

**Light Rail or Buses in the Downtown Seattle Transit Tunnel:  
Assessment of Benefits to King County Metro  
and Regional Public Transportation**

**Revised Final Report, November 17, 2001**

**ITR Tunnel Team Report to  
King County Council Transportation Committee**

**by**

**John Niles, Dick Nelson, and Jim MacIsaac  
Integrated Transport Research, Inc.**

### **Note to Readers from the Authors**

This final report does not substantially change the findings, recommendations and conclusions of the draft released on July 25, 2001 but clarifies language and makes technical corrections pointed out by readers. We have also appended a number of short reports bearing on the topic we and others have released since July 25. In addition to addressing the future use of the Downtown Seattle Transit Tunnel, this report is intended to stimulate discussion regarding the future of public transportation in the Puget Sound region at this critical juncture for decision makers. We appreciate the cooperation of staff from King County Council, Metro, and Sound Transit in providing us with the planning documents and other information from which we reached our findings, conclusions, and recommendations. We seek open, collegial dialogue with those having different data, conclusions, and recommendations for regional transit, and we encourage review and critique of this report by all readers. Please contact any of the individual authors to provide feedback.

### **Authors**

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## **Light Rail or Buses in the Downtown Seattle Transit Tunnel: Assessment of Benefits to King County Metro and Regional Public Transportation**

### **Executive Summary**

This report was prepared by the Seattle consulting firm Integrated Transport Research, Inc. in response to an assignment made in early June 2001 by the King County Council Transportation Committee to assemble and analyze information that bears on the future use of the Downtown Seattle Transit Tunnel by Sound Transit's Link Light Rail.

The 1.3 mile Downtown Seattle Transit Tunnel (DSTT, or simply, the Tunnel) is the centerpiece of the local and regional King County Metro bus system. Across the entire County, Metro serves 100,000,000 riders per year. The Tunnel lets 25 regional express routes – producing about a quarter of the rush hour bus traffic in downtown Seattle – move buses two to three times faster than those on surface streets of the Central Business District (CBD). The Tunnel served 8,700 riders during the afternoon peak hour in 1998, with daily boardings of about 23,000.

ITR has concluded that conversion of the Tunnel to light rail is likely to make downtown Seattle street congestion in the 2010 to 2020 period much worse than the alternative of simply routing more buses through the Tunnel. Putting more peak hour buses into the Tunnel in the near term is recommended by the Link Project Review Committee, the Downtown Seattle Association, and this study. The Tunnel could support double the current peak period bus volumes: 300 per hour using the existing buses and route structure.

By examining Metro and Sound Transit planning documents, we have identified several reasons that downtown Seattle congestion would worsen with light rail running in the Tunnel:

- Some or all of **Metro's 25 current regional express Tunnel bus routes** would be permanently routed onto downtown streets, with the frequency of these routes increasing over time to serve more customers.
- Existing **local Metro bus service to downtown Seattle** would likely see only a small reduction despite impressions that light rail will be a substitute service that eliminates many buses. If customer demand for public transport from locations not served by Link light rail is to be met in the future, local Metro bus service to downtown would have to be expanded.
- Expansion would also occur with **non-Metro regional express bus services** to downtown Seattle that could not sensibly be rerouted to be intercepted at light rail stations outside of the CBD.
- **Joint bus and rail operations** following reopening of the Tunnel would not allow safe underground passage of enough Tunnel buses to compensate for the previous three sources of bus growth on the streets of downtown.

Existing planning studies of light rail from Northgate to South 200<sup>th</sup> reveal that rail in the Tunnel would cause approximately 680 buses to travel in the year 2020 afternoon peak hour on downtown streets, 48% higher than today's level of 460 buses. The number of

buses in downtown in 2020 would be even higher if the Link light rail system were truncated short of Northgate or S 200th. Noteworthy is that this number of buses on the downtown streets would be higher than the number achievable with the DSTT remaining an all-bus facility.

Joint bus-rail operation in the Tunnel adds additional cost and risk with no substantial benefits. The risks arise primarily from the unprecedented prospect of intermixing buses weighing 66,000 pounds with 600,000 pound trains in a confined space with four or five station stops. Safety in peak periods will have to be achieved by limiting the frequency of buses and trains, thus setting a limit on capacity.

Ramping up the number of buses running through the Tunnel in the afternoon peak hour without interference from trains offers more and better regional transit service to downtown Seattle at lower street congestion levels than the alternative of putting Link light rail in the Tunnel.

Our findings contradict Sound Transit's 1994 conclusions that light rail is necessary to supplement bus service in order to provide sufficient future transit service to downtown Seattle without congesting streets with a growing number of buses. This contradiction springs from the fact that the system level alternatives analysis contained in the 1993 Joint Regional Planning Committee Final Environmental Impact Statement for regional transit did not provide officials with an unbiased, realistic comparison between feasible bus/rail and all-bus/transitway alternatives that provide comparable service levels.

The "fatal flaws" in the 1993 bus/transitway option (specifically, buses facing congestion in the Seattle CBD, in the University District, and across the Ship Canal) could and should now be revisited to see if they can be corrected using Sound Transit's funding sources applied to a stronger bus plan designed by Bus Rapid Transit specialists. Revisiting an updated, expanded express bus plan is an important option given the fact that an approved, feasible, and funded light rail plan does not yet exist today, five years into the ten-year Sound Move Plan passed in 1996. Federal approval of the emerging light rail starter line will not come until 2002. Sound Transit officials have admitted that the long-run vision for a light rail system may have to be truncated at its Phase One terminus points

Fortunately, the Federal Transit Administration is placing new emphasis on Bus Rapid Transit (BRT) as a lower-cost substitute for light rail. This provides further incentive to examine the option of implementing an updated BRT system as a total replacement for Link light rail.

At the same time, the forecast that Link light rail (if built) would carry mostly Seattle riders between points within Seattle underscores the intra-Seattle transit opportunities that could be filled by monorail, in-city BRT corridors, or other options that are under study now in the Seattle Intermediate Capacity Transit project and by the Elevated Transportation Company.

### **Summary of Findings**

These findings are detailed in the full report that follows:

Finding 1: Operating Link light rail in the Tunnel would mean that the regional inter-city express bus service for which the Tunnel was originally built would be replaced with intra-Seattle light rail service.

Finding 2: If the Tunnel were converted to rail use either jointly with buses or exclusively, express bus service quality would decline for suburban riders.

Finding 3: Joint bus-rail operation in the Tunnel introduces additional costs and operational uncertainties to Metro over simply converting the Tunnel to exclusive rail.

Finding 4: Joint bus-rail operation in the Tunnel would introduce additional safety risks over simply converting the Tunnel to exclusive rail.

Finding 5: Converting the Tunnel to partial or full light rail use would degrade transit capacity and increase traffic congestion on downtown streets both during and after the two-year period of conversion.

Finding 6: Seattle downtown bus volumes and congestion could be reduced by expanding the volume of buses in the Tunnel above present levels.

Finding 7: New bus propulsion technology, combined with a low-floor design, would permit faster loading times and cause fewer delays than the present buses used in the Tunnel, and thus would increase its effective bus capacity.

Finding 8: The passenger capacity of the Tunnel in peak hour conditions is sufficient to carry projected 2020 passenger loads with either buses or light rail trains providing service.

Finding 9: Projections of post-2020 transit ridership based on the growth of employment, commercial services, and residential population in the Seattle downtown indicate the need for planning new transit corridor capacity and demand management measures.

Finding 10: Sound Transit's north-south Link light rail line, if implemented, would offer transit performance inferior to regional express bus routes on upgraded roadways.

Finding 11: The cost-effectiveness of an all-bus alternative for regional high-capacity transit in the Puget Sound region has not yet been compared to a light rail system like the one proposed by Sound Transit.

Finding 12: The overall quality of the Puget Sound regional transit system could be maintained and improved by retaining the Tunnel for all-bus operations, increasing the numbers of regional routes using the Tunnel, integrating long- and short-haul routes, and enhancing the roadway system for congestion free bus travel.

Finding 13: The existing express bus services of Sound Transit, Metro, Community Transit, and Pierce Transit have many of the attributes of Bus Rapid Transit (BRT), and could be enhanced to bring them closer to BRT.

Finding 14: Because Bus Rapid Transit (BRT) is a new Federal transit mode emphasis, Federal and Sound Transit funds could be reprogrammed to support an extensive Puget Sound regional BRT system.

## **Developments Since July 25, 2001**

The first public release of this report was July 25, 2001. Since that date, there have been new developments in the planning process for future use of the downtown Seattle Tunnel.

On August 21, Sound Transit released its own Tunnel analysis report for the guidance of the Sound Transit Board of Directors. This new report was prepared in conjunction with King County Metro, and titled *Evaluation of Joint Operations in the Downtown Seattle Transit Tunnel*. The Sound Transit report, summarized in Appendix F, reaches very different conclusions than this one, the most important of which are described in Appendix G, a document prepared September 17 by the ITR Tunnel Team for King County Council.

One important point of difference is how the respective reports interpret the impacts of housing, employment, and shopping growth forecasts for downtown Seattle. Metro and Sound Transit assert that bus service in support of forecast growth can be capped to keep downtown bus volumes at 2002 levels through 2016. Their planning theory is that buses from all parts of the region will feed passengers to the light rail spine and not travel into downtown. How this theory will work in practice has not been detailed, so public acceptance of growing levels of bus-rail transfers has not been assessed.

In contrast, ITR concludes that future public transportation demand between downtown Seattle and the many regional destinations not served by light rail means that ongoing growth in bus service will have to be programmed. This means that more buses with each passing year would travel in and out of downtown as a supplement to light rail service. Additional information on downtown Seattle growth was assembled by the ITR Tunnel Team and is provided in Appendix H. The performance of future bus-rail integration is the single biggest unexplored issue in understanding tomorrow's quality and cost of public transportation service in King County as light rail service grows.

A further assessment of the issues highlighted in the stark contrast between the Tunnel reports of Sound Transit and ITR is provided in Appendix I, a memorandum prepared by ITR for the King County Council, dated September 20. Additional issues include planning for the worst-case accident and calculating the ultimate growth in peak hour passenger capacity of the Tunnel after converting from all-bus service now to all-rail in the long-term future.

King County Council's assessment of the evidence in both reports led them to pass a formal Motion 11291 on September 24, 2001, asserting County Policy on the use of the Tunnel. This Motion lists about a dozen conditions for a new agreement between King County and Sound Transit for the use of the Tunnel for light rail. For example, in line with the findings of this report, the Motion requires that a condition of agreement will be confirmation that the light rail system will significantly increase new transit riders in King County and increase the number of new transit riders in the tunnel compared to maximizing the use of buses in the tunnel. The full text of this motion is in Appendix J.

Finally, in early October, the ITR Tunnel Team released additional analysis by DMJM+Harris engineers on the long-run peak hour passenger capacity of the Tunnel under conditions of exclusive light rail use or exclusive, optimized bus use. See Appendix K. While the capacity calculation for light rail confirmed Sound Transit's analysis and has resulted in some technical revisions to this report, the new findings for

all-bus capacity are several times larger than Sound Transit's conclusions in their August 21 report.

The technical work in Appendix K confirms the finding made originally by the ITR Team on July 25, namely, that the all-bus capacity of the Tunnel is the equal of the light rail capacity for serving future demand for public transit service to downtown Seattle. This is a critical piece of planning data for King County and City of Seattle decision making on the costs and benefits of enduring a costly, disruptive multi-year process to convert the downtown Tunnel from bus use to rail use. These data also bear on Federal decision making about whether to support Link Light Rail with a grant of Federal dollars to significantly alter a transit facility for rail use when it has not yet been operated at full capacity with bus service.

What follows in the main text beyond this point tracks closely with the July 25 public release draft of this report.

## **Background**

On June 7, 2001 Seattle consulting firm Integrated Transport Research, Inc. began work as requested by the King County Council Transportation Committee on assembling and analyzing information that bears on the future use of the Downtown Seattle Transit Tunnel by Sound Transit's Link Light Rail. The Tunnel is owned by King County, and lies along an undersurface right-of-way owned by City of Seattle.

Constructed in the second half of the 1980s, the Tunnel is often cited as a model for modern bus operation. It has been operated since 1990 as a facility for convenient and congestion-free access for a custom-manufactured fleet of 236 dual-powered (diesel and electric) Metro buses made by Breda. Metro and the City of Seattle originally designed the 1.3 mile-long tunnel as a way to speed "regional" transit services through downtown Seattle.

The Tunnel lets buses on 25 regional express routes – producing about a quarter of the rush hour bus traffic in downtown Seattle – move two to three times faster<sup>1</sup> than those on surface streets. The Tunnel served 8,700 riders during the afternoon peak hour in 1998, and about 23,000 total per weekday.<sup>2</sup> Nearly all of the regional buses (Metro routes numbered 100-599) approach downtown Seattle via I-5 and I-90 express lanes, and the Tunnel was designed to accommodate these express buses efficiently and directly. Map 1 in Appendix B shows the Metro bus routes now assigned to the Tunnel.

Today the Tunnel provides a congestion-free corridor for about half of all regional buses serving downtown Seattle plus some local express routes from north Seattle. The City benefits by a reduced intrusion of suburban autos; suburban King County benefits by fast regional service to and through downtown Seattle that competes with private auto travel. The Tunnel has capacity to serve all of the regional bus routes entering downtown Seattle, if there were enough of the dual-powered buses available. Reassignment of more regional routes to the Tunnel from downtown surface streets would require expansion of

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<sup>1</sup> Three times faster according to a Metro statement at <http://transit.metrokc.gov/bus/tunnel.html>. Two times faster as described in Metro bus schedules.

<sup>2</sup> Metro Transit Survey, Spring 1998.

the dual-mode buses. Such action was deferred when King County agreed in 1999 that the Tunnel should be reassigned to Sound Transit for exclusive use by light rail.

The public policy intent to convert the Tunnel eventually to passenger rail transit use was signaled during construction by embedding train track rails in the Tunnel. The Regional Transit Plan – Sound Move – approved by the voters in November 1996 expressly stated that the first phase of an electric light rail line, later to be called Central Link, would be built through the Tunnel, although the Plan also states that light rail trains and buses might share the Tunnel. During the period 1997 through 1999, Sound Transit finalized a light rail plan that was officially approved at all levels of government in the form of a Final Environmental Impact Statement and the Local Preferred Alternative (LPA). These documents specified exclusive use of the Tunnel by trains for the stated reasons of minimizing costs, maximizing transit service speed and reliability, and reducing safety risks associated with the possibility of collisions in mixing buses and electric trains.

An interlocal government agreement between Sound Transit, City of Seattle, and King County was negotiated in late 1999 and early 2000 to govern transfer of the Tunnel from King County to Sound Transit. This agreement was approved by the King County Council and the other governing bodies and became operative on June 1, 2000. At the time of the agreement, construction of the light rail line was planned to have begun in January 2001. The transfer of the Tunnel from King County to Sound Transit was scheduled in the agreement to take place in September 2004, at which time buses would stop running through the Tunnel and a two year period of construction begun to make it suitable for light rail trains. While four out of five bus stations in the Tunnel would become light rail stations, the fifth station, Convention Place, was first to become a staging area for equipment used in constructing a new tunnel to the University District, and to later become a bus transit center, with King County developing housing and commercial areas in the airspace over the bus bays. Around 2007, after a period of testing, light rail service from the University District to Lander Street was to have begun, with trains running through the Tunnel every few minutes during peak periods.

However, during the year following the finalization of the Tunnel Transfer Agreement, Sound Transit found that the cost of the light rail plan as specified in the November 1999 FEIS exceeded the Federal and local resources available. In January 2001, before the final determination of infeasibility in April 2001, the Sound Transit Board of Directors had begun directing the agency staff to study options for Plan revisions. By June 2001 the light rail project had entered a period of extensive revision, and the likelihood increased that Sound Transit would be unable to fulfill the terms of the Transfer Agreement. Because light rail would begin operating at lower train frequencies in its first years, the agency began studying, again, the possibility of combining its trains with Metro buses in the Tunnel. So-called joint operation would reduce the number of buses on downtown streets in the early years of light rail when it was not running as far, as fast, or as frequently as it would later when the original full alignment (LPA) were built out.

In response to the changes in the light rail plan, the King County Council passed a resolution in February 2001 requesting the County Executive to begin renegotiating the terms of the Tunnel Transfer Agreement. Joint bus-rail operation, a light rail station at Convention Place, and delays in the start of conversion would all change the net costs to be borne by King County as a result of Tunnel transfer, and thus the compensating



payments it would want to receive from Sound Transit. Furthermore, the newly reintroduced concept of Metro buses operating jointly in the Tunnel with Sound Transit light rail trains for ten or more years raises the issue of which agency should own the Tunnel, King County Metro, Sound Transit, or an undefined third agency responsible for light rail transit operations. Sound Transit, for its part, in May 2001 began indicating in briefing materials that there are options for paying King County less, not more, for use of the Tunnel under a revised light rail plan that delays light rail in the Tunnel.

The ITR Tunnel Team consultants have examined all available documents (see Appendix C) describing the Tunnel, the existing Transfer Agreement, existing and planned Metro bus operations, previous studies of joint operation, and Sound Transit's plans for Link Light Rail, including the new South focus. Based on this examination, we have reached a number of findings, conclusions, and recommendations as described in this report.

### **The Regional Bus System**

The Puget Sound Region has a well-regarded regional and local bus transit system, with a number of different operators. The regional bus system began as a replacement for electric train service in the 1930s, and the region made a recommitment to bus service in the early 1970s after the voters twice defeated region-wide heavy rail proposals. The chronology in Appendix A puts the use of buses and trains in the Seattle region into historical perspective.

Bus service in the Sound Transit electoral region is provided by five public transit agencies, four of which provide service into downtown Seattle: King County Metro, Community Transit based in Snohomish County, Pierce Transit based in Pierce County, and Sound Transit's ST Express covering regional routes across all three counties. (Operation of ST's buses is contracted to the local transit agencies.)

Map 2 in Appendix B shows regional bus routes in King, Snohomish, and Pierce County, and indicates the wide breadth of geographic coverage of bus transit service.

The largest of the local systems is Metro Transit, which was honored in 1983 and 1992 by the American Public Transportation Association as the best-run large public transportation system in North America. Metro operates a fleet of about 1,300 vehicles – including standard and articulated coaches, electric trolley buses, dual-powered buses, and streetcars – that in 2000 carried 100 million riders within King County, a 2,134 square mile service area. Metro serves riders who are disabled with accessible fixed route service (all Metro buses have wheelchair lifts and all routes and trips are accessible), as well as paratransit van service and a taxi scrip program. Additionally, there were 691 Metro vanpools in service at the end of 2000, the nation's largest vanpool fleet. Vanpool ridership in 2000 was 2.9 million.

The regional bus system is an integrated system, consisting of express and local (including feeder) buses, the HOV freeway network, some arterial HOV lanes, some exclusive transitways, park & ride lots, and transit centers. Even with the planned addition of light rail service, three-fourths of transit trips in the region will use buses.

More than \$1.5 billion has been invested to date in the regional freeway HOV network. Even though incomplete, the network, shown in Map 3 in Appendix B and described in Appendix E, is extensively used by buses to speed their travel times through congestion

Sound Transit Express buses today carry about 20,000 riders per weekday, from points as far away as Everett and Gig Harbor to downtown Seattle, as shown in Map 4, Appendix B. One of Sound Transit's Express bus lines currently operates in the DSTT.

### **Findings Regarding Conversion of the DSTT to Rail Operation**

Conversion of the Tunnel from bus use to light rail use is the centerpiece of the Sound Transit Central Link Light Rail plan. There have been two possible scenarios involving modification to permit light rail operations:

- Conversion of the Tunnel from all-bus to light rail exclusively with no intermediate period of mixed bus-rail use. This was the plan that was being followed in 1999-2000.
- Conversion of the Tunnel from all-bus to an interim use for light rail intermixed with buses with probable future use as an all-rail facility. As of this writing, this second scenario is the most likely.

**Finding 1: Operating Link light rail in the Downtown Seattle Transit Tunnel would mean that the regional inter-city express bus service for which the Tunnel was originally built would be replaced with intra-Seattle light rail service.**

Today the Tunnel is primarily dedicated to "regional" transit riders with trip lengths of 10 to 20 miles. The buses now using the Tunnel are mainly regional express buses carrying passengers between downtown Seattle and suburban locations, with trip lengths of 10 to 20 miles. About 80% of bus trips using the Tunnel now are regional. Map 1 in Appendix B shows the current Tunnel routes. Following the conversion of the Tunnel to light rail usage as part of the Phase One Link light rail alignment from Northgate to S 200th, the proportion of regional trips in the Tunnel would change radically.

The next exhibit illustrates the origin-destination patterns of the 157,000 rides per day predicted by Sound Transit in 2020 assuming the rail line will reach from Northgate to South 200<sup>th</sup>. It assumes that all regional routes from south King, Pierce and Snohomish counties will be terminated at outlying rail stations.

If taken over for light rail use, the Tunnel will effectively become a Seattle local transit facility. About 85% of the passengers that Link would carry would be riding as part of journeys between originating points and destinations completely within Seattle. The expected bus interceptions at Northgate, South 200<sup>th</sup>, and intermediate points generating suburban riders would account for just 15% of Link riders.

Starter segments that do not go as far north or as far south as the complete Northgate to South 200<sup>th</sup> alignment would have even higher in-city ridership proportions.



Distribution of 2020 Trips Using the DSTT

**Finding 2: If the Downtown Seattle Transit Tunnel were converted to rail use either jointly with buses or exclusively, express bus service quality would decline for suburban riders.**

An important consequence of shifting the Tunnel's ridership from regional express bus to local light rail is that the quality of bus service would fall for those now on direct Tunnel buses that start from suburban transit centers and park & ride lots. Many of these buses would be displaced from the Tunnel to downtown Seattle streets. Some routes would be truncated at outlying light rail stations, assuming light rail reaches outlying stations. If their bus does in fact terminate at a light rail station, the riders face a forced intermodal transfer and probably a longer door-to-door travel time. This is likely to be a long-term consequence, since light rail service directly connecting the suburbs and downtown Seattle is not specified in the 2030 Metropolitan Transportation Plan of the Puget Sound Regional Council, and is unlikely to be funded beyond the Phase One approved in 1996.

*The Downtown Seattle Surface Report: Alternatives to Improve Transit Operations*, April 14, 1999, indicated that travel times across downtown Seattle for Tunnel buses forced to surface streets would increase by 8 to 12 minutes.

**Finding 3: Joint bus-rail operation in the Downtown Seattle Transit Tunnel introduces additional costs and operational uncertainties to Metro over simply converting the Tunnel to exclusive rail.**

A number of costs to Metro in the conversion of the Tunnel to exclusive rail use were recognized in the existing Transfer Agreement through the establishment of financial

terms. These costs – including coverage of extended Tunnel debt service payments (\$12.5 million annually), compensation to Metro for lost transit fleet and driver productivity as a result of diverting Tunnel vehicles to congested surface streets, and direct expenses associated with light rail construction net of Convention Place redevelopment revenues – would be different and possibly increased in a conversion to joint operation, and thus the necessary financial terms would be different.

Metro also faces additional costs for a previously unanticipated extension of the period when a Tunnel-compatible fleet of buses would be needed, because Tunnel buses would continue to operate for ten to fifteen years beyond the 2004 date contemplated in the existing Transfer Agreement. Metro estimates the cost of extended Breda operation through 2009 at over \$7 million annually, as noted in the recent document *Six-Year Transit Development Plan for 2002 to 2007: Discussion of Issues and Areas for Policy Development and Direction*. (Of course, permanent use of the Tunnel by a growing number of buses as recommended later presents a different cost scenario, one that needs to be integrated with long-run fleet technology planning.)

Operational uncertainties arise under joint operation because the routing of buses would be changed several times, instead of just once. The first time would be when the Tunnel closes for installation of rails. The second time would be when the Tunnel reopens two years later for joint operation. Additional changes, perhaps a third and a fourth, would occur when light rail train frequencies are increased with the opening of outlying stations, and selected bus routes are displaced from the Tunnel to surface streets. Finally, when light rail headways (the time between trains) decrease to under four minutes, buses in the Tunnel would be displaced completely, as in the original plan for exclusive light rail. The sequence described here would occur over a decade or more, as opposed to the previous Tunnel closure plan, which would require a single decisive end date for Tunnel bus operations.

**Finding 4: Joint bus-rail operation in the Downtown Seattle Transit Tunnel would introduce additional safety risks over simply converting the Tunnel to exclusive rail.**

The Tunnel, if used by both trains and buses, would be a unique transit facility in all of the world. Sound Transit proposes to use four-vehicle train sets in peak periods with a fully loaded weight of more than 600,000 pounds. The Breda Tunnel buses now in service weigh about 66,000 pounds when fully loaded. Mixing the operation of two transit vehicles of such differing size and weight – with the lighter one carrying liquid fuel – and in an underground tunnel with station stops connected to multi-story buildings – is nowhere else to be found in the world today. Consequently, there are no existing safety standards based on experiential information that may be examined for guidance in tunnel design and operation.

In such a case, both design and operation must be carried out with a sufficient safety margin to minimize the risk to Tunnel users in case of an accident. The combustible load of the Tunnel, which is principally the fuel carried by the buses, must be balanced by the emergency ventilation and fire suppression systems. Thus, studies that simulate joint operation can only provide a theoretical benchmark for Tunnel capacity. Safe design and operating capacity must be based initially on good technical judgment, followed by adjustments that are suggested by experience.

Neither the City of Seattle nor King County currently have adopted design and operating standards or codes for the Tunnel, whether for all-bus, joint, or all-train operations. Since the national fixed-guideway standards from the National Fire Protection Association have been changed several times since the Tunnel was opened in 1990, there may be a need for a safety review and possible retrofit of the Tunnel even if it continues to be used as an all-bus facility.

**Finding 5: Converting the Downtown Seattle Transit Tunnel to partial or full light rail use would degrade transit capacity and increase traffic congestion on downtown streets both during and after the two-year period of conversion.**

Bus volumes will grow on downtown Seattle streets during and after the period when the Tunnel is closed for conversion to light rail, assuming that official plans for promoting residential and employment growth in downtown Seattle continue to be implemented.

To illustrate this point and others we have prepared a series of bar graph charts below that plot estimated bus volumes in future years using available data from Metro's bus-rail service integration plans and extrapolating growth of transit ridership in the downtown from Metro projections. Even-numbered years are shown for four scenarios:

- Chart 1: Conversion of the Tunnel to exclusive light rail in 2010 with no further use by buses.
- Chart 2: Conversion of the Tunnel to exclusive light rail after joint use by trains and buses 2010-2020.
- Chart 3: Retention of the Tunnel for use by buses exclusively with moderate growth in the number of Tunnel buses.
- Chart 4: Accelerated efforts to maximize use of the Tunnel up to its all-bus capacity.

Using data in Metro planning documents, we forecast that bus volumes will grow beyond any existing Sound Transit mitigation plans for traffic revisions or trip reduction measures that attempt to control resulting bus vehicle congestion in peak periods. A reasonable capacity limit for the PM peak hour on downtown Seattle streets is approximately 650 buses, as shown by the horizontal red line on Charts 1 through 4.<sup>3</sup>

During Tunnel closure for rail conversion in 2008-09, shown in the bar for year 2008 in Charts 1 and 2, we estimate that the afternoon peak hour bus volume on downtown Seattle streets will soar to 750, a 63% increase over 460 buses today. After Tunnel conversion, the volume will be at least 150 buses higher than today's level – with or without mixing buses and trains in the Tunnel, as shown in the bars for years 2010 to 2020 in Charts 1 and 2. This reality of higher bus volumes on the street is not fundamentally changed as new light rail segments open, if and when they do open. Comparing Chart 1 that illustrates rail-only use of the Tunnel with Chart 2 showing joint bus-rail operation makes the point that joint operation does reduce the number of buses on the street, but not below the 650 bus street volume capacity level in the 2014 to 2016 period.

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<sup>3</sup> *Downtown Seattle Surface Report: Alternatives to Improve Transit Operations*, April 14, 1999. We include First Avenue in the total of 650.

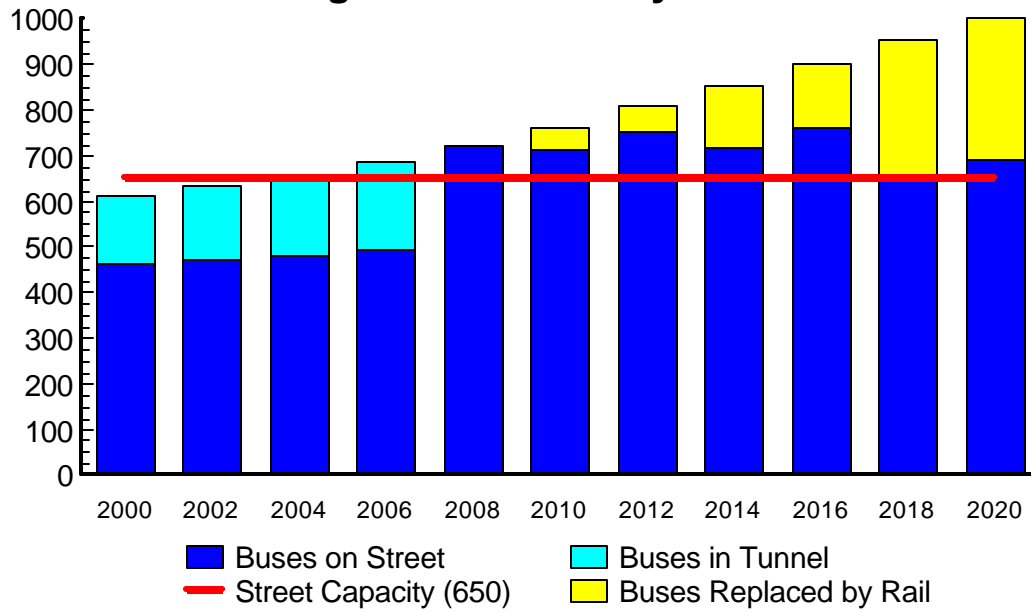
We assume in our forecast that transit growth in downtown will follow present growth trends of 2.5 percent annually, that the Tunnel conversion to rail will be in the period 2008-2009, that the initial light rail operating in 2010 will go from Convention Place to S 200<sup>th</sup>, that Link will be extended north to the University District by 2015, and that the line will reach Northgate by 2020. We also assume, based on an examination of previous studies and the *Transit Capacity and Quality of Service Manual* from the Transit Cooperative Research Program of Transportation Research Board, that the DSTT could operate in peak periods with a volume of 150 buses per hour per direction with present technology, and 165 buses per hour per direction with new low-floor and no-wire technology likely to be available in 2020.

Appendix D provides further detail on different scenarios for using the DSTT through 2020. Our analysis of bus-rail integration plans produced by Metro estimates a likely reduction of 55 buses in the PM peak hour in downtown Seattle if the starter light rail line from Convention Place Stations to S 200<sup>th</sup> were operating. We estimate the bus reduction in the peak hour to be 140 when University District to S 200<sup>th</sup> is running, and 310 if the light rail line were to reach Northgate.

The growth we forecast in Metro bus service to meet the growing transit demand that is not served by light rail would result in an increase in bus volume on downtown Seattle streets of 34% over today's level by 2010 if joint bus-rail operation were established, or 55% over today's level if exclusive use were chosen. The comparable growth in bus volume on downtown streets would be just 10% if the Tunnel were simply committed to expanded express bus-only use to meet the 2010 transit demand.

Chart 1

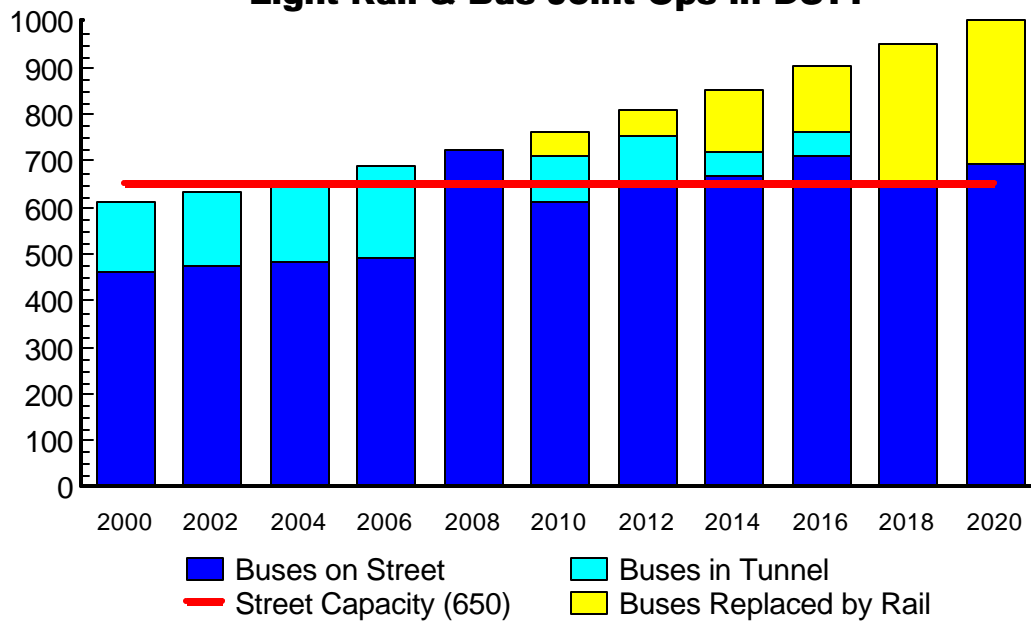
**Peak Hour Bus Volume, Downtown Seattle  
Light Rail Exclusively in DSTT**



Light Rail Assumptions: 2008 - Tunnel Closes; 2010 - Link Opens;  
 2015 - U District Link; 2018 - Northgate Link

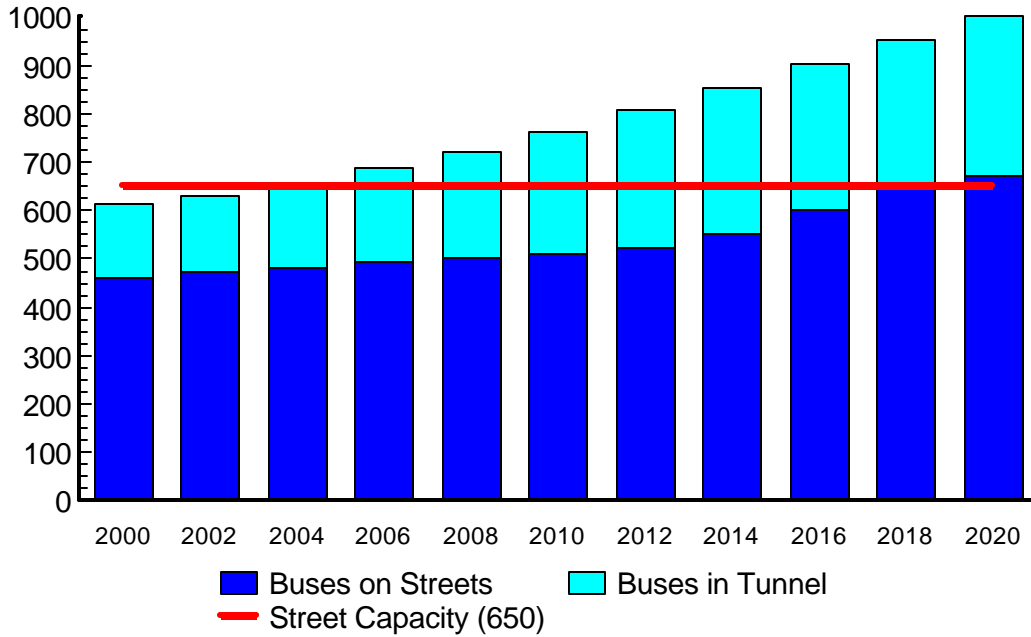
Chart 2

**Peak Hour Bus Volume, Downtown Seattle  
Light Rail & Bus Joint Ops in DSTT**



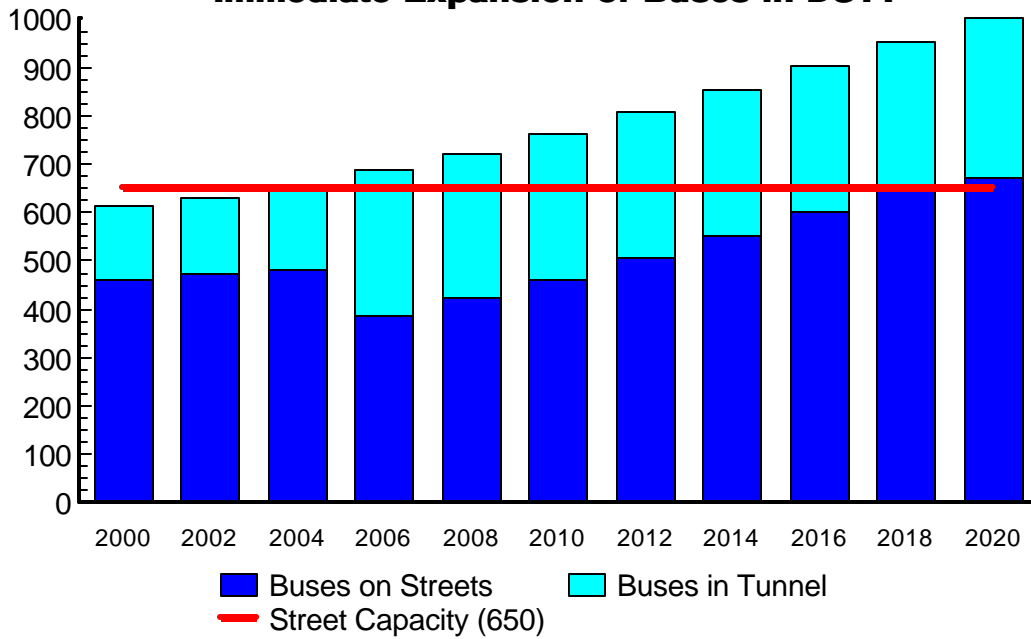
Light Rail Assumptions: 2008 - Tunnel Closes; 2010 - Link Opens;  
 2015 - U District Link; 2018 - Northgate Link

Chart 3  
**Peak Hour Bus Volume, Downtown Seattle**  
**All Buses in DSTT**



Assumes No Light Rail

Chart 4  
**Peak Hour Bus Volume, Downtown Seattle**  
**Immediate Expansion of Buses in DSTT**



Assumes No Light Rail



**Finding 6: Seattle downtown bus volumes and congestion could be reduced by expanding the volume of buses in the Downtown Seattle Transit Tunnel above present levels.**

A close examination of a likely phasing of joint operation in the Tunnel and light rail expansion reveals that downtown street traffic in the 2010-2020 decade would be considerably worse compared to the alternative of simply ramping up the number of buses in the Tunnel.

The two years for Tunnel conversion (the bar on Charts 1 and 2 for 2008) with no buses at all in the Tunnel will obviously add to congestion over a scenario of expanding the number of Tunnel buses, as shown in Charts 3 and 4. However, after the Tunnel reopens and joint operation begins, our findings contradict the conventional wisdom that bus volumes will drop below today's level after rail begins. We estimate that the growth of transit ridership and bus service would outstrip the Tunnel's bus capacity when trains are also running through it. This is shown on Chart 2 by the blue bars for years 2012 through 2016, which rise above the red capacity line of 650 buses.

With light rail operating only between Convention Place Station and South 200<sup>th</sup> in years 2010-2012 (see Chart 2), the number of peak hour buses to be reduced on downtown streets is just 150, comprised of 100 in the Tunnel and another 50 that can be intercepted at outlying rail terminals. That compares to the potential for 260 buses in the Tunnel instead of on downtown streets if no trains were operating.

If light rail were to reach the University District by 2014, we extrapolate that the number of buses able to operate in the PM peak hour jointly in the Tunnel with a more frequent light rail schedule would have to drop to approximately 50. At the same time, the number of buses intercepted would rise to 140. That brings the reduction in the number of street buses up to 190, but still lower than the 300 that could be in the Tunnel by then in an all-bus alternative, as shown in Chart 3.

The stated reason for Sound Transit's consideration of joint bus-rail operation is that merging buses with trains would more fully utilize Tunnel capacity in the early years of light rail operations, and thus reduce the number of buses on downtown Seattle streets. But in the probable joint operation scenario we depict, mixing buses with light rail in the Tunnel provides no street capacity improvement benefits over the alternative of simply expanding the number of buses in the Tunnel.

Perhaps in recognition of this kind of analysis, the Link Project Review Committee chaired by former Seattle Mayor Charles Royer recommends that the Tunnel not be converted to rail unless light rail is running from downtown to Northgate. The Downtown Seattle Association earlier made this same recommendation.

The Project Review Committee further recommended taking steps to maximize the number of buses operating in the Tunnel as a means of reducing bus congestion on downtown Seattle streets. That scenario is shown in Chart 4, which for the 2006-2010 period provides a reduction in street congestion below the 2004 level.

**Finding 7: New bus propulsion technology, combined with a low-floor design, would permit faster loading times and cause fewer delays than the present buses used in**

**the Downtown Seattle Transit Tunnel, and thus would increase the effective bus capacity of the Tunnel.**

We forecast that new technology hybrid buses will allow more reliable and faster passage through the Tunnel by 2020. These buses would have on-board electric power as well as internal combustion engines, allowing pole-free, no-emission operation and easier passing in the Tunnel. This feature, combined with three double doors and a low floor design that facilitates faster passenger loading because no stepping up and down is needed, would increase the effective bus passenger capacity of the Tunnel.

Furthermore, we estimate that computer-based signaling and sensor applications would assist a year 2020 driver in achieving sufficiently close bus spacing and rapid, precision docking to permit four bus platoons to move smoothly from station to station and exit the Tunnel every 85 seconds. We forecast, therefore, that the 1985 cited limit of 290 buses<sup>4</sup> in the peak hour could be expanded to 330 as a result of implementing these technologies by the year 2020. Independently, following the first released draft of this report, a calculation by DMJM+Harris showed that approximately 400 buses in the peak hour would be possible with a simplifying of the bus routes in the Tunnel.

Tri-Met, the public transit agency in Portland, Oregon has bought and is operating a fleet of 40 foot commercial New Flyer hybrid diesel-electric buses with reported sufficient battery life to power the bus for five to seven miles without using the diesel. These buses are reported to have "prohibitive" costs in the present, but the agency expects the price to come down with volume production.

King County Metro has announced it has partnered with New Flyer and General Motors-Allison to test the performance and reliability of the nation's first articulated hybrid diesel-electric bus. This test is to be conducted as one part of developing specifications for a replacement vehicle for the Breda fleet of Tunnel buses. New buses are scheduled to be acquired in 2003-04, according to Metro.

**Finding 8: The passenger capacity of the Downtown Seattle Transit Tunnel in peak hour conditions is sufficient to carry projected 2020 passenger loads with either buses or light rail trains providing service.**

Whether buses or trains in the Tunnel would yield the highest ultimate capacity depends on how frequently vehicles can be scheduled through the Tunnel, and how many people can fit aboard the vehicles.

The ITR Tunnel Team in September, 2001 turned over the calculation of ultimate Tunnel passenger capacity in all-bus and all-rail configurations to the international transportation engineering consulting firm DMJM+Harris to provide independent evidence on this topic. The resulting report is in Appendix K.

The calculations illustrate that passenger capacity either way is about 15,000 passenger in the peak hour. This theoretical capacity exceeds achievable capacity, since trains over a full hour will likely not average more than 75% of standing loads, per the Portland, Oregon MAX light rail experience of under 70%. We use Sound Transit data to forecast the projected 2020 afternoon peak hour maximum light rail train loading in the Tunnel to

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<sup>4</sup> Downtown Seattle Transit Project Final Environmental Impact Statement, 1985

be 10,700 passengers (near Westlake Station)<sup>5</sup>, so train capacity of 15,000 is therefore more than sufficient.

**Finding 9: Projections of post-2020 transit ridership based on the growth of employment, commercial services, and residential population in the Seattle downtown indicate the need for early planning of new transit corridor capacity and demand management measures.**

When we examined bus volumes in a growing CBD in year 2020, a significant problem was revealed that will occur with either light rail or a maximized flow of buses in the Tunnel: downtown Seattle street capacity for buses is likely to be reached or exceeded.

Using a baseline estimate of 1,000 buses for service to downtown Seattle in 2020, light rail from Northgate to South 200<sup>th</sup> would eliminate about 320 buses from the PM weekday peak hour in downtown Seattle, leaving 680 on the streets there, as shown in Charts 1 and 2 above. If an all-bus scenario were pursued, the number on downtown streets would be slightly fewer, 670 buses supplemented with 330 in the Tunnel, as shown in Charts 3 and 4 above.

Given the vagaries of forecasting two decades into the future, these numbers are virtually equivalent. Whether there are 680 buses on the street in 2020 with light rail in the Tunnel, or 670 on the street with an all-bus approach, or a slightly lower number if either one of these approaches reduces buses more than we have estimated, the capacity of downtown Seattle streets is likely to be exceeded.

As bus volumes on the street increase, the various mitigation steps planned by Sound Transit, City of Seattle, and Metro would help traffic keep moving and are important with or without Tunnel joint operation, and with or without light rail to Northgate. However, stronger measures will be required.

The City of Seattle is responding to the congestion problem with buses, monorails, street cars and other modes as possible elements of an intermediate capacity transit plan. The City also has a range of demand management efforts under consideration as described in its Transportation Strategic Plan. These programs, in contrast to implementing Sound Transit light rail in the Tunnel, are a more appropriate response to the problem of bus capacity limits on the surface streets and in the Tunnel beyond year 2020.

We note (for completeness) that another alternative to building more transit capacity would be to take public policy steps to slow the rate of residential and employment growth in the Seattle downtown area.

**Findings Regarding Light Rail Compared to Bus Expansion**

The need for Link light rail is founded on the conclusion reached by Regional Transit Authority planners in 1994 that bus access to the University District, Capitol Hill, and downtown Seattle will be increasingly stymied by congestion in the decades ahead, and that nothing reasonable can be done to alleviate or mitigate buses caught in congestion in those three neighborhoods. The addition of passenger rail to the regional transit system was deemed necessary for long-term capacity.

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<sup>5</sup> Determined by analyzing Sound Transit's Central Link Preliminary Operations Plan, June 1999, adjusted to include the Northgate extension using additional boardings shown in the Central Link light rail Environmental Impact Statement.

Thus, in addition to expanding express bus service, regional leaders in 1996 put before the voters a plan for the construction of Central Link light rail from Northgate to S 200th, with buses to be replaced by trains in the existing downtown Tunnel. This light rail segment was originally intended to be Phase One of a more expansive 125-mile system extending north to Everett and south to Lakewood, with a branch across Lake Washington to the Eastside as well.

And, under Sound Transit's long-range plan, light rail was to eventually replace many of the express buses deployed in Phase One, which were considered as an interim high-capacity system.

Recent decisions by Sound Transit and the Puget Sound Regional Council suggest that cost realities will force consideration of express bus as the long-term high capacity transit system in most of the remaining regional corridors if Phase One light rail were built. As of 2001, Sound Transit officials no longer hold a commitment to build light rail beyond Phase One.<sup>6</sup>

**Finding 10: Sound Transit's north-south Link light rail line, if implemented, would offer transit performance inferior to regional express bus routes on upgraded roadways.**

The express bus service operating from the Tunnel and shown in Appendix B, Map 1 already takes advantage of an extensive HOV network, as do other routes that operate on downtown streets. A series of HOV improvements for bus routes described in Appendix E would offer express buses more congestion avoidance, the reliability of light rail, and higher speeds.

Light rail is not a stand-alone transit system, since it inherently cannot provide the geographic coverage of a bus network, and it requires an extensive bus feeder system to produce even modest passenger loads. For most regional transit users, a ride on Link requires a transfer from or to a connecting bus ride, which adds to the total travel time for the journey.

If more regional express bus service were upgraded to run with the speed of trains, light rail would be a costly and unnecessary addition to regional transit service. In some cases, downtown bus service already operates at the speed of the planned Link light rail service. For example, Metro bus route 194 from the University Street Station in the Tunnel to Sea-Tac Airport (Lower Roadway, Main Terminal, near Baggage Claim) has a scheduled run time of 30 minutes. Link light rail would provide a run time of approximately 27 minutes plus the time to walk or ride from the light rail station to the Main Terminal building.<sup>7</sup>

**Finding 11: The cost-effectiveness of an all-bus alternative for regional high-capacity transit in the Puget Sound region has not yet been compared to a light rail system like the one proposed by Sound Transit.**

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<sup>6</sup> Transcript of testimony by Paul Matsuoka, Sound Transit Deputy Executive Director, before the King County Council Transportation Committee, July 11, 2001.

<sup>7</sup> Schedule for route 194 at [http://transit.metrokc.gov/bus/schedules/s194\\_0.html](http://transit.metrokc.gov/bus/schedules/s194_0.html) shows 30 minutes travel time. Light rail time of 27 minutes is from the Link Final Environmental Impact Statement, Table 2.1-1.

The claimed conclusion in 1994 that light rail provides a transit alternative for access to the University District, Capitol Hill, and Downtown Seattle that is superior in performance and cost to a bus alternative is a judgment that has never been tested against a comprehensive express bus plan prepared by qualified professionals with specialized skills and enthusiasm for making the most of modern bus technology.

The only partially relevant comparison ever made was the 1993 Final Environmental Impact Statement for the Regional Transit System Plan where an alternatives analysis was made between rapid (heavy) passenger rail and an all-bus system that included a dedicated bus transitway from Northgate to Tukwila and east across Lake Washington to Bellevue. The all-bus alternative analyzed in 1993 did not include all of the roadway improvements and other capital facilities that would have produced a higher capacity system. Also, the rail alternative included both light rail and the commuter rail, while the relevant comparison would have treated commuter rail equivalently in both alternatives – either totally in or totally out for both light rail and the all-bus alternative.

The all-bus alternative (TSM/Transitway) was scaled to a capital cost of \$5.5 billion (1991 dollars) and achieved daily 2020 ridership of 480,000, while the passenger rail alternative was scaled at more than twice the all-bus price, \$11.5 billion (1991 dollars) and yielded 560,500 daily riders, as noted in Table 4 of the Executive Summary of the 1993 FEIS. At the same time, the all-bus alternative was conceptualized without elements that would have increased capacity. These can be fairly characterized as built-in fatal flaws. An example of a fatal flaw in the 1993 FEIS was the required makeover of the I-5 express lanes into an exclusive HOV transitway from Northgate to downtown Seattle. Yet proposed spending on entrance and exit ramps, priority treatments, terminal facilities, and rolling stock was limited, which reduced capacity from 22,400 persons per hour to 9,400, as noted in Technical Appendix F, describing capacity calculations in the 1993 FEIS. Clearly, if the capital spending on the all-bus alternative had been analyzed at a higher level in the early 1990s, the all-bus ridership forecast could have been elevated to the level of the passenger rail alternative and the all-bus alternative would have been more attractive.

**Finding 12: The overall quality of the Puget Sound regional transit system could be maintained and improved by retaining the Downtown Seattle Transit Tunnel for all-bus operations, increasing the numbers of regional routes using the Tunnel, integrating long-haul and short-haul routes, and enhancing the roadway system for congestion free bus travel.**

The overall quality of transit service for both urban and suburban residents depends on the integration of routes and modes in ways that allow people to travel across a region, according to need, quickly and with the least amount of inconvenience. That was the vision of a regional rail system connecting urban centers and fed by short bus routes. If that vision is no longer viable, then it makes more sense to build an all-bus system that takes advantage of the greater flexibility of buses. Buses can use bus-only and HOV facilities, but are not constrained to them when regular arterials with transit signal preemption will suffice.

A sensible integrated system could be designed, based on express buses for long-haul routes and other buses of various sizes on short to medium length routes, some of which feed the express routes. The North King County subarea would then be helping to pay for

a more-cost effective regional system, a system that many of its residents would use to access jobs and nonwork venues outside the city.

**Finding 13: The existing express bus services of Sound Transit, Metro, Community Transit, and Pierce Transit already have many of the attributes of Bus Rapid Transit (BRT), and could be enhanced to bring them closer to BRT.**

The Federal Transit Administration proclaims, "Think Rail, Use Buses" as the quickest way to describe Bus Rapid Transit. According to the FTA, BRT combines the quality of rail transit and the flexibility of buses. It can operate on exclusive transitways, HOV lanes, expressways, or ordinary streets. A BRT system utilizes intelligent transportation systems technology, priority for transit, cleaner and quieter vehicles, and rapid and convenient fare collection.

Professor Scott Rutherford at University of Washington adds that BRT may be driver steered, guided mechanically or electronically, and that it can be incrementally implemented in a variety of environments, from totally dedicated to transit (surface, elevated, underground) to mixed with other traffic on streets and highways.<sup>8</sup>

BRT in general provides a competitive alternative to LRT. Research into consumer attitudes toward modes demonstrates that there is no inherent rail advantage over bus beyond measurable characteristics such as riding comfort, speed, service reliability, and cost. The point of BRT is to provide buses that have the same measurable characteristics as trains, in order to take advantage of the lower cost of implementing bus service.

We would add that because fewer transfers are involved than in a combined bus and rail transit system, there is potential to decrease travel time and increase the transit ridership through a more attractive service.

Sam Zimmerman of DMJM+Harris notes that BRT offers incremental development possibilities: Build phase I with current rolling stock, simple stops, some stations using a mixture of dedicated and general traffic right-of-way. In phase II add special rapid transit vehicles, additional dedicated right-of-way, and more elaborate stations and fare system. In phase III upgrade technology to include full ITS guidance capabilities and evolve to all dedicated right-of-way.<sup>9</sup>

Thus, the development of BRT begins in a region with existing bus service and builds upon it. Sound Transit's ST Express bus service (operated under contract by Metro, Community Transit, and Pierce Transit) was portrayed to the voters in the 1996 election that funded the Sound Move Plan as having BRT qualities:

"Regional express bus lines would provide all-day, frequent, two-way service to centers including Bellevue, Kirkland, Redmond, Issaquah, Mercer Island, Woodinville, Bothell, Lynnwood, Mountlake Terrace, Everett, Shoreline, West Seattle, Renton, Burien, Tukwila, Sea-Tac, Federal Way, Kent, Auburn, and Tacoma. Many routes would use a new HOV Expressway, combining over 100 miles of continuous, state-funded HOV lanes and RTA-funded HOV ramps, so transit may travel in separated rights-of-way on congested freeways."

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<sup>8</sup> Presentation made March 12, 2001 for the Sound Transit Special Forum on Bus Rapid Transit, posted at <http://www.soundtransit.org/BusForum/Cover.htm>

<sup>9</sup> See note 7.

Sound Transit in recent statements has indicated interest in the possibilities of Bus Rapid Transit for future phases of high capacity transit.

**Finding 14: Because Bus Rapid Transit (BRT) is a new Federal transit mode emphasis, Federal and Sound Transit funds could be reprogrammed to support an extensive Puget Sound regional BRT system.**

The Federal Transit Administration (FTA), has been working with a consortium of 17 communities around the country to foster the development of BRT as a high quality service that will significantly reduce transit travel time, reduce congestion and improve air quality. The consortium' is working to generate new bus procurements over the next two to four years.

Light rail construction in Seattle has not yet started. The build out of Phase One just to the University District is now estimated as impossible to complete until 2013. With the justifications for building light rail now eight years old and with the conversion of the Tunnel from bus to rail at issue, recent developments suggest an opportunity to revisit the decision to build light rail, an opportunity to decide if in fact the bus system should be expanded and enhanced more dramatically than planned by Sound Transit with ST Express.

Already in the Puget Sound region, a number of HOV lane and access ramp projects have been proposed that would individually and collectively improve express bus transit. These projects could be funded by Sound Transit under its existing authority. The Sound Transit Board has the authority and the procedures – stated in Resolution 98-22 – to modify the Sound Move Plan to change the relative levels of investment in light rail and express bus.

With respect to a reconsideration of Phase One light rail in light of the findings in this report, the Federal dollars in the \$500 million Full Funding Grant Agreement for Link light rail could probably be reprogrammed to support BRT if there were political will. A BRT system that substitutes for light rail in essentially the same University District to Lander Street corridor as the Link light rail Locally Preferred Alternative and Minimum Operating Segment One would likely be favorably considered under federal funding guidelines. In other words, Sound Transit would not be forced to go to the end of the money line and completely start over.

A regional BRT system would likely be up and in operation in less than half the time now needed to complete Sound Transit's light rail plan.

## **Conclusions**

The new problems exposed here in converting the Tunnel to light rail use, when added to the years of delay in Sound Transit's effort to achieve an approved budget, schedule, and alignment for light rail outside of downtown Seattle, lead us to conclude that the time is ripe to revisit the choice between light rail plus bus and all-bus.

Exploiting the capabilities of high-tech Bus Rapid Transit (BRT) for an enhanced regional service would likely prove in this comparison to be a better use of the Tunnel – more supportive of Sound Transit's regional system goal – than diverting a prime right-of-way to a short rail line that will inevitably consume all of the region's capital resources for new transit construction.

We have described these advantages :

- Expanding bus service in the Tunnel offers a better prospect for keeping downtown congestion under control than depending upon light rail to reduce the number of buses downtown.
- Capacity to move people into, out of, and through downtown Seattle is better supported by a network of express buses using the Tunnel than by adding light rail trains to a limited level of bus service in the Tunnel.

Transportation leaders in King County, as well as in Snohomish and Pierce County, are now at a crossroads. Even great amounts of money will produce little if spent trying to build out the regional light rail plan. High costs and limited revenues mean that the population and development of the region will expand faster than a light rail system can accommodate. A light rail system will fall further and further behind Sound Transit's goal of building a regional transportation spine. And because light rail rather than the even more expensive heavy rail was selected, it will be a slow system unable to compete with faster express buses operating in the same corridors. So the choice is to continue down that expensive and ineffective path, or turn to a new path that could lead to a flexible, well-integrated, and affordable regional system.

A revised Sound Move plan emphasizing frequent, rapid express bus service operating on HOV and exclusive or semi-exclusive busways between Northgate and Lander Street would provide superior service at lower cost than any contemplated light rail configuration between those two points.

Express buses operating regionwide on both freeway and arterial HOV lanes (and some busways) could be engineered with clever design and Intelligent Transportation System enhancements to provide fast and highly reliable service between those points. The cost would likely be significantly less than light rail tunnels and above-grade alignments because the major investments needed involve several improvements to the HOV lane network and its connecting ramps that are largely in the planning pipeline. The reduction in cost may reach billions of dollars, with no significant difference in the quality of service. In fact, many bus riders would experience faster trips than if they rode a light rail train that must stop several times en route. And transit improvements would be in place much sooner.

**Recommendations for maximizing transit ridership, minimizing cost, and reducing bus traffic on Seattle CBD streets:**

1. Authorize use of the Tunnel by Sound Transit for buses only.
2. Reprogram money now budgeted for Central Link light rail to expanding Bus Rapid Transit (BRT) in the Sound Move Plan.
3. Work to implement a regional BRT plan that integrates ST Express and Metro bus services and that maximizes the use of the Tunnel.



## **Appendix A**

### **Seattle Area Transit Chronology**

- 1889: Electric streetcars begin to operate in Seattle.
- 1892: Seattle served by 48 miles of streetcar track and 22 miles of cable railways, all privately owned by over a dozen companies.
- 1896-1910: Interurban rail lines from Everett to Tacoma built privately.
- 1918: City of Seattle buys the in-city private streetcar system.
- 1920-1950: Collapse of electric rail transit across North America in competition with automobiles and buses.
- 1928: Seattle to Tacoma electric rail service ends.
- 1936: Seattle Municipal Street Railway is operating 410 streetcars and three cable car lines over 231 miles of track, plus 60 buses on 18 routes.
- 1937: Seattle to Renton electric rail service ends.
- 1939: Seattle to Everett electric rail service ends.
- 1940-41: City of Seattle eliminates streetcars in favor of buses.
- 1964: Passage of Urban Mass Transportation Act first authorizes Federal funding of mass transit capital construction.
- 1965: Beginning of Forward Thrust coordinated capital spending planning, including proposal of a Seattle regional heavy rail subway.
- 1968 and 1970: Citizens in King County vote against heavy rail subway plans.
- 1970s-80s: Worldwide rise of "light rail" as low-cost rail alternative.
- 1970: First express bus service begins in region between Northgate park & ride and downtown Seattle, called "Blue Streak."
- 1972: Seattle bus system revitalization approved by voters; Metro Transit is formed from Seattle Transit and suburban bus systems.
- 1973: Metro Transit establishes free bus zone in downtown Seattle, called "Magic Carpet."
- Early 1980s: Regional rail transit evaluation and planning begins again in the central Puget Sound region.
- 1985-90: Downtown Seattle Transit Tunnel built to accommodate Metro buses linking Seattle CBD and suburbs, and as a first step in a future light rail system.
- 1986: Multi-Corridor Project Study by Puget Sound Council of Governments and Metro specifies regional light rail as a future solution to downtown Seattle congestion.
- 1988: King County citizens vote in favor of accelerating rail transit planning in an advisory ballot.
- 1990: Washington Growth Management Act becomes law, a foundation for

transportation planning in the State.

1990: Puget Sound Council of Governments issues its Final Environmental Impact Statement for the VISION 2020 Growth Strategy and Transportation Plan, specifically leaving the technology choice for regional rapid transit as unspecified.

1990: DSTT begins operation using diesel-electric, articulated Breda buses.

1993: Exclusive-guideway rapid rail and bus plan compared to a bus-transitway alternative in the Regional Transit System Plan EIS shows the all-bus alternative has "fatal flaws," a finding now disputed by some transit analysts.

1993: Washington State Legislature authorizes the Central Puget Sound Regional Transit Authority (RTA).

1993-94: RTA decides light rail is a sufficient implementation of rapid rail and prepares a rail and bus plan for voter approval

1995: First RTA rail and bus plan defeated by voters.

1995-96: RTA scales back rail components in a second regional transit plan, called Sound Move.

1996 Revised RTA light rail plan passed by voters; Sound Move Plan states that buses and trains will share the Downtown Seattle Transit Tunnel (DSTT).

Late 1990s: Worldwide rise of "Bus Rapid Transit" as a viable alternative to rail transit, with DSTT sometimes cited as an example of a BRT exclusive guideway.

1999: Sound Transit, King County, and City of Seattle decide to convert DSTT to exclusive rail starting in 2004.

June 2000: King County, City of Seattle, and Sound Transit sign Tunnel Transfer Agreement setting terms for conversion of DSTT to light rail starting revenue operations in 2007.

Fall 2000: Sound Transit light rail plan begins to founder under criticism about rising costs and concerns about bus Tunnel capacity.

February 2001: Downtown Seattle Association (DSA) withdraws support for the Sound Transit light rail plan until it is compared to non-rail alternatives.

March 2001: Joint bus-rail ops in DSTT resurrected by Sound Transit as a potential solution to downtown Seattle bus congestion until time when light rail extends to Northgate.

April 2001: Based on Inspector General recommendation, USDOT blocks Federal funding for Seattle light rail until plan is revised and resubmitted.

June 2001: Link Project Review Committee chaired by Charles Royer recommends that DSTT continue as a bus-only facility until rail to Northgate is ready to begin; Downtown Seattle Association makes the same recommendation and continues to withhold support for Sound Transit light rail plan.

June 2001: Unspecified life/fire/safety issues are revealed by Sound Transit as the most significant potential obstacle to joint bus-rail operation in the DSTT.

August 2001: Sound Transit issues a report, *Evaluation of Joint Operations in the Downtown Seattle Transit Tunnel*, asserting joint bus-rail operation is feasible and the most efficient use of the Transit Tunnel until light rail is extended to Northgate. Downtown bus volumes are projected to remain at or below 2002 surface bus volumes until at least 2016.

September 2001: King County Council passes a motion stating County terms for renegotiation of the agreement that permits Sound Transit to run trains in the Transit Tunnel. One of about a dozen required conditions for a new agreement is that light-rail use of the Tunnel will not result in a significant degradation of existing bus service if joint use with trains is adopted.

September 2001: The Sound Transit Board votes to continue planning for a starter light rail line that extends from the north end of the Transit Tunnel to a point near Sea-Tac Airport, and assumes joint bus-rail operation in the Transit Tunnel.

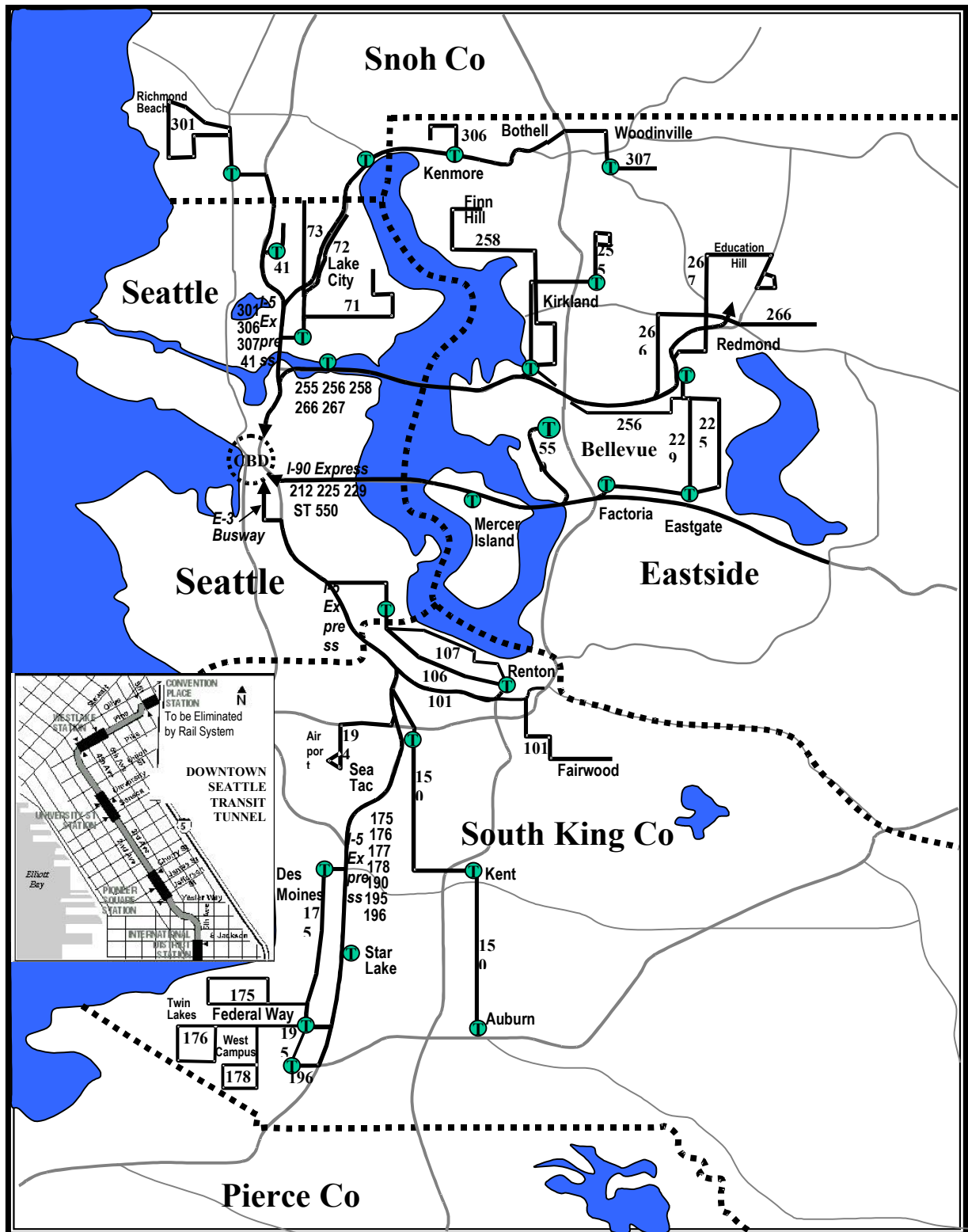
October 2001: King County Council Transportation Committee releases a technical memo from transportation consulting firm DMJM+Harris that uses peer-reviewed methodology to calculate that the long-run passenger capacity of the Transit Tunnel using an all-bus configuration is equal to the capacity in a rail-only configuration.

November 2001: Sound Transit Board Member and King County Councilman Greg Nickels elected Mayor of Seattle; he pledges to begin construction of Link Light Rail by July 1, 2002.

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Sources: *Assessment of Community Planning for Mass Transit: Volume 9 – Seattle Case Study*, United States Congress Office of Technology Assessment, February 1976; HistoryLink, an evolving online encyclopedia of Seattle and King County history at <http://www.historylink.org>; Public Interest Transit Forum at <http://www.gt-wa.com/PITF>.

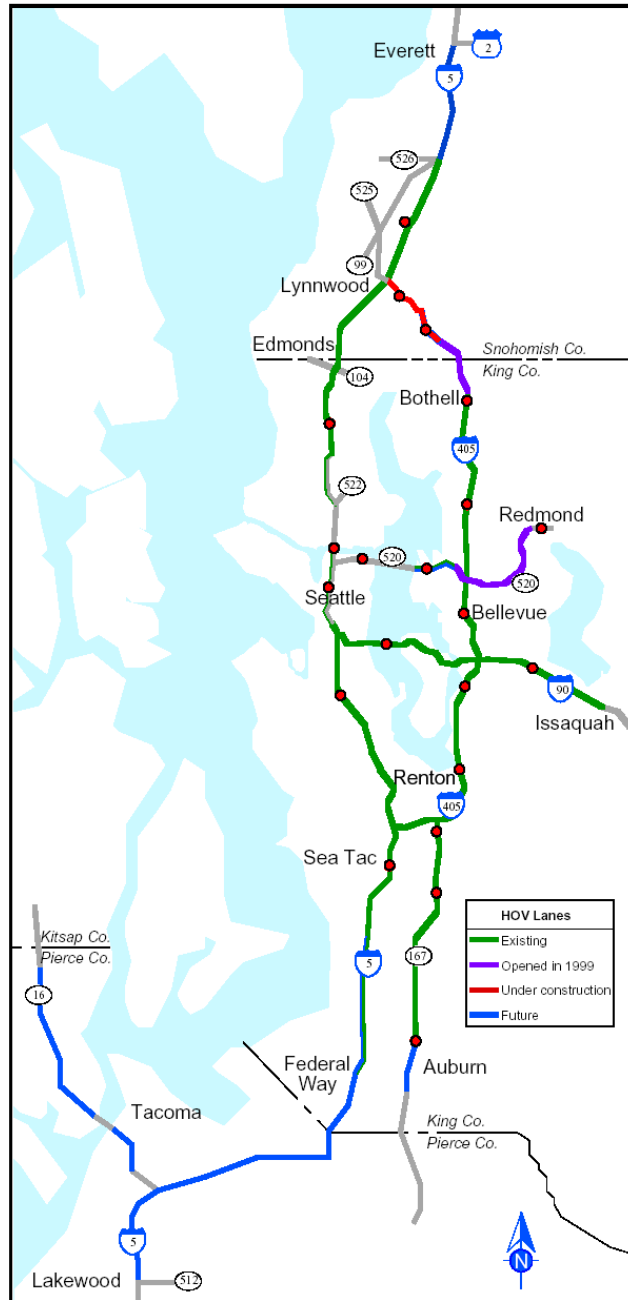
## Appendix B, Map 1 Existing Metro Bus Tunnel Routes



## Appendix B, Map 2 Regional Transit System



### Appendix B, Map 3 Puget Sound Region HOV System

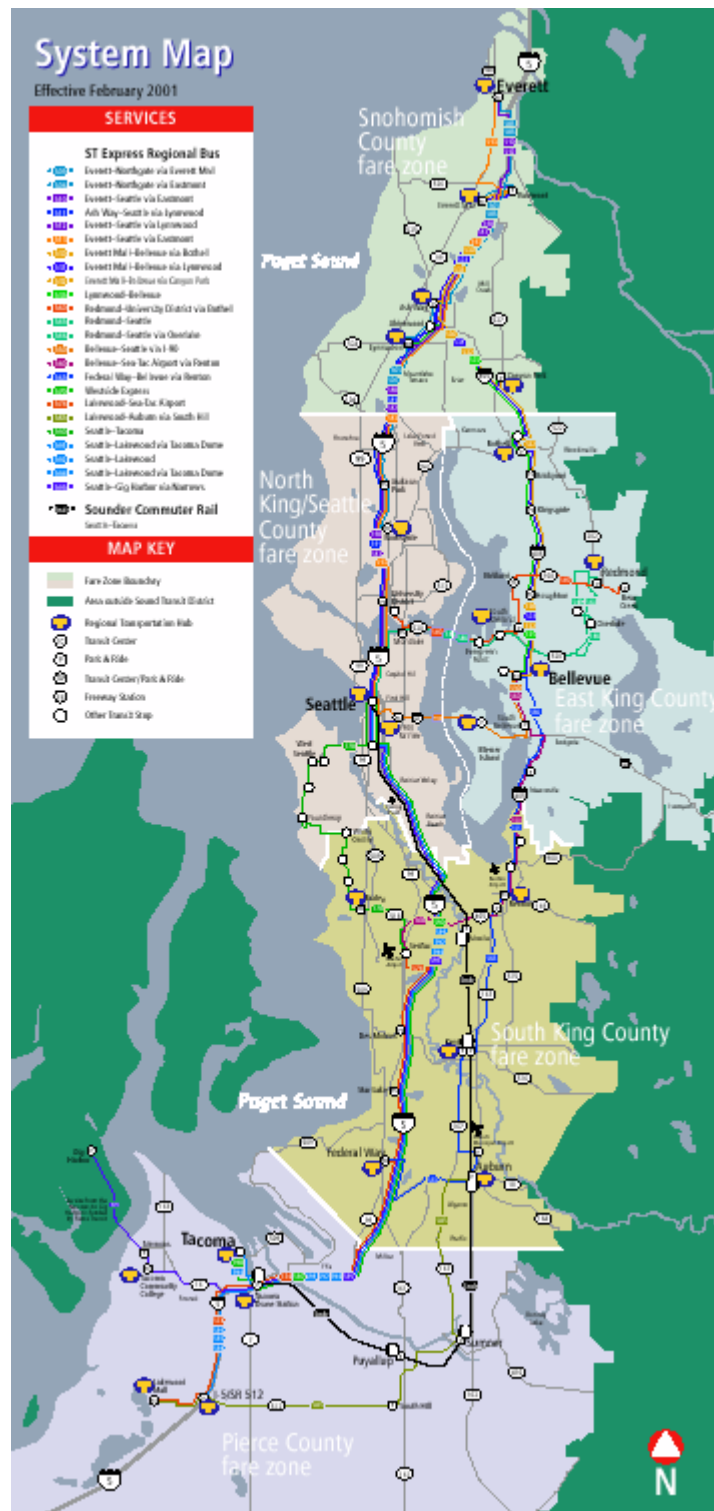


HOV Lanes on Central Puget Sound Freeways (as of 1999)



## Appendix B, Map 4

### ST Express Bus Routes



## **Appendix C**

### **Documentation Related to Tunnel Transfer and Joint Use**

#### **Downtown Seattle Transit Project (DSTP)**

Downtown Seattle Transit Alternatives. Draft Report, Task 2E, MetroTRANSITION Phase IV, Prepared by PB for Metro, March 20, 1979.

Remainder of Chapter IV Evaluation on Downtown Seattle Transit Alternatives, Memo from King Cushman (PB) to Downtown Seattle MetroTRANSITION Task Force, April 25, 1979.

MetroTRANSITION Downtown Seattle Task Force, Final Report, April 28, 1980.

Downtown Seattle Transit Project: Preferred Alternative. Metro, October 1983.

The Downtown Seattle Transit Project, Metro, 1984.

Downtown Seattle Transit Project: Light Rail Design Requirements. Prepared by Parsons Brinckerhoff, April 4, 1985.

Downtown Seattle Transit Project: Operations Plan. Metro, March 30, 1990.

Downtown Seattle Transit Project: Safety Review Document, Metro, Publication 427, September 1990.

Management Audit: Metro Tunnel Rail Installation Process. Prepared by KC Auditor's Office, Report No. 98-04, September 29, 1998.

#### **CBD Capacity and Circulation**

Seattle CBD Bus Capacity Threshold, Cordon Analysis. Contained in MultiCorridor Project, Summary Report and Recommendation, 1986.

Downtown Transit Capacity. Metro Internal Memo by Bob Harvey and David Beal, June 12, 1991.

Analysis of Capacity Constraints in Selected Activity Centers, Draft Technical Memorandum, May 13, 1992, Submitted to Metro by Parsons Brinckerhoff/Kaiser Engineers.

Downtown Seattle Bus Capacity Summary Presentation Materials (draft). Memo from Don Davis (PB/Kaiser) to Jim Parsons (Metro), August 14, 1992.



Downtown Circulation Study. Downtown Circulation Advisory Group Recommendation to SEATLAN, November 1998.

Seattle CBD Surface Street Bus Volume Analysis. Prepared for Sound Transit by Jerry V. Dow, DSV International, September 1999.

Downtown Seattle Transit Operations. Sound Transit, September 28, 1999.

Letter from Paul Matsuoka to Maggi Fimia re. Capacity of the DSTT. April 27, 2001.

### **Mitigation of Bus Impacts on Downtown Streets**

LOS Analysis for Tunnel Closure Alternatives, Section 5.5.1.2 of Transportation Technical Report for Sound Transit Central Link Light Rail DEIS, December 1998.

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Exhibit 1-A: Tunnel Assets (DSTT Transfer Agreement)

Exhibit 1-B: Easements (DSTT Transfer Agreement)

Exhibit 3: Retained Assets (DSTT Transfer Agreement)

Exhibit 9: Required Improvements for Buses on Streets (DSTT Transfer Agreement)

Exhibit 10: Bus Stop and Other Work Needed to Support Light Rail Construction (DSTT Transfer Agreement)

Exhibit 11: Replacement Bus Layover Space Requirements (DSTT Transfer Agreement)

Exhibit 12: Bus Facility Improvements Associated with Light Rail (DSTT Transfer Agreement)

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## Appendix D-1: PM Peak Bus Volume in Three Configurations of the Downtown Tunnel

Choices for the Downtown Seattle Transit Tunnel (DSTT)	2000 baseline conditions		2008-2009, during tunnel conversion, or with maximum bus use of the DSTT <sup>1</sup>		2010, with light rail between Convention Place and S 200 <sup>th</sup> , or all-bus equivalent requiring 50 more peak hour buses <sup>2</sup>		2015, with light rail from U District to S 200 <sup>th</sup> , or all-bus equivalent requiring 140 more peak hour buses <sup>3</sup>		2020 with light rail from Northgate to S 200 <sup>th</sup> , or all-bus equivalent requiring 320 more peak hour buses <sup>4</sup>	
	Downtown Streets	DSTT	Downtown Streets	DSTT	Downtown Streets	DSTT	Downtown Streets	DSTT	Downtown Streets	DSTT
<b>DSTT conversion to exclusive light rail</b>	460	150	750	0	715	0	735	0	680	0
<b>DSTT conversion to interim bus-rail joint operations</b>	460	150	750	0	615	100	685	50	680	0
<b>DSTT remains all-bus and Central Link not built</b>	460	150	500	250	505	260	575	300	670	330

Estimates of ITR Tunnel Team using Metro and Sound Transit documents describing transit growth and bus-rail integration, prepared 8/6/01

<sup>1</sup> Assumes passenger growth rate projected by Metro to 2005 continues to 2010.

<sup>2</sup> Assumes that either exclusive rail or joint bus-rail operations would require the same level of bus service in downtown Seattle.

<sup>3</sup> Assumes that either exclusive rail or joint bus-rail operations would require the same level of bus service in downtown Seattle.

<sup>4</sup> Assumes no-wire electric-power for tunnel buses is available and allows a 10 percent increase in tunnel bus volumes.

## Appendix D-2: Performance Comparison of Three Future Choices for the Downtown Seattle Transit Tunnel (DSTT)

Light rail status:	Under Construction	Under Construction	CPS to S 200 <sup>th</sup>	University District to S 200 <sup>th</sup>	Northgate to S 200 <sup>th</sup>
Choices	2009 increase in peak hour buses on downtown streets over today during tunnel conversion time period <sup>5</sup>	Increase in transit travel time across downtown for tunnel buses rerouted to surface streets during tunnel conversion	2010 increase in peak hour buses on downtown streets over today during light rail start up time period <sup>6</sup>	2020 increase in peak hour buses on downtown streets over today <sup>7</sup>	2020 increase in peak hour buses on downtown streets over today <sup>8</sup>
<b>DSTT conversion to exclusive light rail</b>	750/460 = +63%	8 to 12 minutes	715/460 = +55%	840/460 = +83%	680/460 = +48%
<b>DSTT conversion to interim bus &amp; light rail joint operations</b>	750/460 = +63%	8 to 12 minutes	615/460 = +34%	790/460 = +72%	680/460 = +48%
<b>DSTT remains all-bus and Central Link light rail not built</b>	500/460 = +9%	N/A	505/460 = +10%	670/460 = +46%	670/460 = +46%

Prepared by ITR Tunnel Team, 8/6/01

<sup>5</sup> No operations in Tunnel during DSTT conversion; maximum bus volume in the Tunnel for all-bus choice.

<sup>6</sup> Assumes up to 100 buses per hour in the Tunnel for joint operation.

<sup>7</sup> 840 buses on the street with exclusive rail in the DSTT; 790 buses on the street with 50 in the DSTT under light rail joint operations; 670 on the street and 330 in the Tunnel with DSTT all-bus.

<sup>8</sup> No buses in the Tunnel with light rail to Northgate and 320 buses eliminated for first two choices; 330 peak hour Tunnel buses assumed for all-bus choice.



## **Appendix E:**

### **Potential HOV System Improvements to Enhance Bus Rapid Transit**

#### Bus Rapid Transit Benefits of the Regional HOV System

High Occupancy Vehicle (HOV) lanes allow transit vehicles, vanpools, and carpools to bypass congestion in general purpose lanes. By reducing travel times and increasing the reliability of travel schedules, HOV lanes serve as an incentive for travelers to change their mode from single occupancy to multiple occupancy vehicles, thereby producing direct travel cost benefits to the users as well as public benefits in the form of reduced air and water pollution, and, perhaps, even less congestion for the remaining SOV drivers. An improved, integrated HOV system would allow express buses to provide fast and reliable high capacity transit service connecting urban centers. In effect, it would be a regional Bus Rapid Transit (BRT) system without the extensive and expensive dedicated right-of-ways that are characteristic of some BRT systems.

#### HOV System Status

Development of the Puget Sound HOV freeway lane network began in the early 1970s. As of January 2001, 191 lane miles of the 297 lane mile three-county “core” system had been completed and opened to traffic, and another 14 lane miles were under construction. Approximately one third of the system, 92 lanes miles, remains to be funded and constructed, although some design work has been done.

In addition to the lanes, the other key components of the HOV system are access ramps, freeway-to-freeway connectors, transit stations, and park & ride lots. A number of these enhancements have been made or are underway. Many more have not progressed beyond the planning stage.

More than \$1.5 billion (2000 dollars) has been invested in the HOV system. It is estimated that an additional \$1.65 billion will be needed to complete the HOV core program. This does not include the cost of ramps and connectors needed to make it a seamless system.

Strategically located arterial HOV and bus-only lanes complement the regional facilities. Examples are the 4<sup>th</sup> Avenue bus lane in the Seattle CBD and the Pacific Street bus lane in the University District, both of which speed bus movement in congested corridors. Studies have identified numerous opportunities for additional arterial HOV improvements in the each of the region’s three counties.

#### Transit on the HOV Lanes

The regional HOV lane system is used by buses on 75 King County Metro routes. Today, these routes account for approximately 2,200 daily one-way bus trips and 550,000 riders. Additionally, all 24 Sound Transit Express bus routes use the HOV lane system, as well

as 26 Community Transit commuter routes that serve the Seattle CBD and the University District. These express bus routes are supported by almost 200 park & ride lots with space for about 24,000 vehicles.

In some cases buses use only short segments of the system. In other cases, regional express buses run for considerable distances on the HOV lanes. Along with vanpools and carpools, buses increase the person carrying capacity and throughput of the HOV lane compared to the general purpose lane. For example, the southbound HOV lane on I-5 at a point just north of the Seattle city boundary at North 145<sup>th</sup> Street carries about 5,500 people per hour in the morning peak hour. Half of these commuters are carried in only 75 buses, the other half in carpools and vanpools. The HOV lane itself carries almost the same number of travelers as the three general purpose lanes combined.

### Major Impediments to Transit Utilization of the HOV Lanes

Effective use of the regional HOV lane network by buses is limited in several general ways and in numerous specific situations. Bus travel times and schedule reliability is impacted where connections between the HOV lanes on intersecting freeways are not present or limited, when buses must cross several general purpose lanes to enter or exit an HOV lane, and when buses must merge with general traffic because HOV lanes are not continuous. Here are some examples of these impediments:

- Buses starting in South Snohomish County and North Seattle cannot be routed east across the Evergreen Point Bridge because there is no connection from the I-5 express lanes to SR-520 for southbound vehicles. People traveling from the North end to the Eastside must either go to the Seattle CBD where they can transfer to a bus going east across the bridge, or they must transfer to a bus going through the University District and then transfer once again at Mountlake.
- Buses starting in the Seattle CBD and going to the Eastside cannot use the I-5 Express lanes northbound because there is no connection to SR-520. These buses must enter the I-5 Northbound general purpose lanes at Olive Way and contend with often-congested traffic in those lanes all the way to the Eastside.
- Buses that serve some University District destinations cannot exit (and enter) from the express lanes because there are no direct ramps. Buses on several routes must stay on the general purpose lanes until they can use existing ramps on NE 45<sup>th</sup> Street and NE 50<sup>th</sup> Street.
- A number of routes that leave the Seattle CBD for destinations South of the City use the E-3 busway that runs from the International District Station to Spokane Street, and then the HOV lanes on I-5. However, there is no direct ramp connecting the busway and the HOV lanes, so buses must navigate through a number of signalized intersections and the general purpose ramps in the Spokane Street corridor.

### Identified HOV System Improvements in North and South King County Sub Areas

The Washington State Department of Transportation (WSDOT) in the mid 1990's undertook a comprehensive study of the key enhancements needed to complete the core HOV system. These enhancements included additional HOV lane miles, freeway-to-freeway connections, and access ramps. The study evaluated the improvements on the basis of a number of measures of effectiveness including travel time saved and cost. A cost-effectiveness ratio, the cost per minute saved, was calculated for each project. Based on this value and other more subjective criteria, the enhancement was either recommended or not recommended. Other studies and plans by the Regional Transit Project and King County Metro have included these and other enhancements. Most of these projects have been included in Destination 2030, the newly adopted (May 2001) Metropolitan Transportation Plan for the Puget Sound Region.

The following table lists proposed but unfunded HOV system improvements that are located within Sound Transit's North King County and South King County sub areas. All except one are either access ramps or freeway-to-freeway connectors. One is a contra flow lane that would be feed by a reversible ramp. The ramp is recommended only if the lane is built. The total cost for these improvements, based on the last available estimates, is about \$300 million. No attempt has been made in this analysis neither to verify these estimates nor to adjust for inflation so as to allow the costs to be stated either in current or year of expenditure dollars.

**Recommended but Unfunded HOV System Improvements in the I-5 and I-90  
Corridors  
(In Seattle and Sound Transit's North King County Sub Area)**

<b>Project</b>	<b>Description</b>	<b>Cost- Effectiveness Rating*</b>	<b>Estimated Cost (Millions – 2000 \$)</b>
Busway Extension and Ramp	E-3 busway extension with transit ramps connecting to I-5 HOV lanes near Spokane Street	4	\$48.7
Bus-only Lane	Barrier-separated southbound contra flow transit lane on west side of I-5 express lanes from Ravenna Blvd. to Stewart Street	5**	\$58.8
HOV Lane Connector	Reversible HOV ramp connecting I-5 express lanes to SR520	5	\$14.6
Bus Lane	I-5 northbound bus-only lane on right shoulder of I-5 between Olive Way and SR520	n.a.	\$17.0
Bus Ramp	Direct bus access ramp from I-5 express lanes to University District at NE 50 <sup>th</sup> Street	5	\$7.2
Bus Ramp	Direct bus access ramp to proposed southbound contra flow transit lane on Westside of I-5 express lanes, at NE 42 <sup>nd</sup> Street	3	\$28.4
HOV Ramp	Direct access to/from South at NE 145 <sup>th</sup> Street	5	\$9.9
Trolley Ramp	Direct access ramp at I-90/Corwin Place allowing trolleys to use DSTT via D-2 roadway	4	\$12.9
HOV Lane Connector	Freeway to freeway HOV lane connection at Southcenter, Southbound to Westbound, North west Quadrant	2	\$45.6
HOV Lane Connector	Freeway to freeway HOV lane connection at Southcenter, SE Quadrant	4	\$46.2

\* On a scale from least effective (1) to most effective (5).

\*\* Rated on travel time saving only.

#### Funding Strategies for Improvements

The table reflects the decision of Sound Transit to focus its resources on rail transit infrastructure in the North and South King County sub areas, while at the same time it is funding HOV and BRT enhancements in the other sub areas. This is understandable from a cost perspective – the high cost of the Phase One Link light rail and the Sounder

commuter rail programs – but not necessarily from the perspective of transit improvements that can measurably improve regional mobility in the immediate future.

Investments in the projects indicated above could deliver benefits to transit riders and potentially other commuters much more quickly than will light rail under current assumptions regarding the likely dates for completion of the segments that comprise Phase One. These projects could be funded by Sound Transit and its partner agencies utilizing currently authorized local revenue sources, state funds, federal funds, or all three.

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## **Appendix F: Executive Summary of Sound Transit's Tunnel Report, August 21, 2001**

This report documents the findings of studies performed by Sound Transit, in cooperation with King County Metro, concerning the modifications needed to operate both light rail and buses in the Downtown Seattle Transit Tunnel (DSTT).

As a result of these studies, this report concludes:

- With modifications, advances in equipment and operational changes it is feasible to operate both trains and buses in the transit tunnel.
- Downtown surface streets will not be clogged with increased bus volumes. Under joint operations, bus volumes on downtown surface streets are projected to remain at or below the estimated 2002 surface bus volumes until at least 2016 when rail might be extended past Northgate or to the Eastside.
- Until the light rail system is extended, joint operations will allow the most efficient use of the transit tunnel. Joint operations will provide flexibility for the transit tunnel to serve commuters who come into downtown from the east, north, and south. Joint operations will maximize use of the transit tunnel until the rail system is built further north and other downtown capacity issues like the Alaskan Way viaduct are addressed.
- In the long term, the most efficient use of the transit tunnel is rail-only. As a rail-only tunnel, it can ultimately carry three times the number of passengers as a bus-only tunnel.

Downtown Seattle is the transportation hub of Central Puget Sound and its continued vitality depends on easy access to jobs, stores, housing and cultural and sporting events. As Seattle continues to grow, transit buses and trains will provide an increasingly important transportation alternative for those living, shopping, working or visiting downtown.

The 1.3-mile DSTT is already helping keep downtown Seattle moving. The tunnel was opened in 1990 to enable transit buses to operate through downtown free of surface street congestion. Today there are 25 bus routes running through the tunnel with more than 23,000 boardings every day.

But the transit tunnel was also built with the idea of someday running light rail trains. This report, which builds upon the information presented in the 1998 *Downtown Seattle Transit Tunnel Report*, shows that with modifications, advances in equipment and operational changes it is feasible to operate both trains and buses in the transit tunnel. The 1998 report's major concerns about the joint operation of trains and buses have been answered.

For instance, a new tunnel signal system has been developed that would maintain a safe distance between buses and trains. With that system in place, trains and buses would not be allowed to operate in the same tunnel section or be in a station at the same time.

Joint operations can continue until after the Central Link light rail system expands past Northgate, which is likely past 2015 or beyond.

Under joint operations the afternoon peak-hour rail and bus passenger capacity (two-way) in the tunnel is estimated at 16,480 passengers.

There is an increased interest in studying joint bus/rail operations in the transit tunnel. While the entire Central Link light rail segment is envisioned from Northgate to South 200th Station past Seattle-Tacoma International Airport, the Sound Transit Board is currently considering starting with a smaller initial segment. The smaller segment would run from about the airport to an interim north terminus at either the Royal Brougham Station or the Convention Place Station located inside the transit tunnel.

As part of the study of that initial segment, the Board is also interested in the possibility of joint operations in the transit tunnel. This report looks at some of those issues.

### **Bus Volumes**

- Today there about 470 buses operating on the surface streets in downtown Seattle and 140 buses running in the transit tunnel during the afternoon peak-hour. Following the two-year period it will take to retrofit the transit tunnel for light rail, the surface bus volumes are expected to return to levels similar to today with joint operations.
- With joint operations, bus volumes on downtown surface streets are projected to remain at or below the estimated 2002 surface bus volumes until at least 2016 when rail might be extended past Northgate or to the Eastside.

### **Transit Tunnel Capacity**

- A computer simulation model estimates that with light rail trains arriving about every six minutes, up to 60 buses and 10 trains could operate in each direction in the transit tunnel during the afternoon peak hour.
- The one-way, peak-hour capacity for light rail only in the transit tunnel is estimated at 16,440 passengers per hour. The one-way, peak-hour capacity for buses only in the transit tunnel is estimated at 5,700.
- With an interim north terminus at Convention Place and service to South 200th Station in SeaTac, the 2020 daily ridership for joint operations is estimated at 50,000 total daily rail boardings, with 27,600 of these boardings taking place in the DSTT. Rail-only use of the DSTT with bus intercept terminals at Convention Place, International District and Lander results in 64,200 daily rail boardings, however, most of the increase in daily boardings are related to the forced bus to rail transfer at Convention Place, International District and Lander.

### **Speed**

- Under joint operations, rail speeds would be reduced to better match bus speeds. This will not significantly change the travel time.
- Bus riders will experience an average 1.5 minutes of delay as buses wait to merge between trains in the transit tunnel.

### **New Bus Technology**

- King County Metro and Sound Transit plan to begin testing a low-floor hybrid diesel-electric bus which would eliminate the need to operate tunnel buses that use trolley poles and would increase operating flexibility and reliability in the transit tunnel.

- This hybrid bus will also allow level boarding at the stations by using a ramp instead of a lift for riders in wheelchairs.
- King County Metro and Sound Transit plan to have a fleet of these hybrid buses in place starting in 2004 as replacements for the current Breda dual mode coaches.
- Testing later this year will determine whether these buses will be able to operate through the tunnel exclusively on stored electric power or if some use of the diesel motor will be required.
- Joint operation in the transit tunnel is still feasible even if Metro decides to replace its fleet with conventional buses using electric trolley poles. A solution for buses with poles crossing the light rail overhead system has been developed, but additional design and testing will be required.

#### **Cost**

- The retrofit of the transit tunnel for rail use only is estimated at \$25 million (YOE). The additional cost to retrofit the transit tunnel for joint operations is estimated at \$43 million and covers such items as trackwork, the overhead electrical contact system, communications and signal systems, emergency ventilation system and the fire suppression system.



## **Appendix G**

### **DSTT Technical Issues Highlighted by Comparing the ITR Tunnel Team Report and the ST/Metro Joint Operations Report**

#### **Prepared Statement by John Niles (ITR, Inc.) to the King County Council Committee of the Whole, September 17, 2001**

On July 25, 2001, Integrated Transport Research, Inc. provided a report to the King County Council Transportation Committee titled "Light Rail or Buses in the Downtown Seattle Transit Tunnel: Assessment of Benefits to King County Metro and Regional Public Transportation." On August 21, 2001, Sound Transit and King County Metro issued a report to the Sound Transit Board titled "Evaluation of Joint Operations in the Downtown Seattle Transit Tunnel." The first report by me and colleagues Jim MacIsaac and Dick Nelson is the justification for some of the language in the Tunnel Accountability Motion under consideration today. The report by Sound Transit and Metro contains some different findings and conclusions, and I will here outline some of the differences that reveal unresolved problems.

The ITR Tunnel Team has never questioned that joint operation of buses and trains is feasible in the Tunnel. The big question is how many of each vehicle type can be mixed and accommodated during rush hour. **Sound Transit reports that its simulation shows 50 to 60 buses per hour in the Tunnel interspersed with 8 to 10 trains per hour will be possible. However, the risk and uncertainty associated with achieving operations at this combined frequency in a unique, joint operations configuration has not been completely assessed in Metro/Sound Transit Tunnel Report.** I assume that during operational testing before revenue operations begin that authorities will adjust vehicle spacing and resulting schedules in the Tunnel to provide an adequate margin of safety. But now, years before operational testing begins, there is no experience anywhere in the world with mixed bus and light rail use of a tunnel like the DSTT controlled by a specially-designed signaling system that must work for two different vehicle types. While Sound Transit has simulated high volume operations in a computer model, actual operating conditions and the limits of safety systems may dictate operational requirements to run vehicles at slower speeds and with greater spacing. Metro/Sound Transit evaluation gives insufficient indication of this uncertainty, and of the system performance consequences associated with lower peak hour volumes of vehicles.

**One big difference between the two reports is the large and startling difference between our respective forecasts for the number of buses likely to be required on the streets of downtown Seattle when light rail is running in the DSTT.** ST/Metro says that under joint operations, bus volumes on downtown surface streets are projected to remain at or below the estimated 2002 surface bus volumes until 2016. In contrast, if current and future transit customers are to be served, then we see the number of buses growing much higher, by hundreds, because of growth of downtown employment and commercial services, and the unlikely prospect that major restructuring of bus routes around rail can be realized.

In a letter to Councilmember Maggi Fimia dated September 5, 2001, Sound Transit Executive Director Joni Earl lays most of the difference between the two forecasts on the differences in assumption about the growth of bus trips over the next several decades. Metro says 1% annually. ITR says 2.5% is a more realistic number, one we obtained from older Metro planning documents issued before the time when joint operations was being justified.

**ST/Metro's assumption of 1% annual trip growth contradicts other planning information quoted in the Metro/Sound Transit Tunnel Report and also in the September 13 Link Light Rail progress report.** A 1% figure is also at variance with City of Seattle growth policies and targets.

Here is what Sound Transit said about growth of downtown on page 19 of their Tunnel report: "By 2010, downtown is expected to have 224,000 jobs (an increase of 38,000), 35 million square feet of office space (21 percent increase), 8 million square feet of retail space (25 percent increase), 15,000 hotel rooms (67 percent increase) and almost a doubling of residents to 30,000." These demographic growth figures suggest that transit demand to and within the Downtown will grow at rates considerably higher than 1% per annum. They reflect the goals of Seattle's 1994 Comprehensive Plan that set an annualized growth target of 1.7 percent for Downtown Seattle urban center employment out to 2014. The Seattle Growth Report 2000 indicates that between 1995 and 1998, Downtown Seattle achieved 34 percent of its 20-year planning target in just the first four years. Revised, higher employment growth in downtown is used by Sound Transit in its September 13 Link Light Rail Progress Report to forecast higher ridership on South Lake Union light rail. All this sounds more like 2.5% than 1% to us.

Since bus service will continue to serve Downtown from places not served by light rail, we think bus service will need to grow, and our report reflects that. In contrast, **Metro's now stated future intent is to hold down the number of buses on CBD surface streets to today's volumes after the Tunnel has trains operating in it.** They will do this through what they call "moderate restructures" that will apparently cause many of today's bus routes to be eliminated, rerouted, and/or truncated at train stations. What they call "moderate restructures" we call "forced transfers." It is standard industry operating procedure after trains are added to a bus-oriented transit system.

Despite the commitment to restructure bus service, **Metro has not clearly reported the likely bus route and travel time changes for transit customers who will see a change from one-seat bus rides to bus rides that are combined with a transfer at a light rail station.** We think this coming change in overall multimodal transit system configuration and performance from the customer point of view is a major issue for regional transit decision makers. Bus route restructures will affect ridership, will affect how well transit competes with automobiles, and will affect what people think about local government's use of dollars for transit. In particular, the future routing and performance of the Metro Express Bus routes serving downtown from the suburbs that will be removed from the DSTT and replaced by trains is still not explained.

Another big difference between the two reports is the calculation of passenger capacity for the Tunnel under exclusive bus and exclusive light rail scenarios. **Sound Transit calculates light rail passenger capacity as three times bus capacity. We think the capacity is more nearly equal for trains and buses.** This is because we recognize the light rail headway constraints that exist under the limited Phase One Northgate to SeaTac plan, whereas Sound Transit describes DSTT capacity for a future time when there is full build out of Link from Everett to Tacoma and Seattle to Bellevue.

**But a new issue on the table is our challenge of Sound Transit's calculation of light rail capacity were that full build out to occur.** Sound Transit seems not to have followed established professional techniques in carrying out their calculation of the maximum passenger capacity of the DSTT running exclusive light rail in 2030. Sound Transit does not lay out and justify its numbers for the three components of train headway: (1) minimum separation time between trains, (2) maximum station dwell time for trains, and (3) an operating margin reflecting variability in the previous two numbers plus all safety considerations.

Sound Transit repeats in its Tunnel report without explanation its historical claim that the DSTT is ultimately capable of 2 minute light rail headways. This design capacity would be reachable after joint operations have concluded and buses no longer run through the Tunnel, and IF the light rail system were fully built out with a line across Lake Washington. This high-capacity performance is held out as a goal which justifies building a starter light rail line. This long-range goal requires that southbound four-car light rail trains coming in from Northgate every 2 minutes would be able to enter the DSTT in a steady stream at Convention Place during the morning peak period. The trains must be able to keep moving through four closely spaced station stops with many people disembarking and some boarding, with a 90 degree bend limiting speed along the way, and emerge at 2 minute intervals beyond International District Station. From running a new simulation of its own, the ITR Tunnel Team has further confirmation that this would prove to be impossible. Our Tunnel report states that a 2.5 minute light rail Tunnel headway is the design limit.

**Furthermore, for buses, Sound Transit and Metro have not carried out their calculation of the 2030 design capacity of the DSTT with reasonable recognition of likely available future technology, and with recognition of modest public investments that would expand bus capacity.** For example, they talk about buses going slow because passengers will ask questions of drivers. Can't there be service agents on the platform to answer questions? They say there is insufficient room to stage buses into platoons at the Convention Place and IDS stations. Can't efficient, platoon staging areas be built somewhere beyond the confines of the Tunnel? Metro's experience say bus capacity will max out at 125 buses per hour per direction. Doesn't precision guidance technology over the next 20 years hold some promise of closer spacing of buses? Buses are shown on page 25 of the Metro/Sound Transit Tunnel report to have just 57 seats. Would it be possible to specify and build buses with more seats between now and 2030?

The ITR Tunnel Team is continuing to study this long-run capacity question for both buses and trains in the DSTT. For the moment we stand on the conclusion in our report

that the long-run capacity of the Tunnel with either trains or buses is approximately the same, and in any event more than adequate for projections of future customer demand. This conclusion is reinforced by the growing improbability of light rail ever going beyond the Phase One alignment from Northgate to Sea Tac airport.

**Finally, the alternative of redirecting ST's light rail resources toward expansion of ST Express Bus Service with more HOV and other "Community Connections" remains to be adequately considered.** The budget and schedule overruns in Sound Transit's ongoing program to achieve a meaningful regional light rail system added to the potential problems of downtown surface street disruption and declining transit service quality that likely come with installing train service in the DSTT make the option of expanding ST Express Bus compelling. An improved, integrated HOV system would allow express buses to provide fast and reliable high-capacity transit service connecting urban centers. In effect, it would amount to a regional Bus Rapid Transit (BRT) system without the extensive and expensive dedicated right-of-ways that are characteristic of some BRT systems. The ITR Tunnel Team has found a significant list of unfunded HOV system improvements in I-5 and I-90 corridors, already listed in the PSRC Metropolitan Transportation Plan of May 2001 and recommended as cost-effective by Washington DOT. Sound Transit resources could be directed toward these projects for immediate improvements in high capacity transit service. Some express bus services using the Tunnel today are providing faster trips to downtown Seattle from outside of Seattle than can ever be delivered by light rail.

In conclusion, we on the ITR Tunnel Team working for the King County Transportation Committee have been accused of bias against light rail. Indeed, we do have a publicly stated point of view that there are better ways for agencies like Sound Transit to use scarce public resources to deal with travel growth and improve regional mobility, ways that are more effective and less expensive than Link light rail. Our point of view is based on independent and often unsponsored analysis of factual information, much of it contained in official documents of Sound Transit, Metro, and the regional planning agency.

**Let's settle the question of what's the right thing to do by carrying out the Tunnel Accountability Motion's requirement for an independent analysis that compares light rail against a high-capacity system that retains bus service in the Tunnel.**

## Appendix H

### City of Seattle's Proposed Downtown Growth Revisions

The City of Seattle Strategic Planning Office has recently proposed amendments to the year 2020 employment and household forecasts by the Puget Sound Regional Council<sup>10</sup>. The amendments are based on actual development trends in the center-city area comprised of three Forecast Analysis Zones (FAZs). These zones are South Lake Union/Uptown (FAZ 6123), Denny Triangle Belltown (FAZ 6020), and the Downtown Commercial Core (FAZ 6010). Sound Transit used the new forecasts to development ridership estimates for possible Link light rail alignments in the South Lake Union area<sup>11</sup>.

The following table summarizes the proposed revisions for the three FAZs combined in comparison to the current PSRC forecasts.

	2000 Base Year	2020 PSRC Forecast	Annual average growth	2020 City Revised Forecast	Annual Average Growth
Employment	244,680	278,605	0.65	330,160	1.51
Households	18,363	43,015	4.35	42,287	4.29

The new proposed forecasts for 2020 suggest a large increase in Downtown employment and essentially no change in the predicted Downtown residential population. On an annual average basis, the growth rate of employment is now predicted to double to 1.5 percent per year. Under the new assumptions, residential population will grow at about 4.3 percent per year as previously predicted.

<sup>10</sup> Letter from Denna Cline, Strategic Planning Office, to Ahmad Fazel, Sound Transit, August 3, 2001.

<sup>11</sup> South Lake Union Route Update, Sound Transit Central Link September Progress Report, September 13, 2001, pp. 42-44.

## **Appendix I**

### **Public Policy Issues For The Downtown Seattle Transit Tunnel**

#### **Report to the King County Regional Transit Committee Prepared by the ITR Tunnel Team September 20, 2001**

The ITR Tunnel Team serving as consultants to the King County Council Transportation Committee appreciates the recent work of staff from King County Metro and Sound Transit in preparing a comprehensive response to an inquiry from King County Councilmembers Fimia, McKenna, and Thomas on some important aspects of planning for future bus and light rail operations. The response was a ten page letter dated September 17, 2001, signed by Rick Walsh, General Manager, Metro Transit.

We have studied the information in the letter carefully, as well as the Metro press release of September 19, 2001 on four initiatives to guide future transit investments. We have concluded that the following major issues remain to be addressed regarding the proposed use by Sound Transit of the Downtown Seattle Transit Tunnel (the Tunnel).

This document supplements earlier findings and recommendations produced by the ITR Tunnel Team and posted on the web at <http://www.metrokc.gov/mkcc/Members/d1/>.

#### **1. Planning for emergency systems in the Tunnel is not based on a credible worst-case accident.**

The planned upgrades of the tunnel's emergency (fire/life safety) systems assume one stopped tunnel bus on fire as a worst case. Collisions apparently have been ruled out because of an assumption that the signal system and operator action will prevent more serious accidents, including collisions involving two or more vehicles. *The ITR Tunnel Team recommends that the possibility of transit vehicle collisions under peak loading conditions be the basis for defining the credible worst-case accident, and for designing fire suppression and ventilation system improvements.*

#### **2. The frequency of vehicle passage through the Tunnel in peak load conditions has not been planned to reflect the possibility of the credible worst case accident.**

Joint operations that would use the maximum capacity of the tunnel have been determined to be feasible under a peak hour volume of up to 8 to 10 four-car trains and 50 to 60 buses in each direction. Sound Transit established these volumes by computer simulations. Given that a collision was not established as a worst-case accident, we are concerned that margins of safety used in simulations did not adequately take into account the possibility of collisions involving vehicles of very different mass and stopping distance. *We recommend that the possibility and consequences of a collision between transit vehicles should be taken into account when establishing safe operating speeds and headways, and in estimating ultimate tunnel capacity.*

**3. Metro is planning a series of changes to bus service with potentially negative transit performance and quality implications for King County travelers to the Seattle CBD. There are cost implications for taxpayers, as well. These changes have not yet been sufficiently analyzed.**

Metro plans to eliminate enough downtown bus routes to keep the bus volumes on CBD surface streets through 2016 at year 2002 levels despite public policy efforts to concentrate additional employment sites, high-density housing, and retail activity in the Seattle CBD. At the same time, these “moderate” restructures will necessarily have impacts on travel times when bus routes that formerly served downtown are changed to truncate at outlying trains stations instead. Furthermore, growth of bus service to downtown Seattle to meet travel demand from areas not served by rail is expected to be limited by a lack of resources, even as high-frequency, extended-hours light rail train service creates more demand for buses meeting trains. Finally, these restructures are problematic, as Metro admits, and if done may require the continuation of existing routes. *We recommend that Metro and Sound Transit take immediate action to describe future bus service scenarios along with their performance and cost impacts, and display this information to decision makers and the public.*

**4. The light rail segment completion and operation assumptions in the Metro/Sound Transit Evaluation Report of August 21, 2001 are too optimistic about estimated completion dates and future geographic coverage.**

For example the build out to S. 200<sup>th</sup> is indicated to occur by 2009 while the Sound Transit Central Link progress report of September 13 indicates this will not happen before 2012. Light rail extensions to Everett, Tacoma, and Redmond are described as though they are funded and programmed, but they are not even listed in the most recent Metropolitan Transportation Plan from the Puget Sound Regional Council. In fact, Sound Transit specifically requested that the term “high capacity transit” be substituted for “light rail” in the MTP. *We recommend that the staff assumptions that influence crucial decisions on the Tunnel be brought up to date and made consistent with official plans and decisions.*

**5. Metro’s plan for transit in downtown Seattle does not reflect the City’s policy goals for high growth in employment, housing, tourism, and retail activity in downtown, nor does it reflect recent growth rates.**

The City of Seattle’s 1994 Comprehensive Plan set an annualized growth target of 1.7 percent for Downtown Seattle urban center employment out to 2014. The Seattle Growth Report 2000 indicates that between 1995 and 1998, Downtown Seattle achieved 34 percent of its 20-year planning target in just the first four years. And the Sound Transit September Central Link progress report indicates that the City has adjusted upward employment forecasts for the Central Business District and surrounding neighborhoods. Yet Metro is planning for just 1% annual trip growth in its forecasts for bus volumes on Seattle CBD surface streets and the Tunnel. *We recommend that Metro, Sound Transit, and the City jointly provide a definitive forecast of employment and other drivers of*

*transit demand in the Downtown area, and indicate how transit demand will be met at the same time existing policies regarding congestion and mode share will be implemented.*

**6. Sound Transit's calculation of ultimate passenger capacity in the Tunnel in a rail-only configuration – 16,400 per hour one way – is too optimistic, based on hopes for the future that are not likely to be realized.**

For this calculation to come true the region would need billions of dollars for full build out of light rail to Everett, Tacoma, and across Lake Washington, far beyond current funding and plans. For the comparative bus-only capacity calculations, no further investments of any kind are assumed. Further, our analysis suggests that realistic dwell time assumptions and the physical characteristics of the Tunnel would overturn the persistent Sound Transit claim that the Tunnel can ultimately accommodate four-car trains at two minute intervals. *We recommend that the two-minute headway claim not be accepted as true until documentation with an analytical determination of the ultimate exclusive rail passenger capacity is issued.*

**7. Metro's estimate of ultimate passenger capacity in the Tunnel in a bus-only configuration – 5,700 per hour one way – is unnecessarily conservative, not reflecting today's opportunities, nor tomorrow's potential.**

Metro is aware of – but has not planned nor cost-estimated – numerous technologies and capital improvements applicable to bus transit that could be expected to contribute to a higher peak hour bus capacity than the 125 per hour stated in the Evaluation Report. Technology improvements include longer buses with more seats, and optical guidance for precise docking at stations stops. Capital improvements include larger staging areas to assemble buses into ordered platoons. The result of not including these potential improvements contributes to an alleged three to one ultimate capacity advantage for trains over buses in the Tunnel. *We recommend Metro prepare new bus capacity calculations for the Tunnel based upon reasonable assumptions about changes in staging areas that can be undertaken in the short term and technological improvements over the next 30 years.*

Furthermore, Metro has not ever conducted a feasible, relatively inexpensive, operational test of higher bus frequencies that would provide substantial information on the bus-only capacity of the Tunnel with today's technology. Using no more than 75 buses, and with supervisors and independent observers in every station, this test could be carried out in one late night event while the Tunnel is closed and downtown streets are empty. Buses would travel through the Tunnel in one direction, and then return along surface streets to re-enter the Tunnel at the same end, thus providing a continuous stream of buses. *The ITR Tunnel Team recommends that a bus capacity test be conducted as part of an effort to evaluate the alternatives available for best use of the Tunnel.*



## **Appendix J**

### **King County Council Motion 11291**

**Proposed No.** 2001-0409.2

**Sponsors** Hague, Thomas, McKenna, Irons,  
Pullen and Fimia

A MOTION relating to the transfer of the downtown Seattle transit tunnel to Sound Transit, setting forth requirements for either a renegotiated transfer agreement or waiver of contingencies to the current agreement.

WHEREAS, Sound Transit, the city of Seattle and King County entered into the Downtown Seattle Transit Tunnel Transfer Agreement on June 1, 2000, and

WHEREAS, the 1.3-mile-long downtown Seattle transit tunnel ("tunnel") is an integral part of the local and regional King County Metro bus system, which, even operating at under its capacity serves six million riders per year, twenty-three thousand per day, and

WHEREAS, the tunnel allows twenty-seven Metro routes, which provide regional service to move buses through downtown at a rate two to three times faster than those on surface streets of the central business district during peak hour, and

WHEREAS, the Tunnel Transfer Agreement assumes that the tunnel, under the terms of Sound Transit Resolution 99-34, will be converted by Sound Transit to exclusive light rail use, and that the amount and form of compensation to be paid by Sound Transit to King County will be based on exclusive rail use of the tunnel, and

WHEREAS, Sound Transit and the King County Executive are now actively considering the possibility that the tunnel may be configured for a multiyear period of joint bus and rail operations, and

WHEREAS, Metro's dual-powered fleet of tunnel buses have a planned retirement date of 2004, with replacement or refurbishment costs required thereafter, and

WHEREAS, the Tunnel Transfer Agreement assumes that the transfer will occur September 24, 2004, and states that the Tunnel Transfer Agreement will expire if the transfer does not occur by January 1, 2007, and

WHEREAS, a long-standing justification for replacing buses with light rail trains in the tunnel is to improve peak-period utilization, and

WHEREAS, the regional transit committee and King County council unanimously adopted the 2001 mission and goals of the transit division which include under Objective 3 “Reach agreement with Sound Transit and the City of Seattle on the long-term use of the Downtown Seattle Transit Tunnel and surface streets which does not degrade the existing bus system,” and

WHEREAS, during the two-year period of tunnel closure for conversion to rail likely to begin in 2006, congestion will worsen with the addition of Metro’s twenty-seven current tunnel bus routes moved onto downtown streets, and

WHEREAS, the economic viability of Seattle’s downtown retail core, as represented by the Downtown Seattle Association, is vital to our region and must be protected through efficient movement of buses and trains on the surface and in the tunnel;

WHEREAS, joint bus and train operation in the tunnel adds additional risk arising primarily from intermixing buses and trains, for the first time in the nation, as passengers load and unload at stations, and

WHEREAS, Sound Transit’s long-held vision for a light rail system from SeaTac to Northgate may only run from Convention Place to S. 154th St. by 2009, and

WHEREAS, some level of joint operations with buses and rail appear feasible until at least the time that light rail is extended to Northgate, which will probably not be until after 2014, and

WHEREAS, Section 1.2 of the Tunnel Transfer Agreement lists contingencies that must be satisfied or waived before the transfer of the tunnel to Sound Transit, and

WHEREAS, while the county is prepared to perform its obligations under the current Tunnel Transfer Agreement, it appears at this time that Sound Transit will not be able to satisfy one of these contingencies, i.e., that Sound Transit will not construct by January 1, 2009, the Minimum Operable Segment as defined in the transfer agreement, from NE 45th Street to a maintenance base adjacent to South Forest Street in Seattle;

NOW, THEREFORE, BE IT MOVED by the Council of King County:

As of the date of passage of this motion, the county's policy is not to amend the Tunnel Transfer Agreement or waive any of the contingencies in Section 1.2 of the agreement unless the following conditions have been satisfied:

The county's department of transportation has determined and the county council has confirmed that any new plan for light-rail use of the tunnel adopted by the Sound Transit board will not result in a significant degradation of existing bus service on the surface streets, the E-3 busway or in the tunnel if joint use with trains is adopted;

The county's department of transportation has determined and the county council has confirmed that sufficient headways can be maintained for bus routes operating in the tunnel to sustain ridership;

The county's department of transportation has determined and the county council has confirmed that regional bus transit service access to the bus tunnel will be preserved for transit patrons not directly served by light rail. This would include bus transit routes from the I-90, SR 520, and SR 522 corridors as well as bus transit routes from the I-5 corridor where bus-passenger transfers to light rail would not be competitive in terms of speed or convenience for bus passengers;

Sound Transit and King County have resolved satisfactorily any operational and safety issues with respect to joint use, and Sound Transit has agreed to defend, indemnify and hold King County harmless against any liability arising from the negligence, recklessness or deliberate acts of Sound Transit during joint bus-rail and bus operations in the tunnel;

Sound Transit pays to King County an annual amount for its share of tunnel use under any joint operations scenario and pays for all retrofit costs required for joint rail and bus operations in the tunnel; such annual payment amount shall include but not be limited to (1) a pro rata share of outstanding debt service on the tunnel, said pro rata share to be 100 percent during any period in which the tunnel is closed to transit use for conversion work, (2) a pro rata share of all operations and maintenance costs of the tunnel, and (3) said pro rata shares of debt service and operations and maintenance costs shall automatically rise to 100 percent to be paid by Sound Transit once the actual number of buses jointly operating in the tunnel with rail transit drops below thirty-five buses per hour in each direction in the p.m. peak hour, provided

that, upon assumption of 100 percent of the tunnel costs by Sound Transit, King County shall pay a use fee for remaining bus operations in the tunnel,

Sound Transit, King County and the City of Seattle demonstrate fiscal commitment to the surface street improvements outlined in the existing tunnel agreement;

The Sound Transit board has adopted a light-rail plan for extending the light rail line north at least as far as Northgate in Seattle which identifies an alignment, approximate total cost, construction schedule and funding plan;

Sound Transit continues its fiscal commitments to other key elements in the existing tunnel agreement, including bus facilities at rail stations, bus operating delays during tunnel retrofit and during construction, employee parking at Ryerson Base, and the like;

Sound Transit and King County reach agreement on the terms of use and compensation for any rail alignment through and Sound Transit use of Convention Place station, including any impacts on King County's planned transit-oriented-development at the site;

Sound Transit can demonstrate and the county council has confirmed that the light rail system will significantly increase new transit riders in King County and increase the number of new transit riders in the tunnel compared to maximizing the use of buses in the tunnel.

Contingencies are included for renegotiating the new tunnel transfer agreement in the event that any new light rail alignment is adopted by the Sound Transit Board.

Motion 11291 was introduced on 8/20/01 and passed as amended by the Metropolitan King County Council on 9/24/01, by the following vote:

Yes: 7 - Mr. von Reichbauer, Ms. Fimia, Mr. McKenna, Mr. Pullen, Ms. Hague, Mr. Thomas and Mr. Irons  
No: 5 - Ms. Miller, Mr. Phillips, Mr. Pelz, Ms. Sullivan and Mr. Gossett  
Excused: 1 - Mr. Nickels

KING COUNTY COUNCIL  
KING COUNTY, WASHINGTON

## Appendix K

**DATE:** October 5, 2001  
**TO:** King County Council Members Maggi Fimia, Les Thomas, Rob McKenna  
**FROM:** John Niles, ITR Tunnel Team Project Manager  
**SUBJECT:** Downtown Tunnel Peak Hour Passenger Capacity, All-Bus vs All-Rail

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Attached is a new technical report describing the peak hour passenger capacity of the Downtown Seattle Transit Tunnel (the Tunnel). The report was prepared in September by DMJM+Harris, acting as a subcontractor to Integrated Transport Research, Inc. DMJM+Harris is a worldwide, employee-owned transportation engineering consulting firm whose 2,200 professional staff provide a full range of planning, design, program and construction management and operations services for public transport and other infrastructure-related services, including involvement in many light rail systems.

**Implication of this new report:** Sound Transit and Metro argue that in the long run future, in an imaginable but unfunded and unplanned regional light rail configuration for the region, the design capacity of the Tunnel running only trains would be over 16,000 passengers per hour. Sound Transit and Metro report that an all bus configuration could never achieve this. **The attached document shows that Sound Transit and Metro are simply wrong in this argument. Buses could be configured to run in the Tunnel and provide a similar capacity.** This is substantiation of the conclusion of the Tunnel Team stated in our July 25, 2001, draft report to the Transportation Committee.

**Background:** The Tunnel is a key facility for future high capacity transit in the Puget Sound region, and Sound Transit and Metro highlighted their calculations of all-bus and all-rail Tunnel capacity in their August 21 report, "Evaluation of Joint Operations in the Downtown Seattle Transit Tunnel." Sound Transit reported on page 27, "The one-way, peak-hour capacity for light rail in the transit tunnel is estimated at 16,440 passengers. The one-way, peak-hour capacity for buses only in the transit tunnel is estimated at 5,700 riders."

The ITR Tunnel Team judged that this calculation was not carried out with comparable assumptions for buses and light rail, and also was not carried out according to established professional standards for how such calculations should be made. The assignment from ITR to DMJM+Harris was to calculate the one-way, peak-hour passenger carrying capacity of the Tunnel in all-bus and all-rail configurations. We thought that bus capacity calculated by Sound Transit was low because of distorting assumptions intended to make trains look better. This judgment was confirmed in the attached report.

**DMJM+Harris reports in the attached document that the rail-only and bus-only capacity of the Tunnel is approximately equal under a comparable assumption of some passengers standing comfortably without touching. The estimated capacity with either buses or trains is 15,000 passengers per hour.** While this number is approximately what Sound Transit reported for light rail, the number for buses is 2.6 times higher. Because some planners believe that passengers are less willing to stand on

buses than on trains, DMJM+Harris also calculated the Tunnel capacity using buses on which people only sit. In this circumstance, they calculate the capacity to be approximately 13,000 passengers per hour, which is 2.3 times higher than Sound Transit's report.

**Of further note is the DMJM+Harris estimation that the Tunnel could support a one-way peak hour volume of buses in the range of 145 to 207, suggesting a much higher vehicle capacity than the 125 bus estimate reported by Metro and Sound Transit.** This difference is a result of Metro basing its capacity estimate on experience from the 1990s, while DMJM+Harris bases its estimate on documented worldwide experience and assumptions of technology improvement and likely operational changes in the decades ahead when higher capacity will be needed in the region. The experience cited is from cities around the world that have high bus transit ridership and high corridor bus volumes.

The attached report uses peer-reviewed professional methodology published by the National Research Council. The calculations are based on the assumption that buses and trains are both able to approach and leave the Tunnel at a frequency that is limited only by conditions in the Tunnel. For Link Light Rail, this means an exclusive guideway light rail line leading north from the Tunnel, and a line across Lake Washington feeding in from the south to supplement the line through the Rainier Valley.

For buses, the highest capacity achievable would require that buses flowing through the tunnel be organized as a "transit spine" service, similar to the way that light rail trains are organized from the first day of operation. In the many decades that will pass before customer demand would reach the levels that may make organizing buses this way necessary, many different bus routes could be operated in the Tunnel, which is the practice today.

The Tunnel Team argued previously that reorganizing transit around a high-capacity spine and feeder buses would cause transit service quality to decline. **However, if a high-capacity transit spine were judged necessary at some future point, trains are not necessary to implement it. Buses could also be organized into a spine configuration, and the attached report states that these buses would move just as many people through the Tunnel as trains would.**

**Further available and related research:** Other research not included in the attachment finds that there is no intrinsic preference of passengers for light rail over buses, as described in a briefing to Sound Transit on Bus Rapid Transit by DMJM+Harris on March 12, 2001 and posted at <http://www.soundtransit.org/BusForum/Cover.htm>. A September 2001 report from the U.S. General Accounting Office (<http://www.gao.gov/new.items/d01984.pdf>) examines Bus Rapid Transit and finds it a promising alternative to light rail, with many favorable cost and performance characteristics. Appendix E of the Tunnel Team's draft report provides a list of unfunded right-of-way improvements in the I-5 Corridor that would improve the ability of express buses to cut through congestion; it is available at <http://www.metrokc.gov/mkcc/members/d1/TunnelTeamAug7add1.pdf>.

**REVIEW AND ANALYSIS OF SOUND TRANSIT EVALUATION OF  
JOINT OPERATION IN THE DOWNTOWN SEATTLE TRANSIT TUNNEL  
Technical Revisions and Comments Added November 5, 2001**

**TECHNICAL MEMORANDUM**

**EXECUTIVE SUMMARY AND INTRODUCTION**

One of the issues that is critical to planning and implementing transit in the Seattle Region is the role to be played by the Seattle CBD Transit Tunnel. That role is, in turn, dependent on the capacity of the tunnel under three scenarios: 1) the tunnel continues to operate as a bus-only tunnel; 2) the tunnel operates as a mixed, bus and LRT tunnel and 3) the tunnel operates as an LRT-only tunnel.

The purpose of the work undertaken in support of the deliberations of the King County Council on the future functions and disposition of the tunnel was to determine the capacity of the tunnel under the first and last scenarios – bus-only operation and LRT-only operation. The work described below was ***not*** intended to serve as an “alternatives analysis” useful for judging the relative desirability of LRT and BRT in a Seattle context.

The basic assumption for the analysis was that tunnel capacity should be determined under operating policies and procedures that are safe, feasible, and reflective of the unique characteristics of the respective mode but consistent where relevant. At the same time, the assumptions were made under the objective of maximizing passenger throughput.

Given the range of possible operating policies and procedures for each respective mode, the assumptions also reflect best professional practice and actual experience as shown the U.S. National Academy of Sciences Transportation Research Board’s Transit Capacity and Quality of Service Manual and the U.K.’s Transportation and Road Research Laboratory’s The performance of busway transit in developing cities.

**The results of the analyses are as follows:**

**Capacity Of Tunnel Bus-Only Operation**

Assumption that vehicle capacity would be limited

To a seated load, on average over the peak hour: **13,000 passengers per hour**

**Capacity Of Tunnel Under Bus-Only Operation**

Assumption allowing standees at

normal U.S. standing density (3/Sq. meter): **15,000 passengers per hour**

## Capacity Of Tunnel Under LRT-Only Operation

Assumption allowing standees at  
normal U.S. standing density (3/Sq. meter):

**15,000 passengers per hour**

## BACKGROUND

DMJM+HARRIS has been retained by ITR to help analyze the capacity of the bus and proposed alternative light rail service that could operate through the King County's Metro Bus Tunnel in a 2030 forecast year. The work described below was not intended to serve as an "alternatives analysis" useful for judging the relative desirability of LRT and BRT in a Seattle context.

The 1.3-mile Seattle CBD Transit Tunnel runs along 3<sup>rd</sup> Avenue and Pine Street, serving as an uninterrupted expressway through downtown Seattle. There are currently twenty-five bus routes operating through the tunnel, with five stations (two termini, three in the tunnel interior) linked to hotels, convention centers, shopping centers and major traffic generators. The tunnel currently carries 25% of the daily bus vehicle trips through downtown Seattle.

This report presents a comparison between the "design" transit capacities of light rail and bus services during the peak hour. The capacities of the two modes were reviewed in the context of the Central Puget Sound Region's 2030 Metropolitan Transportation Plan that predicts that the population of the central Puget Sound region is forecast to grow by over 1.5 million persons by the year 2030. The regional economy is projected to grow by nearly 735,000 new jobs during the same time period.

The estimated values shown below were derived under the basic assumptions that both the bus and rail systems would incorporate the best technologies available in the year 2030, and they would be operated in a fashion that would maximize the usefulness of the tunnel facility. In the context of the rapid growth expected in the Seattle region and CBD, this would mean that the respective operating plans for LRT and BRT would be designed to maximize tunnel throughput rather than limit capacity and performance in any arbitrary way.

Several reports and web sites were reviewed on this subject. This analysis is focused on capacity and supply side rather than the demand side perspective. The calculations of transit capacity were based on procedures in the Transportation Research Board's 1999 Transit Capacity and Quality of Service Manual (TQSM)<sup>1</sup>, the industry standard in the U.S.

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<sup>1</sup> Danaher, Alan. "Part 2: Bus Transit Capacity." *Development of Transit Capacity and Quality of Service Principles, Practices and Procedures*. Transit Cooperative Research Program Research Results Digest 35, 1999.



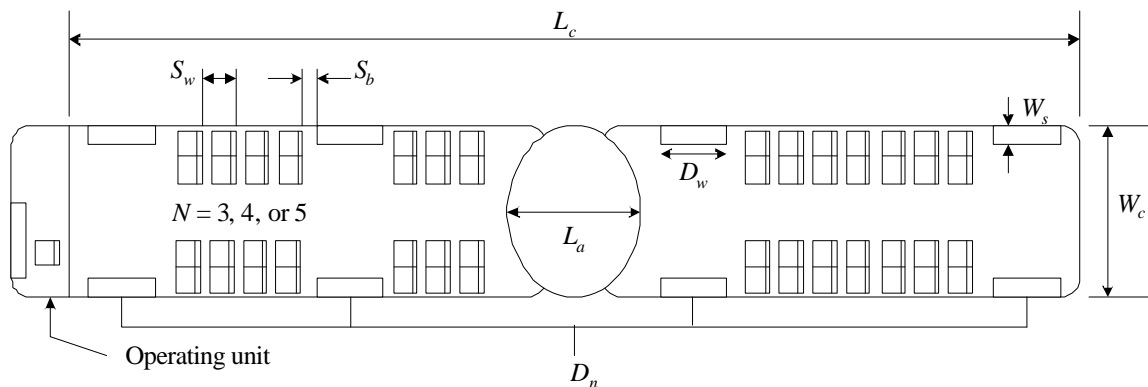
The reasonability of the BRT results were checked against existing volumes for current BRT systems as reported in the U.K. Transport and Road Research Laboratory (TRRL) monograph, “The performance of busway transit in developing cities.” (TRRL, Crowthorne, Berkshire, RG11 6AU, England, Gardner, Cornwell, and Cracknell, 1991)

## 1. LIGHT RAIL-ONLY OPERATION

The proposed light rail service will operate on a dual track throughout the line. On-line stops are to occur at the five current stations along the tunnel. Each peak train will consist of four vehicles powered by electricity from an overhead wire. It is assumed that the light rail system will incorporate the best available technology. For the purpose of safety and service reliability, a communications-based, moving-block signal system has been recommended to control headways between trains. In order to reduce queuing and boarding time, fare collection will be done off-board (prepaid) via an advanced electronic fare collection system prior to passengers arriving at the platform.

### 1.1 LRT Vehicle Capacity

Vehicle capacity is determined from a specific calculation from the TCQSM rather than applying a factor to a seated load. Estimation of the person capacity of a light rail car is achieved by determining the interior dimensions of a light rail vehicle, the number of seats and area available for standing. The calculation is based on the assumption that at capacity, all vehicles carry the maximum number of seated passengers plus a number of standees dictated by a policy that reflects the type of operation (local versus express), trip length and the number and width of doors. Figure 1 shows a typical design for an articulated light rail vehicle, a design with the following parameters:



**Figure 1. Typical 90 foot Light Rail Car**

## Dimensions

- 90 feet vehicle interior length, 5 of which are occupied by the control cab (in a more operationally flexible double-ended vehicle, the cab would take up 10 feet). leaving 85 feet of the effective length (passenger space). 8 feet vehicle interior width.
- 10 feet articulation length
- Four doors on each side. Each door is 4.5 feet wide. The step well is 2.5 feet wide.
- Four transverse seats per row.
- A density for standing passengers (3.20 ft<sup>2</sup>/passenger) reflecting normal U.S. practice for an average peak hour.
- Other dimensions and parameters are assumed conforming to default suggested in the TCQSM.

Consulting Equation 3-9 from 1999 TCQSM (pp. 3-32), vehicle capacity is computed as:

$$V_c = \left[ \frac{(L_c - 0.5L_a)W_c - 0.5D_n W_s D_w}{S_{sp}} \right] + N \left[ \left( 1 - \frac{S_a}{S_{sp}} \right) \frac{L_c - L_a - D_n (D_w + 2S_b)}{S_w} \right]$$

The definitions and values of the variables are given in Figure 1 and Table 1. The results of the calculation show 132 passengers per car. Assuming a train consists of 4 cars, the total number of passengers per train would amount to 528 passengers.

**Table 1. Calculation of Vehicle and Train Capacity**

Variables	Description	Value	Unit
$L_c$	Vehicle interior length	85	feet
$L_a$	Articulation length	10.0	feet
$W_c$	Vehicle interior width	8.0	feet
$D_n$	Number of doorways	4	doorways
$D_w$	Doorway width	4.50	feet
$W_s$	Stepwell width	2.50	feet
$S_{sp}$	Space per standing passenger	3.20	ft <sup>2</sup>
$S_a$	Area of single seat	5.40	ft <sup>2</sup>
$N$	Seating arrangement	4	seats
$S_b$	Single setback allowance	0.67	feet
$S_w$	Seat pitch	2.25	feet
$V_c$	Vehicle capacity	132	passengers/car
$N_V$	Number of cars per train	4	cars/train
$V_t$	Train capacity	528	passengers/train

The results appear to be very close to the previous study that applied a more approximate approach with a 1.85 load factor. It should be noted, however, LRT vehicle capacity may vary from the table above as a function of the final design of the vehicle. Any changes

to the vehicle length and width will considerably vary this quantity, while changes in other variables do not have as much effect on the end result.

It should be noted that the standee density utilized, 3.2 square feet per standee applies over an average peak hour. In the peak 15 minutes *within the peak hour*, demand can be 33% (or more) higher than average over the hour. An average hourly capacity over an hour of 132 passengers per car would translate to  $1.33 \times 132$  or 176 for each car in the peak fifteen minutes, still well within acceptable U.S. standee comfort standards.

## 1.2 Station Dwell Times

One of the major tunnel throughput components to be considered in determining the transit capacity is station dwell time. Station dwell times are the number of seconds the train must be stopped at the station in order to service passenger alightings and boardings. The station dwell time can be defined as a function of passenger flow rate and door closing-opening periods.

In this analysis, it is assumed that, at the peak station, 30 percent (50% more than the average station) of its total capacity will alight and board trains in the peak hour. With an off-board fare collection system, the TCQSM gives 2 seconds as the expected boarding and alighting time per passenger for both boardings and alightings. The boardings and alightings are unbalanced with 40% at the peak door. Thus, total passenger boarding and alighting times accounts for  $2 \times (.3 \times 132 \times 2 \times .4) = 64$  seconds. Accounting for the 6 seconds for the door opening-closing time, the maximum and hence critical dwell time becomes 70 seconds.

## 1.3 Vehicle Throughput

Maximum one-way vehicle throughput is primarily a function of the design operating headway, which itself is a function of the light rail system's physical and operating characteristics. The operating headway consists of three major components. These include, minimum separation between trains and a safe operating margin as well as the maximum station dwell time calculated above.

Minimum train separation is mainly a function of train performance. The light rail speeds are limited by the "weakest link", in the case of the tunnel, a 90-degree horizontal curve with the radius of 265 feet. The 10% tilted track should be employed in order to increase the train speed on the curve. The friction between the wheel and the track is assumed to be 0.35. This results in the maximum operating speed 42 mph at this section.

Dwell time (calculated in the previous section) and operating margins were added to the minimum separation to form a safe operating headway. Assuming moving-block signaling with fixed safety separation, Equation 3-5 (pp. 3-16) from the TCQSM suggests that the minimum light rail transit headway could be determined as:

$$H(s) = \frac{L + S_{mb}}{v_a} + \frac{100}{K} \left( \frac{v_a}{2d_s} \right) + t_{jl} + t_{br} + t_d + t_{om}$$

The parameters and values were selected or computed using the approach for Automated Guideway Transit (AGT) suggested in the TCQSM.

The calculation yields the resulted minimum headway of 109 seconds, or the maximum line capacity of 33 trains per hour. To simplify the scheduled headway, to fit a full number in one hour, headway of 120 seconds was used.

This results in a projected line capacity of 30 trains per hour. Tables 2 and 3 show the definition and values of parameters and the calculation of light-rail transit headways. This is consistent with Sound Transit's number.

**Table 2. Maximum Line Speed On Curve (Weakest Link):**

Curve	90	degree
Radius	265	feet
Superelevation	0.10	
Coefficient of friction	0.35	
Curve Length	416	feet
Max operating speed at the weakest link	42	mph
	62	ft/s

**Table 3. Light-Rail Transit Headway And Line Capacity Using Moving-Block Signaling System**

Variables	Description	Value	Unit
$L$	Length of the train	360	feet
$S_{mb}$	moving-block safety distance	100	feet
$v_a$	Station approach speed	50	ft/s
$K$	Braking safety factor	75	%
$t_{jl}$	Time lost to braking jerk limitation	0.5	seconds
$t_{br}$	Operator and brake system reaction time	1.5	seconds
$t_d$	Dwell time	70	seconds
$t_{om}$	operation margin	20	seconds
$d_s$	service deceleration rate	4.3	ft/s <sup>2</sup>
$H(s)$	Station Headway	109.0	seconds
$C_L$	Line Capacity	33	trains/hr

## 1.4 System Capacity Under LRT-Only Tunnel Operation

The system capacity was calculated from the maximum number of passengers per train and the line capacity. The multiplication of the two quantities yields an average system capacity of **15,840 passengers per hour**. Again, this is consistent with Sound Transit's estimate.

## 2. BUS RAPID TRANSIT –ONLY OPERATION

It is assumed that by 2030, all BRT tunnel bus service will operate on an exclusive busway or HOV facility, possibly including some form of guidance (e.g., optical guidance as is currently operational in Rouen and Clermont-Ferrand, France and soon to be in Las Vegas or mechanical guidance as is currently in operation in Nancy, France). Hybrid buses (currently in operation in NYC and around the World) will run in platoons of two, powered by an overhead electric wire, battery or fuel cell in the tunnel and a thermal engine in some combination of the above outside the tunnel.

An increased flow of buses through the tunnel, and thus greater passenger capacity, would require that the twenty-five tunnel bus routes be reduced to a lower number. As the tunnel approaches its capacity, it is assumed below that only two trunk routes would be operated, (North-South through CBD and CBD to I-90 East *or* I-90 east through CBD continuing North and CBD-South). Other current tunnel routes will be converted into a trunk/feeder configuration beyond the scope of this study to describe.

This will insure that only full buses operate through the tunnel and that there is a minimum of platform movement as people seek the appropriate loading bay. This also would result in higher service frequencies on trunk routes and enhanced platooning efficiency if “double headers” were utilized (dispatching two buses at a time, operating as a physically unconnected train).

Given the platform lengths assumed for LRT, it is assumed that there will be four bus bays in each station. Each of the bays should have a sufficient length to accommodate a 60 foot articulated bus. In this analysis the bus rapid transit capacity is calculated based on a nominal seated only and seated plus standing scenarios.

### 2.1 Vehicle Capacity

The person capacity per bus is computed by determining interior dimensions of a bus and space occupied by each passenger. The calculation is based on the assumption that there is sufficient demand and that all of the buses carry the maximum number of seated and standing passengers. Based on the standard in TCQSM, the dimensions of a typical articulated bus are 60 feet in length and 8.5 feet in width. There are 65 seats in the bus. BRT per vehicle standing capacity, consistent with the calculation for LRT, was derived as follows:

Based on the available standing space in the bus (145 ft<sup>2</sup>) and space per standing passenger (3.20 ft<sup>2</sup>/person, standard U.S. practice for an average peak hour and the same standard as used to compute LRT vehicle capacity), the amount of standees in the bus would be  $\frac{145}{3.20} = 45$  persons.

Therefore, for the nominal fully seated load scenario, a capacity of 65 seats was assumed. During the peak of the peak (usually about 15 minutes in length), transit demand and hence bus loads can be expected to be 30-40% higher than they would be over the average peak hour as a whole. Accordingly, a capacity assumption of a fully seated load of 65 over an average hour would translate into an easily accommodated total of 80, or 15 standees in an area of 145 square feet. This comes to almost 10 square feet per person, 3 times the U.S. standard.

Under the seated plus standing scenario, there would be 65 seats and 45 standees for a total of 110 persons in a bus.

To illustrate the reasonability of a 3 people per square meter standee density over an average hour, it implies that in the peak fifteen minutes, the number of people accommodated in a bus would be a maximum of  $1.33 * 110$  or 146. The number of standees under these conditions would then be approx.  $146 - 65 = 81$ , with a standee density of  $145/81$  or approx. 1.8 sq. foot per person. As would also be the case for the LRT analysis above, this is close to normal European practice of 4 standees/square meter (a level at which the average standee will not be in physical contact with anyone) average over an entire hour.

## 2.2 Bus Stop Dwell Time

With off-board fare collection, low-floor articulated buses, the assumed BRT equipment in 2030 have boarding time per passenger of to 1.0 second (TCQSM, p. 2-17). Similar to the light rail scenario, it was assumed that 30% of the passengers would be getting on and the same percent would be getting off of the bus at the busiest of five CBD stations. Therefore, in this analysis, there are 20 boarding passengers in the nominal all-seated scenario and 33 boarding passengers for the seated plus standing scenario. For separate boarding and alighting doors, the boarding and alighting time could be cut in half, but that is not assumed here. Dwell time is determined by the time required to serve passenger at the busiest door, plus the time required to open and close the doors. The dwell time equation is as follows:

$$t_d = (P_b t_b + t_{oc})e \text{ Where:}$$

$t_d$  is the dwell time in seconds;

- $p_b$  is the boarding passengers per bus through the busiest door at the busiest station, which is 20 passengers for the seated only and 33 for the seated and standing scenario;
- $t_b$  is the passenger boarding time, second/person (1 second in both scenarios - TCQSM, p. 2-17);
- $t_{oc}$  is the door opening and closing time in seconds (6 seconds, 3 seconds for opening and 3 seconds for closing); and
- $e$  is the efficiency of multiple linear loading areas at bus stop (85% - TCQSM p. 2-17).

Therefore, the dwell time for the non-standing scenario is 22 seconds (20 passengers boarding), and 33 seconds (33 passengers boarding) for the standing scenario.

### 2.3 Vehicle Throughput

Vehicle throughput (which is also called vehicle capacity in TCQSM) is calculated as a function of the number of effective bays at the critical station. Bay capacity is, in turn, affected by dwell time, dwell time variability, and clearance time.

In this analysis, the clearance time for bus rapid transit for both scenarios is assumed 7 seconds, 5 of which is for the bus to travel its own length and the other 2 accounts for start-up time.

The equation for the vehicle capacity of bus bays in buses per hour is (TCQSM, p. 2-21):

$$B_{bb} = \frac{3,600(g/C)}{t_c + (g/C)t_d + Z_a c_v t_d}$$

where:

- $B_{bb}$  is the maximum number of buses per bay per hour;
- $g/C$  is the ratio of effective green time to total traffic signal cycle length, which is 1.0 for a stop not at a signalized intersection in both scenarios (TCQSM, p. 2-19);
- $t_c$  is the clearance time between successive buses (7 seconds);
- $t_d$  is the average dwell time (22 seconds for non-standing and 33 seconds for standing);
- $Z_a$  is the one-tail normal variate corresponding to the probability that queues will not form behind the bus stop. Advanced control technology is assumed to cut the failure rate down to 10 %,  $Z_a=1.28$  (TCQSM, p. 2-19); and
- $c_v$  is the coefficient of variation of dwell times, which is 60% of coefficient of variation of the dwell times in both scenarios (TCQSM, p. 2-17).

The results of the calculations are shown in Table 4.

**Table 4. Maximum BRT Vehicles per Loading Bay/Hour**

	Seated-Only Scenario	Seated + Standing Scenario
Dwell time/vehicle	22	33
Cv	0.6	0.6
Number of Vehicles/Bay/Hr.	78	55

The equation for total vehicle throughput is given as (TCQSM, p. 2-21, Equation 2-5):

$$B_s = N_{eb} B_{bb} = N_{eb} \frac{3,600(g/C)}{t_c + (g/C)t_d + Z_a c_v t_d}$$

where:

$B_s$  is the maximum number of buses per hour; and

$N_{eb}$  is the number of effective bays (3).

The results of the calculation, assuming four total loading bays (360 platform length /90 feet per 60 foot bus) is shown in Table 5. The number of effective bays, per exhibit 2-17 of the TCQSM would be 2.65.

**Table 5. Maximum BRT Vehicles per Hour**

	Seated-only Scenario	Seated+Standing Scenario
Vehicles/Bay	78	55
Effective # of Bays	2.65	2.65
Total Tunnel Vehicles/Hr.	207	145

Therefore, the vehicle capacity for each bay under the seated only scenario is 78 buses per hour and 55 buses per hour under the seated and standing scenario. The vehicle throughput for the seated only capacity scenario is 207 buses per hour and 145 buses per hour for seated and standing scenario.

A flow of one hundred and forty five buses per hour for a 4-bay station means that the average bus will be spending  $3600/(145/4) = 99$  seconds a) stopping in a station; b) serving passengers and c) leaving. This is about 40% more than that calculated above for an average LRT train, even though most high volume bus systems (Curitiba, Bogota, Sao Paulo) operate bus platoons which are operationally similar to trains.



## 2.4 System Capacity

### Maximum Passenger Throughput/Hour

	Seated-only Scenario	Seated+Standing Scenario
Vehicles/Bay	78	55
Effective # of Bays	2.65	2.65
Total Tunnel Vehicles/Hr.	207	145
Passenger capacity per Vehicle	65	110
Passengers/Hr.	13,455	15,950

The system capacity was calculated from the maximum number of passengers per bus and the vehicle throughput. The multiplication of the two quantities yielded a system capacity of **13,455 passengers per hour for seated– only scenario, and 15,950 passengers per hour for the scenario where vehicle capacities reflect seated and standing passengers over an average peak hour.**

## 3. Reasonability Assessment

As noted above, the reasonability of the BRT results were checked against existing volumes for current BRT systems in developing countries as reported in the U.K. Transport and Road Research Laboratory (TRRL) monograph, “The performance of busway transit in developing cities.” (TRRL, Crowthorne, Berkshire, RG11 6AU, England, Gardner, Cornwell, and Cracknell, 1991)

That report gives the performance experience with BRT in the developing World. While the factors effecting ridership attraction are not transferable between the U.S. and other countries (or necessarily in the U.S. from one corridor to another), vehicle throughput capacities under various physical and operating conditions are. Per vehicle person capacities (in effect how close to others passengers are willing to stand) are very related to societal norms, so they are not, in essence transferable and will not be discussed here. According to the TRRL report, based on actual experience, one can expect a fully segregated busway/bus station with 4 bays and *on-line stops* but no passing (an analogue to the Seattle tunnel) with very high transfer demands (the Seattle CBD bus tunnel has very little transfer demand, if any, making these numbers conservative) to have a bus flow capacity from 97 to over 187 per hour, depending on:

- the number of different routes
- whether buses are platooned (travel as a group through the tunnel)
- platoon size
- whether bays are pre-assigned by route or any bus is allowed to stop at any bay

Under the assumption that there was only one or two LRT-like BRT tunnel trunk routes (a distinct possibility if tunnel capacity is approached), then the throughput with four bays and fare pre-payment goes to over 200 per hour, per TRRL guidance. Thus the vehicle throughput 145-207, calculated with TCQSM procedures, are reasonable expectations given experience outside the US.

#### **4.0 Perspective**

To put the capacity numbers calculated above in scale, it should be noted the busiest heavy rail full Metro rail transit links in the U.S. outside New York are BART's Trans - Bay tunnel accessing a CBD with 400,000 employment and WMATA-Metrorail's Blue-Orange tunnel from Foggy Bottom to Rosslyn in the Washington area, accessing a CBD with over 455,000 employment. They carry 14-16,000 passengers in the peak hour, peak direction (Exhibit 1-46 in the TCQSM).

The busiest LRT tunnel in the Nation is Boston's Green Line Park St. tunnel that carries about 10,000 passengers per hour per direction in the peak hour (Exhibit 1-23, TCQSM) into and out of a CBD with 400,000 jobs.

These numbers suggest that both LRT and BRT should have more than sufficient passenger capacity to handle demands likely in the future in Seattle.