H-1 Freeway Ramp Closure: Simulation and Real-world Experiment

Panos D. Prevedouros, Ph.D.
Associate Professor of Civil Engineering
Department of Civil Engineering, University of Hawaii at Manoa
2540 Dole Street 383, Honolulu, Hawaii 96822
phone: (808) 956-9698
fax: (808) 956-5014
e-mail: pdp@hawaii.edu

July 24, 1998

ABSTRACT

Honolulu’s H-1 Fwy. fulfills the MUTCD description for severe congestion. It needs, therefore, some form of flow management for the resolution of bottlenecks. Ramp closure experiments in Detroit resulted in remarkable improvements to freeway flow. Ramp closure also lends itself to temporary experimentation. Ramp metering is less disruptive but storage and acceleration length requirements make it largely impractical for most on-ramps of the H-1 Fwy.

Simulations on a 10.5 km segment of the westbound H-1 Fwy. using KRONOS were able to replicate existing conditions well and identified a prime candidate on-ramp whose closure or metering would produce considerable flow improvements.

A 2-week ramp closure experiment with traffic cones was undertaken along with extensive data collection (volumes, moving observer travel times, AUTOSCOPE-derived speeds). The simulated and actual results are compared. Motorists’ perceptions of the experiment were positive despite the mixed results and modest actual improvement.
INTRODUCTION

The purpose of this paper is to present findings from research on the improvement of flow conditions along Honolulu’s H-1 freeway, one of the busiest and most congested 6-lane freeways in the nation. Given the overall research objective of bottleneck identification and subsequent planning for short- and long-term resolution, the research proceeded in the following steps:

1. investigation of characteristics of the H-1 Fwy.;
2. investigation of ramp closure and ramp metering characteristics and applicability to H-1 Fwy.;
3. establishment of base case for freeway simulation;
4. analysis of alternative ramp closure/ramp metering scenarios with freeway simulation;
5. recommendation for real-world experimentation;
6. experiment and evaluation design;
7. normal and experiment period data collection (volumes, travel times, speeds, perceptions);
   and,
8. comparison of data (normal vs. experiment).

The presentation in this paper is structured basically along the aforementioned research steps. The last section presents the conclusions and summarizes the lessons learned.

FREEWAY ACCESS STATISTICS AND EFFECT OF ACCESS TO MAINLINE SPEED

A search was conducted for information which could be used to compare the density of access ramps on H-1 Fwy. with other urban freeways in North America. The results are shown in Table 1. The statistics for this table were obtained from detailed maps or sketches from various sources including TRB papers, reports and GIS maps. The estimates presented in Table 1 are quite approximate because segment lengths were either constrained by the map’s coverage or soft selection rules were used, such as termination of a segment within 8 km of the CBD or when the ramp density became low. Despite these shortcomings, Table 1 effectively illustrates the vast differences in ramp density on central segments among urban freeways.

Forty freeway segments are presented and ranked based on their density of ramps per kilometer. H-1 Fwy. westbound (WB) ranks 6th and H-1 Fwy. eastbound ranks 11th in density of ramps. Furthermore, the 5-km long WB segment between the King St. off-ramp and the Vineyard Blvd. off-ramp has a ramp density of about 5.0 ramps per kilometer which puts it on par with the top ranked freeway in Table 1, the Dan Ryan Expressway in Chicago, IL. However, the Ryan Expressway is 4 to 6 lanes wide per direction and, most importantly, most off-ramps are on the right side of the Expressway and most on-ramps are on the left side. In contrast, H-1 Fwy. has 3 lanes per direction, and all ramps are on the right side. Notably, most freeway segments that outrank the H-1 Fwy. are managed with ramp metering. These data imply that some form of freeway management, either ramp closures or metering, is required for the central part of the H-1 Fwy.

Lomax et al. (1) estimated freeway speed models as a function of ADT and frequency of on-ramps in NCHRP Project 7-13, including the following metric model (eq. 47 in ref. 1):

\[
\text{SPEED} = 147.1 - 3.2 \times \frac{\text{ADT}}{\text{L}} - 4.6 \times \text{ACCESS}
\]

where, \(\text{SPEED}\) = average peak hour speed in km/h; \(\frac{\text{ADT}}{\text{L}}\) = average daily traffic per lane; and, \(\text{ACCESS}\) = frequency of freeway ramps per km.
Using this formula and historical Hawaii State DOT (HDOT) counts, speeds were estimated for eight H-1 Fwy. segments as follows:

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>RAMP</th>
<th>SPEED (km/h)</th>
<th>LOCATION</th>
<th>RAMP</th>
<th>SPEED (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Likelike</td>
<td>ON</td>
<td>48</td>
<td>Kapiolani</td>
<td>OFF</td>
<td>74</td>
</tr>
<tr>
<td>Liliha</td>
<td>ON</td>
<td>24</td>
<td>McCully</td>
<td>ON</td>
<td>47</td>
</tr>
<tr>
<td>Ward</td>
<td>ON</td>
<td>31</td>
<td>Lunalilo</td>
<td>ON</td>
<td>19</td>
</tr>
<tr>
<td>Punahou</td>
<td>OFF</td>
<td>56</td>
<td>School</td>
<td>ON</td>
<td>19</td>
</tr>
</tbody>
</table>

(*) On ramps merge with left lane; most off ramps are adjacent to the right lane.

TABLE 1: Comparison of Space Distribution of Freeway Ramps
(Central parts of freeways, arranged by "ramps per kilometer")
This simple formula proved effective in identifying the suspected bottlenecks on both
directions and can be used to roughly estimate the potential benefit of ramp closure. Closure of
two ramps on the westbound direction (i.e., the Lunalilo and School on-ramps identified above as
bottlenecks) results in a speed estimate of 35.3 km/h compared with the 32.2 km/h estimated
under existing conditions, a 9.6% improvement. The impact of ramp closure to surface streets,
however, may negate the freeway improvement. Simple methods like the one above are
appropriate for an initial assessment of “black spots”. A thorough analysis at the corridor or
network level is required prior to deciding on long term actions.

RAMP CLOSURES AND RAMP METERING

Only one study of ramp closures, conducted in Detroit, Michigan, was found and is
summarized herein. The lack of ramp closure studies is not surprising because: 1) many
metropolitan areas have implemented metering-based controls, and, 2) freeway congestion in
metropolitan areas has, in part, relocated to suburban areas, following the exodus of residents
from the central city and the development of large activity and employment centers in the suburbs.
Typically, suburban freeway segments have modern design with high-speed and well spaced
ramps (e.g., H-2 Fwy. on Oahu), which make the use of ramp closure for congestion control
largely irrelevant. Ramp closures, however, are applicable and beneficial to central city freeway
segments designed in the ’50s and ’60s, as the following study demonstrates.

In the early 1960s, the Michigan DOT conducted research to develop a freeway control
system in central Detroit that would reduce congestion, improve capacity and provide a safer
travel environment (2). Their real world application consisted of experimental ramp closures
during peak periods. The foci of the study where nine on-ramps in the most central 5 km segment
along the John C. Lodge Fwy. Table 1 shows that the H-1 and Lodge freeways are comparable in
terms of ramp density.

Three weeks before the ramp closure experiment, various traffic measurements were taken
on the freeway and on the surrounding streets which were expected to carry the diverted traffic.
Cameras were used extensively to monitor the condition of the freeway before and during the
experiment. (Lines were placed on the TV monitors to provide reference points for measuring
travel times. This is not necessary at present as devices like AUTOSCOPE accommodate speed
detectors on every lane and automatically measure speeds and report averages for user-selected
intervals.) The results of the experiment were remarkable (3):

- Actual volumes serviced by the freeway increased 3.5% to 13.7%.
- Freeway traffic stoppages due to congestion decreased 22% to 92.5%.
- The length of the stoppages was reduced by 28% to 86%.
- Average freeway speed (averages over all periods and locations) increased markedly from 43
to 60 km/h in the A.M. period, and from 41 to 62 km/h in the P.M. period.
- Comparison of congestion duration with and without ramp control was made. Northbound
  traffic congestion periods were shortened by 37 minutes, and southbound traffic congestion
  periods were shortened by 16 minutes, on the average.

Traffic conditions on Detroit streets were investigated at 48 surrounding intersections.
The traffic diverted from several ramps in the Detroit study indicated a high percentage (22%) of
short trip travelers. For some ramps, all diverted traffic was not freeway oriented, that is,
virtually none of the traffic entered the freeway on open downstream ramps. At some other
ramps, the opposite was observed, that is, nearly all diverted traffic proceeded to the next open
freeway on-ramp downstream. In general, little or no detrimental effects were observed on Detroit's signalized intersections.

In summary, several similarities between the Lodge freeway in Detroit and the H-1 freeway in Honolulu are apparent. Both have a very dense spacing of ramps. Both freeways have ramps that cause slow downs due to geometric characteristics and short acceleration lanes. Both freeways have ramps with significant amounts of short-trip traffic. And, both freeways do not employ ramp metering for flow control (ramp metering presently exists on the Lodge Fwy.). If the Detroit experience is transferable, then, overall corridor conditions may improve by limited ramp closures along the H-1 Fwy.

The MUTCD (3) specifies a number of conditions, if one of which is present, ramp metering should be considered for freeway management. A criterion is freeway operating speeds which remain at less than 50 mph (80 km/h) for at least half an hour. Furthermore, “[f]reeway operating speeds less than 30 mph [50 km/hr] for a half-hour period would be an indication of severe congestion (3).” The central part of the H-1 Fwy. (both directions) clearly fulfills this MUTCD condition for severe congestion. Specifically, recent data show that WB H-1 Fwy. speeds are below 50 km/hr for at least one hour during the morning peak period (Table 2).

Ramp metering was first installed on the Eisenhower Expressway in Chicago in 1963 following successful metering applications in New York tunnels and lane closures in Detroit (4). By 1995, ramp meter controls had been installed in the freeway systems of 23 metropolitan areas. Improvements of 5-6% in volumes carried over pre-metered conditions have been observed in several areas (4). A major benefit of ramp metering is the transitioning function of splitting up platoons for merging with the freeway mainline so that flow breakdowns are avoided. A positive concomitant outcome of ramp metering is the diversion of some short trips from the freeway. Selected area-specific results are summarized below.

Seattle has experienced many benefits from their freeway management system which includes ramp metering: Despite a 10% to 100% growth of traffic on various segments on the I-5 freeway, speeds have remained steady or increased by up to 48% and accident rates have fallen to a level of 62% based on the pre-freeway management period (5). Similarly, the Minnesota DOT observed a capacity increase to the level of 2,200 vph per lane compared to the level of 1,800 vph per lane prior to metering; average speeds rose from 55 to 74 km/h and accidents on a segment of I-35W dropped from 421 to 308 per year (4). The experience with ramp metering has been positive in Denver as well (6). They report speed increases of up to 58% and a decrease in accidents of 5% during the periods when the meters are on as opposed to an increase of 16% during the non-metered periods. Furthermore, they observed much-larger-than-anticipated capacity gains with freeway flows of 2,450 vph per lane and a less than expected diversion to local streets. Actually the prevalent form of change observed was in arrival time, thus, a concomitant benefit of the Denver ramp metering was peak spreading (6). The implementation in France and the Netherlands of ALINEA, a local ramp-metering strategy, improved the base conditions without ramp metering and in several occasions was superior to coordinated ramp metering. ALINEA was found to also improve traffic conditions on the arterial network adjacent to the freeways (7). A study by JHK Associates (8) identified the following impacts of ramp metering on parallel arterials:
Yagar (9) expertly summarized the benefits of ramp metering which include the minimization of total travel time, improvement in capacity utilization, avoidance of routes that increase system or societal costs, application of some order and control over merging maneuvers, improvement of corridor travel time consistency and (in several cases) public acceptance.

The benefits of ramp metering were presented above. However, there is as yet no clear verdict on the true network-wide benefits of ramp metering. Several studies which are summarized below attest to this.

First, Yagar (9) states the following disbenefits: lengthening of average trip, reduction of land values, preferential treatment for through traffic (e.g., favoring suburb-to-CBD travel; this also was noted in the Detroit study of ramp closures), alteration of the historical status quo, and metering system installation and operation costs.

An extensive simulation study (10) using INTRAS was applied to the Garden Grove Fwy. in Orange County, California. It concluded that a significant amount of diversion from the metered ramps must occur in order to improve the overall network performance with ramp metering, and that requires a supply of alternative routes with sufficient capacity (and good LOS). Even in their best case scenario, however, the improvements were characterized as modest and nowhere near the 40% to 50% improvements shown in other studies. The authors stress that the other studies ignore the details of the alternate routes and caution that no improvements may be realized if the alternate route network is poor.

Banks (11) conducted ramp metering research on San Diego’s freeway system. He observed that (similar to the H-1 Fwy.) most congestion on the San Diego freeway system is caused by normal flow breakdown rather than incidents. He concluded that ramp metering can eliminate mainline queuing and delay only if metering rates are set low enough to keep flows below the mainline capacity which likely will cause worse overall delays due to ramp queuing and diversion. In subsequent research, Banks (12) raises further doubts about the utility of ramp metering: “there is substantial risk that metering will be counter-productive unless it is precise, and there is reason to doubt that the necessary precision is possible.” He mentions, however, that ramp-metering probably will be beneficial in breaking platooned arrivals caused by signals upstream of the ramp. Specifically, Banks found that the major cause of breakdowns at the merging point of on-ramps and freeways were platoons of vehicles generated by traffic signals at the vicinity of the on-ramp.

Hellinga and Van Aerde (13), using INTEGRATION to investigate ramp metering strategies, added support to Banks’ (11) contention that ramp metering needs to be precise in order to be effective. In one case study, they found that “initiating ramp metering just 2 minutes earlier than optimal can negate any metering benefits.”

In addition to these concerns, major design elements make the successful implementation of ramp metering problematic. The maximum discharge flow of a metered, single-lane on ramp is 900 vph; the metering of ramps with higher volumes is problematic and requires extensive analysis.
The three primary elements of successful metering in addition to moderate (i.e., less than 900 vph) demand are storage space, adequate acceleration distance and sight distance (4).

A TTI report (14) on ramp design specifications for ramp-metering applications recommends a minimum acceleration and merging length of 350 meters given that vehicles begin with zero speed at the onset of green on the meter and need to achieve freeway speed. In addition, a sufficient storage length must be provided for the traffic waiting at the ramp meter so that non-freeway bound traffic is not affected by the queuing. Arrival rates between 200 and 800 vph are tabulated in the report along with average acceptable delay ranging between 1 and 5 minutes. Assuming an arrival rate of 800 vph and average acceptable delay equal to 3 minutes, the required vehicle storage length is about 300 meters. The two lengths yield a total length of 650 meters or 2,100 feet which is non-existent at the majority of H-1 Fwy. on-ramps.

The implications of these to the H-1 Fwy. are that: 1) Storage and acceleration length requirements make ramp metering for the H-1 Fwy. useless for all except two ramps; 2) the volume on several on-ramps is very high; metering with a long cycle is almost equivalent to closure since less than 30% of the ramp volume will be permitted entry; 3) ramp metering cannot correct substandard geometric properties; and, 4) ramp metering does not offer relief from the close spacing of ramps along certain segments of the H-1 Fwy.

Given that the H-1 Fwy. clearly fulfills the MUTCD condition of severe congestion, some form of in-flow management is required. Selective ramp closure is a major option, which could be combined with ramp metering on the two on-ramps that fulfill acceleration, storage length and sight distance requirements.

SIMULATION OF RAMP CLOSURE

FRESIM (18) and KRONOS (16,17) were the primary choices for freeway simulation, with INTEGRATION (15) selected for detailed network assessment, once freeway ramp management scenarios were selected from freeway simulation. The KRONOS freeway simulation software (16) developed by the University of Minnesota for the Minnesota DOT was finally chosen for several reasons including input requirements, on-screen and printed outputs (e.g., its color-coded flow emulation is a fast and effective mode of presentation to both engineers and the public), variety of measures of effectiveness, previous experience in Hawaii applications and technical support. FRESIM was run in parallel, but its much slower execution speed, the requirement to put off-ramp volumes in a percentile form (which became time consuming for this project by having to adjust the flows on eight off-ramps), the need for multiple replications and the continuous updates (in 1996 and 1997) for the preparation of FHWA’s TSIS/CORSIM software package made it less desirable for this application. In addition, FRESIM could not achieve average simulated speed estimates close to field-derived speed estimates, as shown below.

KRONOS uses a simple continuum model to represent freeway flow. It’s been continuously enhanced since its initial version (16), and various versions up to KRONOS 8 are described in the literature (17). Unlike other macroscopic simulation programs, KRONOS explicitly models interrupted flow behaviors such as lane changing, merging, diverging, weaving, and spillbacks. Version 8.2 (early 1997) was used in this study.

Several simulations were undertaken for establishing a reliable base case that replicates flow conditions well. Along with the simultaneous collection of all volume data (mainline and ramps), surveillance cameras at four cross sections were used to tape four hours in the morning and afternoon peak periods. These tapes were subsequently analyzed with AUTOSCOPE for the
determination of approximate speed profiles. KRONOS parameters were fine tuned to replicate the speed trends observed on the tapes, particularly the arrival of the congestion shockwave at upstream locations and the relief from congestion towards the end of the simulation period.

Parenthetically, it should be mentioned that Honolulu does not have a school bus system (thus, a large number of children are taken to school by car) and that the state and federal sectors begin work at 7:45 A.M. and 8:30 A.M., respectively. As a result, Honolulu’s rush hour is 30 to 60 minutes earlier that of a more typical large U.S. city.

After some fine-tuning of the capacities and the flow model parameters, KRONOS delivered acceptable speed estimates for three critical cross-sections of the freeway, as shown in Figure 1. Ward Ave. (middle graph) is the location of a primary bottleneck and the location of the experiment. Old Waialae Ave. (top graph) is about 3 km upstream of Ward Ave., and School St. (bottom graph) is about 1 km downstream of Ward Ave. According to Figure 1, KRONOS’s speed profiles for both the A.M. and P.M. periods are in good agreement with the AUTOSCOPE derived speeds from surveillance tapes. FRESIM’s speed profiles were less close to the actual ones.

Once a reliable base case was established, the simulation of alternative ramp-closure and ramp-metering scenarios was relatively simple. In order to model motorist re-routings due to ramp closure or metering, origin-destination information was needed. Destination surveys (with sample sizes of at least 300) at key on-ramps were conducted. These enabled us to determine the percentage of on-ramp traffic exiting at each subsequent off-ramp as well as likely alternative routings given the motorists’ stated destination.

More than thirty alternative scenarios were investigated. Both the KRONOS output (simulation of existing conditions) and experience derived from driving, helicopter surveillance, and discussions with HDOT staff showed that the Lunalilo St. on-ramp is the major bottleneck along the direction analyzed. (Recall that the simple formula in the introduction also identified this on-ramp as a potential bottleneck).

A major advantage of the particular network geometry is that the Lunalilo St. on-ramp extends to become the right lane of the 2-lane Vineyard Blvd. off-ramp, Figure 2 (top drawing). Therefore, the proposed closure is in effect a re-routing to a wide, high-design arterial street, Vineyard Blvd., which offers re-entry onto the freeway. Specifically, on-ramps at about 0.5, 1 and 3 km allow re-entry onto the freeway. In addition, the ramp destination survey showed that in the morning period, 21% of the Lunalilo St. on-ramp traffic exits at the Vineyard Blvd. off-ramp. This closure/re-routing is also depicted in Figure 2 (bottom drawing). The remaining one lane of the Vineyard Blvd. off-ramp is sufficient to carry the freeway traffic exiting at this location.

INTEGRATION was employed to assess the impact to city streets due to the re-routing of the Lunalilo on ramp. INTEGRATION also replicated well the bottleneck caused by the Lunalilo on-ramp and the spillover of congestion to the city streets due to the capacity reduction

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1 Two cars made repeated passes under the 3 surveillance cameras and AUTOSCOPE speed estimates (on the pop-up window of vehicle detection, classification and speed) were compared for accuracy. After small adjustments of the field-of-view settings for proper distance measurement, all AUTOSCOPE speed estimates of the probe vehicles were within 5 km/hr (3 mph) of the speeds recorded by the drivers. Because of odometer uncertainty, etc., speeds are not precise, but they are representative in terms of approximate magnitude and pattern over time.
on the ramp. As expected, it showed that the re-routing which eliminates the merging activity was very beneficial to the city streets that feed the on-ramp. Both INTEGRATION and TRANSYT-7F showed that under various diversion assignments due to the ramp closure, the Vineyard Blvd. arterial would be able to handle the diverted traffic during the A.M. peak period.

Based on these findings, and after a series of presentations to officials and the public, a decision was made by the HDOT and the FHWA to conduct a two week experiment on H-1 Fwy.

**RAMP CLOSURE EXPERIMENT**

It would take the space of a dedicated paper to describe in detail the design and execution of the experiment. Instead, a list of its major components is presented below.

- Traffic cones were placed in 3 m (about 10 ft) intervals to define the closure.
- 2 police officers at the beginning and end of the coning were used for oversight.
- 3 portable variable message signs were placed:
  - one on the freeway, about 300 m (1,000 ft) before the beginning of the coning, notifying motorists of the coning and that the off-ramp is open;
  - one at the signalized intersection that feeds the Lunalilo on-ramp notifying the motorists of the diversion of the ramp. This VMS was placed 2 weeks in advance with a proper message about the forthcoming experiment; and,
  - one at the end of the coning notifying large vehicles to avoid a specific on-ramp due to turning radius problems.
- Continuous monitoring and taping was conducted at six locations, including the experiment site through freeway/arterial surveillance CCTV.
- Continuous volume data collection was conducted at all on and off-ramps in the corridor.
- Several hours of helicopter surveillance and taping were done.
- Ten vehicles and crews were used to conduct travel time surveys along seven routes with departures every 30 minutes.

All the above occurred both for the “base” week (first week in October 1997) and the two experiment weeks (last week in October and first week in November 1997). The experiment period was selected so that school, state or federal holidays were minimal.

The coning and portable VMS, the travel time surveys and the questionnaire survey production and distribution were contracted out by the HDOT to three qualified parties. HDOT was responsible for the volume counts and the overall coordination. The City of Honolulu provided Police, helicopter and CCTV camera surveillance.

The actual results from the experiment were mixed and modest, at best, and did not match the researchers’ and the HDOT’s expectations. There are several reasons for this, but first we provide a representative sample of the outcomes as well as comparisons, where feasible.

Average speeds for specific times (of departure) during Wednesdays were derived from the travel surveys. These are shown as “actual” speeds in Table 2. Control, was the first week in October 1997; the experiment began in the last week of October 1997. During the control period, much like in 1996, a sharp decrease in average speed at 7:00, 7:30 and 8:00 is observed. During the first Wednesday of the experiment, a similar pattern was observed, but the average speeds were lower and there was a slower relief from congestion at 8:30 A.M. It must be noted that this Wednesday (day 3 of the experiment) was the worst day in terms of travel times collected by probe vehicles, and it was free of (known) incidents.
TABLE 2: ACTUAL AND SIMULATED SPEEDS (in km/hr)
A.M. WB H-1 with and without the Lunalilo Closure

<table>
<thead>
<tr>
<th>Wednesday; time:</th>
<th>6:00</th>
<th>6:30</th>
<th>7:00</th>
<th>7:30</th>
<th>8:00</th>
<th>8:30</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACTUAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control (1997)</td>
<td>105</td>
<td>100</td>
<td>52</td>
<td>47</td>
<td>48</td>
<td>96</td>
</tr>
<tr>
<td>Experiment (1997)</td>
<td>101</td>
<td>83</td>
<td>55</td>
<td>41</td>
<td>43</td>
<td>70</td>
</tr>
<tr>
<td><strong>SIMULATED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K8-Oct.'96 (base)</td>
<td>101</td>
<td>78</td>
<td>57</td>
<td>46</td>
<td>47</td>
<td>46</td>
</tr>
<tr>
<td>K8-experiment</td>
<td>101</td>
<td>85</td>
<td>56</td>
<td>55</td>
<td>67</td>
<td>94</td>
</tr>
<tr>
<td>K8-exper.-incident</td>
<td>101</td>
<td>89</td>
<td>33</td>
<td>45</td>
<td>41</td>
<td>52</td>
</tr>
</tbody>
</table>

(Note: K8 = KRONOS freeway simulation software, version 8)

The first row of the “simulated” speeds shows the base case with October 1996 data. The match with the actual control speeds is pretty good. However, the match of the Lunalilo St. on-ramp closure (labeled K8-experiment) simulation results with the actual experiment speeds is similar in shape and in close agreement for several time intervals, but about 40% to 60% too optimistic for the critical 7:30 and 8:00 times.

Many attempts were made to replicate these actual speeds. We found that the coning created a type of impedance akin to an incident, instead of a uniform capacity reduction on a given segment. After several attempts it was discovered that a simulated incident lasting 15 minutes that occurred at 7:00 A.M. which entailed the complete loss of the right lane produced results close to those observed during the worst day of the experiment. This outcome largely validates the hypothesis that the combined impedance of cones, police, VMS, scattered cones (e.g., occasional accidental or intentional breaches of the coning), coning truck, etc. created incident conditions which caused the rapid and long lasting propagation of congestion.

Despite the above, travel times at the freeway segment affected by the experiment (e.g., 5-6 km upstream of the experiment) improved slightly, as the means for each time period show in Figure 3. Furthermore, the resolution of the bottleneck at the Lunalilo St. on-ramp which created repetitive oscillations of the freeway flow (backward propagating congestion shockwaves, which, in-turn, were amplified by shockwaves generated at three upstream heavy-volume on-ramps) resulted in much more consistent travel times during the experiment period (Figure 3).

As predicted with INTEGRATION, travel times on routes feeding the on-ramp decreased, by about 2 minutes (essentially all delay was eliminated). Travel times for paths requiring re-entry to the freeway increased by 2 to 4 minutes, depending on the specific destination and the re-entry ramp chosen.

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1. KRONOS’ incident modeling is limited, in terms of minimum incident duration, to the data interval, 15 minutes in this case.
The plethora of travel time and speed observations allowed to establish the fact that there was a learning effect regarding this experiment. Table 3 shows that the coning of the freeway’s auxiliary lane was rather shocking to the drivers, because in the first few days there was a dramatic decrease in average speed at the cross section of the experiment site, as estimated with AUTOSCOPE from an overhead surveillance camera. (Note: the numbers 2, 3,…9 represent the day of the experiment.)

**TABLE 3: Evolution of Speeds Across the Three Freeway Lanes (7:45-8:00 A.M.)**

<table>
<thead>
<tr>
<th></th>
<th>NORMAL</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>7</th>
<th>8</th>
<th>9</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Tue</td>
<td>Wed</td>
<td>Thu</td>
<td>Tue</td>
<td>Wed</td>
<td>Thu</td>
<td>Tue</td>
</tr>
<tr>
<td>LEFT LANE</td>
<td>50.9</td>
<td>51.4</td>
<td>52.9</td>
<td>44.0</td>
<td>46.4</td>
<td>47.6</td>
<td>40.4</td>
</tr>
<tr>
<td>MIDDLE LANE</td>
<td>43.6</td>
<td>45.2</td>
<td>47.5</td>
<td>37.8</td>
<td>43.4</td>
<td>44.6</td>
<td>44.1</td>
</tr>
<tr>
<td>RIGHT LANE</td>
<td>34.8</td>
<td>38.2</td>
<td>39.0</td>
<td>26.8</td>
<td>35.8</td>
<td>32.8</td>
<td>38.5</td>
</tr>
<tr>
<td>AUX. LANE</td>
<td>38.9</td>
<td>40.0</td>
<td>40.3</td>
<td>18.6</td>
<td>34.2</td>
<td>27.9</td>
<td>29.9</td>
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The auxiliary (conned) and the right freeway lane experienced the greatest reduction in average speed. At the end of the two weeks, the average travel speeds had recovered to their normal levels. It must be noted that the NORMAL speeds shown above are downstream of the bottleneck. Much slower speeds are experienced upstream of the bottleneck under normal conditions. Although only the 7:45-8:00 A.M. period is shown, all 15 minute periods from 6:00 to 10:00 A.M. showed a similar trend.

The best result was achieved on the last (10th) day of the experiment and it is depicted in Figure 4. A notable travel time improvement in the order of 15% was recorded. In addition, the car’s fuel consumption indication (which over two years and about 100 refuelings has given an error of actual vs. indicated average fuel consumption of less than 3%) showed a consumption improvement in the order of 25%.

The motorists’ reaction to the experiment was rather unexpected. Although the actual results were mixed, the motorists responses were clearly positive. Their perceptions here measured with a questionnaire survey distributed at most on-ramps in the corridor a week after the experiment had ended.

The basic premise of the questionnaire design was that the freeway cross-section past the Lunalilo St. on-ramp has 4 lanes. As such, the freeway motorists can occupy ¾ths of the capacity and the balance goes to the on-ramp motorists. Indeed 1500/6000=25% were planned and 1370/5400=25% of the surveys were actually distributed to Lunalilo St. on-ramp motorists. According to the responses, the Lunalilo St. on-ramp motorists comprise 20% of the 1,403 responses. The overall response rate of 26% is considered good given the absence of reminders and incentives, and the distribution to drivers in queues (as opposed to receiving it at the convenience of their home).

The percentile (%) responses to the question “**what do you think about weekday morning coning of the Lunalilo St. on-ramp?**” can be summarized as follows:

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A majority of 51% of the freeway motorists found the experiment good or very good; only 10% of freeway motorists found the experiment bad or very bad. On the other hand, an unexpectedly high percentage (48%) of the Lunalilo St. on-ramp users found the experiment neutral, good or very good.

Analyses of the post-closure surveys revealed that:
- Motorists on the first on-ramp upstream of the experiment (Punahou St. on-ramp) were most pleased (3.9/5.0 rating) with the results and thought that travel times had shortened.
- Greater proximity to the experiment zone corresponded to higher average perceived travel time savings, as follows (2=much faster, 1=faster, 0=neutral, -1=slower, -2=much slower):
  1. Punahou = 0.68 (500 m distance from experiment zone)
  2. Alexander = 0.46 (750 m distance from experiment zone)
  3. 11th Ave = 0.24 (3 km distance from experiment zone)
  4. Kahala = 0.15 (5 km distance from experiment zone)
- Motorists who exited at or past the experiment zone gave consistently higher ratings than those who exited earlier. Indeed, motorists who exited early and did not experience the experiment site perceived longer travel times.

Overall, a result with strong promise for positive long-term outcomes was achieved.

CONCLUSIONS
This paper presented a review of past experiences with ramp closure and ramp metering and the results from a ramp closure experiment on interstate freeway H-1 in Honolulu in fall 1997. Ramp closure is a total bottleneck removal solution, but its application entails political and possibly operational problems (e.g., too much diversion to city streets, effects on bus routes, etc.), but no such problems occurred in the specific case presented. Ramp metering, on the other hand, is a less drastic solution. Fine-tuned application of metering at key locations and periods can have positive network-wide effects, but a metering system on H-1 Fwy. is impossible without extensive alignment changes.

Lessons learned from the experiment include the following:
- Experimenting on a major interstate-class freeway is doable, safe, rather affordable and a likely “winner” for the HDOT. It is apparent that even when the results are mixed or modest, the effort by the HDOT to improve the service is appreciated by the majority of the motorists.
- Short-term real-world experimentation cannot achieve simulated results because equilibrium and normal driving conditions cannot be achieved within a couple of weeks.
- Careful simulation can both represent existing conditions and reveal likely traffic outcomes from modifications.
- Large organizations such as the HDOT and the City of Honolulu can cooperate successfully even for such short-term projects that place extraordinary demands on several staff members.

Additional information on the project whose partial outcome is this paper can be found at http://www.eng.hawaii.edu/~pdp/abstracts.html.
ACKNOWLEDGMENT

This paper is a product of the research on “Investigation of the Effects of Limited Ramp Closures along the H-1 Freeway” supported by the Hawaii DOT and the FHWA. The contents of this paper reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of Hawaii DOT or the FHWA. This paper does not constitute a standard, specification or regulation.

The HDOT project manager for the Lunalilo St. on-ramp closure, Mr. Douglas Meller, must be acknowledged. He was instrumental in contracting tasks, and bringing the right parties together to work synergistically during the experiment with its considerable demands for daily set-up, supervision and continuous data collection.

REFERENCES


Figure 1. AUTOSCOPE and simulation estimates of freeway speed with KRONOS 8 and TSIS-FRESIM.
Figure 2. Normal and experiment layouts of the Lunalilo Street on-ramp and the Vineyard Boulevard off-ramp along the westbound H-1 freeway.

Figure 3. Range of travel times during normal and during experiment (ramp closure) conditions.
Figure 4. Travel time and fuel consumption comparisons between the last day (Friday, November 7, 1997) of the WB Lunaililo St. on-ramp closure experiment, and the following Friday with normal flow.