

Congestion War: Arterials vs. Freeways: How Do You Get Out From Downtown? Analyzing the Barbur Blvd. Corridor and I-5

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ABSTRACT

Traffic congestion routinely builds and then dissipates on arterials and on freeways. However, the magnitude and characteristics of congestion on each facility type can be different. The objective of this paper is to describe the results of a research project aimed at determining whether traffic congestion is worse on arterials or on freeways during peak periods when two parallel routes are available. This project was conducted using a unique data source available from transit buses in Portland, Oregon. Bus travel times on express routes along I-5 were compared to routes on the parallel arterial, Barbur Blvd. Using actual bus travel time data, the research considered whether divergence of traffic is beneficial. This paper summarizes previous studies and comparisons to the current study are made. Diverting traffic for travel time equilibrium was considered along the study corridor. A simple model was created to examine travel equilibrium. These data indicated that morning peak traffic already operated at equilibrium flow and afternoon traffic favored the arterial over the freeway. The model applied traffic diversion from the freeway to the arterial. The results showed lower time savings than expected. When examining the feasibility of diverting traffic, the original assumptions of route equality were disproved. Finally, the paper suggests examining more data, and also that a comparison between travel time equilibrium and the addition of freeway capacity from lane expansion be conducted for future research

INTRODUCTION

Intelligent Transportation Systems (ITS) infrastructure that is used to monitor traffic conditions can be used to guide or misguide the traveling public. Radio announcers receive information from a Traffic Monitoring Operations Centers (TMOC) and provide pieces of it to the public over the airwaves. Freeway crashes, causing enormous queues and congestion to peak hour traffic, are often announced with arterial "escape routes." Arterial streets lack the capacity to carry the traffic volume that freeways have, while maintaining their land usability and route connectivity. This research was necessary to determine whether the effects of traffic congestion on freeways and arterials can relieve one another during peak traffic commutes or major incidents. The following question is addressed: does the distribution of traffic congestion improve overall travel conditions? This research also studied whether divergence of traffic using ITS methods is beneficial.

Traffic engineering analysis principles were used to conduct this research. The principle of travel demand and traffic forecasting was used to determine ideal traffic route distribution and system equilibrium. First, travel time was compared between an arterial and a freeway. A comparison was made for peak hour travel without major incidents. Based on the results, traffic assignment was determined whether to send arterial traffic onto the freeway or freeway traffic to the arterials. Results are discussed

to generate a qualitative measure as to whether traffic distribution is harmful or helpful. Finally, the time savings are compared to the addition of freeway lane capacity.

STUDY CORRIDOR

Each freeway in the Portland area has at least one example of a frontage road or parallel arterial that could be studied in relation to traffic divergence. This study compared a section of Interstate 5 (I-5) in southwest Portland with its, parallel arterial route, Barbur Blvd. The Barbur Blvd. corridor was naturally the first to be studied for a variety of reasons. Barbur Blvd. is designated Oregon's state highway route 99 west. A highway is a natural alternative path to a freeway and thus, ideal for such a traffic divergence study. The corridor stretches roughly eight miles with traffic observation visibility in at least three places. The two roads only cross (overpass) twice, but seven freeway interchanges connect them along the eight-mile stretch. The corridor is shown in Figure 1.

This corridor has been the subject of past research and an arterial freeway management plan. New data was gathered on the corridor to compare previous studies. In the first study, Oregon Department of Transportation (ODOT) worked with the City of Portland to place and test Variable Message Signs (VMS) on Barbur Blvd. (Kloos. et al. 2005). During the test, speed data were collected on Barbur Blvd. to determine travel time. Directing traffic between I-5 and Barbur was discussed for future plans, based on traveler knowledge of road conditions from VMS. The second study (El-Geneidy and Kimpel 2002) used six data collection methods, including data from Tri-County Metropolitan Transportation District (TriMet), for speed comparisons. Though the corridor was studied for comparative speeds, the goal of their research was to compare the accuracy of the collected data methods, rather than to determine route superiority. Because determination of corridor travel time has not been found in either of the previous studies, Barbur Blvd. was chosen for this research. TriMet bus data were also available to be studied and manipulated for this project.

TRIMET DATA

Two sets of data are used to compare the routes. First, bus dispatch system (BDS) data from all buses routed along the corridor on Wednesday, January 29, 2003 are compared. Bus stops are plotted to create time points along the stretch. Since stops are made along Barbur, but not by the express buses on I-5, the freeway speeds are not entirely decisive. Next, the same comparison is made from special data with recorded time points on I-5. TriMet recorded data as though buses passed stops along I-5 for all the bus runs on November 3-24, 2002 inclusive. The recorded time points along I-5 will be referred to as "pseudo-stops."

TriMet has 26 rows of data collected at each stop in their transit system using a special archived global positioning system (GPS). The November data added a special 27th row. Ten of these rows were used in this study: service date; route number; trip number; vehicle number; stop time; arrive time; leave time; location; train mileage and the new field, stop sequence.

ROUTE CHOICE

To determine data need, the routes without pseudo-stops were compared. Five bus routes travel on parts of this corridor and were considered for comparison in this study: routes 12, 64, 94, 95, and 96.

Route 12 is a frequent service bus that travels from downtown Portland to Sherwood. It includes the 8.4 mile section along the Barbur Blvd. corridor parallel to I-5 from Fifth & Main to a Tigard bus stop just past I-5 exit 293B (11619 Pacific Highway). Route 95 is an express bus that only travels during morning and afternoon peak hours. It passes both the Fifth and Main beginning point and the 11619 Pacific Hwy ending point of route 12. In between, it travels on I-5. Route 64 only travels on the short segment of I-5 between exits 293B and 297. It follows a different route before and after the I-5 segment. Route 94 is a peak hour express bus along Barbur Blvd that stops less frequently than route 12. Route 96 is yet another express bus. It travels on I-5, but does not exit within the corridor in this study. Common beginning and ending stop locations were desired for comparison. Three of the bus routes were eliminated. Routes 64 and 96 lacked common stops for the study. Because route 94 skipped stops near I-5-connections, the data would not characterize I-5 as closely as route 12. The remaining buses (routes 12 and 95) shared the most similarities with each other and provided the one to one route comparison desired. Figure 1 outlines the two bus routes; circling locations where they separate from each (Fifth and Main) other and come back together (Exit 293B).

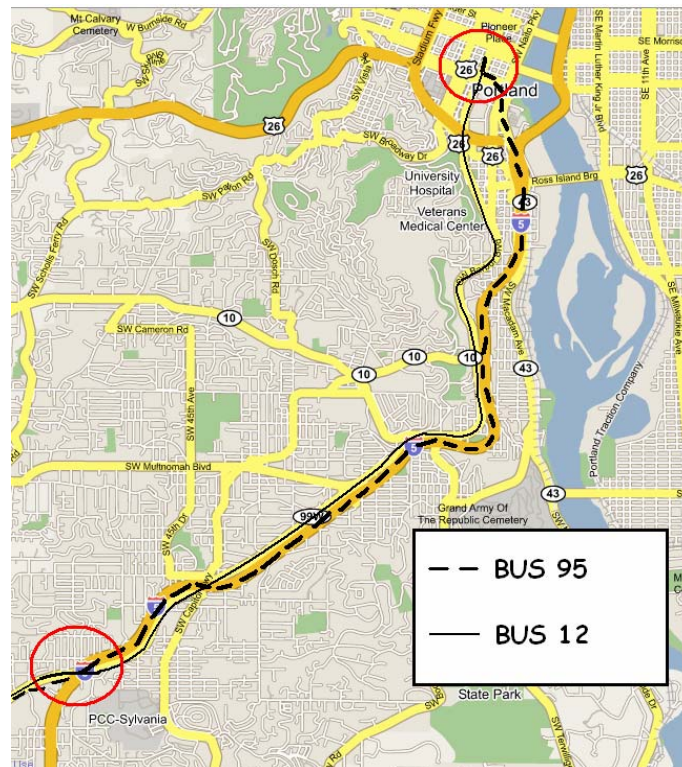


Figure 1: Routes 12 and 95 along the study corridor. Map Source Google.

All buses traveling on I-5 can be analyzed from the November data irrespective of the common exit point. For common start and stop times, however, route 95 is used again. Vehicle trajectories are compared for the week of November 4-8.

DATA ANALYSIS

TriMet data includes the fields, route number and vehicle number, so as to keep overlapping bus schedules from becoming confused when sorting by time. Calculations were made from the raw TriMet data.

Three time fields were included in the raw data. Stop time indicates the scheduled time point for each stop. Arrive time and leave time list the actual time that the bus arrived and left the stop location respectively. Time between arrival of a stop and leaving the previous stop are calculated and called segment travel time. All of the segment travel times are summed together for total route travel time. Total route travel time indicates the amount of time that a bus spent traveling only. Dwell time is effectively eliminated from the bus route. Comparisons of time and distance use the segment travel time field.

Another calculation is made for travel distance. A field included in the raw data, entitled train mileage, gives distance traveled by a bus since it left the bus terminal. Segment train mileages are calculated between each arrival and the previous departure. Segment train mileages are summed for total trip distance.

Having values calculated for distance and time, plots can be made to compare route travel superiority. The plots would be without meaning unless points within the plot were identified. The TriMet data includes a field called location, where each stop in TriMet's system is identified by a location number.

Graphical Data Analysis

Trajectories were created from the data to identify and illustrate trends. The distribution of morning and afternoon commute travel times for bus routes 12 and 95 are shown together in Figure 2. The figures compare travel time with trajectories beginning at actual departure times. Travel times are plotted twice for route 12, with and without bus stop dwell times, for comparison. Route 95 is plotted only without dwell.

In harmony with known congestion trends, the afternoon peak stretches further, depicting greater travel time difference. For more clarity, travel times are plotted again setting each bus route start time to zero in Figure 4 and Figure 5, respectively.

With bus dwell times eliminated, the illustration should approximately depict travel behavior of vehicles traversing the same. It is unclear whether signalization delay is included in Barbur Blvd.'s trip time because bus stop dwell times sometimes take advantage of near side stops. Because stops are removed, the average travel speed on Barbur Blvd. is greater than the average speed on I-5.

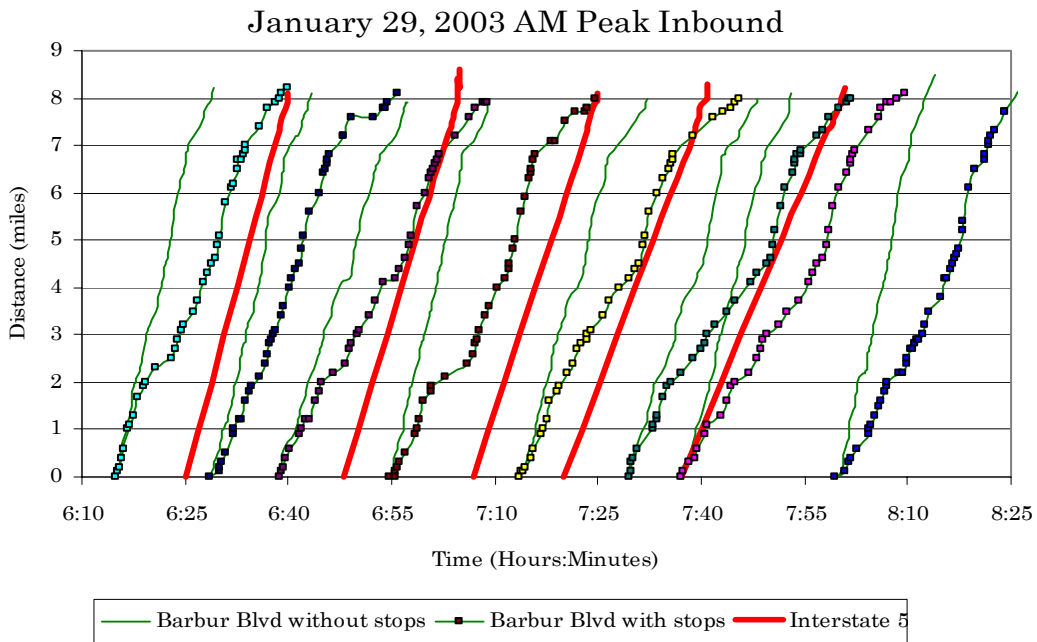


Figure 2: Morning commute travel times on Route 12 (Barbur Blvd.) and Route 95 (I-5).

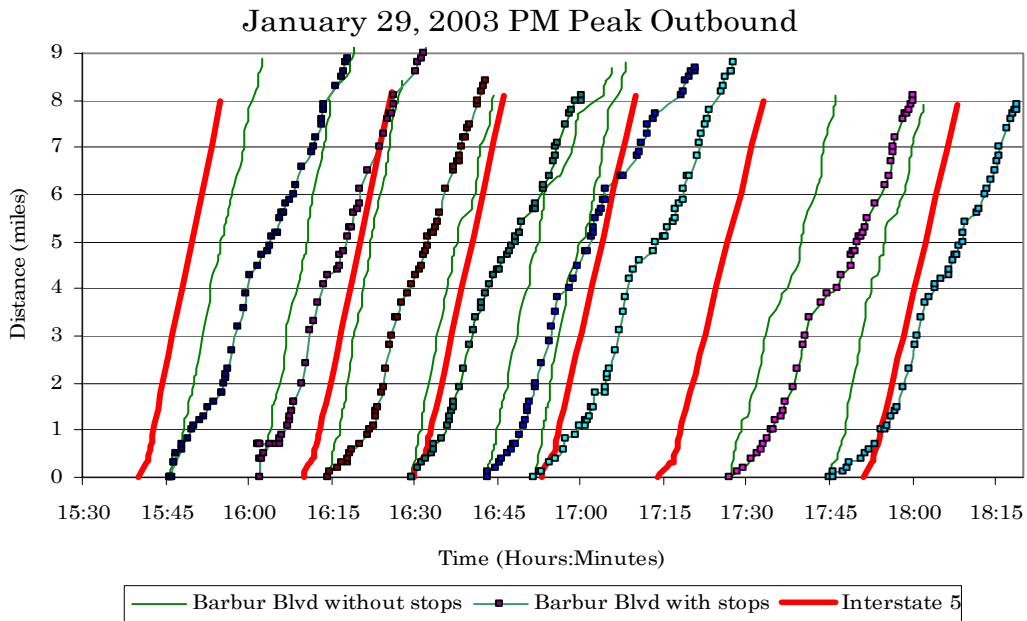


Figure 3: Afternoon commute travel times on Route 12 (Barbur Blvd.) and Route 95 (I-5).

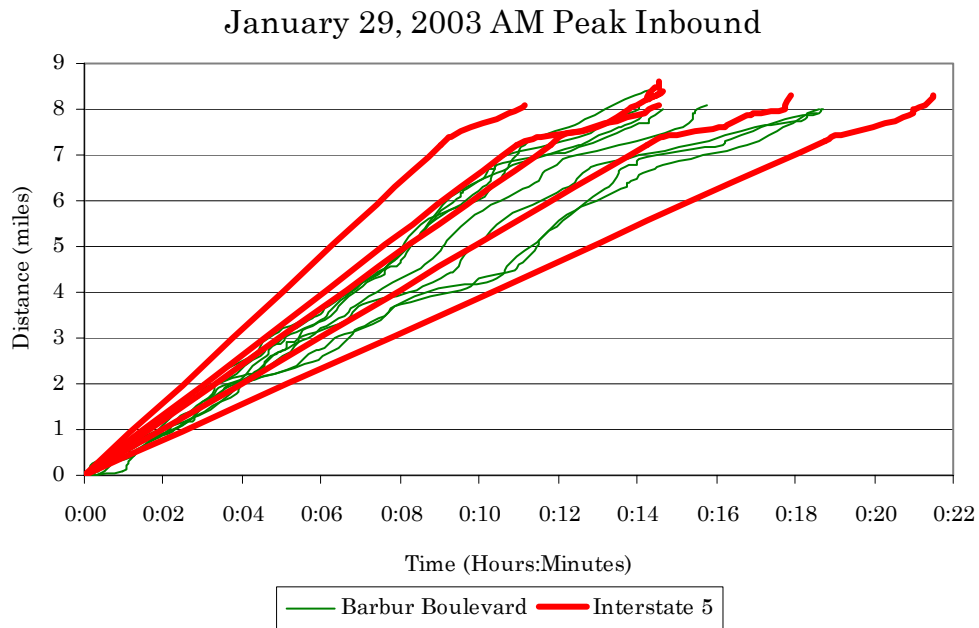


Figure 4: Morning commute travel times on Route 12 (Barbur Blvd.) and Route 95 (I-5).

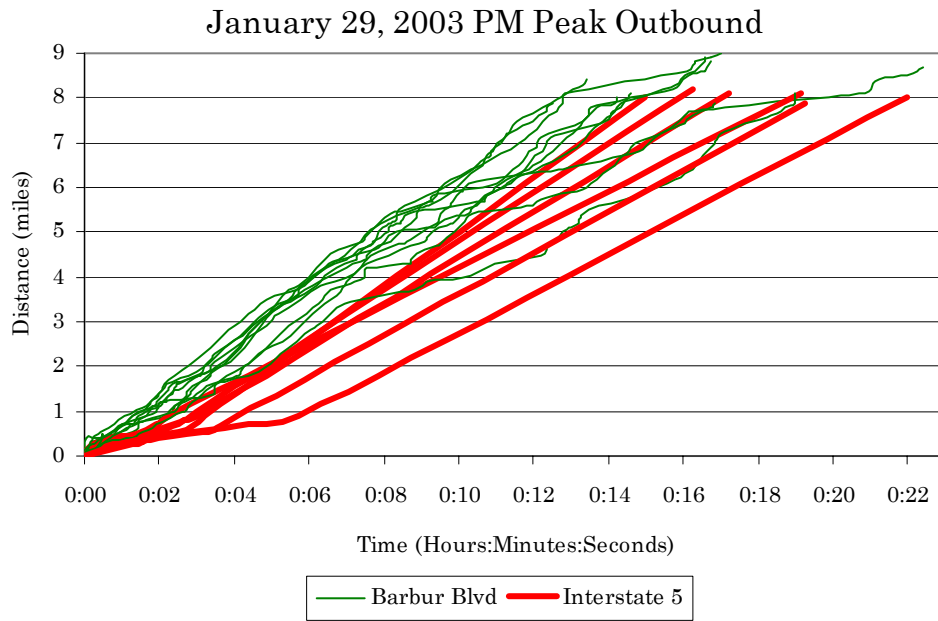


Figure 5: Afternoon commute travel times on Route 12 (Barbur Blvd.) and Route 95 (I-5).

The earliest bus travels through I-5 at 6:25 am quicker than it would have, had it taken Barbur. Each successive morning trip takes longer than the previous one until the final 7:34 I-5 bus takes longer than the Barbur Blvd. buses. Except for the first and last, the morning speeds on both corridors are roughly the same.

The trend in the afternoon buses can be plainly seen from Figure 5. Clearly, every afternoon bus that travels on I-5 arrived at its destination more slowly than the Barbur Blvd. buses. Thus, the more apparent afternoon delay is experienced on the freeway.

The data from I-5 in previous figures shows clear straight lines throughout the 7 mile segment. Since route 95 doesn't stop along the freeway corridor, no time points are plotted, resulting in a straight line, hence travel speed is assumed to be constant throughout the corridor. The November data includes pseudo-stops, showing the variation in travel speed along the freeway portion. Figure 6 and Figure 7 overlay the straight-line January travel runs on top of the November data with varying speed for morning and afternoon peaks, respectively. The November data includes five bus trajectories from Monday, November 4-Friday, November 8.

The overlay shows some fluctuation in speed, but deviates very slightly from the straight line in the January figures. Since the November data follows the very same travel pattern, the January data were used for the travel time calculation in Figure 8.

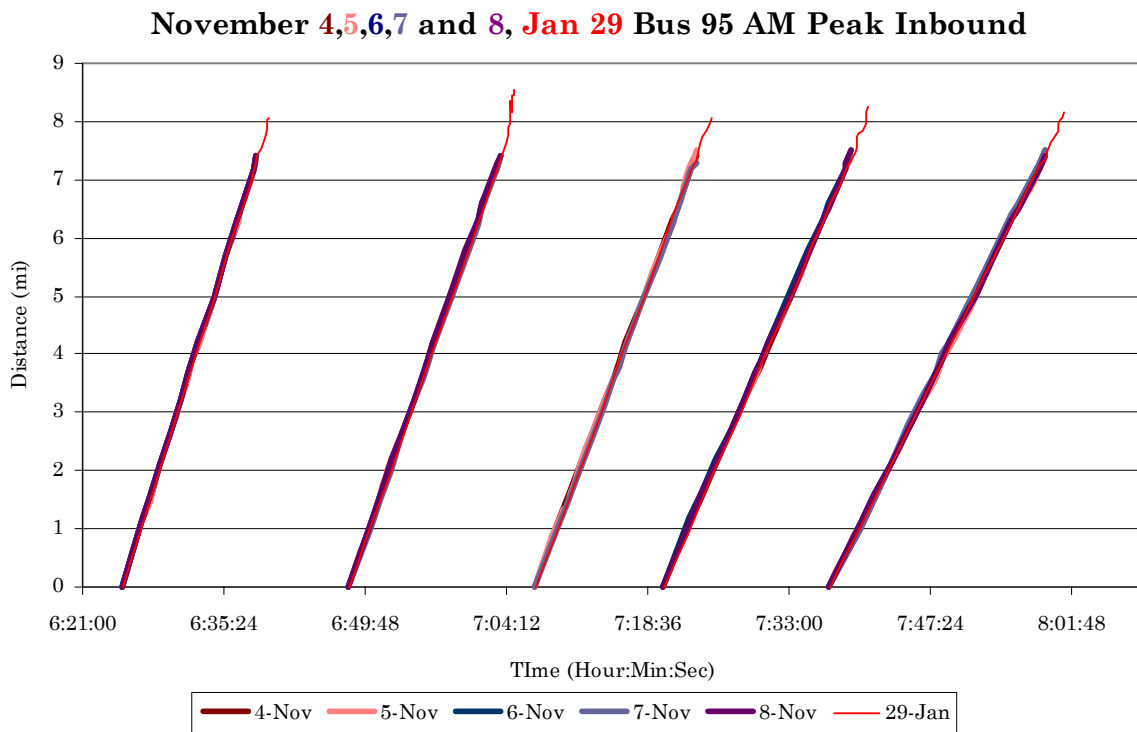


Figure 6: Travel time with (November) and without (January) pseudo-stop time points, Inbound

November 4,5,6,7 and 8, Jan 29 Bus 95 PM Peak Outbound

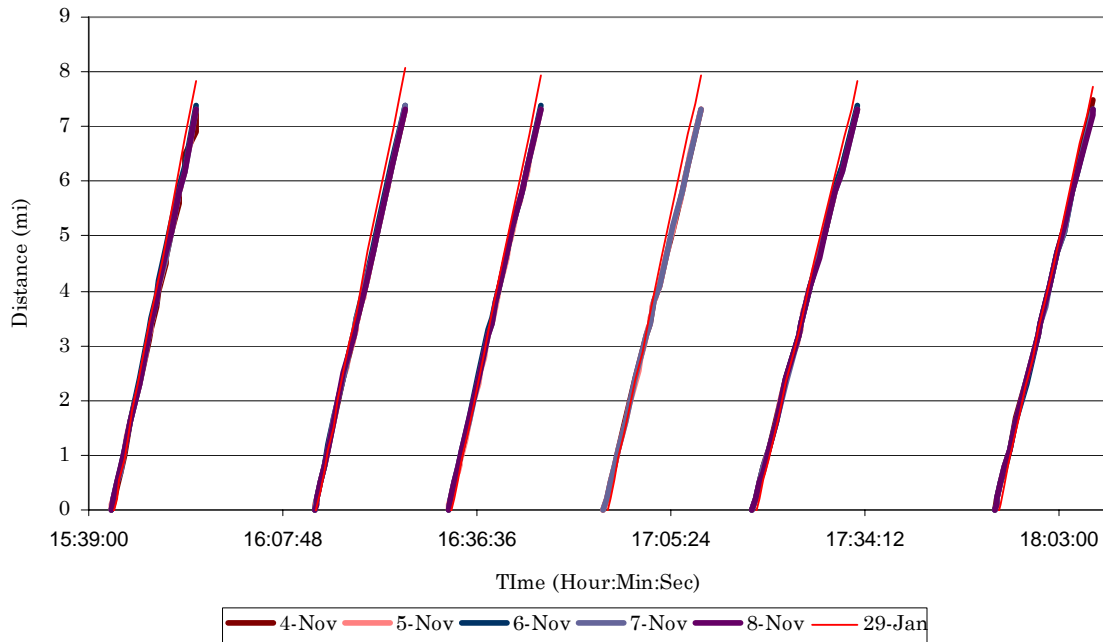


Figure 7: Travel time with (November) and without (January) pseudo-stop time points, Outbound

Afternoon Peak Travel Times January 29, 2003

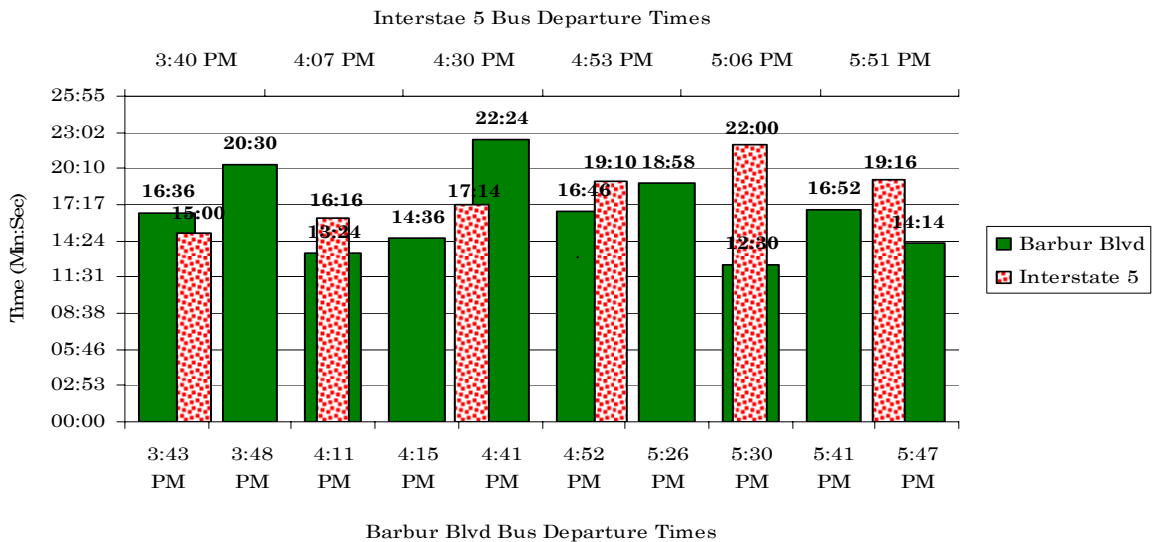


Figure 8: Afternoon Peak Travel Times for Buses on Routes 12 and 95.

The previous Barbur Blvd. and I-5 analysis studied speeds at individual points along I-5 (El-Geneidy and Kimpel 2002). It clearly showed a bottleneck moving throughout time along the corridor. This trend is not captured in Figure 6 or Figure 7. This is due to two factors. First, pseudo-stops were placed far from one another. Second, route 95

headways are at least 15 minutes apart, allowing traffic conditions to change. Speeds on segments of the freeway from the November freeway pseudo-stops help to evaluate whether distributing traffic could create travel time advantages. Additional discussion of traffic routing will follow later in this paper. Figure 8 shows effective travel time for afternoon buses without dwell. Much clearer than route 12 on Barbur, route 95 takes longer as the time approaches the 5:00 peak hour. A comparison of the trajectories shows greater predictability for I-5 than for Barbur Blvd.

Travel Time Comparison Summary

The next step is to compare the trajectories to determine hypothetical traffic assignment. No clear winner existed in the morning peak commute on the days analyzed. Sometimes Barbur was faster, and sometimes I-5 was faster. This situation would be expected to change if a major incident occurred. The afternoon peak clearly showed that the freeway route was slower. Since Barbur was normally a quicker commute, diversion of Barbur traffic to I-5 would not be necessary. Diversion of freeway traffic to Barbur Blvd. would be warranted based on this analysis.

Previous studies suggested that vehicle rerouting should be applied only in situations where at least one lane of Interstate 5 is closed, due to severe crashes. (Kloos et al. 2005.) Capacity restraints affect travel equilibrium and will be calculated later. In heavy commute situations where no lane blockages occur, a routing equilibrium is calculated. Since the data analyzed did not include lane closures, this will be calculated theoretically. To reach travel time equilibrium, a model was created to calculate the traffic volume required to shift from the freeway to Barbur Blvd. during the afternoon peak.

THREE ASSUMPTIONS

Three assumptions were used in developing a simple model to compare these two corridors. The first assumption is that downtown route difference is negligible. Both bus routes began at the same intersection, but they travel through downtown on different streets before entering I-5 or Barbur Blvd., and the difference in delay on those streets is small. The first assumption also considers that the same proportion of the freeway traffic as Barbur's traffic originates from downtown. The second assumption is that since there are seven freeway interchanges along the corridor; drivers can divert from the freeway to Barbur or vice versa with a negligible travel time penalty. The third assumption considers that drivers can navigate to the freeway on and off ramps whether unguided or with VMS assistance.

In actuality, downtown routes have tremendous travel time differences. Figure 9 shows screen lines on a map aside the trajectories. The screen lines show how much time buses used to travel against the corresponding location of their route. Every one of the I-5 buses experienced the slowest speed of their entire route in the first mile. After observation of the trajectories, it is clear that during the afternoon peak, the demand of southbound vehicles from downtown is highest along the streets that approach the freeway. Vehicles entering the freeway from downtown are upstream of the bottleneck that forms where I-5 merges with I-405 and the Ross Island Bridge as well as Harbor Drive (the route used by route 95). Figure 9 is most meaningful during that first mile until the buses enter the freeway.

Since traffic also comes from locations other than downtown, the delay through downtown can approximate diverging upstream traffic from the freeway using the downtown corridor to bypass upstream congestion. This model could compare the two routes from Fifth & Main to Exit 293B or only along Barbur and I-5. A comparison of only the freeway and arterial would not reflect accessibility since they are further apart at the beginning. Traffic that would otherwise enter the freeway from Barbur at a point between Fifth & Main and exit 293B is considered later.

The second assumption adds relevance to the routes chosen for this research. Ramp connection travel times are actually not negligible. Since it is clear from the discussion above that it takes more time to enter the freeway from downtown, it follows that it also takes more time to enter the freeway at other ramps. By observation, traffic queues are large near freeway on ramps. Portland uses ramp metering, which distributes the entry of vehicles more proportional to the volume in a queue. Therefore, ramp queues may discourage drivers from entering the freeway unless the time difference on the alternate route is significantly better. Therefore, traffic entering the freeway upstream of exit 293B is neglected.

The third assumption relates to the idea that VMS guidance can allow drivers to optimize travel time by reaching the freeway or the arterial at the lowest volume areas and possibly crossing back and forth. In practice, this is not feasible due to the design of freeway interchanges along the corridor.

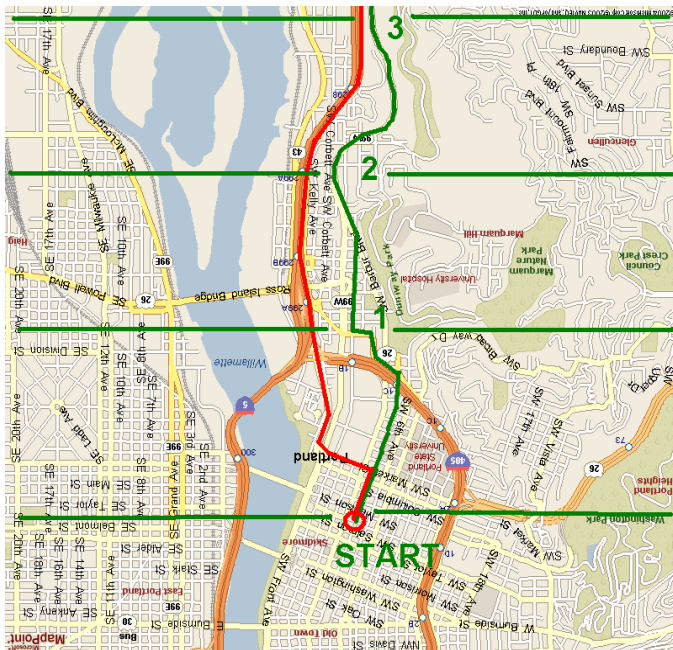
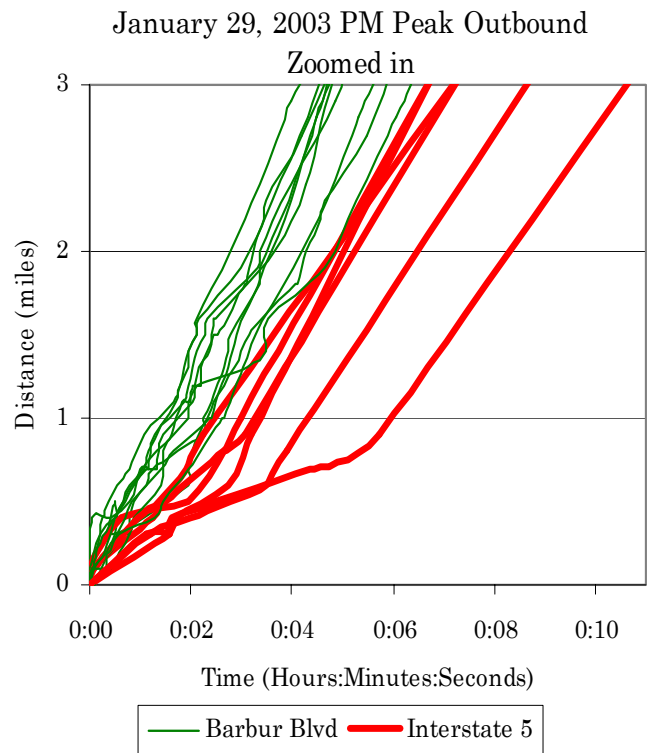


Figure 9: Route Comparison



INTERCHANGE DILEMMA

The interchanges along the Barbur corridor are complex and do not offer all movements. None of the interchanges is a typical diamond or cloverleaf. The complex designs cause those who are not familiar users of the system to have a high chance of getting lost. This prevents unnecessary traffic from clogging the arterial, causing a greater dilemma when rerouting traffic is necessary.

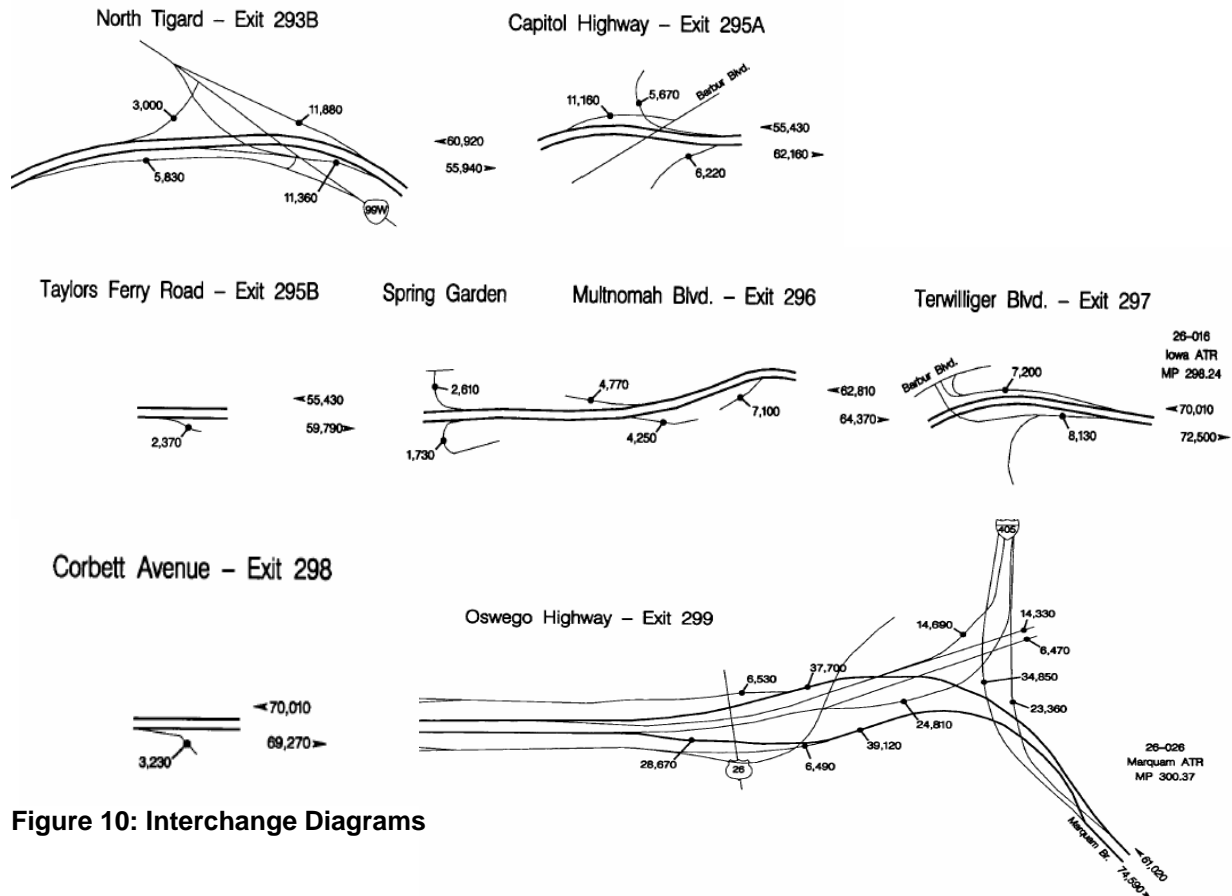


Figure 10: Interchange Diagrams

A brief look at Exit 293B in Figure 10 shows an arrangement of on and off ramps for all directions. It is a mix of a diamond and a directional interchange. A truck lane is included and merges from northbound I-5 to the northbound ramp from Barbur. Southbound I-5 traffic heading to southbound Barbur Blvd. and northbound Barbur heading to I-5 are the directional interchange style. The rest of the ramps are confusing. Fortunately, the directional ramps are the ones for the route 12 and 95 comparison study.

The other interchanges are described to validate the choice of downtown and exit 293B. Further interchanges are shown in the above figure. Some include exits with no entrances or only include entrances in one direction. Drivers unfamiliar with the interchange would become lost, despite the VMS guidance.

Since the three assumptions relate to routing behavior throughout the I-5 and Barbur Blvd. corridor, a travel equilibrium model is not affected. It can be created comparing

only travel on Barbur alone from downtown to exit 293B and I-5 travel alone from downtown to exit 293B.

EQUILIBRIUM MODEL

To calibrate simple traffic equilibrium model, we set travel time on both routes to be equal:

$$t_{12} = t_{95}.$$

where t_{12} is the travel on Barbur and t_{95} is travel on I-5. Second, travel time for each route is approximated by assuming that travel time is equal to the free flow travel time plus a coefficient times the traffic volume:

$$t_n = A_n + B_n x_n.$$

where A_n , is the free flow travel time in minutes, x_n , is the traffic volume in Average Annual Daily Traffic (AADT) and the subscript n is substituted for either 12 or 95 for simplicity. The coefficient, B , is calculated later in this paper.

Route 95	Total Distance (mi)	Time (Hr)	Avg. Travel Speed (mph)
3:40 PM	8.00	0:15:00	32.00
4:07 PM	8.20	0:16:16	30.25
4:30 PM	8.10	0:17:14	28.20
4:53 PM	8.10	0:19:10	25.36
5:06 PM	8.00	0:22:00	21.82
5:51 PM	7.90	0:19:16	24.60
AVG.	8.05	0:18:09	27.04
Route 12	Total Distance		Time
3:43 PM	8.90	0:16:36	32.17
3:48 PM	9.20	0:20:30	26.93
4:11 PM	8.40	0:13:24	37.61
4:15 PM	8.10	0:14:36	33.29
4:41 PM	8.70	0:22:24	23.30
4:52 PM	8.80	0:16:46	31.49
5:26 PM	8.10	0:18:58	25.62
5:30 PM	7.90	0:12:30	37.92
5:41 PM	7.90	0:16:52	28.10
5:47 PM	8.00	0:14:14	33.72
Average	8.40	0:16:41	31.02

Table 1: Afternoon Peak Travel Times January 29, 2003

Free flow speeds for buses are assumed. Route 95 travels on downtown streets and on the freeway. Posted speeds range from 20–55 mph. The free flow speed (FFS) is assumed to be 50 mph. Route 12 travels on downtown streets and on Barbur including a high-speed segment. Posted speeds range from 20–45 mph. Initially, FFS was assumed to be 35 mph. The calculated value was slower than some actual travel data.

The highest average speed from route 12 was 37.6 mph. FFS was changed to 40 mph for the model.

Free flow travel time (A_n) was calculated for the two routes. On I-5, the average trip distance from Table 2 is 8.05 miles. This gives a value for A_{95} of 9.66 minutes. Based on field tests, the assumed travel time is valid. A test run resulted in a travel time near 9 minutes, using a car rather than a bus. Travel time calculation of the 8.4-mile route was 12.6 minutes for A_{12} . A test run gave a travel time of 13 minutes.

Normally traffic volumes are measured for hourly volume or peak hour volume. In this study, average daily traffic (ADT) was available. Since peak hour volume is a portion of ADT, the portion of ADT on Barbur is assumed to be the same fraction as on I-5. The coefficient B_n compensates for the fraction of ADT or peak hour factor. Since both roads are state highways, traffic volumes from 2002 for both roads were available (ODOT, 2004). The average ADT value for Barbur (x_{12}) along the 8.4-mile stretch was 26,000 vehicles per day. The average ADT for I-5 (x_{95}) in the 8.05-mile stretch was 124,000 vehicles per day. ADT values include bi-directional traffic.

The coefficient, B_n was calculated assuming average travel time of peak hour buses. From Table 1, the average travel times for the two buses were 18.2 and 16.7 min. for routes 95 and 12 respectively. The coefficient was the travel time divided by the AADT. B_n values were calculated to be 1.47×10^{-4} and 6.52×10^{-5} for B_{95} and B_{12} respectively.

Travel time equilibrium is easily calculated. The two equations are set equal: $A_{12} + B_{12}x_{12} = A_{95} + B_{95}x_{95}$. The equation solves for equilibrium traffic volumes x_{12} and x_{95} . Since there are two unknowns, substitution is made, setting one x value equal to the combined ODOT average ADT (150,000 vehicles per day) minus the other x value. Equilibrium time is calculated from either side of the equation.

$$12.6 + 6.52 \times 10^{-4} (150,000x) = 9.66 + 1.47 \times 10^{-4} (x)$$

Equilibrium Summary

In equilibrium, 125,000 vehicles use I-5 each day and 24,000 vehicles use Barbur. Each travel route takes 28.1 min. The results were analyzed for reasonableness. ODOT traffic volumes for five lane arterials are sometimes over 50,000 AADT. Barbur is a 5 lane arterial most of the way, but some portions have lower capacity. The recommended AADT can only be verified for accuracy when the hourly volume is determined. This means that regularly 1,800 vehicles move from Barbur to I-5, not vice versa.

Single Lane Blockage

Travel equilibrium cannot be determined for I-5 having one of three lanes blocked without more data from a real occurrence. A theoretical calculation is made for comparison in this paper. Since capacity in either corridor is two lanes per direction, a new B_{95} value is used, which should be greater than the existing value. The B_{12} value cannot be used since facility types are different. It assumes the previous B_{95} value multiplied by the lane blockage difference (3/2) or 6.25×10^{-4} . Theoretical travel time is then calculated:

$$12.6 + 6.52 \times 10^{-4} (150,000x) = 9.66 + 2.20 \times 10^{-4} (x)$$

Equilibrium occurs at 115,000 vehicles on I-5 and 34,000 on Barbur. Equilibrium travel time would be 35.0 min. Without diverting traffic, I-5 travel time would be 37.9 min. Diverting Traffic to Barbur Blvd. would save 1.9 min per vehicle.

Two-Lane Blockage

Travel equilibrium is calculated again for a two-lane blockage. This time, B_{95} is 4.41×10^{-4} .

$$12.6 + 6.52 \times 10^{-4} (150,000x) = 9.66 + 4.41 \times 10^{-4} (x)$$

Equilibrium occurs at 92,000 vehicles on I-5 and 57,000 on Barbur. Equilibrium travel time would be 50.0 minutes. Without diverging traffic, I-5 travel time would be 64.1 min. Diverting Traffic to Barbur Blvd. would save 14.1 minutes per vehicle.

Single Lane Addition

If a lane were added to I-5, travel time would be the same as it is currently when one lane is blocked. For non-blocked conditions, equilibrium travel time would be further improved. One additional freeway lane gains a 6.9-minute benefit to each vehicle.

CONCLUSION

In conclusion, the benefits and problems associated with traffic diversion are weighed and compared against the current situation. Benefits are measured by the difference in vehicle hours per car times total traffic volume using a value of time of \$10.00 per hour for each occupant. Occupancy is assumed to be 1.05; the benefit is \$50,000 per day when a single lane of I-5 is blocked and \$337,000 per day for two lanes blocked. Operations costs to run VMS to guide traffic and study the system are unknown. Other factors affect the decision to implement such a plan. Since this research only looked at a two-route system, the ideal equilibrium route may include interweaving back and forth. Other important factors were not considered in this simple analysis. Pedestrian crossings and local access to businesses are worsened with additional traffic volumes on the arterial.

The solution to freeway congestion is not arterial congestion. The results of this research lead to another solution that needs to be researched. Freeway drivers are in the thru-traffic mindset. Pedestrians risk crossing roads where driver expectation is lessened. Arterial users will experience a lowered LOS with higher traffic volumes. A lack of gaps in traffic will make turning movements difficult for local access. With VMS, seemingly added capacity onto freeways will attract more drivers to use the system. This leads to the comparison of adding lanes to freeway and making the arterials behave as the extra freeway lane. If VMS is not used to guide traffic that drives on the arterials, people find the routes themselves and arterials experience greater traffic flows. Research needs to be conducted to analyze the statement: "you can't build your way out of congestion."

Some research has been done to analyze this statement. The original idea is explained by Cervero, who states "roadway investments spur new travel, known as induced demand, and thus fail to relieve traffic congestion have thwarted road development in the United States" (Cervero 2003). Road investment implies additional freeway lanes or additional freeways. It adds capacity to the system in a safe manner because freeways

are not shared by local traffic or pedestrians. Kockelman states, “a policy of building frontage roads alongside freeway mainlanes avoids the purchase of access rights when upgrading existing highways to freeway standards and can supplement local street networks. It also may affect corridor operations, land values, and development patterns.” (Kockelman 2003) These arguments support that frontage roads and arterials should not be used to guide traffic because it damages neighborhoods.

Traffic cannot bypass bottlenecks created by freeway crashes without adversely affecting arterial streets. Sir Isaac Newton stated that matter cannot be created or destroyed. Simply, when a bottleneck limits traffic flow, the laws of physics require vehicles to occupy space in a queue until they can be transported away from the bottleneck. If capacity exists on a parallel arterial street, the matter (traffic) may leave the trapped system, but the congestion will be transplanted to the arterial if insufficient total capacity exists to improve the system.

ACKNOWLEDGEMENTS

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REFERENCES

- Cervero, R. Road Expansion, Urban Growth, and Induced Travel. *Journal of the American Planning Association*, Vol. 69, Issue 2, Spring 2003, pp. 145-163
- El-Geneidy, A. and Kimpel, T. Intelligent Transportation Systems Data Integration November 12, 2002 <http://www.gcu.pdx.edu/download/NovData/Presentation/>
- Department of Transportation, *Transportation Volume Tables* February 11, 2004 <http://www.oregon.gov/ODOT/TD/TDATA/tsm/docs/2002TVT.pdf>
<http://www.oregon.gov/ODOT/TD/TDATA/tsm/docs/rampbalancing/ramp2004-001-15.pdf>
- Dheenadayalu, Y., Wolshon, B. and Wilmot, C. Analysis of Link Capacity Estimation Methods for Urban Planning Models. *Journal of Transportation Engineering*, Vol. 130, Issue 5, Sep/Oct 2004, pp. 568-575
- Hengel, D. V., Dimento, J. and Ryan S. Equal Access? Travel Behaviour Change in the Century Freeway Corridor, Los Angeles. *Urban Studies*, Vol. 36, Issue 3, Mar. 1999, pp. 547-562
- Hibbert, L. Halting the spread of jams. *Professional Engineering*, Vol. 13, Issue 17, Sep. 20, 2000, pp. 22-24.
- Howard, B. Dashboard Traffic Feeds. *PC Magazine*, Vol. 23, Issue 13, p. 18
- Kloos, W.C. et al. *Creating a Freeway/Arterial Concept of Operations Plan in Portland* <http://www.ite.org/Conference/papers/CB05B0603.pdf> (2005) and http://www.odot.state.or.us/tddresearch/nwtc-Feb_11_Session_2/2B-Barbur Blvd Project.pdf (2003)

- Kockelman, K. M. et al. Frontage Roads: Assessment of Legal Issues, Costs, Operations and Land-Development Differences. *Journal of Transportation Engineering*, Vol. 129, Issue 3, May 2003, pp. 242-253
- Lai, K. and Wong, W. SP Approach toward Driver Comprehension of Message Formats on VMS. *Journal of Transportation Engineering*, Vol. 126, Issue 3, May/June 2000, pp. 221-228
- Morris, M. Portland's LUTRAQ program, *Planning*, Vol. 62, Issue 4, Apr. 1996, p. 12
- Smith, B. L., Qin, L, and Venkatanarayana, R. Characterization of Freeway Capacity Reduction from Traffic Accidents. *Journal of Transportation Engineering*, Vol. 129, Issue 4, Jul/Aug 2003, pp. 362-369
- Warren, W. A Transportation View of the Morphology of Cities. *Transportation Quarterly*, Vol. 47 Issue 3, Jul. 1993 pp. 367-379

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