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**Understanding and Mitigating Capacity Reduction at Freeway  
Bottlenecks**

**Koohong Chung**

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Understanding and mitigating capacity reductions at freeway bottlenecks

By

Koohong Chung

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Requirement for the degree of

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in

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in the

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of the

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Committee in charge:

Professor Michael J. Cassidy, Chair

Professor Carlos F. Daganzo

Professor Alex Skabardonis

Professor John A. Rice

Fall 2004

The dissertation of Koohong Chung is approved:

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chair Date

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Date

University of California, Berkeley

Fall 2004

Understanding and mitigating capacity reductions at freeway bottlenecks

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By

Koohong Chung

Abstract

Understanding and Mitigating Capacity Reductions at Freeway Bottlenecks

By

Koohong Chung

Doctor of Philosophy in Engineering – Civil and Environmental Engineering

University of California at Berkeley

Professor Michael J. Cassidy, Chair

Two freeway bottlenecks, each with a distinct geometry, have been investigated in an effort to understand traffic conditions leading to capacity losses (i.e., breakdown). One bottleneck is formed by a horizontal curve and the other by a reduction in travel lanes. These bottlenecks are shown to exhibit breakdowns after queues form immediately upstream. The vehicle accumulations that arise near these bottlenecks are shown to be good proxies for the mechanisms that trigger breakdowns. Evidence is provided to show that these losses can be recovered, postponed or even avoided entirely by controlling the accumulations.

An algorithm for estimating vehicle accumulations has been developed in this dissertation. This algorithm's estimates are obtained from the counts made by ordinary detectors (e.g. inductive loops) placed in series. The accumulations estimated are those that arise on the intervening (freeway) segments between the detectors. These estimates can be obtained in real-time at short intervals of a second or so.

The systematic errors (i.e., bias) that invariably arise in detector counts are automatically corrected when traffic is freely flowing. The algorithm is thus well suited for monitoring accumulations near a bottleneck prior to capacity drops and the estimates it furnishes can, in turn, dictate control actions (e.g. metering rates) that prolong higher outflows from the bottleneck. The estimates that the algorithm furnishes can also be used for incident detection and delay estimation.

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Professor Michael J. Cassidy,  
Committee Chair

## **DEDICATION**

This work is dedicated to my mother, Oksoo Kim. Without her extraordinary love and support, this work would not have been possible. I also dedicate this work to my brothers and sisters--Sungyong, Sunghye, Koosam and Koee--with much love and sincere appreciation of their support.

## **ACKNOWLEDGEMENT**

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I would like to extend my thanks to friends and colleagues here at Berkeley. It has been my privilege to study with them. They contributed to me greatly as a friend and a scholar. Many thanks to; Mauch Mauch for his valuable comments; Robert Bertini for sharing his data ; Soyong Ahn, Yoonsang Hwang, Kwangrog Kim and Jittichai Rudjanakanoknad for helping me to collect data. Special thanks to Lisa Massland at the City of Toronto for generously supplying the data.

Last but not least, I would like to express my sincere gratitude to a special person in my life, Yumi Oum for encouraging me when I was in doubts and supporting me with trust and love.

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# 1. Introduction

Two different freeway sites have been investigated to understand the reproducible traffic conditions that accompany the capacity reductions (i.e., breakdowns) at freeway bottlenecks. One of the sites is located in Toronto, Canada and the other in Orinda, California. Both sites were plagued by an active bottleneck (i.e., a bottleneck characterized by queues upstream and freely flowing traffic downstream) and breakdowns were observed at these bottlenecks after they became active.

Findings from this dissertation show that the vehicle accumulations in the vicinity of active bottlenecks are good proxies for the mechanisms that trigger breakdowns.

Breakdowns at each bottleneck were preceded by marked increases in the vehicle accumulations and only occurred after these accumulations exceeded a certain threshold, termed critical accumulation in this dissertation. Each site's critical accumulation was reproducible. Recoveries in outflows were observed when the vehicle accumulations diminished sufficiently below the site's critical accumulation.

These findings came to light by monitoring the vehicle accumulations in the vicinity of the bottlenecks using an algorithm that is developed in this dissertation. This algorithm monitors vehicle accumulations using the data from conventional loop detectors placed in series while correcting for systematic error (i.e., bias). The algorithm's estimates have been compared with the actual vehicle accumulations counted from videotape and their differences were only 6% on an average.

In addition to having provided needed information for the present study, the algorithm has a number of useful applications. It is well suited to monitoring the vehicle accumulations in the vicinity of an active bottleneck prior to breakdown and the estimates it furnishes can, in turn, dictate control actions (e.g. metering rates) that prolong higher outflows from the bottleneck. Maintaining higher outflows for a longer period will reduce delay in the freeway system as can be readily verified from standard queuing diagrams (e.g. Newell, 1993).

The algorithm can also be used to detect incidents by monitoring the rate at which the vehicle accumulations increase: an incident causes the vehicle accumulation to increase rapidly while activation of a recurrent bottleneck causes the accumulation to increase gradually. Although the algorithm cannot function in a self-correcting manner once a queue arises on the freeway segment spanning the detectors in series, it can be used to estimate total delays (i.e., the sum of delays to each vehicle) in an off-line fashion (e.g. for planning purposes) after freely flowing traffic has been restored. Section 4.3 describes these applications in more detail.

The following section summarizes the previous related research. Section 3 presents the findings from the two bottlenecks investigated in this dissertation. Section 4 presents; (i) the description of the algorithm for estimating vehicle accumulation; (ii) the results of testing the algorithm; and (iii) applications of the algorithm. This dissertation ends with concluding remark in section 5.

## 2. Related research

This section provides a summary of previous research related to; (i) breakdowns at active freeway bottlenecks in section 2.1; and (ii) findings that lead to the new algorithm for estimating the vehicle accumulations developed in this dissertation in section 2.2.

### 2.1. Past observations of breakdown.

Bertini (1999) investigated freeway bottlenecks using data measured by loop detectors and found the magnitude of their discharge (capacity) reductions varied markedly each day. The long-run average discharge rates were as much as twelve percent lower than the sustained outflows that had departed these bottlenecks prior to breakdowns. Moreover, the latter of these flows were observed for many minutes.

Bertini did not investigate the traffic conditions leading to breakdowns in detail.

However, earlier work by Edie and Foote (1958) provides clues to the traffic conditions that trigger breakdowns. They reported that flows departing the median lane of New York's Holland Tunnel (South Tube) reached 1400 vehicles per hour (vph) or more at free flow speeds of about 25 mph (the tunnel was a low-speed facility). Following the breakdown at the tunnel's bottleneck, its discharge rates diminished significantly to an average of only 1175 vph.

Edie and Foote believed the breakdowns occurred due to what they called the interaction between platoons of vehicles: perhaps the kinds of interaction they had in mind here were drivers prematurely reacting to kinematic waves, or overreacting to waves by adjusting

their speeds more dramatically than their leaders. They demonstrated that greater discharge rates could be achieved by implementing a traffic control strategy believed to prevent these interactions from occurring. They did so by means of a so-called “gap experiment”<sup>1</sup> in the tunnel’s median lane.

Edie and Foote reported that higher discharge rates were obtained by holding down the entry flows to rates that could be accommodated by their bottleneck. They stated that if drivers were sufficiently spaced to create lower densities, greater discharge rates could be achieved by preventing the driver “interactions”. However, the traffic condition(s) to be monitored to alter inflows to the bottleneck and deciding appropriate times to alter these inflows were not examined.

The findings from this dissertation were consistent with Eddie and Foot’s contention: outflows from bottlenecks can be improved by controlling inflows. Furthermore, present findings show that by monitoring vehicle accumulations in the vicinity of a bottleneck, one can determine the appropriate times to alter inflows so as to postpone breakdown or prevent it from ever occurring.

Daganzo (2002) proposed that the changes in drivers’ motivation could cause breakdowns and explained the breakdown mechanism using the flow-density model shown in Figure 2.1. The bottom triangle in the figure defines the loci of the possible

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<sup>1</sup> Whenever 44 vehicles entered the tunnel in less than a two-minute period, Eddie and Foote halted flow for the remainder of that (two-minute) period. On some days, this strategy increased the flows from 1175 vph to around 1300 vph. The average rate for twelve test days was 1248 vph. The gap experiments thus yielded an average increase of 72 vph-- about six percent increase in discharge rate.

stationary states for the shoulder lane. The discontinuous upper lines similarly define all possible states for the median lane.

The behavioral assumptions reflected in Figure 2.1 allow for two possible traffic regimes, termed “2-pipe” and “1-pipe” regimes. The 2-pipe regime includes freely flowing (unqueued) traffic, whereby aggressive drivers termed “rabbits” (i.e., drivers with a high desired free flow speed,  $V_f$ ) and timid drivers termed “slugs” (i.e., drivers with a low desired free flow speed,  $v_f$ ) separately occupy median and shoulder lanes respectively. A “semi-congested” state can also develop within the 2-pipe regime. In this traffic state, rabbits travel in the passing lane in a fast-moving queue at speed  $V$ , with  $v_f < V < V_f$ : rabbits are restricted to a less-than-desired speed by other rabbits ahead. This is represented in the figure by the circle labeled  $A_1$ . Here rabbits choose to drive with small headways because they are “motivated” to pass slugs traveling in the shoulder lane. The latter are represented by the square labeled  $B_1$ .

If  $V$  eventually diminishes to the point of being equal to (or slightly below)  $v_f$ , rabbits no longer enjoy a speed advantage by traveling in the passing lane. A change in driver psychology takes place: rabbits lose motivation and switch from a passing to a non-passing mode. The flow of rabbits thus changes discontinuously and traffic transitions to a fully congested, 1-pipe regime exemplified by the points separately labeled  $A_2$  and  $B_2$  in Figure 2.1. The breakdown can be observed during this transition, and this is

annotated in the figure. The breakdown mechanism described by Daganzo was qualitatively consistent with the breakdown mechanism observed at the Gardiner site<sup>2</sup>.

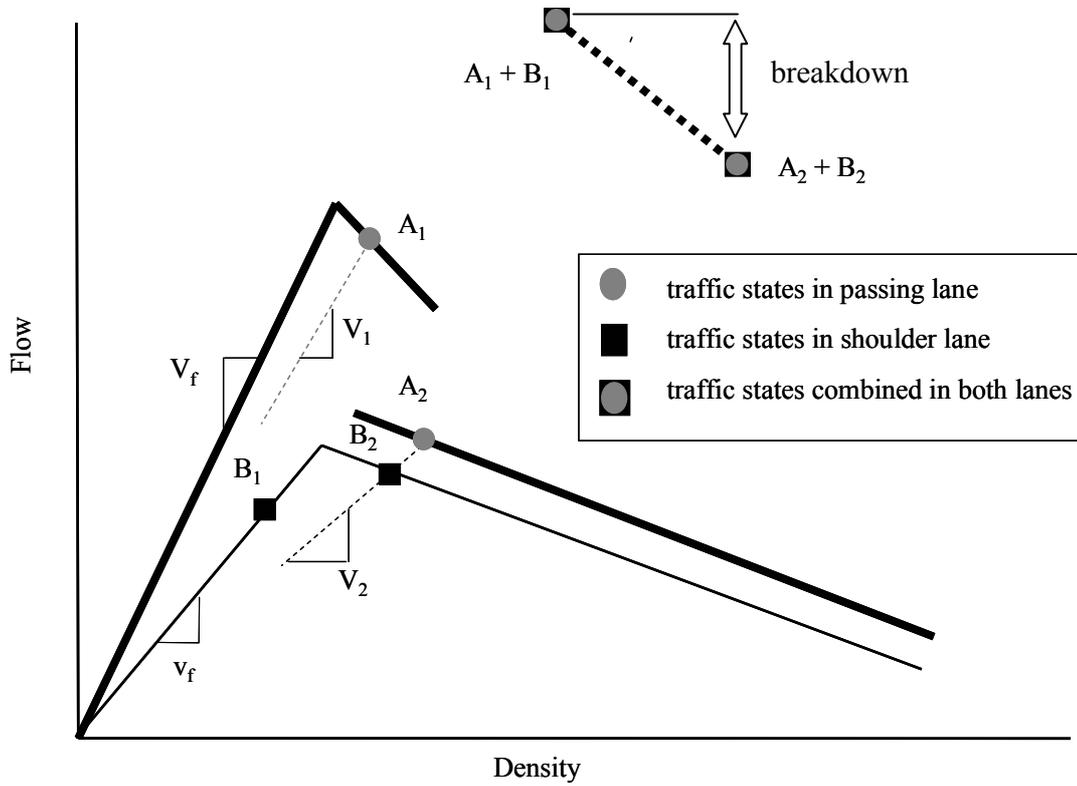


Figure 2.1 Breakdown mechanism described in Daganzo's behavioral theory

<sup>2</sup> The breakdown mechanism described in Daganzo (2002) could not be confirmed at the Orinda site because no occupancy (i.e., dimensionless measure of density) data were available at there.

## 2.2. Past researches leading to a new algorithm for estimating vehicle accumulations

The algorithm for estimating vehicle accumulations takes the vehicle count data from ordinary loop detectors as input and processes these data using; (i) the cross-correlation technique; and (ii) conservation of flow to estimate the vehicle accumulations between the intervening detectors. The cross-correlation technique has been used by other researchers to compute the travel times; these studies measured segment travel times using time differences when identifiable same traffic states were observed between the neighboring detectors.

Daily (1993) used vehicle counts collected over 5-sec sampling intervals in an effort to estimate vehicle travel times and delays. Daily estimated the segment travel time by comparing the deviations in flow from 5-min averages at neighboring detectors; the deviation in flow from the upstream detector was shifted in 5-sec increments until the correlation between the deviations from the upstream and the downstream detectors became greater than 0.4. By using such a technique, however, Daily could not measure the travel time while the traffic was congested, because the deviations in flow propagate backward in congested traffic<sup>3</sup>

Coifman (1999) devised a vehicle reidentification algorithm to estimate travel time. This algorithm compares vehicle lengths measured from upstream detectors with the measurements from downstream to compute travel times. These vehicle lengths were

---

<sup>3</sup> Eddi and Beverez (1967); Lighthill and Whitham (1955); and Mauch (2002)

measured using vehicle occupancy and travel time over double loop detectors: the paired loops in each double loop detector station were spaced about 20 ft apart and the data were sampled at 60 Hz (i.e., reporting data 60 times per second). This method performs well even while traffic is congested, but requires high frequency data as input. Therefore, the vehicle reidentification algorithm is not suitable for analyzing traffic data reported in 20-sec intervals, for example.

Prior to explaining the algorithm for estimating vehicle accumulations in detail, the findings from this dissertation are presented in the following section.

### 3. Findings

Section 3 presents the findings from having investigated multiple days of data from two freeway bottlenecks. Data from five days were taken from a bottleneck formed by a horizontal curve on a stretch of the Gardiner Expressway in Toronto, Canada. Three days of data came from a bottleneck formed by a reduction in travel lanes on a stretch of State Route (SR) 24, in Orinda, California. Findings from the first of these two bottlenecks are presented in section 3.1. They show that the vehicle accumulations in the vicinity of an active bottleneck are good proxies for the mechanisms that trigger breakdowns. Also, evidence is provided to demonstrate that breakdowns can be recovered by controlling the accumulations. Findings from the second bottleneck on SR-24 are presented in section 3.2 along with a description of a remarkable event observed there. This event provides further evidence that breakdowns can be recovered.

#### 3.1. Findings from the Gardiner Expressway, Toronto, Canada

Study of this bottleneck (formed by a horizontal curve) showed that its breakdown mechanism was triggered by drivers maneuvering into the freeway's median lane and was completed when speeds slowed in this lane, such that its drivers lost motivation to travel at small spacings as per Daganzo (2002). Observations further revealed that the vehicle accumulations in the vicinity of the bottleneck are good proxies for this breakdown mechanism. Breakdown only occurred after the accumulation exceeded a certain threshold (the critical accumulation) and the capacity losses at the bottleneck could be recovered once the accumulation dropped below this critical value.

Figure 3.1 shows the 2.1 kilometer (km) segment of westbound Gardiner Expressway used in this part of the work. The small circles in the figure represent the freeway loop detectors, numbered 40 through 80. These detectors record vehicle counts, occupancies (a dimensionless measure of density) and average vehicle speeds over 20-sec sampling intervals.

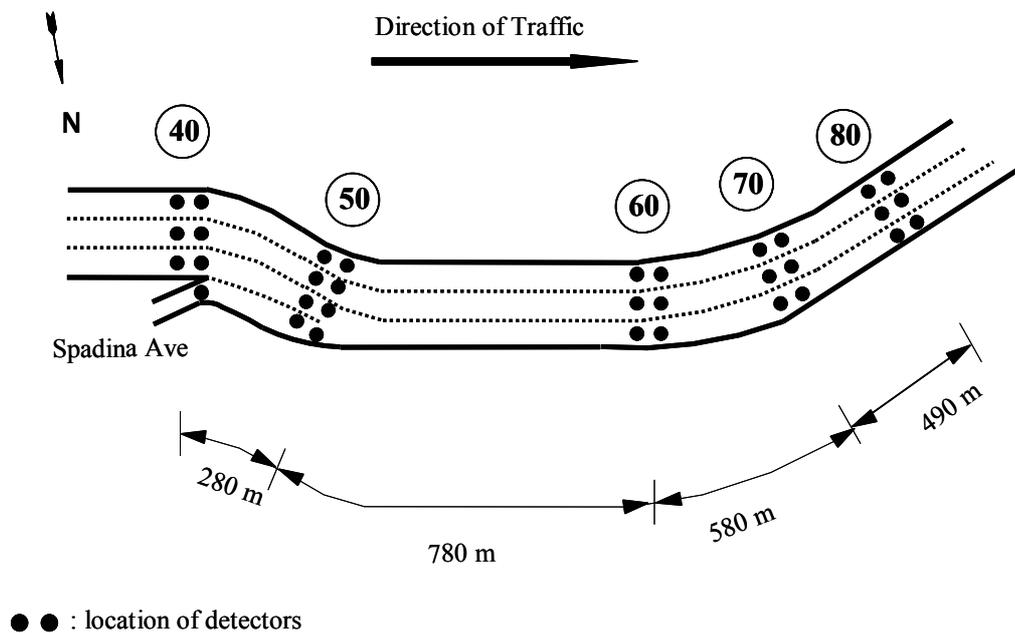


Figure 3.1 Gardiner Expressway, Toronto, Canada

Flows on the Spadina on-ramp were not metered. The freeway is located on an elevated structure and has no shoulders. The site is plagued by a recurrent active bottleneck between detectors 60 and 70 and, as such, is an ideal location for studying the evolution of traffic conditions leading to breakdowns: studying active bottlenecks ensures that breakdowns are caused by endogenous effects and not by exogenous queues from downstream or by reductions in traffic demand.

The bottleneck between detectors 60 and 70 becomes active during afternoon rush periods, as exemplified by the cumulative vehicle count curves in Figure 3.2<sup>4</sup>. These curves were measured during a typical afternoon rush (on March 5, 1997) at locations labeled 50 through 80 (in Figure 3.1): they are denoted as  $O_{50}$ ,  $O_{60}$ ,  $O_{70}$ , and  $O_{80}$ .

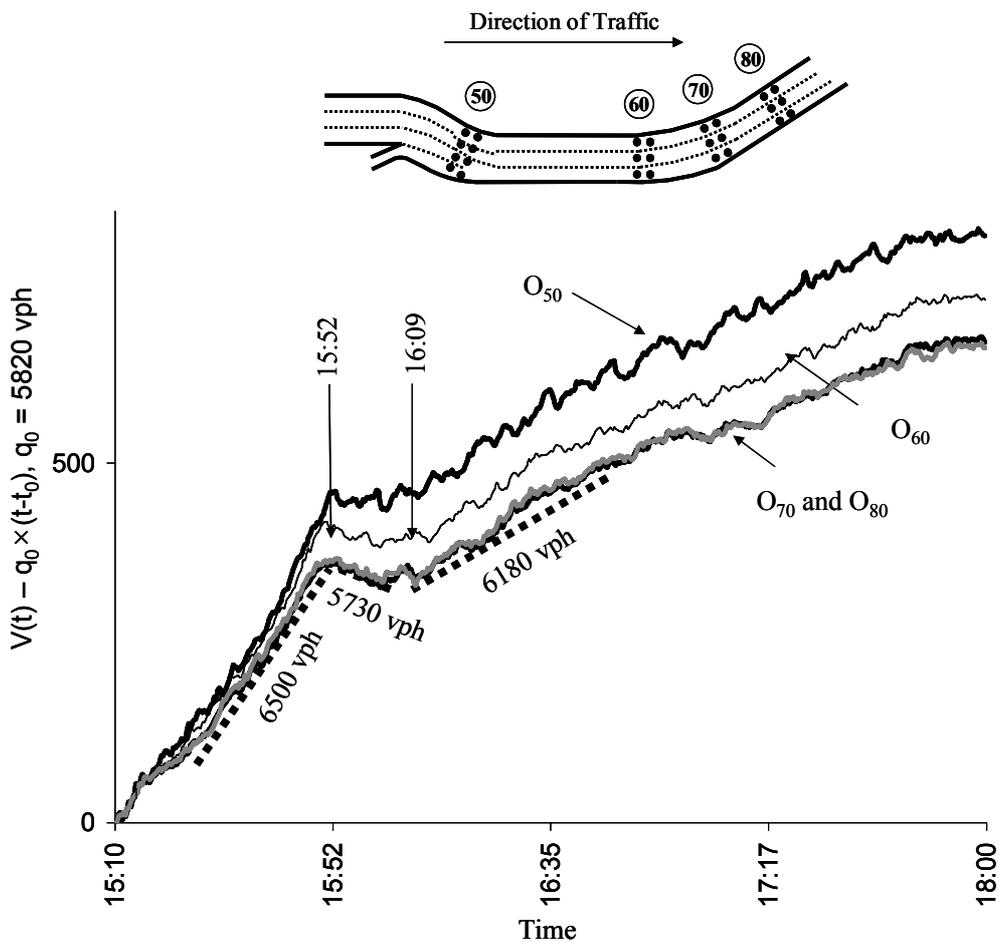


Figure 3.2 O-curves from detectors 50, 60, 70 and 80 (Gardiner Expressway, Toronto, Canada, March 5, 1997)

Their key features were made more visible by plotting them in oblique coordinates so that each displays the quantity  $O(t) = V(t) - q_0 \times (t - t_0)$ , the virtual vehicle count to time,  $t$ ,

<sup>4</sup> Cassidy and Windover (1995); Bertini (1999)

$V(t)$ , minus a background reduction; the latter is some specified rate,  $q_0$ , multiplied by the interval extending from the curves' start time,  $t_0$ , to  $t$ . This coordinate system magnifies the figure's vertical axis, which in turn, amplifies the curves' vertical separations and changes in the curves themselves. Vertical separations between two O-curves are the excess accumulations (queues) in the intervening segment due to vehicular delay. Changes in the curves' slopes indicate changes in flows at the measurement location. (Negative slopes on the curve merely reveal time periods when flow was smaller than the background reduction rate,  $q_0$ .)

Notice how the O-curves at detectors 70 and 80,  $O_{70}$  and  $O_{80}$  remained superimposed during the entire observation period while a queue resided upstream of detector 70. Therefore, these curves collectively show that the bottleneck activated between detectors 60 and 70.

The figure also shows that breakdown occurred at 15:52 as outflows from the site dropped from 6500 vph to 5730 vph. The mechanism of this breakdown was initiated when the vehicles in the median lane gradually slowed down for nearly a 40-min period because of vehicles maneuvering into that lane. After speed in the median lane became slower than that in the shoulder lane (the vehicle speed in the median lane was faster than that of the shoulder lane while the traffic was freely flowing), sudden and pronounced reductions in both speed and flows were observed in the median lane at detector 60. Figures 3.3 through 3.6 collectively show the breakdown mechanism described above.

Figure 3.3 displays flow-occupancy data jointly measured in the median and the shoulder lanes of detector 60. These were sampled over consecutive 5-min intervals (This rather long sampling interval was used to average-out fluctuations in the data.) Each data point is numbered in the figure in chronological order of its measurement. Measurements from the median lane are shown with circles and those from the shoulder lane as squares. The data from the center lanes are omitted from Figure 3.3 to avoid clutter. Had they been presented here, the reader would observe that these data tended to fall between the circles and the squares.

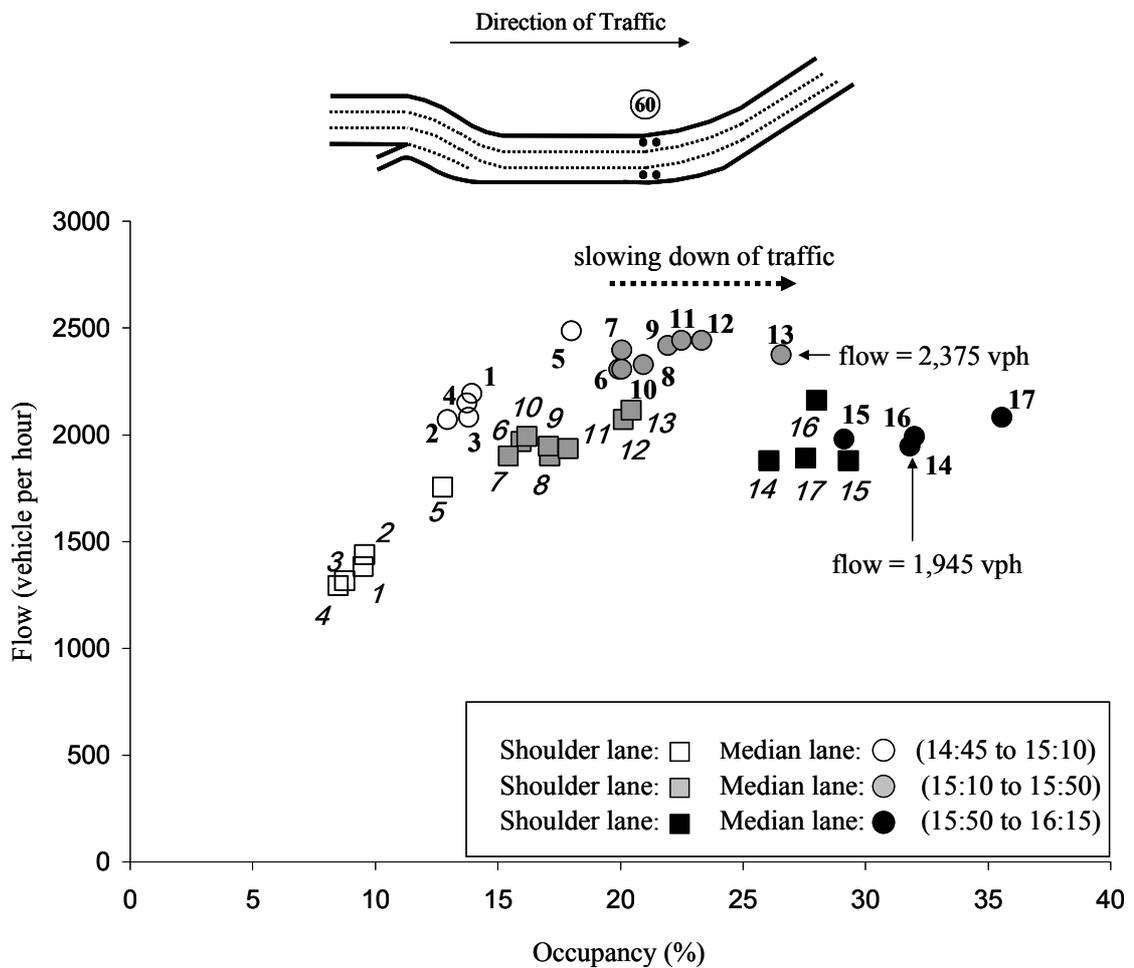


Figure 3.3 Five-minute aggregate flow-occupancy scatter plot from detector 60 (Gardiner Expressway, Toronto, Canada, 14:45 ~ 16:15, March 5, 1997)

The data in Figure 3.3 show that traffic in both the median and the shoulder lanes were freely flowing until 15:10. After this time, the vehicles in the median lane gradually slowed down. Notice how the lightly colored circles labeled 6 through 13 migrated to lower speeds and toward the congested branch of the flow-occupancy relation; these points moved in the direction shown by the dotted arrow in the figure. This gradual reduction in speed was caused by traffic maneuvering into the median lane and these maneuvers are evident in Figure 3.4 and 3.5. These figures display oblique plots of cumulative vehicle counts measured in the median and center lanes at detectors 40, 50, 60 and 70.

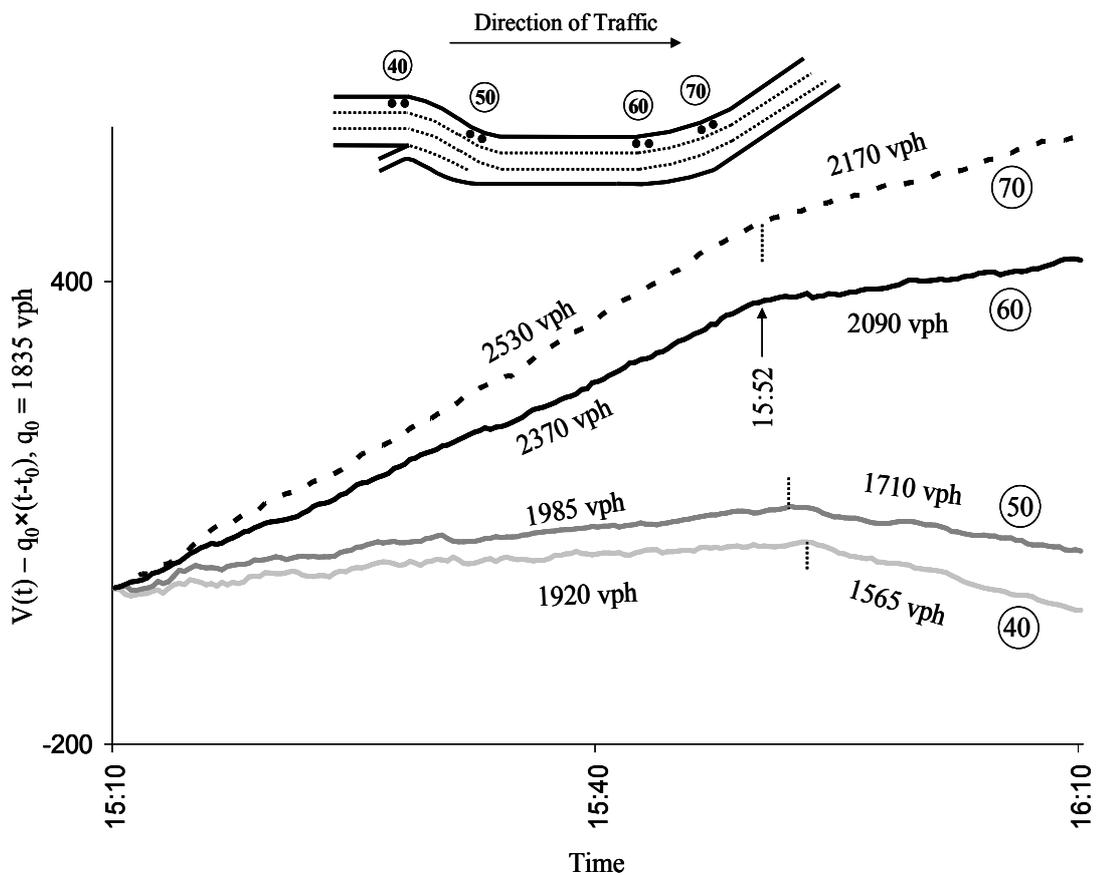


Figure 3.4 O-curves for the median lane at detectors 40, 50, 60 and 70 (Gardiner Expressway, Toronto, Canada, March 5, 1997)

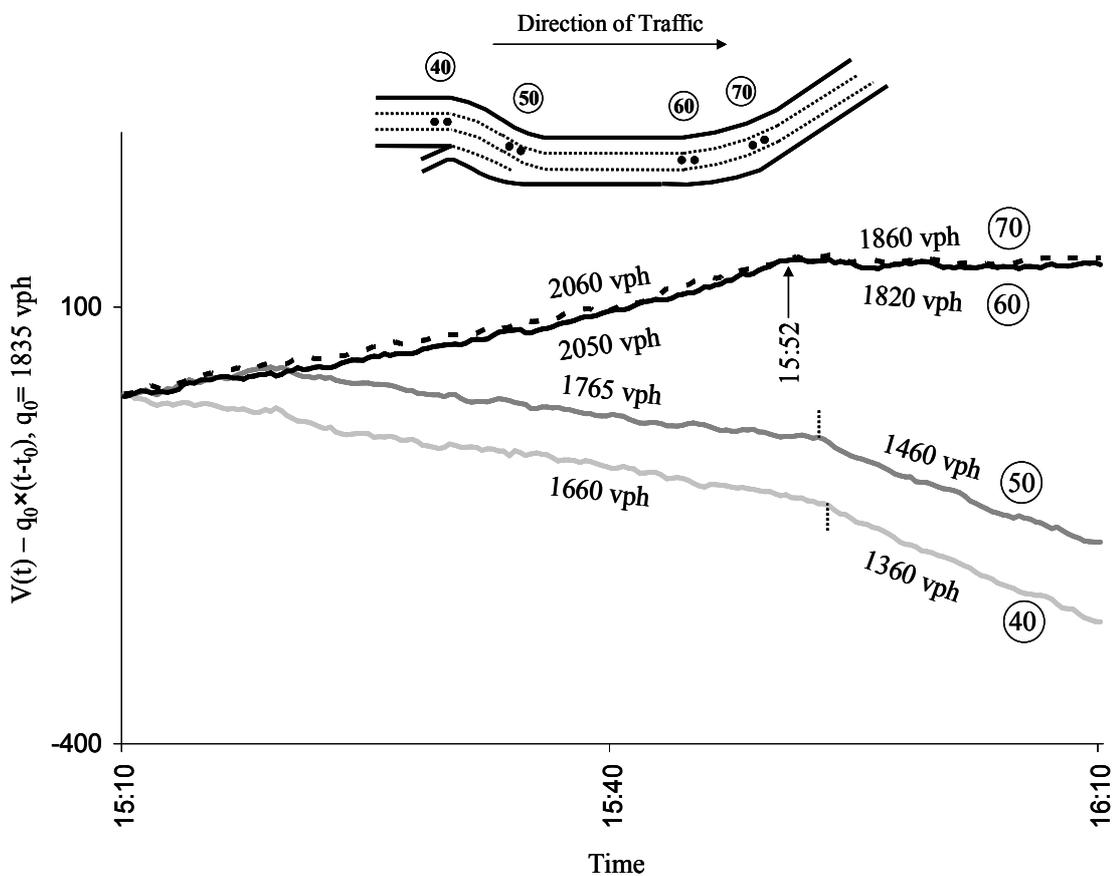


Figure 3.5 O-curves for the center lane at detectors 40, 50, 60 and 70 (Gardiner Expressway, Toronto, Canada, March 5, 1997)

The average flows measured in the median and center lanes at detectors 40 through 70 from 15:10 to 16:10 are annotated in Figure 3.4 and 3.5. Notice (in Figure 3.4) how the flows in the median lanes at detectors 40 and 50 were about the same, even though the Spadina on-ramp resides between them. The flows measured in the center lane (Figure 3.5) at detectors 40 and 50 only differ by approximately 100 vph: the on-ramp flow remained about 1700 vph during the same period. Together, the figures indicate that most of the vehicles entering the freeway via the Spadina on-ramp stayed in the shoulder and auxiliary lanes until they passed detector 50. They maneuvered later into adjacent

lanes after passing detector 50: the flows measured in the median and center lanes at detector 60 were about 400 vph and 300 vph (respectively) greater than the flows measured in the median (Figure 3.4) and center (Figure 3.5) lanes at detector 50.

Breakdown occurred at 15:52 when the speed of the traffic in the median lane became slower than the shoulder lane traffic. This is evident in the lightly shaded circle labeled 13 and the blackened circle labeled 14 in Figure 3.3; they are the data points measured just before and after breakdown. The gradual slowing of vehicles in the median lane that resulted in breakdown can also be detected by monitoring the vehicle accumulations, and this is explained next.

The time series displayed in Figure 3.6 is constructed by taking 5-min moving averages of vehicle accumulations<sup>5</sup> between detectors 60 and 70. A marked increase (of 112 vph) in the vehicle accumulations (see Figure 3.6) was observed from 15:10 to 15:52 and this period coincides with the time period when slowing was observed in the median lane (see Figure 3.3). Findings from multiple days showed that the slowing of vehicles that initiated the breakdown mechanism coincided with a marked increase in the vehicle accumulation. Vehicle accumulations are evidently good proxies for the mechanism triggering breakdown at this bottleneck.

Monitoring the vehicle accumulations in the vicinity of the bottleneck further revealed that breakdowns only occurred after the vehicle accumulations exceeded the critical value and evidence of this is provided in table 3.1. The table presents flows observed before

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<sup>5</sup> The accumulations were estimated from the detector counts using an algorithm described in section 4.

and after breakdown on each study day, the durations of these flows and the vehicle accumulation (between detectors 60 and 70) when each breakdown was observed. Notably, breakdown only occurred after the vehicle accumulation exceeded 89 vehicles. We therefore treat 89 vehicles as the site's critical accumulation.

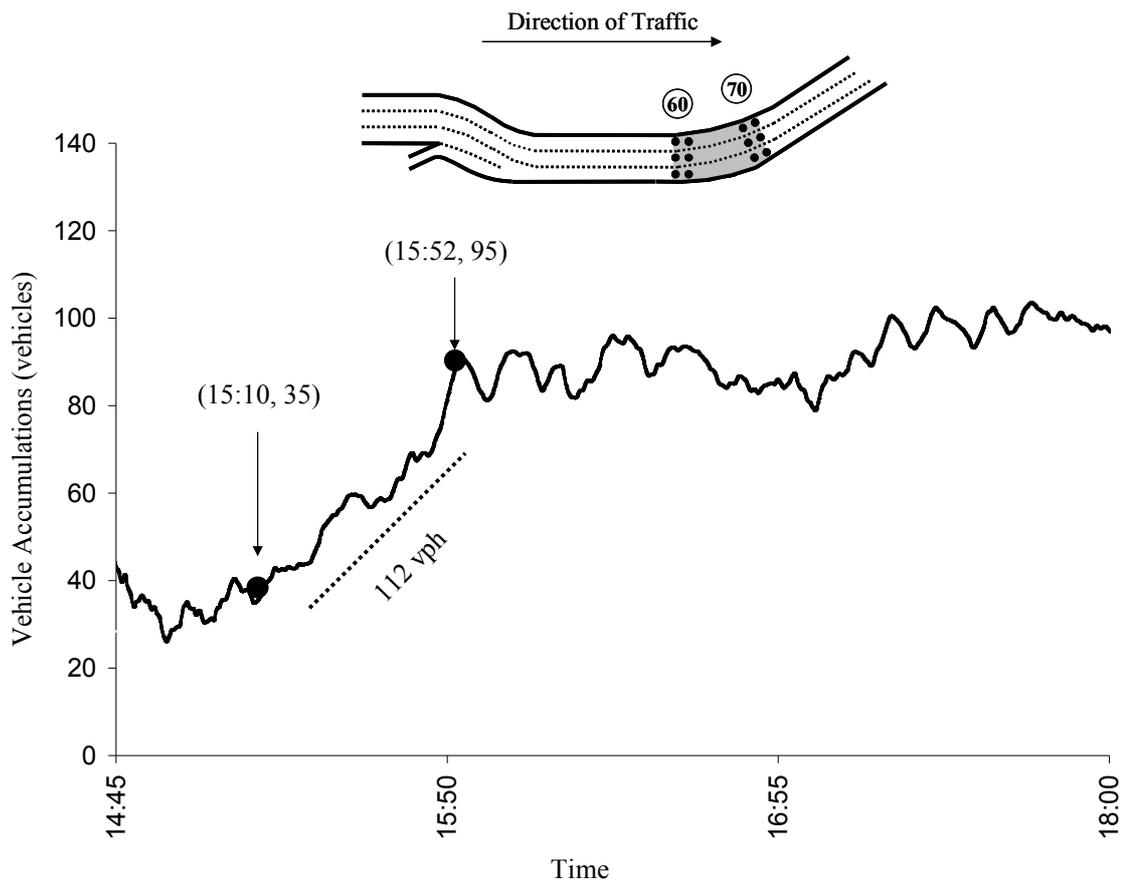


Figure 3.6 Five-minute moving average of vehicle accumulations between detectors 60 and 70 (Gardiner Expressway, Toronto, Canada, March 5, 1997)

Notice the vehicle accumulation never exceeded 75 vehicles on the final day listed in table 3.1. As an apparent consequence, breakdown did not occur. Instead, high outflows in excess of 6,200 vph persisted for the entire rush period (170 mins). This remarkable observation serves as “a natural experiment;” i.e., it unveils the expected outcome from

controlling accumulation exogenously (e.g. by metering an on-ramp), and it shows that breakdown can be avoided entirely if the vehicle accumulation is kept under the site's critical accumulation.

Date	Flow before breakdown (duration)	Flow after breakdown (duration)	Vehicle accumulation
3/5/1997	6500 vph (45 min)	5730 vph (17 min)	95 vehicles
2/11/1997	6150 vph (24 min)	5670 vph (60 min)	104 vehicles
4/28/1998	6300 vph (29 min)	6090 vph (31 min)	100 vehicles
5/1/1998	6280 vph (49 min)	6035 vph (18 min)	89 vehicles
5/12/1998	6230 vph (170 min)	N.A.	< 75 vehicles

Table 3.1 Summary of breakdowns at Gardiner Expressway, Toronto, Canada

The capacity losses at the bottleneck after breakdown can also be recovered if the vehicle accumulation is reduced below the site's critical accumulation. Evidence of this kind was observed on February 11, 1997. The following describes the traffic conditions that led to a capacity recovery.

The O-curves for a period on that day are displayed in Figure 3.7. These curves reconfirm that the active bottleneck resided between detectors 60 and 70. The breakdown occurred on this day at 15:20 and the capacity reduction became more severe at 15:53. The vehicle accumulations between detectors 60 and 70 during the same period are displayed in Figure 3.8.

The recovery process observed at the site was initiated when the flows arriving at detector 50 diminished (to 5120 vph) at 16:12 (see the curves inscribed in the dotted circle in Figure 3.7). The upstream traffic conditions that reduced flows could not be

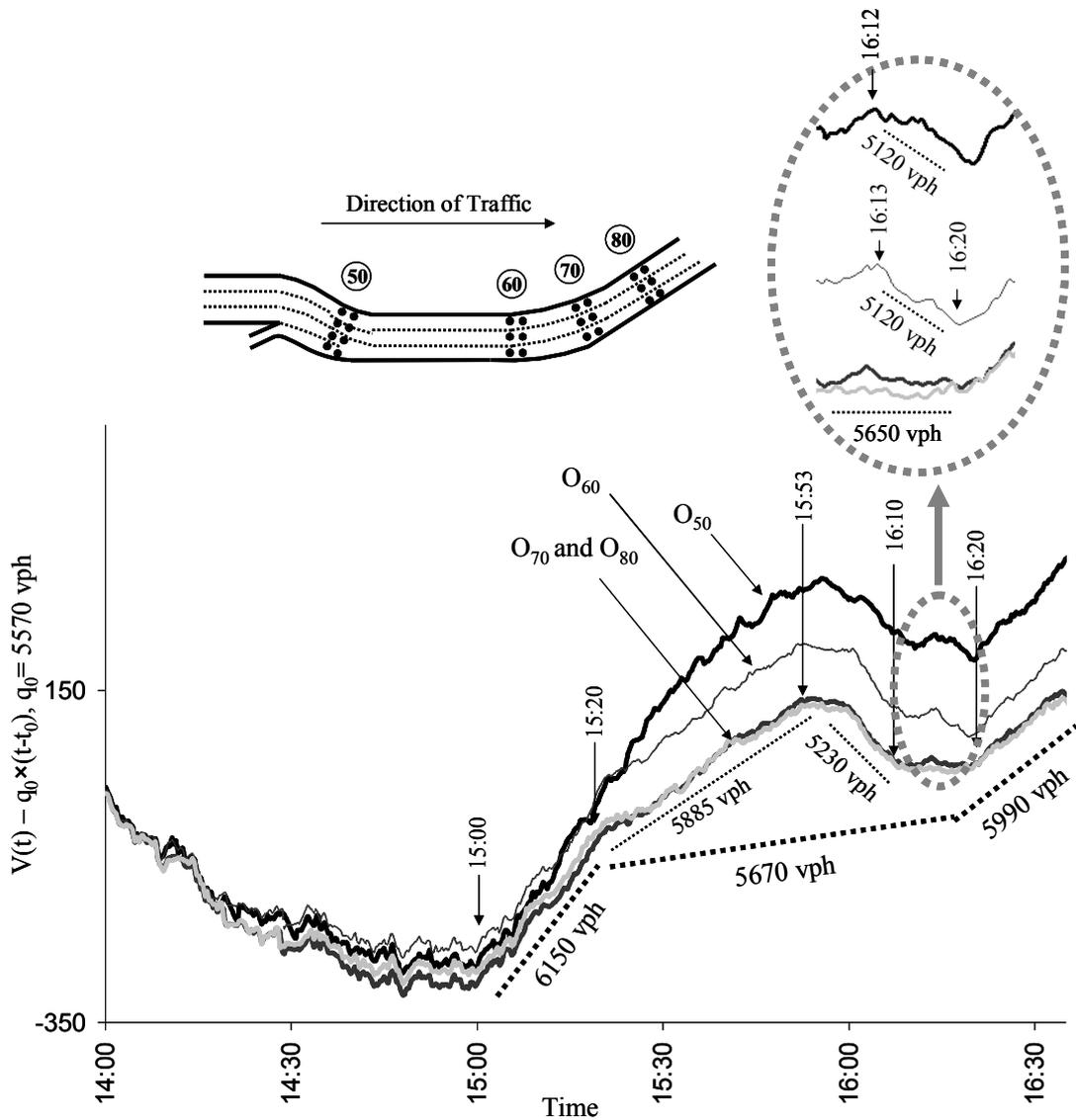


Figure 3.7 O-curves for detectors 50, 60, 70 and 80  
(Gardiner Expressway, Toronto, Canada, February 11, 1997)

uncovered since no ramp data were available on this day. When these reduced flows (5120 vph) reached detector 60 at 16:13 (in the encircled portion of Figure 3.7), the vehicle accumulation between detectors 60 and 70 started to decrease because of the difference in flows entering and leaving the segment (see Figure 3.8). The inflow remained at 5120 vph and the outflow at 5650 vph until 16:20; this too is shown in the

encircled portion of Figure 3.7. When the vehicle accumulation diminished to a lower value (shown to be 50 vehicles in Figure 3.8), the outflow from the bottleneck increased to 5990 vph (Figure 3.7). These findings (i.e., correlations between critical accumulation and the recovery of breakdown) were also reproducible at SR-24, and they are presented in the next section.

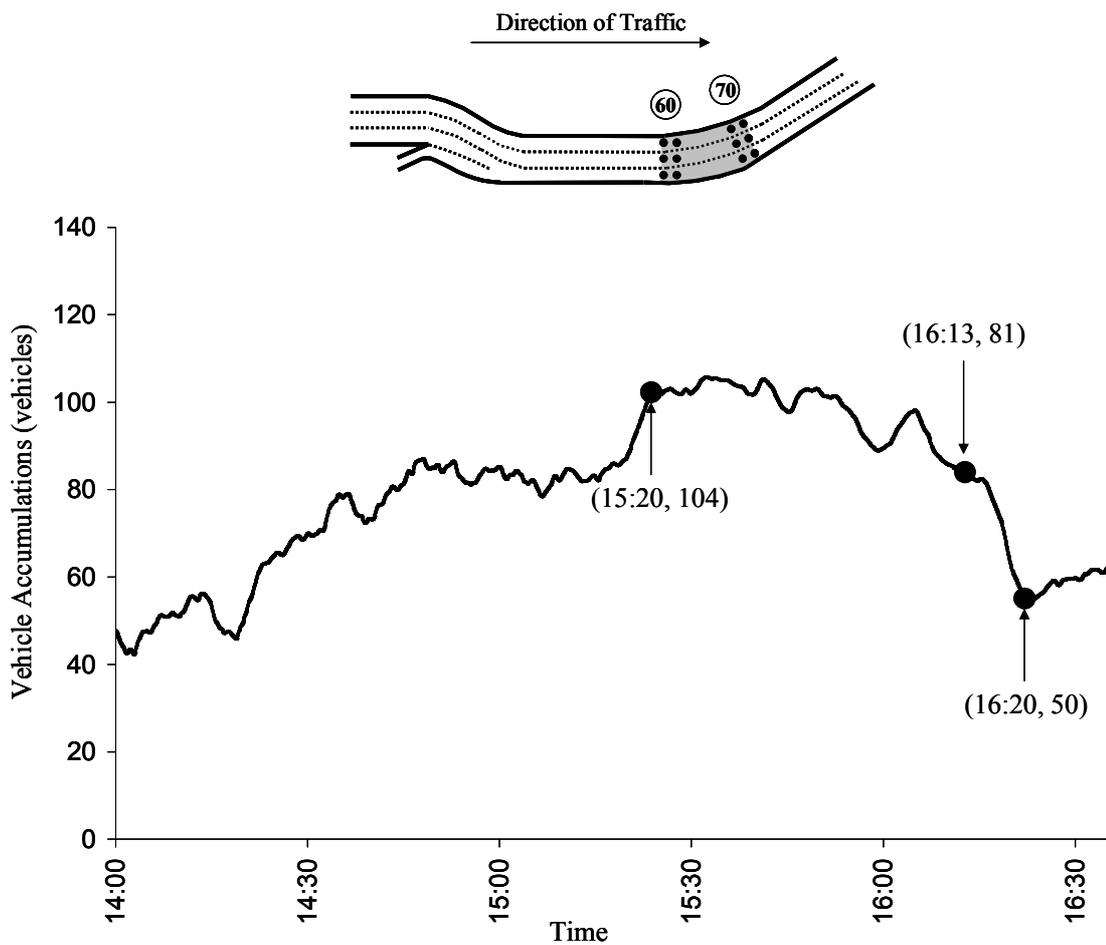


Figure 3.8 Five-minute moving average of vehicle accumulations between detectors 60 and 70 (Gardiner Expressway, Toronto, Canada, February 11, 1997)

### 3.2. Findings from SR-24, Orinda, California

No loop detectors were present at this site. Therefore, four cameras were strategically deployed along this freeway stretch to record individual vehicle arrival times at locations marked as 1, 2, 3 and 4 in Figure 3.9. The vehicle arrival times were manually extracted from the videotapes.

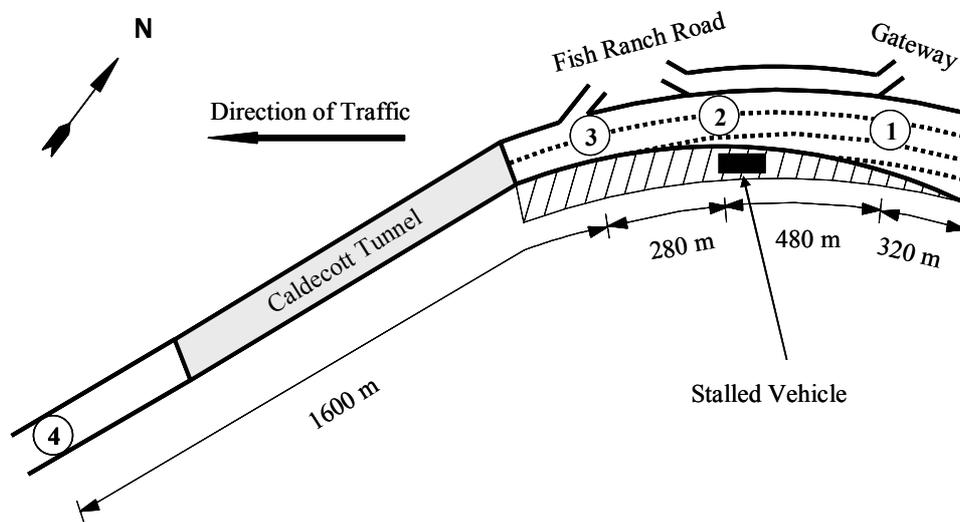


Figure 3.9 State Route 24, Orinda, California

The site is plagued by recurrent active bottleneck that resides between locations 2 and 3 due to the reduction in travel lanes and breakdowns were observed there on a daily basis. Table 3.2 summarizes the findings from the three days studied here: the table presents flows observed before and after the breakdown on each study day, the durations of these flows and the vehicle accumulation (between locations 2 and 3) when the breakdown was observed. Notably, breakdowns only occurred after the vehicle accumulation exceeded 25 vehicles. We therefore treat 25 vehicles as the site's critical accumulation

Date	Flow before breakdown (duration)	Flow after breakdown (duration)	Vehicle accumulation
8/21/2002	4070 vph ( 11 min)	3860 vph ( 40 min)	27 vehicles
8/07/2004	4240 vph ( 36 min)	4025 vph ( 18 min)	25 vehicles
8/14/2004	4355 vph ( 14 min)	3985 vph ( 10 min)	26 vehicles

Table 3.2 Summary of breakdowns at SR-24, Orinda, California

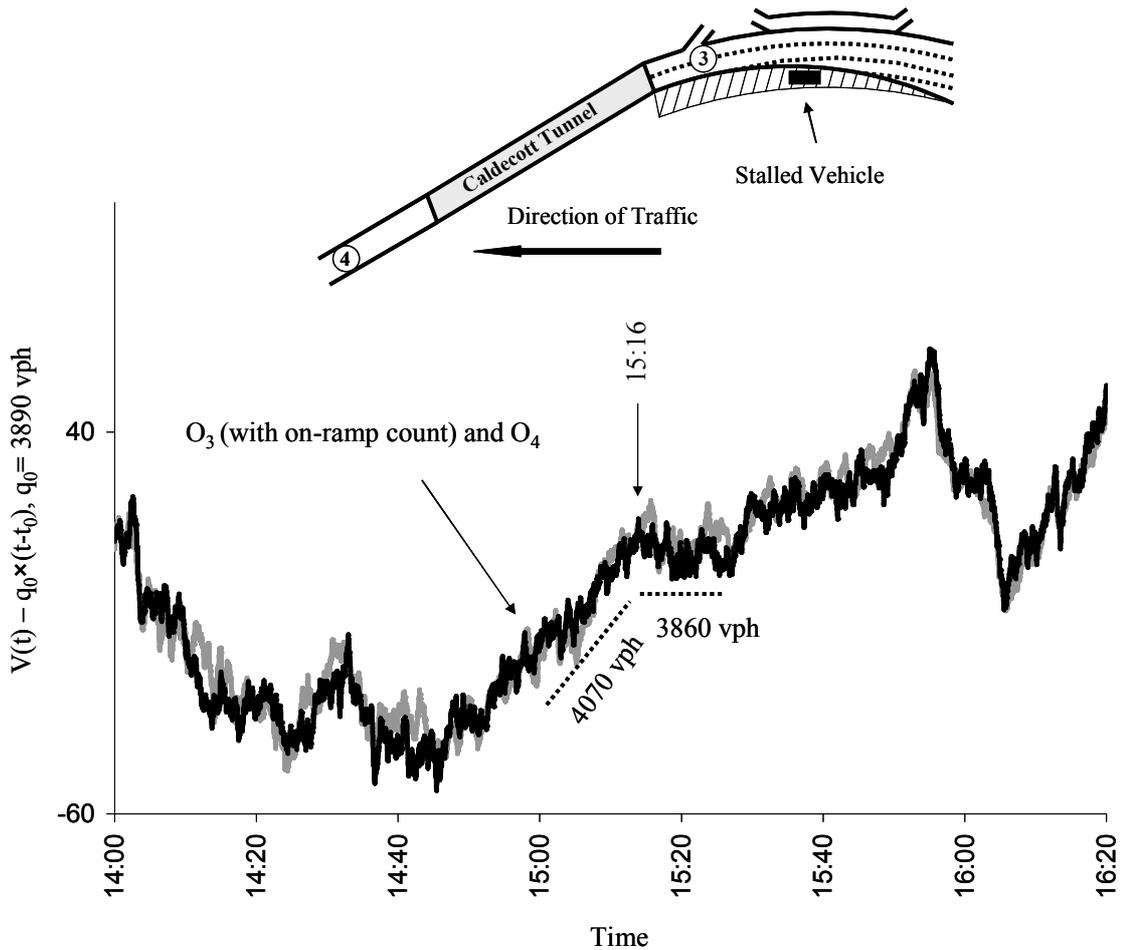


Figure 3.10 O-curves from locations 3 and 4 (SR-24, Orinda, California, August 21, 2002)

A remarkable event was observed on the first day listed in Table 3.2 (August 21, 2002). A disabled vehicle parked in the freeway's median (see Figure 3.9). This event caused the vehicle accumulation in the vicinity of the bottleneck to return to that of a free flow

state. As a result, bottleneck's outflow eventually recovered. The event is described in detail below.

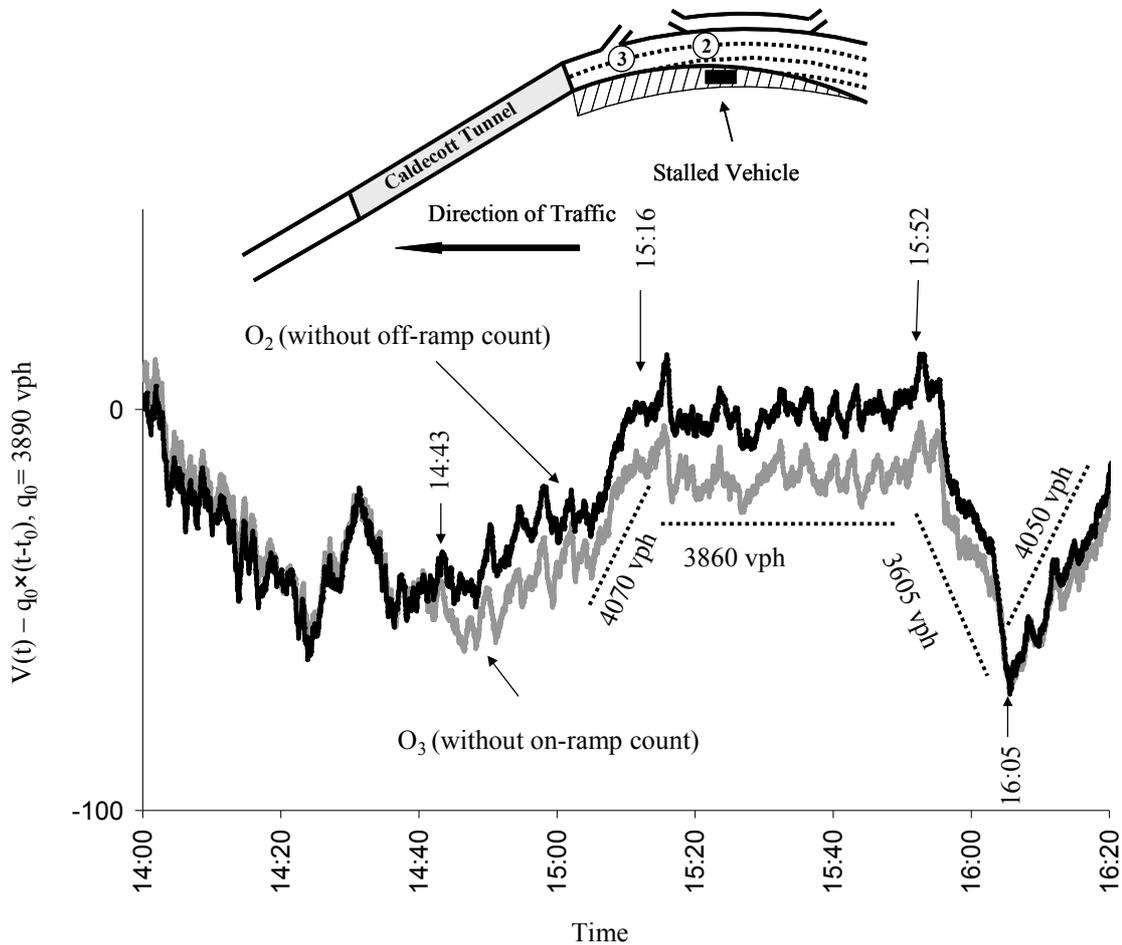


Figure 3.11 O-curves from locations 2 and 3 (SR-24, Orinda, California, August 21, 2002)

Figure 3.10 and 3.11 display the O-curves from locations 2, 3 and 4 on August 21, 2002; they are drawn in pair-wise fashion so that in both figures, vehicle counts were conserved. These curves, however, can be used collectively to verify the location of active bottleneck. The O-curves from locations 3 and 4 shown in Figure 3.10 remained superimposed during the entire observation period, indicating that the traffic between the

intervening segment was always freely flowing. The displacement between the curves from locations 2 and 3 (see Figure 3.11) beginning at about 14:43 reveals the formation of the queue upstream of location 2. Therefore, the curves from locations 2, 3, and 4 collectively show that an active bottleneck resided somewhere between locations 2 and 3.

Breakdown was observed at approximately 15:16 (see Figure 3.11) and it diminished outflows from 4070 vph to 3860 vph; these changes in flows are annotated in Figure 3.11 and they do not include on-ramp flow.

At 15:52, a passenger car made an emergency stop in the median at a location annotated in Figure 3.9, a short distance upstream of location 2. The stalled vehicle remained there until 16:20; this event is documented in video.

Although the stalled vehicle did not block a travel lane, it temporarily reduced the flow departing the site. Figure 3.11 shows that flows dropped from 3860 vph to 3605 vph. Evidently, the vehicle stall initially caused a rubber-necking effect among passing motorists.

The event caused the vehicle accumulations between locations 2 and 3 to return to that of the free flow state. This is evident in the 5-min moving average of vehicle accumulations shown in Figure 3.12. As an apparent consequence of the lower vehicle accumulation, the outflow past location 3 rose substantially; Figure 3.11 shows that at 16:05, the outflow measured at location 3 increased from an average rate of 3,605 vph to 4,050 vph.

This new rate was higher than the queue discharge rate (of 3,860 vph) observed prior to the vehicle stall and this rate persisted for an extended time, as is evident in the figure.

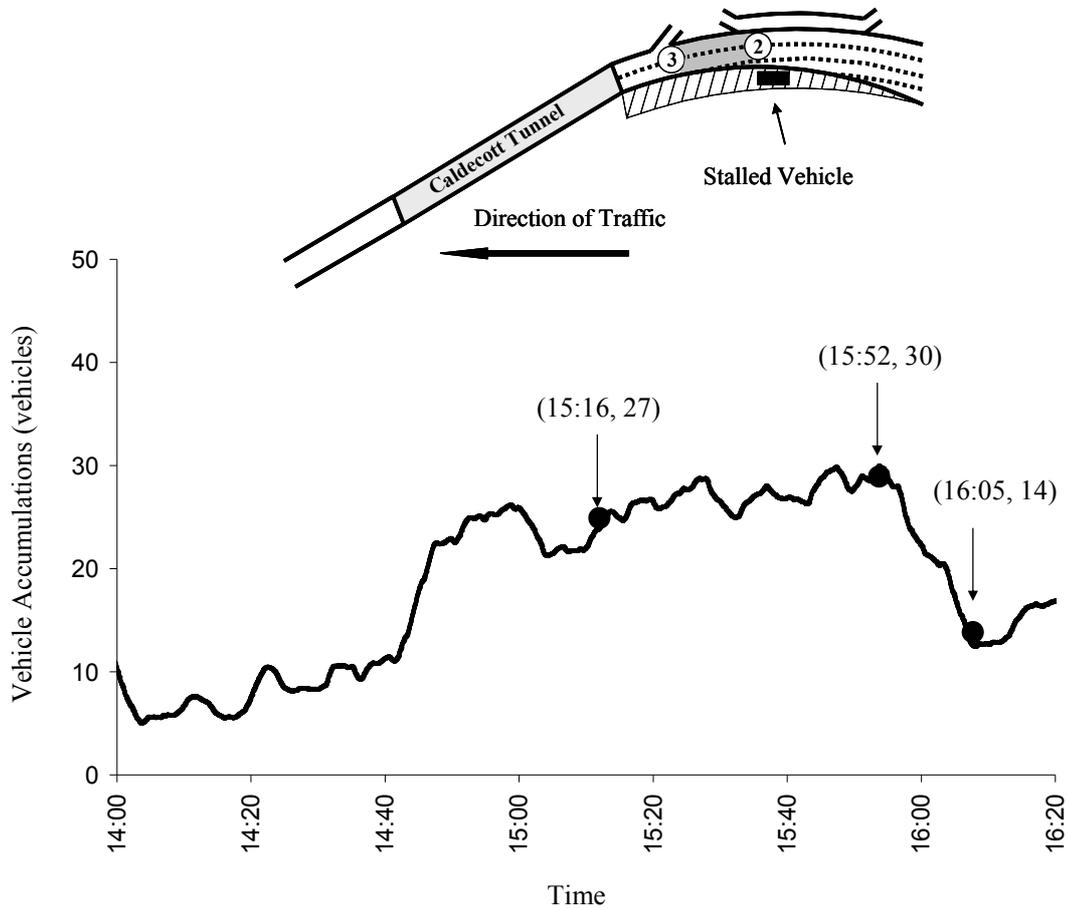


Figure 3.12 Five-minute moving average of vehicle accumulations from locations 2 and 3 (SR-24, Orinda, California, August 21, 2002)

Findings presented in section 3.1 and 3.2 show that vehicle accumulations in the vicinity of active bottleneck are good proxies for the mechanisms triggering breakdown.

Breakdown only occurred after vehicle accumulation exceeded the bottleneck's critical accumulation. Breakdown could be avoided entirely or recovered by controlling the

vehicle accumulations. Breakdown could recover when the vehicle accumulations diminished sufficiently below the site's critical accumulation.

These findings came to light by monitoring the vehicle accumulations in the vicinity of active bottlenecks. Vehicle accumulations at the SR-24 site were monitored in accurate fashion using individual vehicle arrival times (at fixed locations) that were manually extracted from videos. Vehicle accumulations at the Gardiner Expressway, however, could not be monitored in such an accurate manner because the data were taken here were extracted from loop detectors and these naturally exhibited bias (i.e., systematic count errors). The algorithm for estimating vehicle accumulation was developed, in part, to remedy the problem of detector bias. Section 4 explains the algorithm and its applications.

## 4. An algorithm for estimating vehicle accumulation and its applications

This chapter presents; (i) an algorithm for estimating vehicle accumulations from the counts made by ordinary detectors (e.g. inductive loops detectors) placed in series in section 4.1; (ii) the results of testing the algorithm in section 4.2; and (iii) the algorithm's applications (e.g. real-time traffic control, incident detection and delay estimation) in section 4.3.

The algorithm's estimates of the vehicle accumulations can be obtained in real-time at short intervals of a second or so. The algorithm is, thus, well suited for monitoring the vehicle accumulations near a bottleneck prior to breakdown and the estimates it furnishes can, in turn, dictate control actions (e.g. metering rates) that prolong higher outflows from the bottleneck.

The algorithm can also be used to detect incidents by monitoring the rate at which the vehicle accumulations increase: an incident causes the vehicle accumulation to increase rapidly while activation of a recurrent bottleneck causes the accumulation to increase gradually. Although the algorithm cannot function in a self-correcting manner once a queue arises on the freeway segment spanning the detectors in series, it can be used to estimate delays in an off-line fashion (e.g. for planning purposes) after freely flowing traffic has been restored. Section 4.3 describes these applications in more detail.

## 4.1. Algorithm Description

The algorithm's logic is explained with the aid of Figure 4.1. It displays curves of cumulative vehicle count,  $N$ , vs time,  $t$ , measured by the detectors at an upstream location,  $X_U$ , and by the detectors downstream at  $X_D$ .

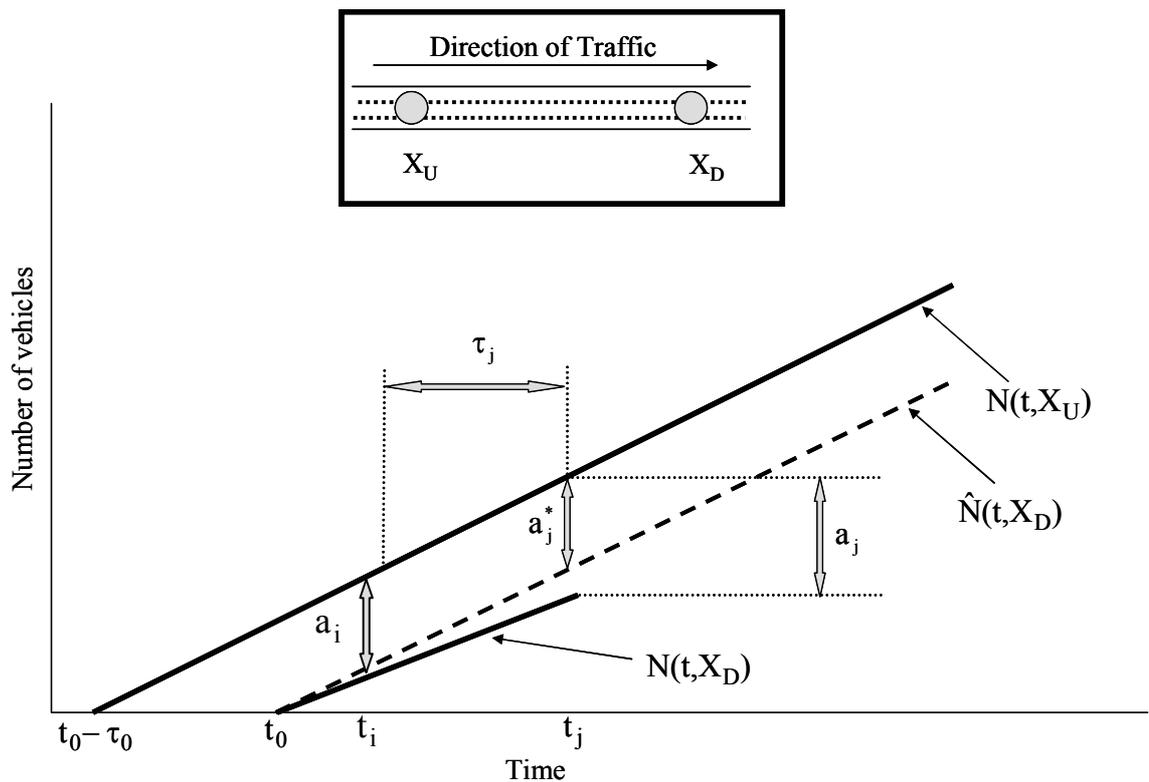


Figure 4.1 Hypothetical input-output diagram

The counts at  $X_D$  began a time  $\tau_0$  after those at  $X_U$ , where  $\tau_0$  is a freely flowing vehicle's trip time between the two locations. At any time  $t_i$ ,  $i \geq 0$ , the accumulation between detectors,  $a_i$ , is the vertical separation between the  $N$ -curves; i.e.,

$$a_i = N(t_i, X_U) - N(t_i, X_D), \text{ as shown in the figure.}$$

The matter is made complicated by the bias that occurs in the detector counts; when left uncorrected, errors in the estimate of  $a_i$  can increase with increasing  $i$ . Bias may occur in the detectors at  $X_U$ , at  $X_D$  or at both. But since the goal here is to estimate an  $a_i$ , it suffices to correct the counts at one location (e.g.  $X_D$ ) relative to those at the other ( $X_U$ ).

The algorithm makes these corrections automatically at various  $t_j$ ,  $j \geq i$ . Doing so requires estimates of  $\tau_j$ , the trip time between locations for a vehicle arriving at  $X_D$  at time  $t_j$ . How the algorithm obtains these estimates will be described momentarily. Note for now that with the  $\tau_j$ , the corrected accumulation,  $a_j^*$ , is  $N(t_j, X_U) - N(t_j - \tau_j, X_U)$ , as shown in Figure 4.1.

The accumulation at any earlier time  $t_i$  can then be corrected by proportioning the difference between  $a_j^*$  and  $a_j$ ; i.e.,

$$a_i^* = N(t_i, X_U) - N(t_i, X_D) + b N(t_i, X_D),$$

where  $a_i^*$  is the corrected estimate at time  $t_i$ ; and

$b$  is a dimensionless correction factor computed as  $(a_j^* - a_j) / N(t_j, X_D)$ .

The  $j$  is reset to zero ( $t_j = t_0$ ) when an  $a_j^*$  is obtained and the above process is then repeated.

An  $a_j^*$  is obtained whenever the  $\tau_j$  can be estimated with reasonable accuracy. The process rests on the assumption that in freely flowing traffic, disturbances (flow changes)

propagate forward with vehicles. This assumption has been adopted in traffic flow theories <sup>6</sup> and has been empirically verified <sup>7</sup> even when unqueued flows approach capacity. Freely flowing vehicle trip times are therefore taken as the times measured for disturbances to propagate from  $X_U$  to  $X_D$  in unqueued traffic.

Following from this assumption, the algorithm matches the flow deviations measured in each freeway travel lane at  $X_U$  with those measured later in time at  $X_D$ . (A similar technique was used in Mauch (2002) for tracing backward-moving disturbances in queued traffic.) The deviations are taken relative to a moving average flow. If, for example, the detectors use 20-sec sampling intervals, the count deviation from the average of 15 such intervals (a 5-min average) is defined here as  $(N - \bar{N}_{15})(t_k)$  for time  $t_k$ , where the subscript  $k$  denotes the detector's  $k$ -th sampling interval,  $k = 1, 2, \dots$ , and is computed as

$$(N - \bar{N}_{15})(t_k) = (N(t_k) - N(t_{k-15}))/15 + (N - \bar{N}_{15})(t_{k-1}),$$

and when  $0 < k < 15$  (i.e., when  $t_0 < t_k < t_0 + 5$  mins), the deviation,  $(N - \bar{N}_k)(t_k)$ , is computed as

$$(N - \bar{N}_k)(t_k) = (N(t_k) - N(t_0))/j + (N - \bar{N}_k)(t_{k-1}).$$

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<sup>6</sup> Lighthill and Whitham (1955); Newell (1993)

<sup>7</sup> Windover (2001)

Notation referring to measurement location is omitted from the above equations. The reader will note nonetheless that deviations over time are separately computed for each travel lane and for each location  $X_U$  and  $X_D$ . These computations occur in real-time, with no need for predicting counts in future times, and deviations can be estimated at small time intervals (e.g. every second) by linearly interpolating the counts measured over the detectors' sampling intervals.

Trip times,  $\tau_j$ , are measured (e.g. to a resolution of 1-sec) by matching a given lane's pattern of count deviations at  $X_U$  with those at  $X_D$ . The algorithm virtually constructs a time series of flow deviations as described above for a lane at  $X_D$  for some extended period (e.g. 30 mins) ending at a time  $t_j$ . The time series for the same lane at  $X_U$  is measured from the same start time (e.g.  $t_j - 30$  mins) but ends at time  $t_j - \tau$ , where  $\tau$  is some value several times larger than a feasible value of  $\tau_j$ . In effect, the  $\tau_j$  is estimated to be the temporal shift that most nearly superimposes the entire curve at  $X_U$  with its corresponding curve at  $X_D$ . The shift selected is the one that yields the highest correlation coefficient.

Whenever this correlation is large (e.g. 0.5 or more) in each of the freeway segment's travel lanes, the algorithm takes  $\tau_j$  to be an average of each lane's trip time weighted by the flows in these lanes. This is the  $\tau_j$  used to obtain an  $a_j^*$ . The start and end times of all time series of flow deviations are next advanced by some time step (e.g. 5 mins) and the process repeats.

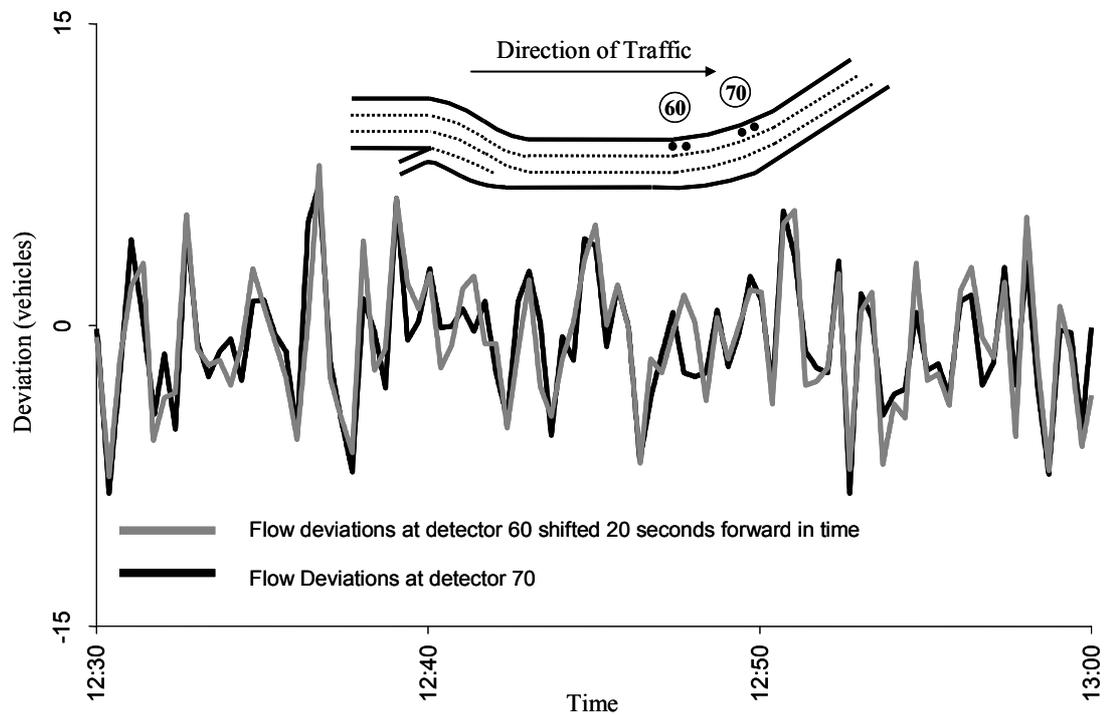


Figure 4.2(a) Example of deviation curves from two neighboring detectors (Gardiner Expressway, Toronto, Canada, March 5, 1997)

Figure 4.2(a) and (b) show how the trip time in the median lane between detectors 60 and 70 at the Gardiner Expressway was estimated by comparing the deviations in flow. Figure 4.2(a) display the deviations in flow observed at the median lane at detector 60 and the deviations in the same lane at detector 70. The curve displayed in Figure 4.2(b) shows how the correlation coefficient changed when the deviation curve from the upstream detector (60) is shifted in forward in time by 1-sec increments. The maximum correlation was obtained when the curve was shifted 20 second. The segment travel time was thus estimated to be 20 seconds.

Deviation curves are also advanced by some time step (i.e., 5 mins) when the correlation in any lane is small (e.g. below 0.5), such that an  $a_j^*$  is not obtained. Low correlations arise when disturbances are altered while propagating from  $X_U$  to  $X_D$ . This can be the result of driver lane-change maneuvers or even erratic behavior on the part of a few drivers. And low correlations almost always occur in queued traffic, since disturbances travel backward in queues.

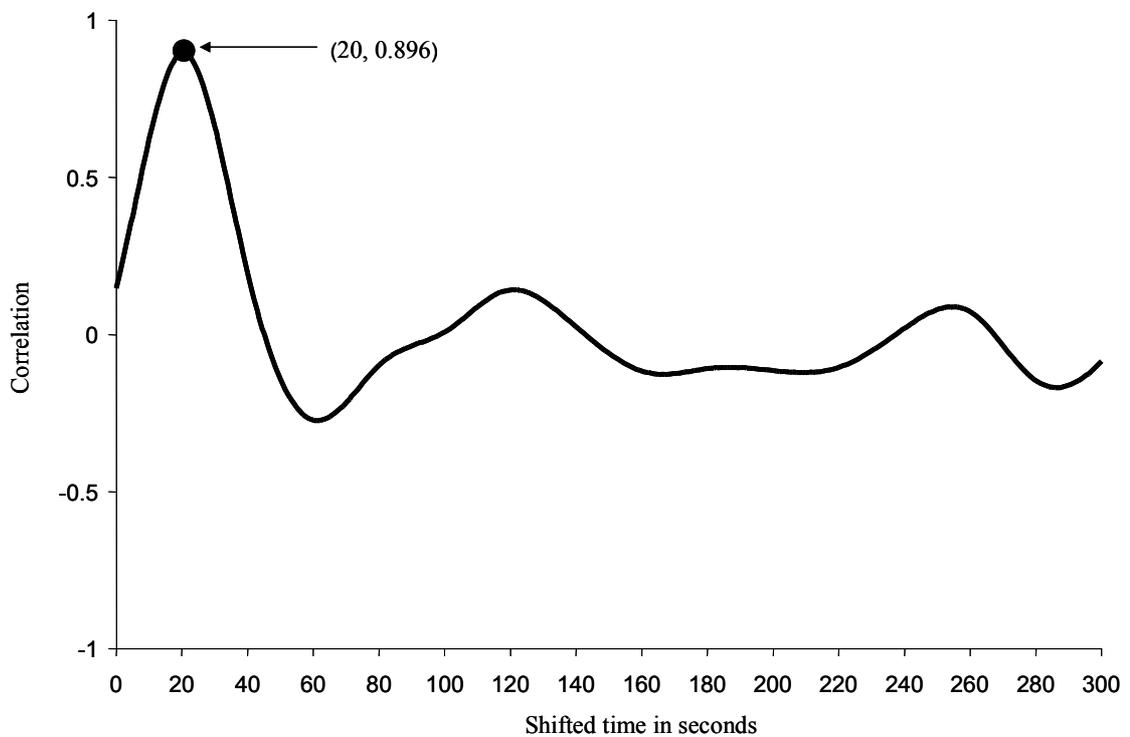


Figure 4.2(b) Estimating segment travel time using cross-correlation technique (Gardiner Expressway, Toronto, Canada, March 5, 1997)

## 4.2. Algorithm Validation

Validation of the algorithm was conducted using data from the site shown in Figure 4.3, a stretch of eastbound Interstate 80 in Berkeley, California. The vehicle counts used as input to the algorithm were collected (over 20-sec sampling intervals) on August 9, 2003 using the inductive loops shown in the figure. Validation data (vehicle accumulations and trip times between the detectors in series) were sampled from video taken from the nearby over-crossing.

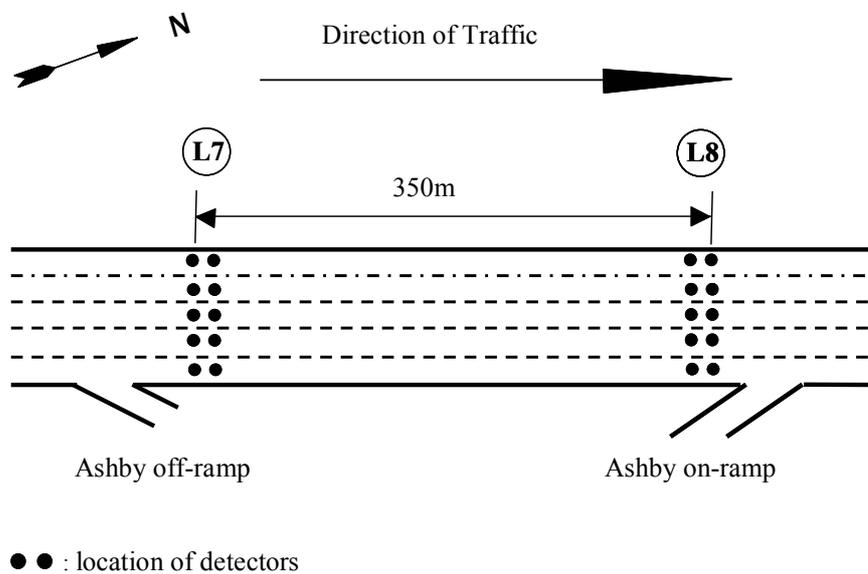


Figure 4.3 Eastbound Interstate 80, Berkeley, California

The algorithm furnished estimates of  $\tau_j$  and  $a_j^*$  up to time  $t = 11:57$  (The time series of flow deviations were constructed at 1-sec intervals for 30-min periods.) Shortly after 11:57, queues formed and persisted on the intervening freeway segment for nearly 5 hours, such that an  $a_j^*$  was not obtained again until  $t = 16:54$ . The correction factor,  $b$ ,

was determined for this later time and used to adjust the estimates of accumulation made during the (entire) queued period.

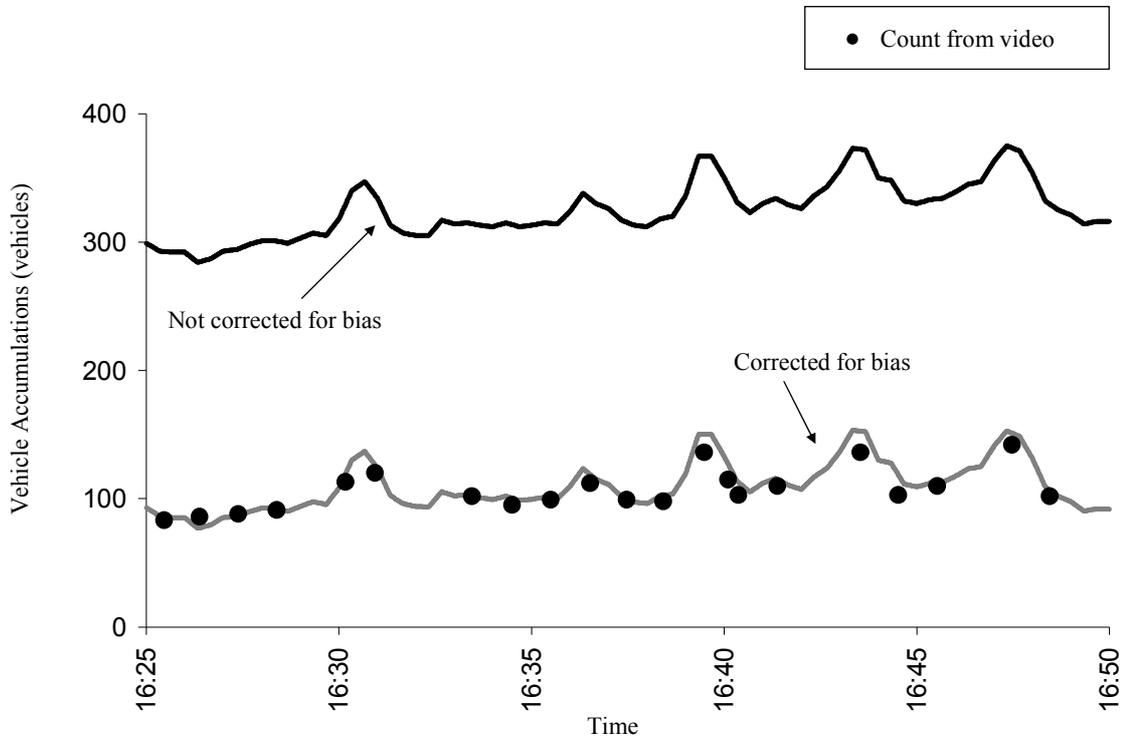


Figure 4.4 Comparison of estimated and actual vehicle accumulations between detectors L7 and L8 (I-80, Berkeley, California, August 9, 2003)

The lightly drawn curve in Figure 4.4 presents these adjusted accumulations for the final 35-mins or so of queuing. The shaded circles are accumulations that were counted directly from the frames of videotape. These circles were extracted at 1-min time steps, except for those times when large trucks obscured from viewing the presence of cars downstream, rendering accurate counts impossible. The (self-corrected) estimates differed on average from the field-measured values by only about 6 percent.

The value of the algorithm's self-correcting feature is underscored using the dark curve in Figure 4.4. This line shows the accumulations the algorithm would have furnished had the bias factor,  $b$ , not been applied. The dark line deviates from the field-measured circles by 200 vehicles or more, a finding that is not surprising given that the (uncorrected) detector counts were allowed to drift for some 5 hours.

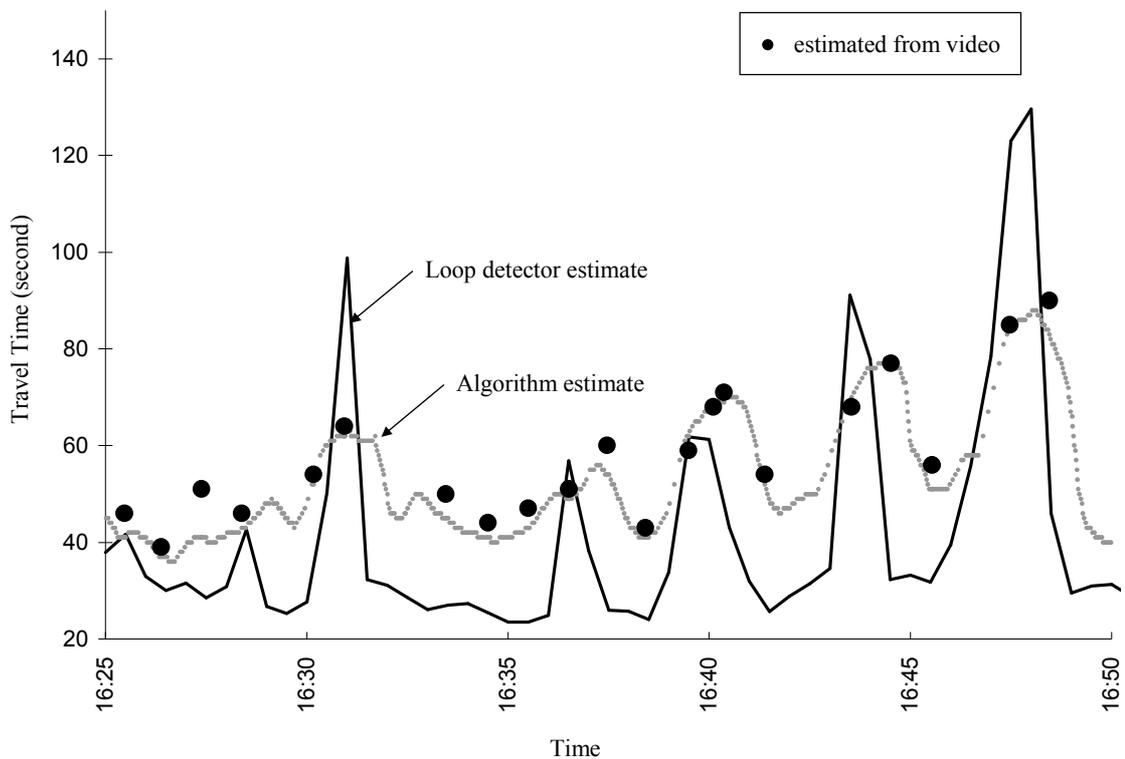


Figure 4.5 Trip time comparison between detectors L7 and L8 (I-80, Berkeley, California, August 9, 2003)

Finally, Figure 4.5 is provided here to validate  $\tau_j$  estimated by the algorithm. The light line in this figure displays the algorithm's (self-corrected) estimates at 1-sec time steps. The shaded circles in Figure 4.5 are trip times sampled from the video; each is the average of 4 vehicles observed in the freeway's shoulder and median lanes. These estimates agree with the field-measured values to within 7 percent.

In contrast, the dark line in Figure 4.5 displays trip times estimated by averaging the harmonic mean vehicle speeds measured (in all lanes) by the upstream detectors with those measured by the downstream ones<sup>8</sup>. These latter estimates tend to differ substantially from the values sampled from the video. The data displayed in Figure 4.5 show that more accurate estimates of the segment travel time can be obtained using the algorithm for estimating vehicle accumulation.

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<sup>8</sup> According to Oh, Jayakrishnan and Recker (2002), this is a common approach to trip time estimation.

## 4.3. Applications of the Algorithm

This section describes how the algorithm can be applied as part of traffic control schemes, for automatic incident detection and for delay estimation. These applications are based on observations from a few days of data and are on-going research topics.

### 4.3.1. Real-time ramp metering strategy

Findings from this dissertation revealed that breakdowns only occurred after the vehicle accumulations in the vicinity of the bottleneck exceeded some critical accumulation.

When vehicle accumulations remained below the critical value, high outflows were sustained for the entire afternoon rush (e.g. on May 11, 1997 at the Gardiner Expressway) and breakdown did not occur. This finding suggests that by controlling inflows (e.g. metering rates) to the bottleneck area in response to measured vehicle accumulation, breakdown can be entirely avoided.

In some circumstances, keeping the vehicle accumulation below the critical value during the entire rush period is not possible due to the limited space available for storing queued vehicles on a metered ramp, for example. Still, damping the rate at which the vehicle accumulation increases can postpone breakdown and mitigate the delay. Maintaining the higher (pre-breakdown) capacity for a longer period reduces system-wide delay.

The algorithm's estimates can also be the basis for implementing control after a capacity drop has occurred. Although the algorithm cannot function in a self-correcting manner once a queue arises on the freeway segment spanning the detectors in series, control

during periods of capacity drop can be deployed in a restrictive fashion. (The severity of this control would be limited by certain local conditions, such as the space available for storing queued vehicles on a metered ramp.) Recoveries in outflows observed on February 11, 1997 at the Gardiner Expressway and on August 21, 2002 at the SR-24 suggest such a strategy is possible.

#### 4.3.2. Incident detection

Incidents can be detected and differentiated from the activations of recurrent bottlenecks by monitoring the vehicle accumulations. Both events cause vehicle accumulations to increase. Depending on the causes (i.e., incident or activation of recurrent bottleneck), however, the rate at which accumulations increase can be notably different. Evidence is shown in Figure 4.6.

The figure shows vehicle accumulations between detectors 60 and 70 at the Gardiner Expressway on March 5, 1997 from 12:30 to 18:00. Marked increases in the vehicle accumulations were observed twice during this period. The first sustained increase in the vehicle accumulations (at a rate of 227 vph) was observed at 13:10, as indicated in the figure. This increase was caused by an incident which is described as the presence of “maintenance crew” in the daily unscheduled traffic event report from Toronto’s Road Emergency Services Communication Unit (RESCU). The incident was recorded in the RESCU report at 13:25; this was about 15 minutes after the marked increase in the vehicle accumulation had been observed. The queue caused by the incident was cleared up by 14:09 (according to the RESCU report).

The second sustained increase in vehicle accumulation (112 vph) was observed from 15:10 to 15:52 (Figure. 4.9). According to the RESCU report, formation of a queue was detected between detectors 60 and 70 at approximately 15:40. The cause of the queue was described as “high traffic volume” in the report; it was caused by the activation of the recurrent bottleneck. The summary of the RESCU report describing these two events is presented in Table 4.1, and the actual RESCU report is included in the appendix A.

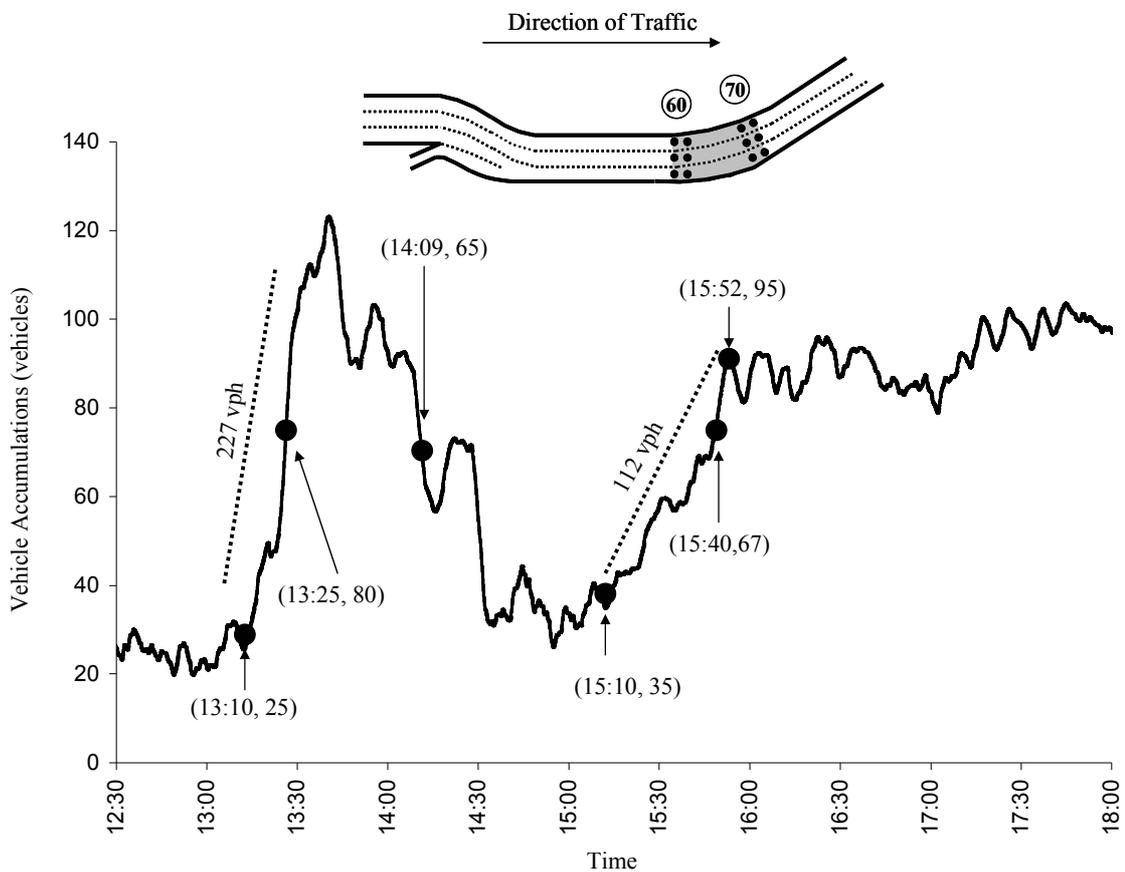


Figure 4.6 Vehicle accumulation between detectors 60 and 70 from 12:30 to 18:00 (Gardiner Expressway, Toronto, Canada, March 5, 1997)

The rate at which the vehicle accumulation increased due to an incident (227 vph) was substantially higher than when it was caused by high traffic volume (112 vph) on March

5, 1997. The highest rate at which vehicle accumulations increased on four other days due to high volume of traffic was 143 vph. Furthermore these rates were sustained for prolonged periods of time; these periods ranged from 10 minutes to nearly 50 minutes. These substantial differences (i.e., the rate at which vehicle accumulations increase) suggest that incidents can be detected and distinguished from the activations of recurrent congestion.

Date	March/5/1997	March/5/1997
Location	Between detectors 60 and 70	Between detectors 60 and 70
Detection time	13:25	15:40
Event Cause	Maintenance Crew	High Traffic volume
Description	Incident blocked one lane	P.M. Peak Congestion
Queue Dissipated time	14:09	19:46

Table 4.1 Description of the two events

#### 4.3.3. Delay estimation

Once vehicle accumulations for an entire day are estimated in an off-line fashion, the delay caused by incidents and recurrent congestion can be computed separately. Figure 4.7 shows the segment travel time estimated by the algorithm between detectors 60 and 70 from 12:30 to 18:00 (on March 5, 1997) and the validity of such estimation has been presented in section 4.2. The area denoted as I, is the delay caused by the incident and R is that of recurrent congestion. These areas can be multiplied with flows during the same period to estimate total delay. These are very important statistics for evaluating performance of freeways and for planning purposes.

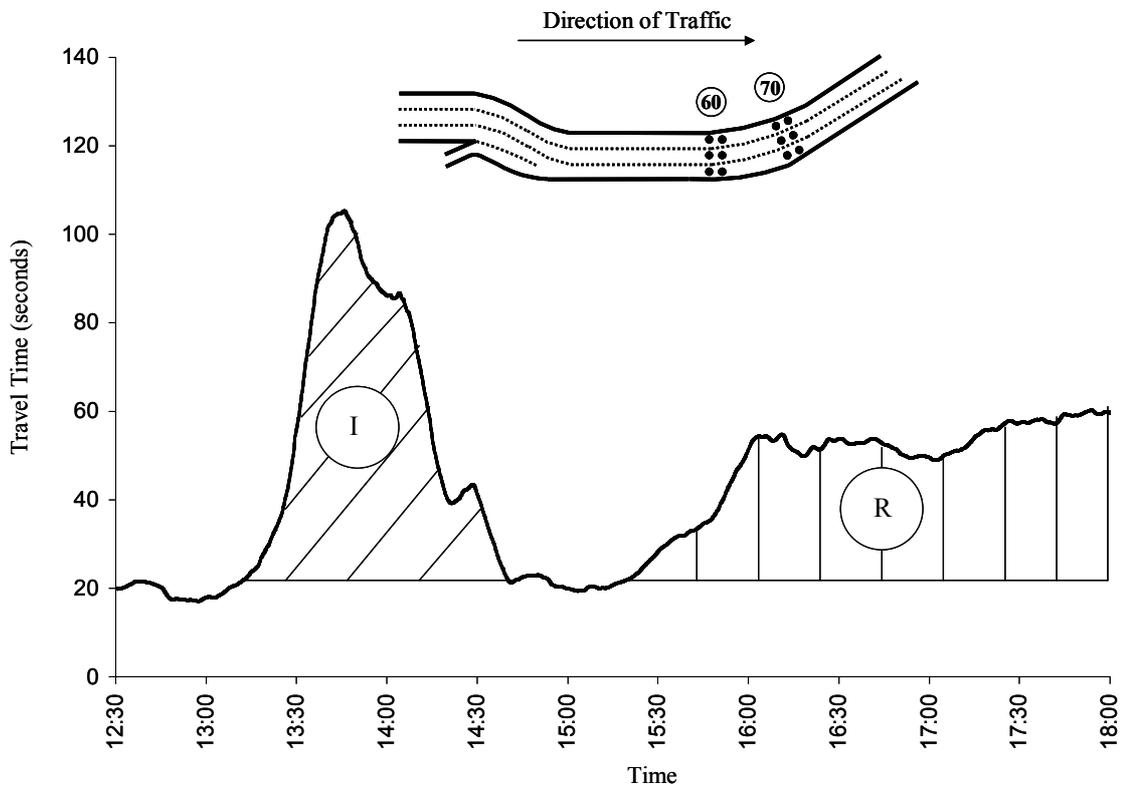


Figure 4.7 Estimated travel times between detectors 60 and 70 under assumption of a FIFO queue discipline (Gardiner Expressway, Toronto, Canada, March 5, 1997)

## 5. Conclusions

Section 5.1 summarizes the findings from this dissertation and section 5.2 presents an outline of areas for further research.

### 5.1. Summary of findings

The breakdown mechanism observed at the Gardiner Expressway was triggered by the freeway on-ramp flow maneuvering into the median lane. The vehicles in the median lane were slowed down due those maneuvering vehicles, and the breakdown mechanism was completed when the speed of the vehicles in the median lane became slower than the shoulder lane traffic. Findings showed that the vehicle accumulations in the vicinity of the bottleneck are good proxies for this breakdown mechanism.

At the SR-24, regrettably, the cameras' vantage points did not offer views of traffic flowing between the four measurement locations and no occupancy data were available. These restrictions made uncovering details of the breakdown mechanism at the SR-24 site impossible. The findings did, however, confirm that the accumulation is a good proxy for this bottleneck's unidentified breakdown mechanism.

Monitoring the vehicle accumulations near the bottleneck revealed many important characteristics of breakdown. Breakdown only occurred after the vehicle accumulation exceeded some threshold (critical accumulation). The critical accumulation was site specific and fairly reproducible. When the vehicle accumulation was reduced sufficiently

below the site's critical accumulation, recovery in outflow was observed. Furthermore, findings showed that breakdown can be entirely avoided by controlling the accumulation.

An algorithm for estimating vehicle accumulations has been developed in this dissertation. The algorithm estimates vehicle accumulations that arise on the intervening (freeway) segments between the detectors. These estimates can be obtained in real-time at short intervals of a second or so. The systematic errors (bias) that invariably arise in detector counts are automatically corrected when traffic is freely flowing.

The validity of the algorithm has been tested by comparing its estimates with actual accumulations counted from videotape. The algorithm's estimates were on average only 6% different from the actual vehicle accumulations. The segment travel times were also estimated using the algorithm under the assumption of a FIFO queue discipline, and the estimated travel times were more accurate (see Figure 4.5) than segment travel time estimated using the speed obtained from loop detector data.

## 5.2. Areas of further research

The algorithm can estimate the vehicle accumulations in real-time at short intervals of second or so. The algorithm is thus well suited for monitoring accumulations near a bottleneck prior to capacity drops and the estimates it furnishes can, in turn, dictate control actions (e.g. metering rates) that prolong higher bottleneck outflows. One such strategy that employs ramp metering has been qualitatively described in section 4.3.1.

This study, however, did not empirically demonstrated how such metering strategy (in section 4.3.1) can mitigate the delay. Cassidy and Rudjanakanoknad (2002) presented a study of one such strategy, and their efforts to develop more systematic ways of controlling freeway traffic using ramp metering is ongoing.

Section 4.3.2 presented an example of how incidents and the activations of recurrent bottleneck can be detected and differentiated by monitoring the vehicle accumulation. Incident reported in this dissertation caused the accumulation to increase at a rate substantially higher than what was generated by a recurrent bottleneck activation. This is, however, based on comparing the observations from only one incident with multiple non-incident days. Additional days of incident data need to be analyzed to develop more systematic ways of detecting incidents by monitoring the vehicle accumulations.

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## Appendix-A

### DAILY UNSCHEDULED TRAFFIC EVENT REPORT (Gardiner Expressway, March 5, 1997)

For 05-MAR-1997 00:00 To 06-MAR-1997 00:00

QUEUE EVENTS

Report Date: 97 3 6 01:16:02

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Event ID : 5406 Event Type : QUEUE  
Detected : 5-MAR-1997 15:39:51 Confirmed : 1-JAN-1900  
00:00:00 Owner : MFREDERICKS  
Queue Source : OPERATOR  
Queue Cause : TRAFFIC VOLUME  
Event State : OPERATOR DECLARED  
Start Location: 99m downstream of STRACHAN, 1206m upstream of DUFFERIN  
on the Westbound\_Gardiner  
End Location : 448m downstream of REES, 0m upstream of SPADINA on the  
Westbound\_Gardiner  
Severity : not severe  
Manual Q Track: disabled  
System Q Track: enabled  
Precipitation : not specified  
Road Condition: not specified  
Description :  
Updated: 5-MAR-1997 15:39:52

#### EVENT UPDATES:

-----  
Updated: 5-MAR-1997 15:39:57 Manual Q Track: enabled  
Updated: 5-MAR-1997 15:48:19 Owner : NOT\_OWNED  
Updated: 5-MAR-1997 15:48:38 Owner : HPANESAR  
Updated: 5-MAR-1997 15:51:22 Event State : CONFIRMED  
Updated: 5-MAR-1997 15:51:51 Description : P.M. peak hour  
congestion.  
Updated: 5-MAR-1997 16:03:15 Owner : NOT\_OWNED  
Updated: 5-MAR-1997 16:03:41 Owner : MFREDERICKS  
Updated: 5-MAR-1997 16:13:02 End Location : 297m downstream of BAY,  
0m upstream of YORK on the Westbound\_Gardiner  
Updated: 5-MAR-1997 16:13:02 Manual Q Track: disabled  
Updated: 5-MAR-1997 16:13:16 Manual Q Track: enabled  
Updated: 5-MAR-1997 18:04:35 Start Location: 599m downstream of  
DOWLING, 815m upstream of PARKSIDE on the Westbound\_Gardiner  
Updated: 5-MAR-1997 18:04:35 End Location : 388m downstream of REES,  
60m upstream of SPADINA on the Westbound\_Gardiner  
Updated: 5-MAR-1997 18:04:35 Manual Q Track: disabled  
Updated: 5-MAR-1997 18:04:39 Manual Q Track: enabled  
Updated: 5-MAR-1997 18:39:05 Start Location: 299m downstream of  
COLBORNE LODGE, 268m upstream of ELLIS on the Westbound\_Gardiner  
Updated: 5-MAR-1997 18:39:05 Manual Q Track: disabled  
Updated: 5-MAR-1997 18:39:28 Manual Q Track: enabled

Updated: 5-MAR-1997 19:18:21 End Location : 645m downstream of  
 SPADINA, 10m upstream of BATHURST on the Westbound\_Gardiner  
 Updated: 5-MAR-1997 19:18:21 Manual Q Track: disabled  
 Updated: 5-MAR-1997 19:18:27 Manual Q Track: enabled  
 Updated: 5-MAR-1997 19:23:51 Owner : NOT\_OWNED  
 Updated: 5-MAR-1997 19:24:01 Owner : HPANESAR  
 Updated: 5-MAR-1997 19:31:42 End Location : 1305m downstream of  
 STRACHAN, 0m upstream of DUFFERIN on the Westbound\_Gardiner  
 Updated: 5-MAR-1997 19:31:42 Manual Q Track: disabled  
 Updated: 5-MAR-1997 19:32:04 Manual Q Track: enabled  
 Updated: 5-MAR-1997 19:46:03 Event State : CONFIRMED(SYSTEM CLEAR)  
 Updated: 5-MAR-1997 19:46:19 Event State : FREE  
 Updated: 5-MAR-1997 19:46:19 Manual Q Track: disabled

DAILY UNSCHEDULED TRAFFIC EVENT REPORT  
 For 05-MAR-1997 00:00 To 06-MAR-1997 00:00  
 INCIDENT EVENTS  
 Report Date: 97 3 6 01:15:57  
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Event ID : 5400 Event Type : INCIDENT  
 Detected : 5-MAR-1997 13:25:22 Confirmed : 1-JAN-1900  
 00:00:00 Owner : RHENDERSON  
 Event Source : OPERATOR  
 Event Cause : MAINTENANCE CREW  
 Event State : OPERATOR DECLARED  
 Severity : not severe  
 Station ID : dw0060dwg  
 Location : 399m downstream of STRACHAN, 906m upstream of DUFFERIN  
 on the Westbound\_Gardiner  
 Blocked Lanes : 00X  
 Left Shoulder :  
 Right Shoulder:  
 2nd Incident : not specified  
 Precipitation : not specified  
 Road Condition: not specified  
 Description :  
 Updated: 5-MAR-1997 13:25:23

EVENT UPDATES:

-----  
 Updated: 5-MAR-1997 14:05:39 Owner : NOT\_OWNED  
 Updated: 5-MAR-1997 14:05:55 Owner : MFREDERICKS  
 Updated: 5-MAR-1997 14:09:02 Event State : FREE  
 DAILY UNSCHEDULED TRAFFIC EVENT REPORT