Diagnosing a Freeway Bottleneck in Portland, Oregon (USA) Using Archived Sensor Data

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Abstract

This paper describes a systematic bottleneck identification and analysis for Oregon Highway 217 in the Portland, Oregon metropolitan region. Bottleneck studies can reveal key information about freeway operations and traffic flow characteristics. They also provide relevant and useful tools when teaching the fundamentals of traffic operations. This study uses 20-second aggregated data collected from eleven mainline and eight on-ramp inductive loop detectors that form part of the regional intelligent transportation systems (ITS) network. The data is archived by the Oregon DOT in the Portland Archival Listing (PORTAL), a unique online database developed, maintained and housed at Portland State University. This study relies on the relationship between vehicle flows and occupancies to produce definitive proof of bottleneck activation during the morning peak period in the southbound travel lanes. Oblique plots comparing changes in flow and occupancy reveal time segments with stationary conditions and times at which transitions between congested and uncongested traffic states occur. An analysis of the data produces quantitative measurements of wave propagation speeds and queue discharge flows. Several days over a period of three months in 2006 are analyzed to confirm the presence of recurrent congestion and to demonstrate reproducibility. A comparison is made between recurrent congestion observed at the bottleneck site with non-recurrent congestion (due to an incident) observed at the same location on a different day. This research may contribute to additional analyses of this corridor including an ongoing ramp-metering study currently being conducted along the 217 corridor, and other analyses of Portland area freeways.

Keywords: bottleneck, freeway operations, congestion, archived data

Introduction

The objective of this paper is to systematically describe the dynamics of traffic conditions during the morning of February 7, 2006, along the 7-mile segment of southbound Oregon Highway 217 (Figure 1). The authors have previously completed two pilot studies of this corridor. While bottleneck studies have been produced for several locations such as I-405 in Orange County, California (Bertini and Myton, 2005), Toronto, Ontario (Bertini and Cassidy, 2001; Bertini, 2005), and Germany (Bertini et al., 2005), no published study has been completed for Oregon 217 or any freeway in or around Portland, Oregon. The opportunity to conduct a research project based upon prior preliminary studies, and in response to the lack of any Portland area bottleneck analyses, was the motivation behind the desire to produce a more detailed, comprehensive examination.

A bottleneck is a specific location on a freeway that separates downstream freely flowing traffic from queued upstream congestion. Daganzo (1997) considers a bottleneck activation to

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occur when the previous conditions are met and deactivation to occur when downstream traffic becomes queued and spills back into the active bottleneck or when demand decreases at the bottleneck site. Bottlenecks can be recurrent, occurring repeatedly at the same location in time and space, or non-recurrent, when an incident such as a crash causes vehicles to accumulate upstream. This paper is concerned with the diagnosis of a recurrent bottleneck between Greenburg Road and Scholls Ferry Road on southbound Oregon 217. A juxtaposition with a crash-related bottleneck at the same location is included in order to compare and contrast selected features such as discharge flow and shock speed.

This paper provides background on comparable bottleneck analyses is presented to illustrate the objectives of this study. Next, an examination of the methodology of this and other similar studies is explained. A brief history and description of the study location, times and dates are offered to provide spatial and temporal context. An explanation of the origin and processing of the loop detector data used in this paper is then presented. The identification and analysis of two bottlenecks that arose during the morning of February 7, 2006 are then described. Following the detailed description of one day of data, the quantitative measurements derived from several days of similar recurrent congestion are discussed. This data are then compared and contrasted with data produced from an identically located incident-related bottleneck in order to illustrate differences between congestion types. Finally, the results and conclusion drawn from this study are combined with suggested opportunities for additional research.

Background

Analysis of freeway bottlenecks using recorded data from inductive traffic sensors can provide improved understanding about basic highway operations. The growing use of ITS technologies underscores the current transportation trend away from the building of new infrastructure and towards the increased focus on improving existing operations. Bottleneck analysis incorporates several aspects of the ITS national architecture: inductive loop detectors, fiber-optic communications, ramp meters, database and computer programming technologies, and a public web interface that provides access to both raw data and an at-a-glance traffic “dashboard” that contains key operations data. The raw data is what provides the input for this and previous bottleneck studies.

Previous studies have measured flow drops following the formation of a bottleneck near on-ramps (Bertini and Myton, 2005; Bertini, 2005; Cassidy and Bertini, 1999a; Cassidy and Bertini, 1999b), typically in the range between 2 and 7%, while some have shown there to be no change in downstream flow following queue formation (Roess and Ulerio, 1994; Hall and Hall, 1990). Additional work has shown bottlenecks forming in the vicinity of off-ramps (Bertini, et al., 2005).
2005), with the average drop in flow between 2 and 13%. All of the above studies examine data from multiple days in order to create multiple measurements of recurrent congestion, in order to reproduce results.

Methodology

The methodology to study bottlenecks has been well established (Cassidy and Windover, 1995; Munoz and Daganzo, 2002; Bertini, 1999). A previous study of these techniques using data from I-405 in Orange County (Bertini and Myton, 2005) provided an easily followed template for this analysis. In the Portland metropolitan area, freeway off-ramps are not equipped with loop detectors. This makes it impossible for an analysis that uses only data derived from loops to use identification techniques that require vehicle conservation. Because of this deficiency in the Portland area ITS infrastructure, the primary technique used to identify and diagnose recurrent congestion in this study uses transformed oblique curves of cumulative vehicle count and occupancy measured at 20-second intervals (Cassidy and Windover, 1995; Munoz and Daganzo, 2002).

To illustrate how the bottleneck identification process is conducted, observe the graphs listed in Figures 2A-2E. Figure 2A shows the cumulative count of vehicles, \( N(x,t) \) at the Scholls Ferry detector over a 2.5-hour study period on February 7, 2006. Since this figure focuses on the entire 2.5-hour period, it tells us very little about traffic conditions on a minute-to-minute basis. To highlight details, a scaling factor representing the average flow over the study time period is subtracted from the cumulative count, producing the results shown in Figure 2B. Now the finer details of the cumulative curve can be seen, and periods of increasing and decreasing flow can be identified. Similar to Figure 2A, Figure 2C is a plot of cumulative occupancy at the Scholls Ferry detector. Again, a scaling factor is needed to identify time segments of increasing and decreasing occupancy. Figure 2D, an oblique graph of cumulative occupancy minus the scaling factor, shows this level of detail. From this plot, changes in occupancy over time can be revealed. A plot of all flows and occupancies during the 2.5-hour period creates the fundamental diagram (Figure 2E) of traffic flow theory, which represents the relationship between flow and density, (or occupancy. These graphs were created based on hourly flows and occupancies measured in each 20-second aggregation data collection period. The direction of the red arrows demonstrates the various transitions that can take place between different traffic states, labeled Unqueued and Queued. For example, a time segment that experience an increase in overall occupancy coupled with a decrease in flow represents a queued traffic state.

To complete the analysis, the oblique flow and occupancy curves are superimposed on the same graph (see Figure 3). Inflection points on each curve, in combination with other noticeable changes in average flow or occupancy are identified. This creates stationary time slices that can be furthered studied using the raw loop data to determined whether or not they represent queued or unqueued traffic states. Average hourly flow and occupancy where measured for each identified time segment, and compared against the two types of traffic states.

Data

The entire 7-mile length of Oregon 217 southbound was examined during this bottleneck analysis. The facility is located in Washington County, west of and adjacent to the City of Portland. For most of its length, the highway has two travel lanes in each direction; near the northern terminus with US-26, the highway has three lanes in each direction (see Figure 1). At
the southern end of 217 is an interchange with I-5. Historically, 217 was an at-grade roadway with signals at each interchange. Over the years, every interchange, with the exception of Kruse Way at the southern terminus, has been replaced with separated grade crossings and ramps. This has resulted in a highway with interchanges that range from 19% to 68% of the minimum distance required between them, based on current ODOT engineering standards for interstates and state highways (Oregon Department of Transportation, 2003). Detector loops are typically located in each mainline travel lane approximately 300 feet upstream of on-ramps and on all (metered) on-ramps.

Figure 2. Methodology examples.

The geometrics of 217 at this location may play a role in bottleneck formation. Approximately halfway between Scholls Ferry and Greenburg Road, the freeway angles left 45 degrees. This bend occurs immediately after the Scholls Ferry on-ramp merge, and may contribute to congested conditions when combined with heavy on-ramp and mainline flows.
There is an auxiliary lane between the Scholls Ferry and Greenburg Road interchanges. During the morning peak, this lane experiences heavy weaving flows and slow speeds, as vehicles exit at Greenburg Road on route to Washington Square, a large regional mall, and Lincoln Center, a large complex of office space.

![Figure 3. Walker Road oblique flow and occupancy plot, February 7, 2006.](image)

All of the Oregon DOT loop detector data for this paper was retrieved from the Portland Archival Listing (PORTAL) data archive located at Portland State University. The raw flow and occupancy data used was aggregated at 20-second intervals. Data used in this study was averaged across all lanes, except when individual lane analyses were conducted. The mornings between 6:30 and 9:30 AM were studied on seven days over a 3-month period. The analysis contained in this paper is specifically focused on Tuesday, February 7, 2006. The remaining days are used for demonstrating reproducibility and the development of results.

While the raw data are aggregated at the 20-second level, activation and deactivation times are given to the nearest minute. Due to communication glitches and loop data collection errors, several 20-second periods contained missing data. The empty periods where assigned data values that equaled the average of the surrounding time periods. While this method is straightforward, it introduces a small amount of error into the analysis. It is thought that this small error can be accounted for given the small variance produced by manually creating missing data; therefore the minute level is used to reporting results.

**Analysis**

This section describes the analysis completed on Tuesday, February 7, 2006. Using MATLAB, a high-level technical computing language used for data visualization, a raw occupancy plot was developed using 20-sec occupancy averaged across all lanes (Figure 4). In the plot, occupancy is interpolated between detector stations and shows an increase in occupancy as a color scale from green to red.
Next, oblique curves of flow and occupancy were developed for each detector station. Figure 5 shows the $N(x,t)$ and $T(x,t)$ curves for the Scholls Ferry detector station. The left axis of the graph represents cumulative occupancy minus the scaling factor of 1,550 seconds per hour (sph), which is equivalent to an occupancy percentage of 21.5%. The right axis shows cumulative flow minus a scaling factor of 3,175 vehicles per hour (vph), measured across both lanes. Vertical lines delineate stationary periods, designating points where either curve changes concavity or experience a noticeable change in slope. Black lines following each curve designate the average slope over that time period, and this value is listed next to the curve, measured in sph or vph. In Figure 5, these ten pairs of average flows and occupancies are then plotted as blue diamonds on the insert scatter plot similar to the one in Figure 2E, labeled by their respective time segment. This helps to determine whether each stationary time segment represents queued or unqueued conditions. Once this determination was made, the corresponding time segment was coded green for uncongested and red for congested traffic.

For Scholls Ferry an examination of Figure 5 shows that prior to 7:19, traffic was moving freely. At 7:19, there was a drop in flow from 3,775 to 3,150 vph and increase in occupancy from 490 sph to 985 sph, corresponding to a queued traffic state. In segment 3, a second decrease in flow to 2,925 vph and a subsequent rise in occupancy to 1,105 sph were observed. The bottleneck was deactivated at 8:03, when occupancy decreased. Even though the flow remained approximately constant during segment 5, the decrease in $T(x,t)$ was large enough that the traffic state was shifted far enough along the fundamental diagram to return to unqueued conditions. This was confirmed by looking at the raw occupancy plot in Figure 4, where it is seen that a change in state from yellow to green occurred at 8:03. The period between 7:19 and 8:03 was designated as the first bottleneck activation at Scholls Ferry. Beginning at 8:26, flow decreased and occupancy increased, signaling the second activation of the bottleneck at this location. Normally, the signals sent during segment 8 would correspond to an unqueued state, but traffic remained heavy enough to still be considered congested. Finally, at 9:07, the increase in flow and decrease in occupancy represented a move back to uncongested flow, which continued until the end of the study period at 9:30. The second activation of the bottleneck was therefore determined to be between 8:26 and 9:07. This was confirmed by the raw occupancy plot in Figure 4.

Since the definition of an active bottleneck means that it is necessary to have downstream traffic unqueued, the Greenburg Road detector data was examined next (Figure 6). While it can be seen that both the flow and occupancy changed throughout the 2.5-hour study period, the fundamental diagram at this location shows that all six time segments defined fell in the unqueued side. Simply put, the Greenburg Road detector remains unqueued throughout the morning, and represents the downstream location that first received queue discharge flows.

Similar analysis took place for each of the upstream detectors from Scholls Ferry (not shown here). Flow-occupancy plots for each station where created, and segment flows and occupancies where plotted on each diagram to confirm queued and unqueued states. Each of the subsequent times identified as the onset of queuing at each station represents the arrival of the bottleneck shock wave. These times correspond to the graph of raw occupancy shown in Figure 4.

Upon the completion of the individual detector analysis, it was possible to measure the signature features of the bottleneck. The queue’s leading edge was formed somewhere between the Scholls Ferry and Greenburg detectors. The distance between these two detector stations is 0.66 miles, or about 3,500 feet. Because of limitations in detector locations, it is difficult to draw major conclusions regarding bottleneck capacity. (Bertini and Myton, 2005) Because the Greenburg off-ramp flow data is not available via the PORTAL system, and was not collected
for this analysis, bottleneck performance measurements such as prequeue and queue discharge flows therefore do not represent a direct measurement of freeway capacity, but bottleneck inflows and outflows can be measured and compared between pre-queue and queue discharge states, and from day to day. At Scholls Ferry, the maximum 5-minute flow across both lanes was calculated to be 4,050 vph.

![Figure 4. Oregon 217 SB raw occupancy plot, February 7, 2006, showing activation and deactivation times at loop detectors stations.](image)

Table 1 contains a summary of the flow measurements calculated from data on February 7. The prequeue flow during the 7:00–7:19 segment was determined to be 3,760 vph which is equal to the seven-day mean for recurrent bottlenecks. “Virgin” refers to the first active bottleneck formed during a study morning – oftentimes this was the only active bottleneck during the 2.5-hour study period. The first bottleneck was activated for a period of 44 minutes. During this time, the discharge flow measured at the Greenburg detectors was 3,550 vph, a flow drop of 5.59%. The discharge flow for the second bottleneck activation was 3,660 vph. Using the same prequeue flow, the flow drop was determined to be 2.66%.

The analysis process was then completed for six additional days. After confirming that queuing existed between Scholls Ferry and Greenburg Roads, the bottleneck features on each study day were then computed into Table 1.

**Results**

It has been shown that there were two active bottlenecks formed between the Greenburg Road and Scholls Ferry detector on February 7. An examination of three months of data resulted in identifying six additional days that experienced similar congestion. These days are listed as part of in Table 1. In previous studies that had higher detector and lower on- and off-ramp densities, active bottleneck discharge flow could be measured (Bertini and Cassidy, 2001; Cassidy and Bertini, 1999a; Cassidy and Bertini, 1999b; Bertini, 1999). Similar to Bertini and Myton (2005),
this paper is reporting bottleneck input flows measured at Scholls Ferry Road, the upstream detector closest to the head of the queue, and bottleneck outflows at the first downstream detector, Greenburg Road, because of the presence of the Scholls Ferry on-ramp between the two sets of detectors.

**Figure 5.** Scholls Ferry oblique flow and occupancy plot, February 7, 2006.

**Figure 6.** Greenburg Road oblique flow and occupancy plot, February 7, 2006.

*Ramp Analysis.* Since the Scholls Ferry on-ramp is located in the bottleneck vicinity, it is assured that the on-ramp flow played a part in bottleneck formation. The on-ramps flows are
analyzed in combination with individual mainline lane flows to determine the characteristics of
the relationship (Figure 7). From the figure, it can be seen that the left-hand or median lane
experienced much higher flow than the shoulder lane during the 2.5-hour study period. The time
periods immediately before both bottleneck activations saw an increase in flow both in each lane
of the mainline as well as on the ramp. For the second bottleneck, this increase in flow took place
approximately between 8:15 and the activation time of 8:26. The flow before the first bottleneck
activation is almost constant across both lanes, and the average flow during this time segment is
used as the prequeue for the analysis presented in Table 1. The on-ramp was almost always
metered during the periods when the bottleneck was active. This is seen from observing the blue
line in Figure 7, which represents a constant flow of 12 vehicles per minute on the on-ramp
restricted by the presence of the ramp meter.

Table 1. Bottleneck characteristics.

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<td>Yes</td>
<td>7:00 - 7:19</td>
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**Reproducibility.** Queue formation and dissipation characteristics were calculated for each of the
additional days studied in this paper. Of particular interest were the measurements of queue
outflow. The results are displayed in Table 1. Recurrent congestion was identified on seven days,
and data from crash-related congestion are also displayed. The flow drop measured across the
two sides of the active bottleneck ranged from –0.53% to 7.09%, with a mean of –3.85%. This is
consistent with previous studies (Bertini and Myton, 2005; Bertini, 2005; Cassidy and Bertini,
1999a; Cassidy and Bertini, 1999b). The standard deviation of the pre-queue and discharge flows
were also measured, and, as expected, the standard deviation of the queue discharge flow is less
than the pre-queue flow. This means that vehicles leaving the bottleneck travel at a more
consistent flow rate than pre-queue traffic.

**Conclusions**

It has been demonstrated that recurrent bottlenecks formed between the Scholls Ferry Road and
Greenburg Road interchanges during the mornings on southbound Oregon 217. Using plots of
cumulative flow and occupancy, it was possible to identify changes in traffic states over a 2.5-
hour period. After the bottleneck activation and deactivations were determined, measurements
were made of prequeue and queue discharge flow. In combination with data from six additional
days of similar periods of congestion, the flow drop downstream of the bottleneck experienced a
0.53% to 7.09% drop in flow, with a mean of 3.85%. Data from a non-recurrent bottleneck
showed a 20.39% drop in flow because of an incident that obstructed the median lane. Individual
lane and ramp analysis revealed increases in flow just prior to activation.
The non-standard geometry of 217 plays a central role in the recurrent congestion experienced at this location. Heavy on-ramp flows at Scholls Ferry in combination with off-ramp flows at Greenburg Rd., create a weaving section that contributes to bottleneck formation. The Scholls Ferry and Greenburg interchange spacing distance is only 47% of the current ODOT standard. This has a deleterious effect on merging and diverging movements that cause additional breakdowns in freeway conditions and exacerbates the speed, severity and duration of observed bottlenecks. Operational improvements in ramp metering rates or facility improvements are needed to reduce congestion at this location under existing conditions, and certainly under volume growth projections in the future.

Future work at this location may include video data collection at consecutive off-ramps near the bottleneck location in order that analyses utilizing conservation of vehicles can be undertaken. Additional studies of other freeways in the Portland area should be completed in order to compare bottleneck performance measurements and operational characteristics. The Oregon Department of Transportation is encouraged to upgrade the loop hardware so that speed and length data may be directly measured, opening up many new possibilities in bottleneck analysis and freight data collection efforts.

Acknowledgements

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References


