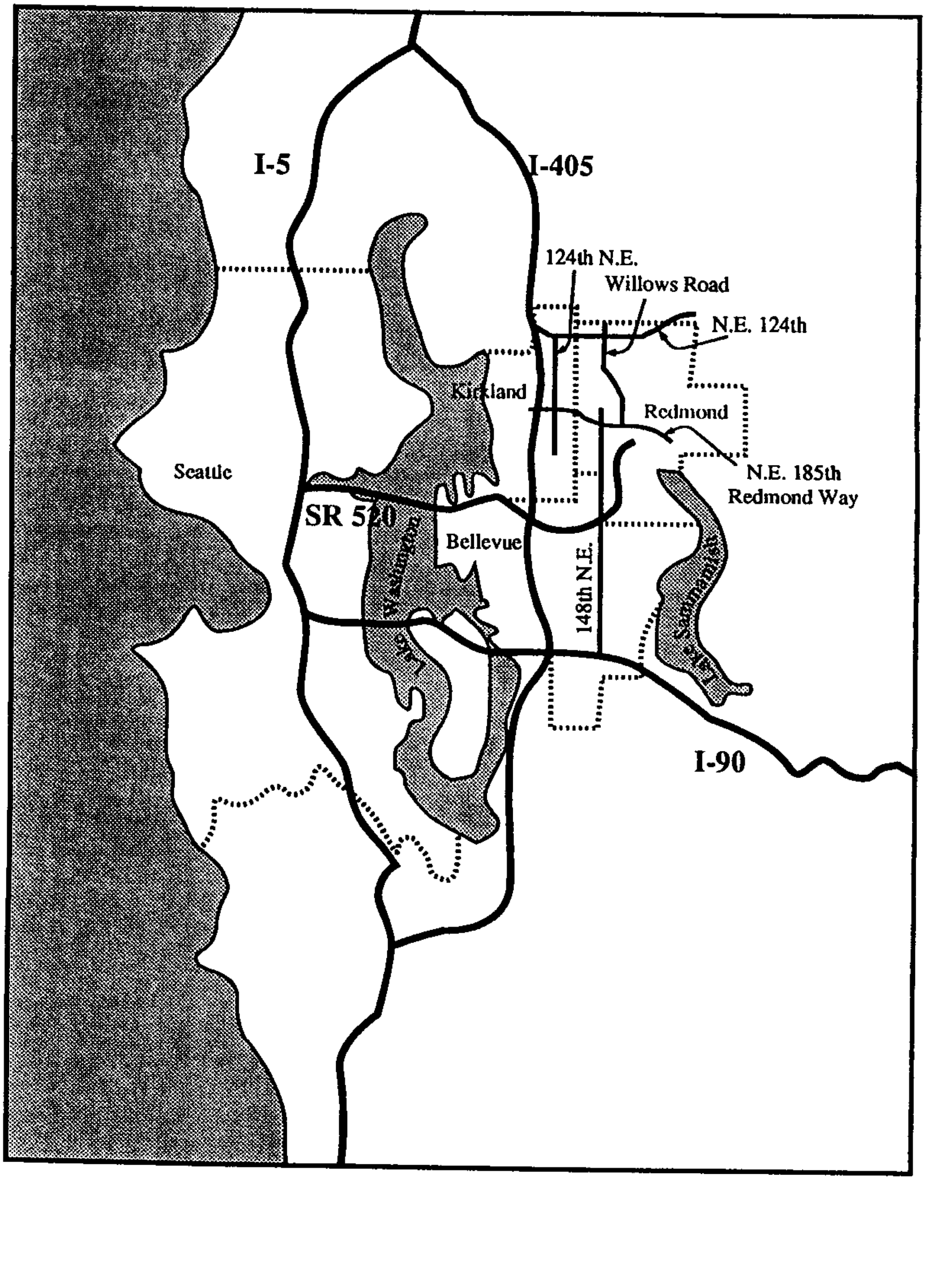

Figure 2. Metropolitan Area in Vicinity of N.E. 85th

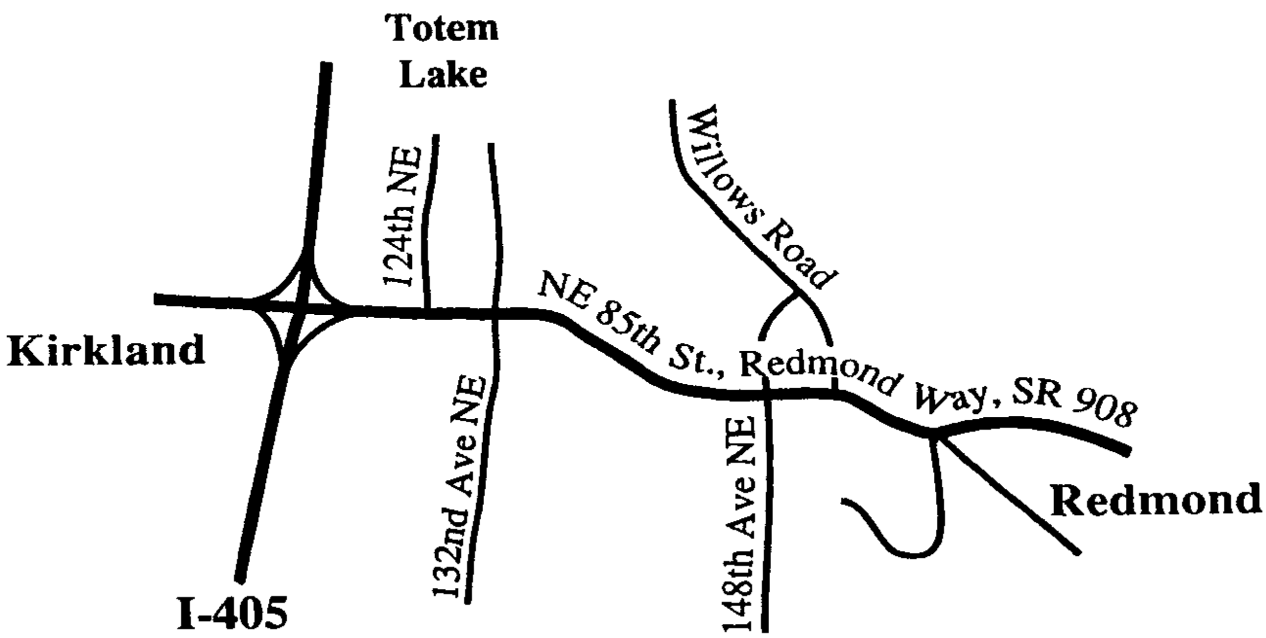

Figure 3. NE 85th Vicinity

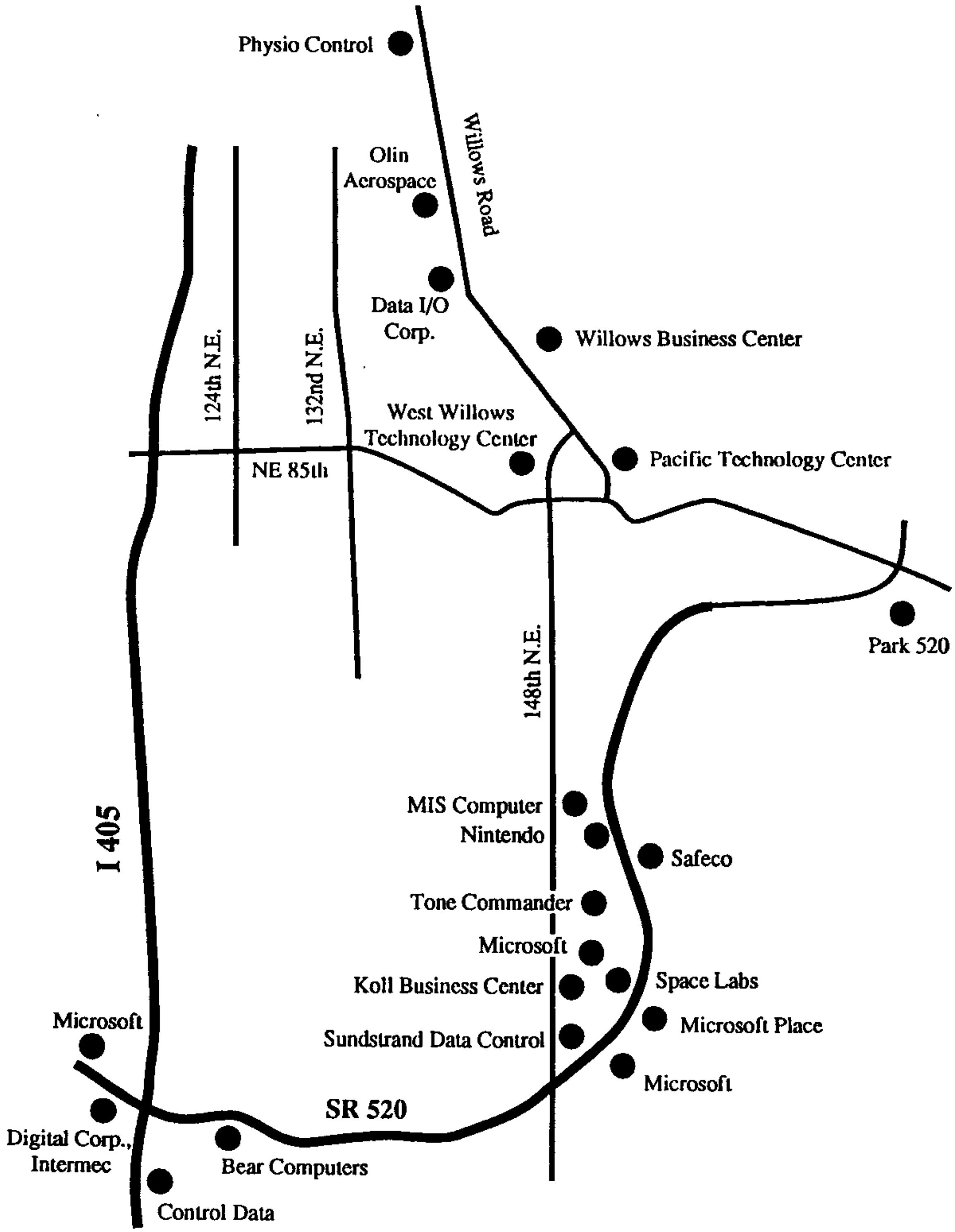

Figure 4. High-Tech Companies in Vicinity of N.E. 85th

TABLE 1

A.M. PEAK HOUR FLOWS (VPH)

	124th N.E. week of: 9/24/90	140th N.E. 6/19/90
EB	1278	1355
WB	1198	1274

This study's motorist survey asked for the address of, or the nearest intersection to, the origin and destination of the trip being made. These locations were aggregated into zones to create origin-destination matrices for the trips along N.E. 85th (see Figures 6 and 7). The zone boundaries of the Puget Sound Council Of Governments (PSCOG) were used. Near the study section, individual zones were used, as the numbers there were greatest. As the distance from N.E. 85th increased, the zones were aggregated into larger groups. Appendix A includes a list of the PSCOG zones included in each study zone. Figure 5 shows the study zones used in the evaluations.

The largest movements from the matrices are shown graphically in Figures 8 and 9. Westbound, 39 percent of the trips were to zones 19 and 20, the Rose Hill business area and downtown Kirkland. This number, compared to only 9 percent going to all parts of the city of Seattle, proves that most travel on the arterial was suburb-to-suburb. The westbound origins showed that 43 percent of the trips began in west Redmond (zones 2, 17, and 18), 25 percent on the Sammamish plateau (zones 12-14), and 14 percent in northeast Kirkland, (zone 19). Therefore, for westbound traffic, N.E. 85th served the zones immediately to the north and east of Lake Sammamish and provided access to Kirkland and all parts of the metropolitan area via I-405.

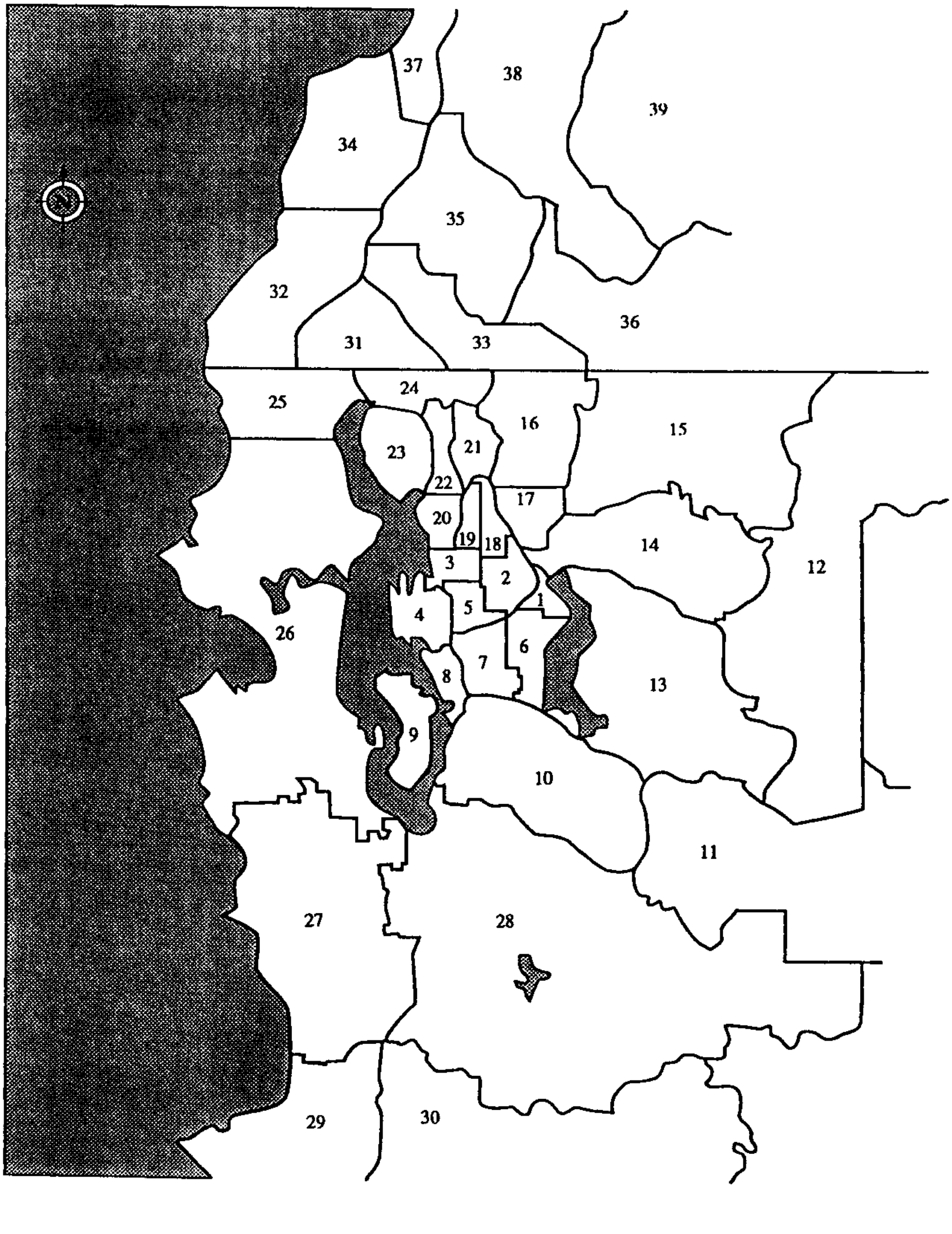

Figure 5. Study Traffic Analysis Zones

EASTBOUND	ORIGIN ZONES																																									Totals
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	
	1																						1	1																			2
	2																1		1	8	40	8	17	25	6	5	1					8	16	2	2	1	1	4	2	5	1		154
	3																	1	1																								2
	4																																										0
	5																			4	2	2	4	1									1										14
D	6																					2		3									1										6
E	7																			1	2	2		1	1																		7
S	8																																										0
T	9																																										0
I	10																															1											1
N	11																			1																							1
A	12																				1								1														2
T	13																							1														1					2
I	14																			3	11		4	7	1	2						3	2		1	1							35
O	15																																										0
N	16			1															1																								2
	17			3	1			1		2	3	1		1					1	4	21	1	1	5	1		7	5	4	1		1	1	1			1	1			1		69
Z	18			1		1				1	2			1	1					3	5	1	1	3			3	1	4				1	1								2	32
O	19										1					1			1		1						1		1	1													7
N	20		1			1													1																			1					4
E	21																		1																								1
S	22																																										0
	23																																										0
	24																																										0
	25		1																																								1
	26																		1		1																						2
	27																				1																						1
Totals		0	2	5	1	2	0	1	0	3	6	1	0	2	1	1	1	1	8	24	85	16	28	47	9	7	12	6	10	2	0	13	22	4	3	2	2	7	2	5	2	2	

Figure 6 - Eastbound Travel Matrix

		WESTBOUND								ORIGIN ZONES																																Totals
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	
	2																				2			1																			3
	3		1										1				2	4																									8
	4		1											1			2	1	7	5			1																				18
	5													1				1		3		1	1																				7
D	6																			1																							1
E	9																	1																									1
S	10																		3																								3
T	12																		1																								1
I	18																		2																								2
N	19	1	3	1									2	2	3			4	2	1							1															1	21
A	20	6	9				2			1	1		9	11	7	4	4	14	11	8		1	1																	1			90
T	21	1	1					1							1			1	2	1																							8
I	22	1	1				2							3	2			1	1																								11
O	23		1											1	1					1																							4
N	24	3	4				2							3			1	2	1	1																							17
	25		1												1																												2
Z	26	1												1	1		1	1	12	10																							27
O	27																		2	1																							3
N	28																		2	4																							6
E	31		1										1	1				1		1																							5
S	32		1											2	2			3	2	1																							11
	33		3										1	1				1	2																								8
	34	2	3											4	2			1																									12
	36		1																																								1
	37	1												3	1				1	2																							8
	40		1											2					1																								4
	41																		3																								3
Totals		16	32	1	0	0	6	1	0	1	1	0	14	36	21	4	10	36	55	40	2	2	3	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	

Figure 7 - Westbound Travel Matrix

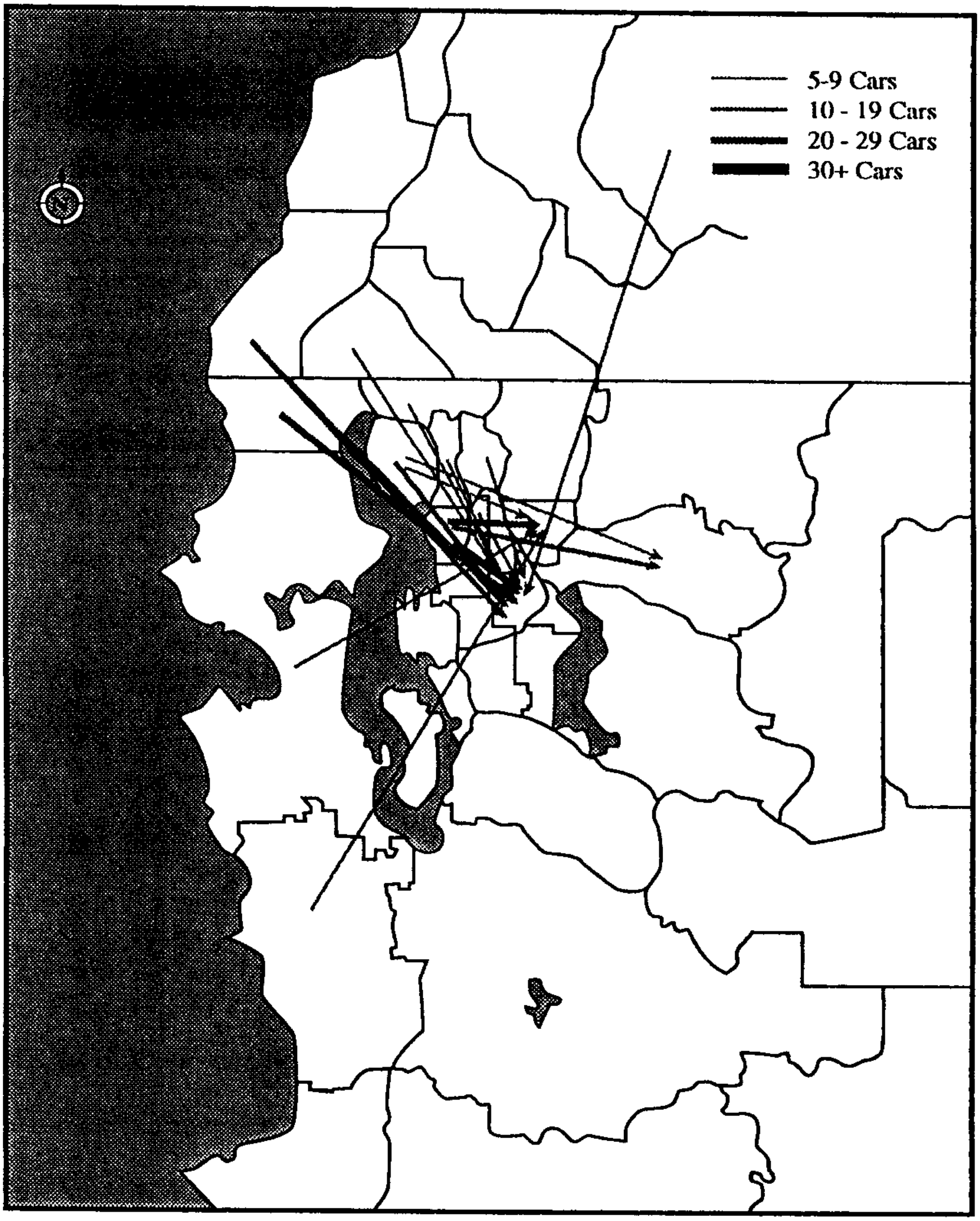

Figure 8. Major Eastbound Zone-to-Zone Movements

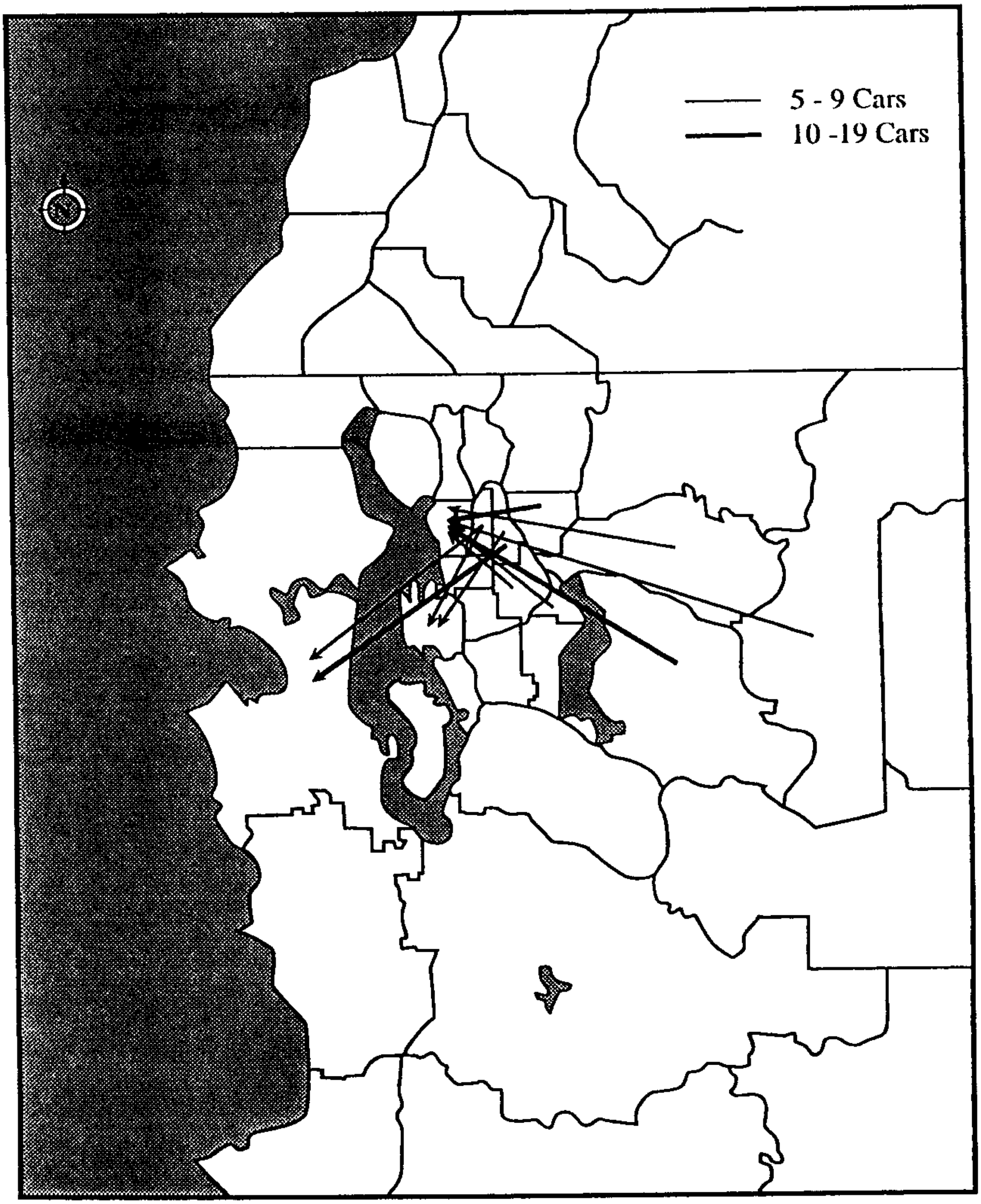

Figure 9. Major Westbound Zone-to-Zone Movements

Eastbound, 84 percent of the trips were to Redmond. They were broken up as follows: 44 percent to the Overlake area, which contains Microsoft, Nintendo, Safeco, and Group Health (zone 2); 20 percent to downtown Redmond (zone 17); 10 percent to the Bear Creek area (zone 14); and 9 percent to the business parks along Willows Road (zone 18). The origins were predominantly from central Kirkland at 32 percent (zones 19 and 20), and from the Kirkland-Bothell-Woodinville area, at 26 percent (zones 21, 22, and 23). One longer route that appeared well-used was 6 percent from the Lynnwood area (zone 32). Again, the predominance of travel was from zones in the immediate Kirkland-Redmond area, suggesting that commuters probably used this road for reasons other than just going to work during the week.

Another important note about the matrices is the number of zones that were the end of a trip on each. Table 2 shows that there were fewer zones on the east end of both directions of trips.

TABLE 2

NUMBER OF ZONES AS ORIGINS OR DESTINATIONS

	Destinations	Origins
EB	20	39
WB	27	24

Obviously, one reason is that the zones were smaller to the west, and there were more of them, but also, the east end of N.E. 85th is closer to both the origins and destinations that used it from that side. To the west, connections with the Interstate and other arterials accessed a much larger and widely distributed population.

INTERSTATE 405 HOV LANES

One very important aspect of the specific conditions of N.E. 85th is the imminent construction of HOV lanes on Interstate 405 (see Figure 2). These lanes currently run from I-405's southern interchange with I-5 to south Bellevue, with a short break in north Renton. Construction to allow continuous HOV travel through to Renton and to continue the lanes north to Woodinville is scheduled to begin within the next year or two. Upon completion of the system, commuters on N.E 85th will have access to a complete ring of HOV lanes around Lake Washington on Interstates 5 and 405, as well as one lane on the I-90 bridge. The incentive for commuters to carpool along the study section is intuitively significant, but unfortunately difficult to measure.

None of the questions on the motorist survey asked people to answer the questions as if the I-405 system were in place. Several people, however, suggested that completion of the I-405 HOV system be in place before any lanes were added to N.E. 85th. This suggests that few people were thinking of the freeway lanes being open. The completed I-405 lanes would create a major change in the environment in which HOV lanes on N.E. 85th would operate, but because of the limited amount of information given and requested on the survey, this remains a factor only in the researchers' judgement.

EFFECT OF PARALLEL ROUTES.

Two parallel routes need to be considered in the evaluation of the N.E. 85th corridor. First is N.E. 124th, two and one half miles (4 km) to the north, which also serves as an outlet for the Sammamish plateau to the I-405 ring around Lake Washington. Although it is not really an alternative for trips to and from the Overlake area or downtown Kirkland, it is close enough to act as a choice route for trips from zones 21 to 24.

The more important parallel route to N.E. 85th is State Route 520 (see Figure 2), which is a radial freeway that runs from the east side of downtown Redmond, through the Overlake area, to downtown Seattle. SR 520's interchange with I-405 in Bellevue allows almost every trip along N.E. 85th, except for the shortest ones, from one side of I-405 to the other, to occur on the freeways. This may be the main reason that the majority of the trips on the study section stayed within the immediate area. Longer trips would have been diverted to the freeways because of the time savings. However, several commuters stated on the surveys that the freeway congestion was so bad that they always took a side road when they had a choice. Some ridesharing must occur here, but the majority of ridesharers must use SR 520.

EXISTING TRANSIT SERVICE

One of the primary effects of SR 520 paralleling the study section is that no long-haul bus routes, and only one local route, use N.E. 85th. In fact, only Route 230, which enters 85th at 132nd N.E., uses the corridor. This route runs only every 30 minutes during peak hours and its function is to simply connect the Totem Lake area with Kirkland and Bellevue. It does not even service a major park and ride lot to allow westbound riders to transfer to a more direct bus. A call for more transit service was one of the most popular comments on the survey, but Metro transit currently has no plans to increase service in the corridor. Providing adequate radial service is presently more of a priority for Metro transit than identifying and supporting circumferential ridership, and so increasing circumferential service is not being considered at this time. A moderate number of buses carrying 30 to 40 people is needed for an HOV lane to demonstrate the people-carrying ability of a general purpose lane. This is definitely a major drawback for the N.E. 85th route, but only one of policy.

BUSINESS / RESIDENTIAL ACCESS

Access -- the number, width, and frequency of the use of driveways through the study section is an important factor that already has been mentioned in this report. It can be directly correlated with accident rate, and to traffic slow downs due to entering and exiting traffic. At least two people commented in the survey that the amount of business access along N.E. 85th was the cause of much of the congestion there.

But again, no research on quantifying these effects has been published as to where the borderlines are. For the section on northbound SR 99, where access is almost unlimited, the accident history suggests that this much access is apparently too much. The accident history on the section of SR 522, with median dividers and fewer driveways is considerably better, but it carries no carpools, which are the fastest vehicles in HOV lanes.

The access conditions along N.E. 85th on the two sides of 132nd N.E. are very different. West of 132nd, the Kirkland zone, is the Rose Hill business district, with banks, gas stations, restaurants, a variety of shops, as well as offices and medical services. East of 132nd, in Redmond, the road has just one restaurant and one daycare center, with the rest of the access from single family homes and several apartment complexes. Table 3 lists the differences between the areas.

The peak hour trips were calculated with the ITE Trip Generation Manual. Many of the Rose Hill trips can, and do, access N.E. 85th via a driveway to a side street. However, of these side streets (side street openings were not considered in the driveway values in Table 3), only two are signalized, 120th N.E. and 124th N.E., and these side streets provide access to only 20 of the businesses. The side street access is, for the most part, no better than that of a driveway.

TABLE 3

ACCESS CONDITIONS ALONG N.E. 85TH

	Kirkland	Redmond
Length of Section (miles)	0.84	1.47
Number of Driveways	48	22
% of Length That is Driveway	40	11
Number of Busnss's in Section	86	2
Peak Hour Trips With One End at Businesses	2508	40

These numbers are presented simply as a starting place for quantification. The effect of commercial density, calculated as driveway openings per mile, or peak hour trips per mile, on arterial HOV applications needs to be evaluated. At this time, the figures for N.E. 85th show the Rose Hill area to be very densely developed in the classic strip development style, i.e., with many individual driveways serving small retail developments of one to four units.

SIGNAL COORDINATION

One way for entering and exiting traffic to have safer access to the arterial is to install more traffic signals. At the time of this study there were six signalized intersections in the study area from I-405 to Willows Road. Two were in Kirkland, at 120th and 124th, three were in Redmond, at 140th, 148th and Willows Road, and one was on the borderline of 132nd. These signals were all fully actuated and running. Adding more signals to provide safer access would entail coordinating the much denser signal spacing. This is, in fact, what the city of Kirkland is facing in the next few years. It has identified the intersection at 122nd N.E. as meeting the criteria for signalization. If this is installed, the traffic signal controllers at 120th and

124th would be upgraded and hard wired to allow computerized coordination. Only if a signal at 128th became warranted would coordination be extended up to 132nd. Officials of both Kirkland and Redmond consider the existing eight block long gaps from 124th to 132nd, from 132nd to 140th, and from 140th to 148th, to be long enough to not require coordination under the existing traffic loads.

POSSIBLE FUTURES FOR N.E. 85TH CORRIDOR

The Eastside Transportation Plan has identified the N.E. 85th corridor as a future site for HOV priority lanes. Area limits of I-405 to Willows Road are given for the project, but all that is said about how the facility will actually look is the general statement "Construct an integrated system of HOV lanes and queue bypass lanes on arterials which connect the regional HOV system with park-and-ride lots and with major activity centers." In addition, the N.E. 85th corridor is indicated as a project for "transit/HOV preferential treatment." Therefore, the actual design of the application has been left to local designers. What are the alternatives?

FULL LENGTH BOTH DIRECTIONS

The limits set by the ETP are justifiable. The western terminus of I-405 is in a critical position to allow continuous HOV priority to and from the HOV lanes that will soon exist on the freeway. Extending the eastern end to Willows Road will serve the four major destination zones for eastbound traffic. These zones are 18 and 19 along Willows Road, 17, downtown Redmond, and 2, the Overlake area, connected to N.E. 85th by 140th N.E. and 148th N.E.

Constructing HOV lanes for this entire length in both directions would be the most effective -- and most expensive -- solution. (The actual time savings of the different scenarios is being modeled at the University of Washington by graduate student Ho Chuan Chen (3).)

FULL LENGTH ONE DIRECTION

Because of the similarities in volumes and trip characteristics of the two directions of traffic, (see survey results) neither direction's results indicate a preference for improvements. The traffic volumes provided by Kirkland show that the eastbound volumes are 5-10 percent greater than westbound volumes for both peak times. However, comments from the motorists cite the westbound, evening commute out of Redmond as the most frustrating.

QUEUE JUMPER LANE(S)

On arterials, the majority of time savings that can be achieved are in bypassing vehicles queued at the signals. This makes queue jumper lanes a lower cost but, logically, still very effective in providing HOV priority. The one condition that makes them a viable alternative is signal spacing which is fast disappearing in the Kirkland section of the arterial. Utilization of queue jumper lanes will be high only if the vehicles have enough room to get around the queue and into the bypass lane, and enough room to get past the signal to re-enter the traffic stream safely. Also, requiring HOVs to repeat this procedure at each signal through the corridor would defeat even the most committed carpooler. The minimum spacing required for repeated queue jump lanes is yet to be determined. Certainly, the existing spacing of one-half mile (0.8 km) along 85th is very close to the minimum area required; in addition, the added signals in the Kirkland zone make the spacing there well below it.

SIGNAL PREEMPTION

Signal preemption can be combined with all of the above alternatives and is itself a system of improving the green split of the through direction when HOV vehicles are detected approaching the intersection. TRANSPO's Highway 99 HOV Study states, "The signal priority improvements would likely be a low priority system which would extend a green phase to provide priority for a bus movement by shortening the green time on other phases. This type of priority would not likely affect the signal cycle relative to its coordination within the system. Signal priority for buses differs from the typical signal preemption for emergency vehicles which can require three to five signal cycles to become resynchronized within a coordinated system." This passage envisions priority for buses with preemption signaling devices. Simple detector loops in the pavement could be used to give priority for carpools as well.

LAND USE CHANGES/MODIFICATIONS

As stated previously, land use modifications are essential to the efficient and safe application of an HOV lane on an arterial. N.E. 85th is not an exception. It is necessary that low scale strip development, prevented from its traditional form, is reworked where it presently exists. Figure 10 shows the building blueprints of the Albertson's and Rose Hill Plaza developments. Ample spacing of side streets exists in this area and the business traffic can access 85th from safer and more regulated side streets. At this time, 120th N.E. is signalized, and 122nd N.E. will be signalized in the next few years. Although these two developments are well laid out, development of side street access was probably influenced more by the fact that the level ground lies well below the grade of N.E. 85th, and because set back access was simply cheaper to build.

The frequency of side streets is vital in eliminating the number of driveways along the arterial. Access to the back of the lots from these side streets needs to be provided, as the lot sizes are often small and property owners have no side access. But who will pay for this access and side street construction, in addition to paying the cost of widening the road for the new lane? But if policy makers decide that the small lot, one business, and eight parking stall developments, placed side by side along the arterial inefficient and unsafe with the growing volumes and treatments of traffic on the roadway, then redevelopment, including combining lots into larger parcels, should happen. This redevelopment could be an important part of the funding of transportation improvements to continue the high grade of access traditionally provided by the arterial.

TRAVEL PATTERN SURVEY

Station No. [ ][ ]　　Date [ ][ ][ ][ ][ ]

Time [ ][ ]　　AM [ ]　　PM [ ]

Do not write above this line.

---

1. Origin of Trip (exact address, or closest intersection or place where this trip started.) ____________________ ____________________	1. [ ][ ][ ][ ][ ]
2. Destination of Trip (exact address, or closet intersection or place where this trip will end.) ____________________ ____________________	2. [ ][ ][ ][ ][ ]
3. Please indicate the number of people in your vehicle on this trip. (Please include driver) ________.	3. [ ][ ]
4. Exact time of departure from origin __________ AM.	4. [ ][ ][ ][ ]
5. Exact time of Arrival at destination __________ AM.	5. [ ][ ][ ][ ]
6. Frequency of trips _____ per day or _____ per week using this route.	6a. [ ][ ][ ] 6b. [ ][ ][ ]
7. Please indicate the purpose of trip (check one) [ ] Work　[ ] Shopping　[ ] School [ ] Social-recreation　[ ] Other	7a. [ ][ ][ ] 7b. [ ][ ][ ]
8. If High Occupancy Vehicle (HOV) lanes were installed in both directions on Redmond Way (N.E. 85th), from I-405 to 148th N.E., how likely would you be to join a carpool for your commute to work? [ ] Definitely would carpool　[ ] Somewhat likely to carpool [ ] Very likely to carpool　[ ] Definitely would not carpool	8. [ ][ ][ ][ ]
9. Which of the following factors would make carpooling to work difficult for you? [ ] Home location (few possible ridesharers nearby) [ ] Work location (few possible ridesharers nearby) [ ] Hours of the day you work (odd times or frequent O.T.) [ ] Number of days of the week you go to work (less than 4 or irregular)	9. [ ][ ][ ][ ]
Comments:____________________ ____________________ ____________________	[ ]

Figure 11. Study Questionnaire

RESEARCH DESIGN

The bulk of the effort in this report has been applied to forecasting the bus and carpool volumes on N.E. 85th in the event of the installation of an HOV lane in that corridor. The researchers have used a freeway model and a skeptical approach because of the lack of definitive forecasting models for arterial HOV applications.

There are, in addition, two other facets of the arterial HOV situation that will be discussed. These are:

- What is the effect of latent demand?
- What are the correct measures of effectiveness to use when judging alternatives to arterial HOV implementation?

Any investigation of these questions is even more dependent on research of freeway applications than of volume projection, but freeway research materials are greatly lacking in the field of latent demand estimation. Considering their limitations, their sources, their incompatibility with arterials, and their facets usable in our research, the research approaches of data gathering, volume forecasting, latent demand, and measures of effectiveness are described in the following sections.

DATA GATHERING - THE SURVEY

Although the data needs for the Parody model are very basic, a survey of commuters on N.E. 85th was needed to supplement the basic directional counts provided by Kirkland and Redmond. Information regarding occupancy of motorist's vehicles and total travel time of trips being made. The researchers adapted a survey that had been used in a study of freeway ramps near the University of Washington. One question relevant only to that study was eliminated, and two questions concerning the likelihood of carpooling and problems associated with carpooling were added. The form is shown in Figure 11.

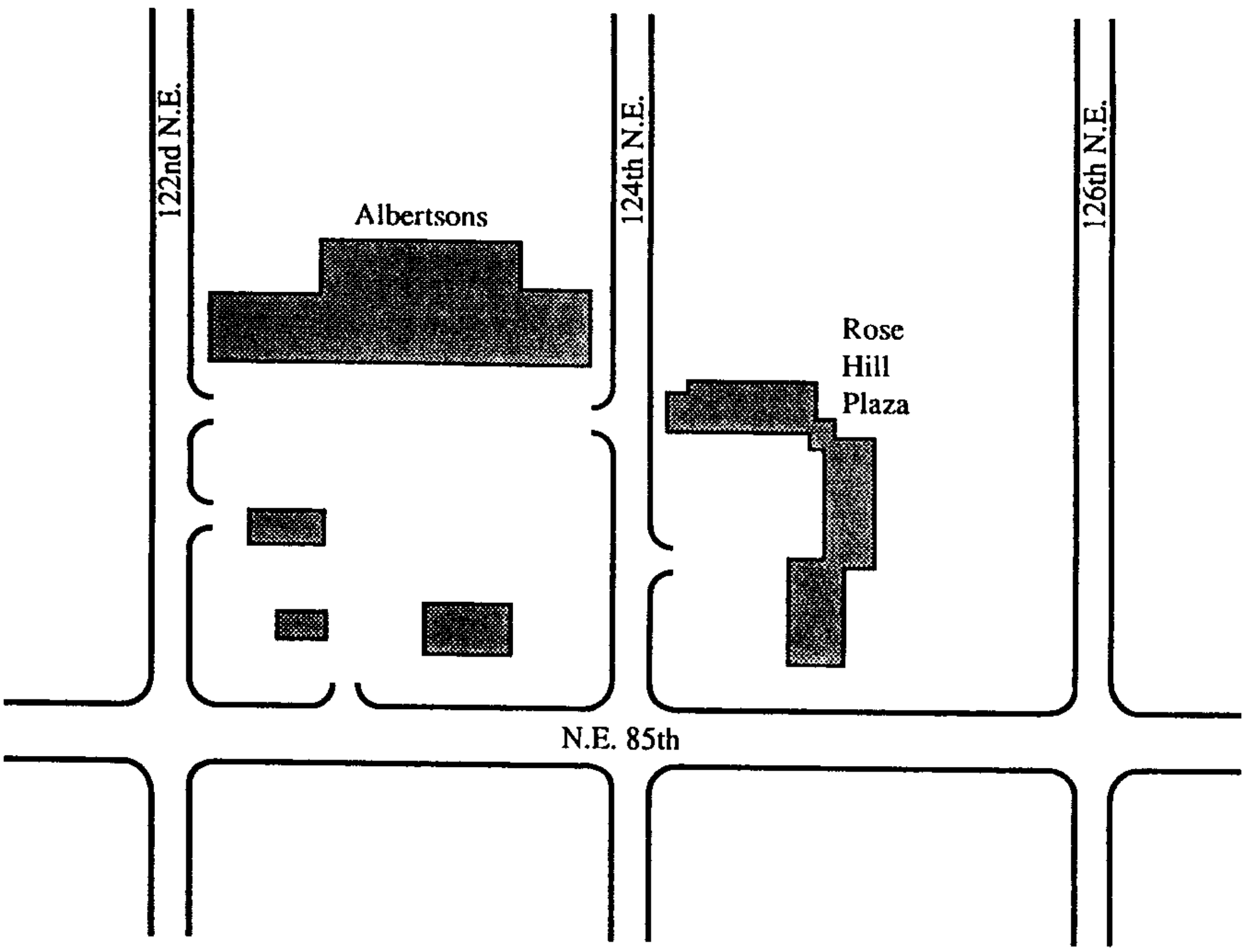

Figure 10. Access Layout of Albertsons & Rose Hill Plaza

Questions 1 and 2 ask origin and destination information. This question was asked to determine the areas served by the majority of the commuters in developing an O-D table for traffic on N.E. 85th. (This has been discussed in Section III.)

Question 3 asks the occupancy of the vehicle on the trip currently being taken. This would provide the percentage of 2+ and 3+ carpools already in traffic, and this percentage number would be compared with the total volumes measured by the cities.

Questions 4 and 5 ask time of arrival and departure to calculate total travel time.

Question 6 asks the number of times per day or week that the route is used. This question provided almost unusable data, perhaps because of the way it was written. (Appendix B has a listing of the problems with the questionnaire that should be corrected before it is used for this type of survey again.)

Question 7 is a question regarding trip purpose. The multiple choice answers were work, shopping, school, social-recreation, and other.

Questions 8 and 9 were added to the survey to help predict HOV usage. The questions asked people if they would use an HOV lane, and if not, why. An evaluation of these questions will be compared to the results of the mathematical model as a low order internal check on the reasonableness of the forecast. (To predict people's actions by asking questions is a science in itself, and the researchers make no pretense that by posing these two questions, scientific accuracy is achieved. Many researchers say that for people to think clearly and without bias of thinking of future conditions takes asking many searching and interrelated questions. Unfortunately, this was impossible for this survey because of space limitations. Also, since there was no personal contact with the drivers surveyed, except for a few seconds at their car windows, the researchers were restricted in their ability to stress the importance of carefully answering the questions, or following up on those who did not return the form. That this form is short easy and non time-consuming to complete should prevent the results from being biased towards those who will bother with a longer, more involved form.

Two thousand copies of the questionnaire were distributed to morning rush hour commuters on N.E. 85th in Kirkland. Because of the impropriety of delaying people's commute by conducting a survey, it was necessary to hand out the questionnaire while the cars were stopped at signals. A brief inspection of the traffic patterns one morning indicated the two best locations for distribution, which were those with the longest queues. (Two intersections were needed because of the previously mentioned balance in the east and westbound volumes.) One thousand questionnaires (yellow) were handed out to westbound traffic at the intersection with 124th N.E. (See Figure 3.) The other thousand (green) were handed out to eastbound traffic at 132nd N.E. (It was important to have the eastbound distribution point east of 124th as a substantial volume of traffic was observed making the southbound to eastbound left turn at that intersection, and it was desired to include that group in the database.)

The remainder of the necessary data for the model was obtained by simple observations or field tests. Bus route frequencies were taken from METRO route schedules. Bus occupancy was not available from METRO, so observations were made during the survey distribution. The researchers acquired study section travel speeds by driving the corridor several times using the "floating car" technique. The results of that evaluation are shown in Appendix C. Finally, the capacity of N.E.

85th was calculated using Equations 9-8 and 9-1 from the Highway Capacity Manual. Equation 9-1 uses the green splits of the subject movements to arrive at the final capacity for each approach.

VOLUME FORECAST

The model used to predict usage of an arterial HOV application is the regression model developed by Thomas Parody of Charles Rivers Associates. (12) It is a "sketch-planning" model, which researchers use to provide a quick response with a minimum of data gathering. Twelve freeway HOV applications with adequate before-and-after data were evaluated resulting in a simple procedure to predict the growth of HOV traffic after one year. So the forecast is basically an average of what has previously taken place around the United States. However, according to the user's guide of this study, "test applications of the prediction procedures described in this report have in many instances yielded results far beyond the accuracy typically associated with sketch planning techniques." HOV planners with WSDOT have used this model with good results. In addition, it is the standard model used by consulting engineers Parsons, Brinckerhoff, Quade and Douglas, Inc. (PBQ&D).

The input required to run this model is existing conditions, including bus and car volumes, occupancies, capacities, travel speeds, HOV lane length, and door-to-door trip times. By inputting the proposed realignment, either adding a new HOV, or taking away an existing general purpose lane, and inputting the occupancy restriction of the priority lane, the model provides shifts in the modal split of the existing traffic volume. The Charles Rivers' report was published with blank worksheets to allow users to run the model with simply a pencil and calculator. The model relies heavily on the difference of travel speed in determining the new mode split. New speeds are estimated for the initial input, and an iterative process continues until an equilibrium is achieved. Therefore, those that use the model have set it up on basic programs for the PC. PBQ&D has converted it to use on LOTUS 1-2-3. For this report, a FORTRAN version, developed by Cy Ulberg of the Washington State Transportation Center (TRAC), was used. (4) The computerizing of the model allows several separate scenarios to be tested in a short time.

Two validity concerns of using this model for a forecast for N.E. 85th are readily apparent. The first concern is regarding the nationwide base of the information used to create the worksheet factors. To assume that drivers in Kirkland-Redmond react the same way as drivers in the rest of the country is an unreliable assumption. Since some success has been achieved with this "quick response" system, these regional differences regarding mode selction and travel time savings seem less important. The biggest problem with using this model is that the regression has all been done for freeway applications. The user's guide, in fact, warns, "as with all models developed in this fashion, they are most applicable when they are used to predict travel flows due to the implementations of similar HOV strategies, and are likely to be less reliable when employed beyond the range of data used to estimate the models." This warning is true for any model. However, generally, the less finely-focused the model is, the wider its applicability. This model simply extrapolates motorist reaction to a travel time savings becaise a faster lane is available. All of the input data necessary can be provided from the arterial without any data manipulation. The model simply sees a lower capacity freeway operating at slower speeds due to congestion.

The biggest concern with using the Parody model for an arterial is where the time savings occurs in the trip. Of the data that were used to create this model, the freeway portion is most likely the middle part of a commuter's trip, and probably the longest in duration. When the Parody model is used for an arterial application, the critical portion may be just a short connection at the beginning or end of the trip.

On the other hand, if the arterial HOV lane connects to one on the freeway, both savings should be able to be evaluated together. If the N.E. 85th segment is looked at in that way, as an extension of the I-405 HOV system, then, at least for the trips coming or going by freeway (admittedly a small portion), the applicability improves.

LATENT DEMAND

Estimation of latent demand, the phenomenon of traffic demand increasing due to the increased capacity, is virtually ignored in all of the HOV volume estimation literature. As it is well understood and easily modeled in one of its forms, it is surprising that it is not addressed. In this situation, where one of at least two parallel routes is improved, the resulting lower travel time causes vehicles to shift from the parallel route(s) to utilize transportation improvement. This is predicted to some degree by both "system optimal" and "user equilibrium" route selection models. The other facet of latent demand, and almost impossible to measure, is the creation of new trips due only to the improvement. The fact that people will make trips that otherwise they would not, because there is more capacity, and (they perceive) less traffic, has been observed, but not explained. The combination of these two effects can be significant, especially when a mode shift of two to five percent is considered meaningful in an HOV application.

That these two facets of latent demand are not addressed is surprising. The draft of TRANSPO's Highway 99 Study states, "As person trips are shifted to the HOV lane, the number of vehicles in the general purpose lanes will decrease (*assuming that the total number of person trips remains constant*)" (italics added). (5) This big assumption is suspect. A report by the Orange County Transit District on their methods of HOV volume forecasting for the Orange County freeways, recognizes latent demand in one limited form. (6) It states that, "HOV trips in the transitway trip tables were increased by the degree of travel-time savings to account for the influence of the benefits of the transitway on propensities to form carpools."

Thus, they are attributing increased HOV volumes to increased available capacity, but they do not mention an increase in general purpose traffic due to a lesser demand on HOV lanes. This is very significant in both of the studies mentioned because the critical measure of effectiveness used by both is the difference in travel time between HOV and general purpose traffic. If it is believed that the general purpose lanes will experience any prolonged relief from congestion due to installation of HOV lanes, they are sure to be disappointed.

Ulberg, in his technical report, "An Evaluation of the Cost Effectiveness of HOV Lanes," recognizes latent demand in a non-quantitative way. (4) The paper explores the benefit cost ratio between adding a general purpose or an HOV lane to a section of Interstate 405. Ulberg's model indicated the considerable benefits of the added general purpose lane alternative because of the higher speeds allowed by a lower level of congestion. His response to this was, "The caveat in this result, however, is that the demand assumed in the year 2000 was based on a lower capacity facility. It is probable that higher demand would not allow the highway to operate as fast as this analysis shows." Taking into account latent demand is one advantage of using the Parody regression model, as it does not try to understand demand, or quantify it, but simply relates an average of how it has occurred in the past.

MEASURES OF EFFECTIVENESS

In the literature evaluating HOV lanes, the measures of effectiveness for designing future and appraising current applications are somewhat different, or perhaps inconsistent. This tends to reinforce the findings of the 1990 TTI study. They conclude their report by stating, "While there is agreement that HOV projects need to be evaluated, a consensus does not appear to exist among transportation professionals regarding the most appropriate measures to be used to evaluate HOV project effectiveness, nor is there agreement on the threshold performance levels that should be used with these measures." In his exhaustive study on HOV applications across the country, Batz arrived at 18 "objectives of HOV priority treatments" (7) (see Appendix D.) These objectives stress increases in person throughput and HOV use, and the corresponding decrease in congestion with its accompanying air and noise pollution. (The belief that HOV lanes will eliminate, or at least reduce, general purpose lane congestion is purported again here.)

The planning and design reports reiterate several of the same criteria in much shorter lists. Tables 4 and 5 show the measures of effectiveness used by Highway 99 and the Orange County studies with the parallel Batz "objectives."

TABLE 4

HIGHWAY 99 STUDY

MEASURES OF EFFECTIVENESS

	Similar Batz Obj.
Corridor Travel Time Advantage	10
Person Throughput	1
Level of Service & Delay	7
Traffic Safety/Accident Potential	5
Transit Stop Location and Operations	3
Community Acceptance	-
Policy Support	-
Operational Flexibility	-
Preliminary Costs and Funding Sources	-

TABLE 5

ORANGE COUNTY STUDY

MEASURES OF EFFECTIVENESS

	Similar Batz Obj.
Improvements in Travel Reliability	7
Freedom From Congestion and Incidents	7
Improved Safety	5
Shortened Travel Time	10

In addition to the recurrent and optimistic notions of relieving congestion and delay, the primary benefit stated in all the works is an improvement in travel time, especially for priority, or HOV, users. The Orange County study says, "Of these benefits, shortened travel time is the most quantifiable in terms of its impacts on user behavior. Therefore, it was the principal variable used in this analysis." (8) The Highway 99 study, which has nine criteria for rating each HOV alternative, eventually uses the travel time savings criterion almost exclusively. Sixteen pages of the 58-page draft report explain the calculations and assumptions for this one criterion. In the final recommendation, it is the only criterion mentioned as a reason one alternative was selected over another.

A threshold value for this very important criterion was introduced by both of these planning studies. Orange County felt that a trip had to be at least seven miles in length, with a travel savings of at least five minutes for the HOV lane, or transitway, to be worth the bother of getting into and out of. The Highway 99 study, again an arterial application, used what they termed the "generally accepted travel time advantage threshold of one minute per mile." (5) Averaged out, the two standards are not that different. Agreement with these assumptions is found in the "bible" of freeway HOV design "High-Occupancy Vehicle Facilities," by Chuck Fuhs. "Time savings realized by line-haul HOVs must be on the order of about one minute per mile over a typical trip from origin to destination. A five-minute time savings overall is considered a minimum, and a savings of eight minutes is considered desirable." (9) But even Fuhs does not substantiate the numbers, which apparently come from previous research.

Planners tend to emphasize incentives to get people into the lane to evaluate a project, while people in operations look at the volumes to see if the incentives worked. In the final analysis, no matter what the time savings is, if the HOV lane has enough traffic in it to appear that it is not a waste of space and money, the application is considered a success.

RESULTS OF SURVEY AND MODELING

SURVEY - QUESTIONS 1 AND 2

The origin-destination matrices created from the data from questions 1 and 2 are shown in Figures 6 and 7. The implications have been previously discussed.

QUESTION 3

This question regarded occupancy. As mentioned in Appendix B in the list of problems with the survey, it was not as easy as it would appear to answer this question. This perception is based on the many surveys that indicated there were two or three people in the car, but who answered "definitely would not carpool" in Question 8. Three possibilities for this type of response seem plausible:

1. One possibility is that for some unusual reason, that person is carpooling that day; perhaps a co-worker needed a ride to work, for example, because his car was being repaired.

2. The second possibility, determined after reading survey comments, is that the second person in the car is a child, who is being taken to daycare. Even though this arrangement is not a "commuter carpool" in the true sense, it is a priority eligible vehicle, and could utilize a two or more person (2+) HOV lane. An increase in work-site daycare facilities, an important benefit for many people and a demanded right by others, will be disadvantageous for the goals of HOV lanes. With work-site daycare facilities, a single occupant commuter, who takes his/her children to work, rather than drop them off near home, can utilize the carpool lane without reducing the number of commute trips. The only advantage is the reduction of the side trip to the daycare on the way in and out.)

3. The final possibility is determined from the answers to Question 7, regarding trip purpose. The westbound traffic shows a much higher percentage of social-recreational and other trips with 2+ occupants; and since Question 8 asks about only *work* trips, these respondents could easily answer "Not Likely", even though they are carpooling at that time.

Table 6 shows the raw data of vehicle occupancy and the corresponding percentages of total trips. The 2+ occupancies are the most notable numbers. Without any HOV priority lanes for miles in any direction, and on a route with relatively short trips, the eastbound 2+ volume is 11.4 percent of all trips, and for westbound it is 17.3 percent! There are obviously other factors supplying a substantial incentive to rideshare.

TABLE 6

VEHICLE OCCUPANCY

		Number	Percentage
EB	1	309	88.54
	2	35	10.03
	3+	5	1.43
WB	1	239	82.70
	2	40	13.84
	3+	10	3.46

The westbound, two-occupant percentage, is 38 percent greater than that for eastbound. For vehicles with three or more occupants, even though the numbers are smaller and less statistically valid, the differential is 142 percent. One explanation for this could be that some of the major origin zones for westbound traffic are much closer to the study area, where surveys were distributed, than for eastbound traffic. Because the survey distribution site was closer to the westbound commuters' homes, it is probable that these commuters received the survey before some of them dropped off their children at school or daycare. It is unfortunate that the survey did not request a description of all occupants in the car.

QUESTIONS 4 AND 5

These two questions were used to determine the average total travel time for the trips during the a.m. commute. All survey trip data (not just work trip data) were used, since all types of trips are reflected in the survey and use this corridor. The travel time results were surprisingly similar, with an eastbound average time of 28:51, and the westbound at 29:31, a difference of only 2.31 percent. (raw data is shown in Appendix E). The travel times were also calculated by occupancy to be used in the model. These results are shown in Table 7.

TABLE 7

TRAVEL TIME BY OCCUPANCY (minutes:seconds)

	Eastbound	Westbound
One person	28:17	29:36
1-2 persons	28:49	29:21
2+	34:37	30:43
3+	35:00	41:13

As would be expected, the people who currently carpool are those whose incentives to carpool are greatest, those with the longest trips.

Outliers were unexpectedly few. The process for determining outliers was to check for trips under 10 minutes, or over one hour. Then, the researchers checked if the time shown was reasonable for a trip between the origin and destination given.

No short trips were eliminated, as they all were between adjacent zones or within one zone. The longer trips, on the other hand, provided some atypical commute trip information. Several commute trips were to locations under five miles away, and yet the travel time given was nearly an hour and a half. Two reasons for this seem most likely: either the commuter made one or more stops during the trip, or the departure or arrival time was compiled in error by one hour. Actually, only about ten times were deleted for this reason. No times between 10 minutes and one hour were checked. There were several times of one hour or more that were used. These were trips to Bellingham, Port Angeles, and Shelton, as well as several trips to Seattle from Whidbey Island.

The researchers infer that the most significant confusion was that people defined a trip as when they left home until they reached their final destinations. If they dropped their kids off, stopped for incidentals, and then continued on to work, that was one trip. This is deduced from the answers to Question 7, which asked the traveler to indicate the purpose of the trip. There were a number of trips with more than one purpose and a tendency for travelers to report longer than possible trips, as noted above. This was due to the unclear nature of the question. The researchers wanted the collected data to reflect the most immediate trip only; however, after evaluating the data, and understanding how the question was interpreted, we realized it was actually the longer linked trip that provided the desired data. It was unfortunate that the question was not defined, "trip," since, obviously, people defined it differently. The important factor here is the percentage of the commute trip spent on the subject section. If the commute includes a stop or two, then that makes the trip justifiably longer. A longer trip, accordingly, reduces the importance of each minute spent on N.E. 85th.

Section travel time was measured directly in the field for both directions (see Appendix C). For eastbound traffic, the travel time was 5:13, or 18.08 percent of the total trip. For westbound traffic, the time was 5:11, or 17.56 percent. These numbers again show a surprising similarity in the traffic patterns of the two directions of traffic on N.E. 85th.

QUESTION 6

The researchers realized that this question was not as clear as it seemed -- whether to answer it regarding one-way trips or round trips. The question was also vague regarding purpose -- whether trips other than the current one were to be considered. Therefore, no useful information was produced from this question.

QUESTION 7

This question was difficult in that, as was mentioned above, the exact limits of the trip in question were not well-defined. Table 8 shows the results.

TABLE 8

TRIP PURPOSE

		Number	Percentage
EB	Work	327	94.51
	Shopping	2	0.58
	School	7	2.02
	Soc/Rec	8	2.31
	Other	2	0.58
WB	Work	256	90.14
	Shopping	2	0.70
	School	6	2.11
	Soc/Rec	11	3.87
	Other	9	3.17

Trips that were recorded as having another purpose besides work, were counted as only work trips. The only notable fact about the figures in Table 8 is the higher number of social-recreational and other trips for westbound traffic. This is probably due to the proximity of the westbound origin zones. People used 85th Street to access the freeway for these other trips. Table 9 shows the occupancy distribution among the purpose categories. Westbound traffic has more than twice the percentage of non-work carpools.

TABLE 9

TRIP PURPOSE vs OCCUPANCY

Occupancy		1	2	2+
EB	Work	297	25	5
	Shopping	2	0	0
	School	6	1	0
	Soc/Rec	5	3	0
	Other	1	1	0
WB	Work	225	24	7
	Shopping	1	0	1
	School	5	1	0
	Soc/Rec	7	3	1
	Other	6	2	1

QUESTION 8

The reasearchers hoped that this question would support the findings of the mathematical modeling. The results are shown in Table 10.

TABLE 10

LIKELIHOOD OF CARPOOLING
(Number and Percentage)

	Eastbound		Westbound	
Definitely Would Carpool	14	4.14	10	3.60
Very Likely to Carpool	22	6.51	15	5.40
Somewhat Likely to Carpool	77	22.78	65	23.38
Definitely Would Not Carpool	225	66.57	188	67.63

This question asked how likely the traveler would be to carpool to work if HOV lanes were installed on N.E. 85th from I-405 to 148th N.E. The numbers are virtually identical, with the greatest difference in any category of only 1.11 percent. Interestingly, the percentage of eastbound motorists in the two groups that were most likely to carpool (10.65 percent), is very close to the existing 2+ carpool volume (11.46 percent). Strangely, for westbound traffic, there were fewer people who were likely to carpool (9 percent), than there were currently doing so (17.30 percent). This phenomenon has been discussed above in Question 3. Also, because the question only asked about the work trip, the high percentage of westbound traffic's non-work carpools would not necessarily answer "very likely to carpool."

QUESTION 9

The last question dealt with some of the problems usually associated with carpooling. Ninety people took the time to write in the following response: the need of having their own car at work for business, or during the day, or during the commute for personal use. The researchers added the response "Need car" to the Problems of Carpooling category (the results are shown in Table 11).

TABLE 11

PROBLEMS OF CARPOOLING
(Number and Percentage)

	Eastbound		Westbound	
Home Location	143	40.97	109	37.72
Work Location	72	20.63	83	28.72
Hours Worked	214	61.32	182	62.98
Days Worked	28	8.02	33	11.42
Need Car	52	14.90	46	15.92

Since in one question multiple answers were allowed, the percentages do not add up. There do not appear to be any significant differences due to direction of travel in the response. The length of the questionnaire prohibited the researchers from finding out more about the most troublesome problem, and if their work schedules involved long hours, unpredictable overtime, part-time work, or an unusual shift, these were deterrents to carpooling. Having to go in early or stay late at work just to get a ride would be very unusual for American suburbanites.

The one problem that appears larger than it really is, is home location. Figures 8 and 9 show that the great majority of commuters along N.E. 85th come from well-established, relatively densely-developed, suburban communities. Especially for westbound traffic, the number of different areas is fairly small. That 40 percent of the motorists believed that no one lives near them that also wants to carpool is most likely a result of never investigating the situation. It would be interesting to see what would happen if everyone were registered in a carpool matching service. Obviously, not everyone would participate, but the mistaken belief that no one works or lives near enough to carpool with would probably be eliminated.

COMMENTS

The comment section at the bottom of the questionnaire was used by 334 of the 638 respondents, or 52 percent. This confirms the theory that those who have something to say on an issue will be the ones who return the survey. The comments included a wide range of ideas, and pleasantly, none were blatantly discourteous. A couple of typical comments were short ones, such as "Hurry!" and "Build more roads!" Not all comments, by far, supported more construction. In fact, several respondents did not want any improvements because they did not want to experience the months or years of construction inherent in the improvement process.

Comments that were more or less transportation-related were grouped into 19 topics, and are shown in Table 12.

TABLE 12

SURVEY COMMENTS

	EB	WB
Fix the SR 520/Avondale Road intersection first	1	6
Taking children to daycare creates carpool problems	6	7
Build HOV lanes on I-405 first	10	3
Build ramp meters on I-405 first	2	1
Build HOV lane somewhere else first	0	1
HOV lane on N.E. 85th is a good idea	2	3
HOV lane on N.E. 85th is a bad idea	6	9
Need car for personal use during the day	6	4
Need car for personal use during commute	9	4
Need car for work	37	38
Suggest regional rail project be built first	6	9
Build more roads	7	5
Improve the transit service	17	11
Coordinate the signals on N.E. 85th	2	5
Prefer 2+ occupancy if an HOV lane is installed	6	2
Prefer 3+ occupancy if an HOV lane is installed	1	0
No more construction	2	2
Build more bike lanes	10	1
Against HOV lanes in general	9	3

As with the carpooling problems question, multiple comments were recorded by individual respondents: 30 of the surveys had more than one response counted in the above table. Notwithstanding, the percentage of transportation related comments from eastbound traffic was 39.83 percent, and from westbound, 39.45 percent. The number of negative comments -- those either suggesting that something else be built first, or simply stating opposition to HOV lanes here or anywhere else -- is 46, or 13.18 percent, for eastbound and 35, or 12.11 percent, for westbound.

The few differences that exist are interesting. Eastbounders state more often than westbounders that they want improvements to I-405, which is understandable since more of them travel on it to and from distant zones. But conversely, they are also more opposed to HOV lanes in general and much more interested in having more bike lanes. The eastbound population, therefore, can be considered somewhat more heterogeneous than the westbound, but this is probably due to their origins being more dispersed.

Other than the previously mentioned comments regarding needing a car at work, the next most common comment concerned improving transit service. Respondents said if they could ride a bus, they would, but either there were no bus routes to their destination, or transit service was not available when they wanted it, or that it took so long it was unreasonable to consider taking the bus. This, as was mentioned in the introduction, is the plight of the suburbanite. Their land use practices have effectively prevented transit from being able to adequately serve all the widely-dispersed residences and employment centers.

PREDICTION OF VOLUMES

The results of running the Parody model with the basic eight alternatives (Eastbound-Westbound, 2+-3+, Add-Take lane) are shown in Table 13.

TABLE 13
MODEL RESULTS
PREDICTED VOLUMES

	G.P.	HOV	BUS PASS.
EB 2+ Add	1366	140/+6.3%	22/+11.1%
EB 3+ Add	1471	21/+13.0%	24/+19.8%
WB 2+ Add	1264	191/+11.5%	44/+9.9%
WB 3+ Add	1373	45/+4.3%	48/+20.3%
EB 2+ Take	618	140/+6.3%	22/+11.1%
EB 3+ Take	711	21/+13.0%	24/+19.8%
WB 2+ Take	572	191/+11.5%	44/+9.9%
WB 3+ Take	668	45/+4.3%	48/+20.3%

All four of the add-a-lane alternatives were sensitivity tested for each of the input variables. The following section describes how each of the variables was calculated, and discusses the effects of using extreme values in the model. Since the sensitivity testing provided similar results for all four alternatives, discussion of the Eastbound, 2+ option, in most cases, can be applied to the other occupancy situations. The complete results are shown in Appendix F. (For all the sensitivity tests, three or four options were tested. Usually, the first number is the highest value considered possible. The next value is normally halfway between the high and the base value. The last option is below the base value, usually at the lowest reasonable value.)

TOTAL TRAFFIC VOLUME

Volumes for east-west traffic on N.E. 85th were provided by the city of Kirkland for the vicinity of 124th N.E., and by the city of Redmond for the intersection of 140th N.E. The Kirkland data were from 15-minute mechanical counts taken during the week of 9/24/90. As the counts were taken just east of 124th, the turning movements at the intersection are accounted for. The highest volume one hour period for each weekday morning commute was identified. All five days were averaged together, resulting in 1278 vph for eastbound and 1198 vph for westbound traffic. The Redmond data, in the form of turning movements at 140th N.E., were for 6/19/90. The highest volume recorded that day was from 7:30-8:30 a.m., similar to the Kirkland counts. To account for the cars leaving and entering at 140th, the turning movements onto and off of N.E. 85th were averaged for both eastbound and westbound traffic. These were added to the through counts, resulting in 1356 vph for eastbound and 1274 vph for westbound. The totals at 140th and 124th were averaged for final volumes of 1317 vph eastbound, and 1236 vph westbound.

The sensitivity testing indicated differences due to mistakes in estimating the volumes. For the eastbound 2+ alternative, volumes of 1800, 1600, and 1000 vph were tested, and by keeping the percentage of priority vehicles constant, these numbers increased as well. The results showed that the percentage increase of HOV lane use remained constant vs. changes in the volumes. Only the total number vehicles changed, in direct proportion to the volume input. Bus passenger volumes remained constant. Therefore, since HOV volumes were only around ten percent of the total volume, a ten percent error in the volume would produce only a one percent error in HOV traffic. Due to the confidence of the counts from the cities, and the small effect of any differences, total volume is not considered to be a sensitive variable.

BUS VOLUME

Accurate numbers for the bus route ridership that used part of the study corridor were not readily available from Seattle Metro. Therefore, the bus occupancy numbers used are from casual observation while distributing motorist surveys. As there are only two buses per hour in each direction, it was not a difficult task. An average of approximately 20 people per westbound bus were observed, and ten per eastbound bus.

For the eastbound 2+ alternative, options of eight and four buses with ten riders each were evaluated. No change in the carpool volumes were made by any change in bus volumes. Even the percentage increase in bus ridership remained the same. The only factor affected was the total number of bus riders, which increased proportionately to the number input. Therefore, since bus volumes and ridership are so low and effects due to changes so minimal, this is not considered a sensitive variable.

PRIORITY AUTO VOLUME

The percentage of the total traffic eligible to use a carpool lane with either a 2+ or 3+ designation was taken directly from the occupancy reports of the motorist survey (Table 6). This percentage was measured against the directional volume calculated from the city-supplied data. One hundred percent of the priority eligible autos were placed in the HOV lane. This is a very liberal assignment.

For the eastbound 2+ scenario, which had a surveyed percentage of 10.03 percent eligible vehicles, alternatives of 20, 15, and 7 percent were tested. The results were very similar to those of the total volume tests. No changes were seen in the increase of carpools' percentage, or in the number of bus passengers. The increase in the total number of eligible carpools was directly proportionate to the number input into the model as existing. This means that any error in the estimation of existing carpools has a 1:1 result in the model's output. This makes priority auto volume a sensitive variable, and one that is dependent on the accuracy of the occupancy reports. Motorists had no reason to be biased in answering this question. However, the researchers can only assume that the 30 percent responding were representative of the entire population.

TOTAL TRAVEL TIME

The prediction model accepts separate travel times for both HOV priority and non-priority vehicles. The times used are shown in Table 7. Even though there is a marked and expected difference in the times as occupancy increases, the fact that the 2+ carpool time is an average of 35-40 reported times, and the 3+ carpool time is an average of only 5-10 reported times, lowers the reliability of their values.

This is unfortunate, as the non-priority travel times, the SOV occupancy, and 1-2 person occupancy values, which are the most statistically valid, are much less sensitive variables. Changes in the non-priority travel times did not affect carpool or bus volumes at all. The only change recorded was an increase in the volume of general purpose traffic as the time was decreased. Priority travel time for the eligible occupancy vehicles turned out to be very sensitive. For both of the 2+ scenarios, which had priority times of 30:43 for westbound and 34:37 for eastbound traffic, the tested times of 45:00 actually produced a decrease in the number of carpools using the lane. And for all cases, lowering the time to 20:00 created increases of 30 percent to 50 percent. However, even though the 2+ and 3+ times are less statistically valid, the correlation of longer travel times with greater occupancy is in agreement with traditional thought. Some confidence, therefore, can be shown in this very sensitive variable.

BUS TRAVEL TIME

The value used for this variable has the least amount of data to support it. The only way to obtain this data would have been to survey the riders on the bus.

Since this was not done, a time of 60 minutes was assumed for all scenarios. This was done for several reasons. The time for a trip by bus includes the time it takes to walk to the stop, wait for the bus, the bus trip itself, and walking from the bus stop to the destination. Since this is a local route, with no connections to major cross-town routes, the trips are fairly short, and trips that take more than 60 minutes are few. Lastly, several of the motorists stated they would like to take the bus, but that it took twice as long than going by car. Since the average car trip was close to 30 minutes, the bus would take one hour. Even though 60 minutes may be longer than most bus trips, it is not even an option available to most N.E. 85th commuters. Again, this is due to the lack of service on the east side of Lake Washington, and the spread out, non-radial transportation network. Many people commuting from the east side would have to take two or three buses to get to work. The added time spent transferring could make some trips close to two hours, if bus service was available at all.

It is unfortunate that the bus travel time was so hard to obtain for this project, as in the model it turned out to be a fairly sensitive factor. The lowest value used, 30 minutes, produced a reduction in the number of carpools. But as just discussed, few people have this type of service currently available to them. The longest time tested was 90 minutes, which averaged about a five percent increase in the number of priority vehicles over that predicted when using one hour. Strangely, the number of bus passengers remained constant, even with the shortest travel time. This is an unusual result and must be a quirk of the model. The literature does not mention any reason why bus passenger numbers are so insensitive. The almost negligible numbers of existing passengers could also indicate there is very little demand for bus use, no matter how short or long the trip is.

SPEED

System speed was measured by driving the route several times in both directions on two different days. The system speed was calculated by dividing the length of the section by the average time it took to drive it, including stops at signals (see Appendix C). The times tested were on weekdays during the morning commute. Traffic was moderate, that is, queuing at the signals was easily handled in one cycle, but the motorists' surveys indicated that traffic at times is much worse than it was on those two days. This indicates that though rush hour speeds would not be much faster, they could, at times, be much slower. The times and resultant speeds turned out to be very close for both directions: 27.6 mph for eastbound traffic, and 27.8 mph for westbound traffic.

System speed was the one variable that affected both carpool and bus volumes. When the speed was increased to just 35 mph, all scenarios showed a 10 to 20 percent decrease in carpools and a slight increase in bus passengers. The most realistic change in speed, however, would be a decrease, and lowering the speed to 20 mph produced increases of 30-40 percent in carpool volumes. This realistically depicts how improvements to general purpose lanes decrease ridesharing, while no improvements, resulting in higher congestion, increases ridesharing. Although this variable was fairly sensitive, the higher values used, 35 and 45 mph, are not realistically attainable without signal coordination.

CAPACITY

N.E. 85th capacity was calculated by using the the Highway Capacity Manual's formulae. Beginning with a value of 1800 passenger cars per hour of green per lane (pcphgpl), Equation 9-8 was used to calculate the capacity of an unrestricted arterial. The only non 1.0 factors were 0.98 for four percent heavy vehicles, 0.97 for right turns, and 0.95 for protected exclusive left turns. Equation 9-1 was used to derive the capacity with the signalization taken into account. For this, the green splits for the eastbound and westbound traffic were needed. As the signals along N.E. 85th are all fully actuated, the only way to determine the green percentage was to observe signal operation during the morning rush hour. Two signals were studied: 124th N.E. and 132nd N.E. At both intersections the eastbound-to-northbound left-turn traffic was greater than the westbound-to-southbound. This allowed the eastbound through traffic to receive a green light several seconds before the westbound traffic on about half of the cycles. Therefore, the eastbound green split calculated out at 56 percent, and westbound at 49 percent, giving an eastbound capacity of 1821 vph, and westbound of 1593. The HOV lane capacity was calculated in a similar fashion, except that the maximum capacity was 1500 pcphgpl. This lower capacity takes into account bus slow-downs and weaving conflicts.

In the end, all of the capacity calculations were unusable, as tested ranges of 1600-2200 vph for the general purpose, and 600-1200 for the HOV lanes produced no changes at all in the results of the forecast. Capacity, therefore, for this application, is a totally insensitive variable.

ADD-A-LANE, TAKE-A-LANE

Although not truly a variable, the model did allow the following variations: adding an HOV lane, adding a new third lane, or taking away one of the existing general purpose lanes. All of these alternatives consider the HOV lane to have been added, due to the political impossibility of taking away a general purpose lane on a lightly congested roadway such as N.E. 85th. Each basic scenario, however, was run once assuming the take-a-lane situation, and even though the model was based on actual take-a-lane applications, the results are somewhat surprising. Whereas the general purpose traffic volume is only half what it would be with two lanes (operating in forced flow conditions), neither the carpool volume nor the bus passenger volume showed any increase! It is not clear why this happened. With the general purpose traffic in a forced flow situation, travel time would be much greater, which should increase the incentive to use the HOV lane.

MODELING CONCLUSIONS

Of the nine input variables, five proved to be insensitive even to extreme ranges. These five were total volume, bus volume, non-priority travel time, general purpose capacity, and HOV capacity. Of the four variables that were shown to have sensitivity within reasonable ranges, the bus travel time is acceptable. The one hour time used is probably on the long side for local trips through the corridor, but this is only because longer trips are almost impossible to make with the current system. The model does show that an improvement to the transit system would attract many of the people who are willing to rideshare. This was corroborated by several of the survey comments.

The three variables with the most sensitivity were the percentage of priority eligible vehicles, the system speed, and the priority eligible travel time. These were all directly tested either in the survey or in field tests. Confidence in the values is high in the case of priority percentage and system speed. The 2+ and 3+ travel times, on the other hand, are dependent on small amounts of data and thus less reliable. But their values are definitely within reasonable limits, and lean in the correct direction.

If there are errors in bus travel time, system speed, or priority travel time, the researchers consider these errors conservative in nature. Observations were made on clear, dry days, and traffic was probably moving at its optimum capacity. The model, then, views the existing conditions and especially travel times at their best. Worsening conditions and more congestion will continue to improve the outlook for adding HOV lanes.

The directional percentages that were observed in the motorist survey are also seen in the modeling results. The westbound volumes, in all cases, are greater than the corresponding eastbound volumes. This does not make a substantial difference in most cases, however, with the predicted low volumes. For the 3+ alternatives especially, the westbound and eastbound volumes are 45 and 21 vph, respectively. This is less than one car per minute on the facility, and definitely not acceptable. The 2+ situation, is significantly better, however. Eastbound HOV volumes are forecast at 140 vph, or 9.3 per cent of total traffic. For westbound traffic, the volumes are even higher, 191 vph, or 13.13 percent. Fuhs, in his book, states that the initial minimum suburban freeway HOV lane volume should be between 400 to 800 vph "depending on what is locally acceptable to achieve an adequate perception of use." (10) The 191 vph totals under 19 seconds between cars, which is close to the 20 second minimum believed by many to prevent the "empty lane syndrome," which encourages violations. Because the arterial HOV lane would have many more vehicles in it entering and leaving the roadway, the 140 vph of the eastbound traffic would probably not appear unutilized either.

The forecasted percentages of carpools are actually lower than the existing percentages. The general purpose traffic, except in a few extreme cases, increased for all alternatives at a greater rate than the HOVs. Only in the few cases where the benefits to carpooling were the most advantageous did the increase in priority vehicles surpass that of general purpose vehicles. This unbalanced growth, it must be remembered, comes from the past data that was figured into the factors of the model. These results can be defended intuitively, however. The data that was entered into the model for N.E. 85th does not show greater congestion. The speeds are still too high for any significant travel savings to be made in the HOV lane. There is virtually no transit through the corridor, and the trips are spread out enough to make carpooling difficult. With all of these problems, the HOV volumes will increase, but not as fast as the general purpose volumes, which still have an excess capacity available.

QUESTIONNAIRE SUPPORT

Table 14 shows the existing carpool volumes versus the forecasts from the mathematical model and the motorists' answers to Question 8.

TABLE 14

CARPOOLING VOLUMES (PERCENT)

	Eastbound	Westbound
Existing 2+	10.03	13.84
Forecasted 2+	9.30	13.13
Survey Likelihood, Definitely plus Very Likely	10.65	9.00

Eastbound volumes are remarkably similar for all three conditions, especially if one considers the motorists' predictions somewhat overstated, which is frequently the case. Westbound volumes again show the problem that resulted from the fact that Question 8 asked about carpooling "to work," and 23 percent of the existing carpools were for non-work trips. If that problem is factored in, the westbound forecasts also only differ by about one percent in total volume. Considering the two methods that were used to arrive at these figures (see next section for discussion of threats to validity), these results are surprisingly similar.

VALIDITY THREATS

The threats to the validity of the numbers shown in the above table, and the consequent conclusions, can be grouped into the following four areas: 1) the basis for the Parody model; 2) the population surveyed by the motorist questionnaire; 3) confusion with some of the questions on the survey, and; 4) calculation of the input parameters for the model.

PARODY MODEL

The apparent shortcomings of using the Parody model for an arterial HOV lane application have been discussed previously. The most obvious problem is that the algorithms in the model were calibrated on freeway HOV lane projects. How can it be concluded that motorists on N.E. 85th will respond similarly to those on freeways? Time savings should be a consistent factor. The incentive of saving one minute on a twenty-minute trip by freeway should be the same as on a twenty-minute trip by arterial. It is when the arterial is a short connection at the beginning or end of a longer freeway trip that the time savings might be perceived differently by the drivers. However, because the O-D tables show that the majority of trips through the corridor do not use the freeway, the whole system can, in essence, be viewed as a freeway trip, only at slower speeds. Those trips that do incorporate I-405 will have access to the HOV lanes there, and the N.E. 85th segment would be seen simply as an extension of the same facility.

That the model is based on national data and does not allow for local uniqueness cannot be denied. How different local data is from national data is very difficult to measure. To defend the use of national data, they were from a wide enough area to negate any one area's individual traits. And further, the success that the model has had in freeway applications shows that Americans are in agreement regarding the time savings necessary to attract carpoolers.

The biggest flaw in the model is that by assuming it is a freeway application, too high travel speeds are applied to the predicted flows. Because the volumes in the general purpose lanes are well under capacity, the model assigns them speeds of almost 60 miles per hour in most cases. This obviously hurts the time travel advantage of the HOV lane, which cannot go faster than 50 miles per hour. Two somewhat contradictory observations can be seen from the sensitivity tests: The high sensitivity of the existing speeds shows how important speed is in calculating the predicted volumes. However, when the total volume was increased up to and over capacity, general purpose speed was effectively slowed to under 30 miles per hour, producing a scenario similar to real conditions. But even with this change, the percentage increase in carpool volume is identical to the initial conditions; even with a 20 mph advantage given to the HOVs.

All in all, the freeway basis of the Parody model does not appear to create any major problems, nor does the national bias. Though the speeds of the predicted flows are not accurate, it is unclear what affect, if any, that has on the predicted HOV volumes.

SURVEYED POPULATION

The first question in conducting any survey is, "Was the target population accurately represented by the survey sample?" To answer that question regarding this survey, since the Parody model was calibrated on a.m. commute data, only that part of the day was measured on N.E. 85th. A mid-week day was used (Thursday) that should have provided access to as many typical commuters as possible. Because of the long peak period, the survey was handed out from 6:15 to 9:30 a.m. The cars that received the survey were chosen by the random function of the actuated signals along the roadway. Those cars that were stopped were offered the survey (less than twenty drivers refused to accept a questionnaire), therefore, the selection was virtually random. Because the signals were actuated, no particular platoons of vehicles had an advantage over another in avoiding a stop. The sample population should accurately represent the target population.

The one problem is, of course, that not all of the surveys were returned. An accurate description of the subgroup of the sample that did send back completed questionnaires is important, but impossible to obtain. Because the survey was so short, perhaps more respondents who do not usually have time to fill out surveys, participated in this survey. Or perhaps, only those who feel strongly one way or another answered, which is well-supported by the kinds of comments received. The fact that nearly 32 percent of the questionnaires were returned and that HOVs are not considered a popular topic in suburbia suggests that not just the enthusiasts responded.

CONFUSION ABOUT THE QUESTIONS

The fact that several of the surveys showed evidence of a change in occupancy between home and work, indicating they dropped off or picked up someone, creates some confusion regarding the actual vehicle's occupancy through the study corridor. Some people traveled with one or more persons in the car but did not consider themselves to be carpooling. It is hoped that the drivers deduced that the data requested were for the part of their trip in the area where the survey was distributed to them, but unfortunately, it is not clear if this is the case.

The other question that could have easily been misunderstood referred to the origin and destination points and times. The times given for the trip lengths clearly included some intermediate stops on several of the forms. The total trip from home to work, including stops associated with child care or shopping, would be more accurately termed the "total trip." Determining the kinds of stops that should be included in a "commute trip" is impossible after the fact. What can be said is that if people were to drive straight from home to work, the average travel times would be shorter. Shorter trips tend to favor HOV lane use.

CALCULATION OF INPUT PARAMETERS

The Highway Capacity Manual's standard formulae indicated that starting with the least sensitive variables, and, thus, the ones that provide the least threat to validity, gives the capacity. But this turned out to be totally insensitive. The total volume of traffic, which was also derived from dependable sources, the cities of Kirkland and Redmond, did not affect the outcome of this model much either.

Bus volume and speed were independently tested in the field. Only one day's data were used for bus volume, but daily fluctuations should have had little effect. Seasonal variation more likely affected the data, as the observation was made in the summer when school was out. There is a high school and a vocational-technical school in the service area. A higher input bus volume increases the bus forecast, but has no effect on carpool volume. System speed was measured and averaged over two days. Both days were without rain or incidents, and traffic flowed well. If the speed were slower, this would tend to increase the predicted HOV volume.

The existing HOV percentage and travel times both for general purpose and HOV, are discussed in Appendix B, "Problems with Survey Questions. Any error in travel times would tend to make the results conservative. It is hard to determine in what way the occupancy question would error, but the sensitivity is not great here.

Bus travel time is easily the most validity threatening variable. Sixty minutes is probablya reasonable estimate for trips currently taken through the corridor. However, this estimate is without a doubt considerably low for the majority of the possible users, and, therefore, taking the bus is not a viable option for them. Using a higher time significantly increases the predicted HOV volumes. But would there be better transit service available through the corridor once or if, an HOV lane were installed?

Several assumptions that are difficult to make when predicting the future of modal travel do not have to be made when using this model. It is easy to count the number of existing carpools on a roadway, but it is much more difficult to foresee how many of those carpools will actually be in the HOV lane at any given time. Also, even though the physical improvement to the corridor is for HOVs only, by how much will non-priority volume increase as well? These are questions that are considered the regression model. The previous research that would be necessary to support such assumptions is built into the forecast mathematically.

EXTERNAL VALIDITY

As was discussed earlier, because arterials interact with the surrounding community in so many ways, and in such varying degrees, it would be very difficult to transfer the findings of this study to any other roadway, except in very general ways. Characteristics, such as number of lanes and traffic volumes, are not as important in describing the character and operation of a roadway as the density of commercial and residential development, signal spacing, its physical location relative to major housing and employment centers, and how or if it connects to the local freeway system are. The defining factors of N.E. 85th are unique, and these results relate to that corridor alone.

FURTHER RESEARCH

There is little information on existing arterial applications of HOV lanes because there are so few of them. In addition, the most similar application, freeway HOV lanes, are different in so many ways that research on them is of little value. The most important issue to investigate, and most likely the most difficult, is finding the relationship between the number of access points along the roadway and safety. The challenge here is that access is not the same in any two places. The type of business served by a driveway has a tremendous effect on the number and timing of trips made to and from it. This leads to correlating land use with safety, as well as with the number of driveways.

The survey did not mention the HOV lanes on I-405, and for the most part, it appeared as if the respondents answered the questions as if those HOV lanes did not exist. Whether the responses would have been different if those lanes were referenced is unknown. Being able to receive the benefit from two connected systems is a large advantage it is clear, and the incentive to carpool should be much greater than wanting a new lane to be added along 85th. The O-D matrix shows that a minority of the trips using the corridor spend a substantial portion of their trips on the freeway.

Any time that arterial HOV lanes are proposed, queue jumper lanes are recommended as a lower priced, limited scale improvement. Experience with single isolated queue jump lanes is much greater than experience with several installations along miles of a suburban arterial. The effect of repeated merging on utilization is unknown. Other factors that would probably be affected by the on-and-off HOV lane are safety and the violation rate.

Improvement of transit service along this corridor and its affect on transit ridership must be investigated. The following facts demonstrate that there is a demand not being served: 1) twenty-eight motorists requested better bus service; 2) there is an identifiable origin and destination pattern through the N.E. 85th corridor, and; 3) there are no existing routes to service this pattern. Using transit facilities is the most typical use of HOV lanes, as it provides travelers flexibility. Without adequate service along N.E. 85th, person throughput will grow slowly.

CONCLUSIONS

Northeast 85th in Kirkland-Redmond is primarily a intra-suburban route, supporting a remarkably balanced east-west morning commute flow. Eastbound commuters generally begin their trips in the Kirkland-Bothell area and have destinations of the Overlake business developments containing companies such as Nintendo, Microsoft, and Safeco. The westbound motorists begin their trips in Kirkland's Rose Hill, Redmond's westside, or farther out on the Sammamish plateau. Their destinations are more varied, but typically are downtown Kirkland and Rose Hill. Only a small portion of the longer trips include some time on the freeways. The majority of the population in this area access Interstate 405 and State Route 520 without ever travelling on N.E. 85th.

Traffic volumes are currently well below capacity, and signal spacing is far enough apart (one-half mile) that signal coordination is not necessary. At times, however, weather or incidents create long queues at every light and sufficiently slow the progression through the corridor. Additional development in the Rose Hill area will require one or two new signals to support the amount of crossing and entering traffic. When the signal density increases, signal coordination will have to be implemented to allow acceptable through traffic volumes.

Transit service through the corridor is almost non-existent, with one bus every half hour in each direction for only the western end of the section. Many motorists declared an inclination to ride the bus if it would go where they needed to go in a timely manner. The densest traffic volume, from the downtown Kirkland zone to the Overlake area, does not experience any kind of direct service.

Travel times for both directions of traffic are surprisingly similar, each near thirty minutes. Both directions also show increases in travel time for vehicles with increasing occupancy, supporting the belief that longer trips provide more incentive for travelers to carpool. Several of the surveyed motorists reported a home-to-work trip that included one or more stops. Many of them said that they carpooled part way, i.e., to a park-and-ride, or dropped off their children, or stopped at the store. In defining a trip length, the researchers determined that these stops were a legitimate part of the total trip as defined by the input for the model.

The two most common reasons indicated for not carpooling were "unusual hours worked," and "isolated home location." A reason that was not provided, but written in by dozens of commuters, was the "need for my personal vehicle during the day." The vehicle was most often used for conducting business, such as outside sales, but having it available for personal use, either during the day or on the way home, was also a critical determinant.

Only the 2+ occupancy level has the existing carpool volume to support the installation of an HOV lane. Approximately ten percent of the traffic in each direction has two or more people per vehicle. Westbound traffic is somewhat higher because of non-work trips that are close to the residential areas. The Parody model forecasts only a slight growth in carpooling volumes after one year, from six to twelve percent of the original HOV volume. However, the general purpose traffic is shown to grow even faster, resulting in the decrease in the total volume's carpooling percentage. Westbound traffic, assuming the existing numbers of non-work carpools continue, would have nearly 200 vph in the carpool lane, and eastbound traffic about 140 vph. All of the results of the modeling do not take into account the added ridesharing benefit that the area would receive once the I-405 HOV lanes are installed. Admittedly, most of the traffic does not use the freeway, but the increased advantages for those who do would be great.

General purpose volumes are not great enough yet to make time savings much of an incentive, but the volumes do exist to provide approximately one legal carpool every 20 seconds during the peak flow periods. The HOV lane will not carry more than 15-20 percent of the people in the corridor until adequate transit service is provided through the corridor, or until volumes regularly reach congested levels. A more difficult question that must be addressed is whether the accident potential can be maintained with the installation of a curb side HOV lane.

The issue, then, is at what level the performance of the HOV lane meets the intent of the ETP plan. How to measure the success must be decided before the beginning of any project. If success is measured by volume or person throughput the facility would be only marginally successful in the first few years. However, if the intent of the ETP is to "provide time advantages for HOVs over ... SOVs," the project does that. Also, very likely, by the time that the I-405's HOV system's construction is complete up to N.E. 85th, the traffic volumes will have increased enough to give a faster priority lane a considerable advantage.

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APPENDIX A

Study Zone	PSCOG Zone(s)
1	208
2	207
3	206
4	195-199
5	200
6	190, 202-205
7	188, 189, 201
8	186-187
9	178-181
10	177, 182-185
11	162, 194
12	193, 229
13	191-192, 209
14	215
15	227-228
16	226
17	214
18	213
19	212
20	210-211
21	219, 222
22	218, 221
23	216-217, 220
24	223-225
25	365-379
26	City of Seattle
27	119-122, 127-135, 138-143, 150-156, 163-171
28	114-117, 123-126, 136-137, 144-149, 157-161, 172-176
29	90-94, 101-105, 110-112
30	88-89, 95-100, 106-109, 113, 118
31	387-391
32	382-386, 394-402, 404-405
33	392, 403
34	411-413, 415, 418, Whidbey Island
35	406-407, 414, 416-417
36	393, 410, ...
37	419, 420-421, 425-431
38	408-409, 423-424, 435
39	Town of Snohomish area
40	North of Marysville
41	Pierce county and south and west

APPENDIX B

Problems With Survey

Overall:	More information should have been provided to the motorist on the schedule of the project in question, the future I-405 HOV lanes, and the people involved in the study. Also, a more informal tone would have made the survey more accessible.
Questions 1-5:	Answers to these questions are somewhat suspect due to the unclear defininition of the exact trip in question. It has been suggested in the body of this paper that referencing the total commute trip, including any brief stops, would have been the most useful definition. Had this definition been clear to all of the respondents, it could be certain that they were all describing the same trip.
Question 3:	It would have been useful to have asked the ages of the riders. This information along with clarification of the specific trip, would have helped the reserachers understand who the ridesharers were.
Question 6:	This question was not clearly posed and was confusing. It should have been something like, "frequency of trips per week using this route, this direction, for the same reason."
Question 8:	The phrase should have been changed from "for your commute to work?" to "to make this same trip?"
Question 9:	There should have been two more options. The first should have been "need car at work," and the second, "other, to be described under comments." Almost certainly, not everyone who needed their car wrote this in.

APPENDIX C

Travel Time Sheet.

EASTBOUND, 7-12-91

	RUN 1 RT LANE	RUN 1 LT LANE	RUN 2 RT LANE	RUN 2 LT LANE
CL SR 405	07:54	00:08		
132nd NE	10:00	02:07		
148th NE	11:52	03:59		
WILLOWS ROAD	12:23	04:45		
Total Travel Time	04:29	04:37		

WESTBOUND, 7-12-91

	RUN 1 RT LANE	RUN 1 LT LANE	RUN 2 RT LANE	RUN 2 LT LANE
WILLOWS ROAD	00:22	32:30		
148th NE	01:57			
132nd NE	03:41	35:10		
CL SR 405	06:27	37:33		
Total Travel Time	06:05	05:03		

EASTBOUND, 8-6-91

	RUN 1 RT LANE	RUN 1 LT LANE	RUN 2 RT LANE	RUN 2 LT LANE
CL SR 405	32:42	48:57	03:59	18:14
132nd NE	35:32	51:15	05:56	20:13
148th NE	38:06	53:53	08:32	22:54
WILLOWS ROAD	38:42	54:51	09:05	23:26
Total Travel Time	06:00	05:54	05:06	05:12

WESTBOUND

	RUN 1 RT LANE	RUN 1 LT LANE	RUN 2 RT LANE	RUN 2 LT LANE
WILLOWS ROAD	41:09	57:50	11:29	25:52
148th NE	42:27	59:03	12:39	26:53
132nd NE	44:12	00:43	14:23	28:24
CL SR 405	46:35	02:40	16:21	30:44
Total Travel Time	05:26	04:50	04:52	04:52

APPENDIX D

Table A-2a

OBJECTIVES OF HOV PRIORITY TREATMENTS (POSITIVE IMPACTS)

1. Increase person carrying capability of roadway
2. Increase bus transit use
3. Increase bus transit reliability
4. Increase carpooling and vanpooling
5. Increase safety
6. Reduce the need for future expansion of the roadway
7. Reduce congestion on the roadway
8. Reduce future capital costs for new construction
9. Reduce auto use on the roadway
10. Reduce travel time for HOV users and overall
11. Reduce travel cost for HOV users
12. Reduce energy use
13. Improve air quality
14. Improve noise quality
15. Improve comfort and convenience for HOVs
16. Increase pedestrian and bicycle traffic
17. Enhance local commercial access and activity
18. Minimize operational costs of roadway administration

APPENDIX F

SUMMARY OF MODEL RESULTS

EASTBOUND, 2+, ADD-A-LANE

Criteria, Tested Value	Vol.	GP Vol./%	HOV Vol./%	BUS
Base		1366	140/+6.3	22/+11.1
Total Volume	1800	1791	192/+6.3	22/+11.1
1600	1648	170/+6.3	22/+11.1	
1000	1039	106/+6.3	22/+11.1	
Bus Volume	8 w/10 @	1378	140/+6.3	89/+11.1
4 w/20 @	1370	140/+6.3	44/+11.1	
Priority Volume	20%	1354	279/+6.3	22/+11.1
15%	1360	210/+6.3	22/+11.1	
7%	1370	98/+6.3	22/+11.1	
NP Travel Time	45	1323	140/+6.3	22/+11.1
35	1345	140/+6.3	22/+11.1	
20	1420	140/+6.3	22/+11.1	
Priority Travel Time	45	1388	126/-4.2	23/+13.8
40	1379	132/+0.2	23/+12.7	
28	1344	154/+16.9	22/+8.1	
20	1297	184/+39.3	21/+2.7	
Bus Travel Time	90	1370	148/+12.5	22/+11.1
75	1369	145/+10.0	22/+11.1	
45	1362	132/+0.0	22/+11.1	
30	1353	116/-12.4	22/+11.1	
Speed	45	1372	110/-16.7	24/+21.1
35	1370	124/-6.3	23/+16.6	
20	1360	170/+28.8	20/+1.3	
GP Capacity	2200	1367	140/+6.3	22/+11.1
2000	1367	140/+6.3	22/+11.1	
1600	1363	140/+6.3	22/+11.1	
HOV Capacity	1200	1366	140/+6.3	22/+11.1
1000	1366	140/+6.3	22/+11.1	
600	1366	140/+6.3	22/+11.1	

EASTBOUND, 3+, ADD-A-LANE

Criteria, Tested Value	Vol.	GP Vol./%	HOV Vol./%	BUS
Base		1471	21/+13.0	24/+19.8
Total Volume	1800	1827	29/+13.0	24/+19.8
1600	1745	26/+13.0	24/+19.8	
1000	1118	16/+13.0	24/+19.8	
Bus Volume	8 w/10 @	1482	21/+13.0	96/+19.8
4 w/20 @	1474	21/+13.0	96/+19.8	
Priority Volume	9%	1454	134/+13.0	24/+19.8
6%	1461	89/+13.0	24/+19.8	
3%	1467	45/+13.0	24/+19.8	
NP Travel Time	45	1423	21/+13.0	24/+19.8
35	1447	21/+13.0	24/+19.8	
20	1530	21/+13.0	24/+19.8	
Priority Travel Time	45	1473	19/+1.0	24/+20.4
40	1472	20/+6.0	24/+20.2	
28	1468	24/+25.3	24/+19.1	
20	1463	29/+51.0	24/+17.6	
Bus Travel Time	90	1475	23/+19.3	24/+19.8
75	1473	22/+16.8	24/+19.8	
45	1466	20/+6.8	24/+19.8	
30	1457	18/-5.7	24/+19.8	
Speed	45	1397	16/-15.7	24/+22.2
35	1430	18/-2.7	23/+16.6	
20	1360	170/+28.8	20/+1.3	
GP Capacity	2200	1471	21/+13.0	24/+19.8
2000	1461	21/+13.0	24/+19.8	
1600	1451	21/+13.0	24/+19.8	
HOV Capacity	45	1473	19/+1.0	24/+20.4
40	1472	20/+6.0	24/+20.2	
28	1468	24/+25.3	24/+19.1	
20	1463	29/+51.0	24/+17.6	

WESTBOUND, 2+, ADD-A-LANE

Criteria, Tested Value	Vol.	GP Vol./%	HOV Vol./%	BUS
Base		1264	191/+11.5	44/+9.9
Total Volume	1800	1687	278/+11.5	44/+9.9
1500	1507	232/+11.5	44/+9.9	
1000	1025	154/+11.5	44/+9.9	
Bus Volume	8 w/20 @	1276	191/+11.5	176/+9.9
4 w/20 @	1268	191/+11.5	88/+9.9	
Priority Volume	25%	1253	345/+11.5	44/+9.9
20%	1258	275/+11.5	44/+9.9	
8%	1270	110/+11.5	44/+9.9	
NP Travel Time	45	1228	191/+11.5	44/+9.9
35	1248	191/+11.5	44/+9.9	
20	1314	191/+11.5	44/+9.9	
Priority Travel Time	45	1294	163/-4.5	46/+14.0
35	1276	180/+5.3	45/+11.5	
20	1214	237/+38.3	41/+11.5	
Bus Travel Time	90	1268	201/+17.6	44/+9.9
75	1267	197/+15.2	44/+9.9	
45	1261	180/+5.4	44/+9.9	
30	1253	159/-6.9	44/+9.9	
Speed	45	1281	144/-15.9	48/+20.9
35	1273	165/-3.2	46/+15.8	
20	1248	238/+39.4	39/-1.4	
GP Capacity	-	-	-	-
HOV Capacity	-	-	-	-

WESTBOUND, 3+, ADD-A-LANE

Criteria, Tested Value	Vol.	GP Vol./%	HOV Vol./%	BUS
Base		1373	45/+4.3	48/+20.3
Total Volume	1800	1828	65/+4.3	48/+20.3
1500	1580	54/+4.3	48/+20.3	
1000	1113	36/+4.3	48/+20.3	
Bus Volume	8 w/20 @	1385	45/+4.3	192/+20.3
4 w/20 @	1377	45/+4.3	96/+20.3	
Priority Volume	10%	1360	129/+4.3	48/+20.3
7%	1366	91/+4.3	48/+20.3	
2%	1376	26/+4.3	48/+20.3	
NP Travel Time	45	1333	45/+4.3	48/+20.3
35	1355	45/+4.3	48/+20.3	
20	1429	45/+4.3	48/+20.3	
Priority Travel Time	50	1375	42/-3.3	48/+20.7
35	1372	48/+11.9	48/+19.8	
25	1368	57/+32.1	47/+18.7	
Bus Travel Time	90	1378	47/+10.4	48/+20.3
75	1376	46/+8.0	48/+20.3	
45	1369	42/-1.8	48/+20.3	
30	1361	37/-14.1	48/+20.3	
Speed	45	1307	36/-16.9	49/+22.4
35	1338	40/-7.1	49/+21.4	
20	1428	54/+25.9	47/+18.1	
GP Capacity	-	-	-	-
HOV Capacity	-	-	-	-