INCIDENT CAPACITY REDUCTION ON FOUR-LANE FREEWAYS USING REAL WORLD DATA: SINGLE LANE CLOSURES

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Table of Content

Research Objective

INTRODUCTION

LITERATURE REVIEW

METHODOLOGY

RESULTS

CONCLUSION

- Incident capacity reduction estimates used in Traffic Incident Management (TIM), Advanced Traveler Information Systems (ATIS), and traffic micro-simulation models
- An accurate estimate of the incident-induced capacity reduction
- Rarely any study has quantified the effect of blocked lane location on the incident-induced capacity reductions
- The effect of blocked lane (single lane) configuration on freeway (4-lane) capacity reduction due to incidents
- Incident data: CHART
- The traffic data: RITIS

Capacity

INTRODUCTION

LITERATURE REVIEW

METHODOLOGY

RESULTS

CONCLUSION

- The definition of "capacity" & its estimation has been through changes
- The implication of physical capacity to be misleading , "revealed" capacity and empirical capacity emerged (varied capacity in different sites, geometric , day)
- Many researchers agree that the capacity of a road segment should be estimated under the existence of active bottleneck
- Active bottleneck: congestion in upstream and unrestricted flow condition downstream
- Threshold of congestion: speed 55 mph (Lorenz and Elefteriadou) , 10 mph drop from free flow (Lu & Elefteriadou), 45mph (Knoop et al.)
- Occupancy > 25% as congested & occupancy < 20% as uncongested and in between as intermediate period (Zhang).

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Capacity Reduction Estimation

INTRODUCTION

LITERATURE REVIEW

METHODOLOGY

RESULTS

CONCLUSION

- Studies on 3-lane & 2-lane highway
- Down stream flow
- Capacity under non-incident condition: standard lane capacities, absolute peak of the speed-flow curve as capacity, 5% top peak of the speed-flow curve as capacity, the average flow 10 min before breakdown
- Capacity under incident condition: average discharge flow in presence of incident, minimum of 10 minute moving average of traffic flow during the incident,
- Effect of lane closure location on capacity reduction: mostly work zone lane closure, the impact of right lane causes lower capacity than left lane closure. Incident, the hypothesis of the independency of lane location and capacity reduction by incident showed the location of blocked lane is important.

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Proposed Method

INTRODUCTION

LITERATURE REVIEW

METHODOLOGY

RESULTS

CONCLUSION

Bottleneck Identification

- Upstream speed < 45 mphl
- Downstream speed > 50 mph (at least 10 minutes)

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Capacity Under Incident Condition

- Draw the Cumulative Count over Time
- Fit the Break Points
- Identify the Major Slope Changes

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Capacity Under Non-Incident Condition

- Slope of Cumulative Count (If Bottleneck Exist)

or

- 15% Reduction of Max Flow in Fundamental Diagram

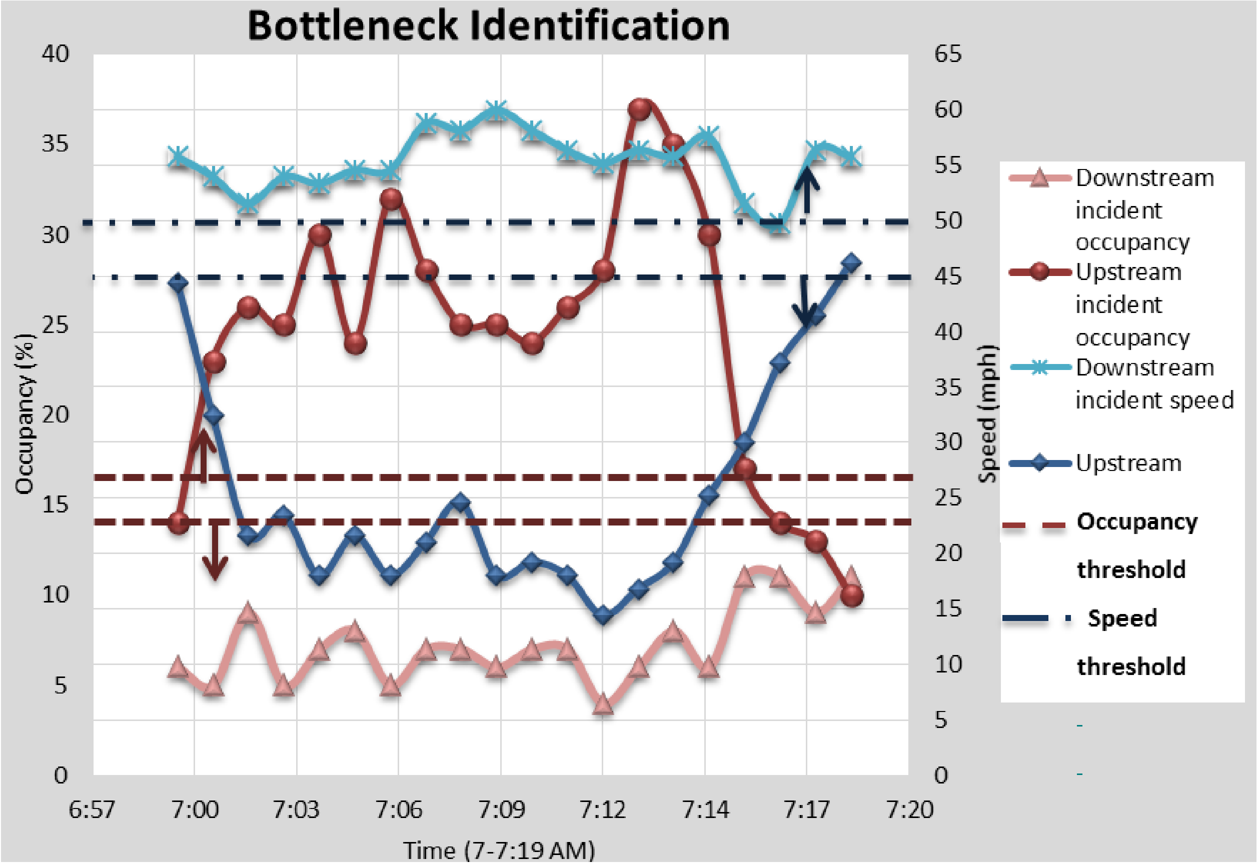
⇩

Available Capacity

- Capacity Under Incident Condition over Capacity Under Non-incident Condition

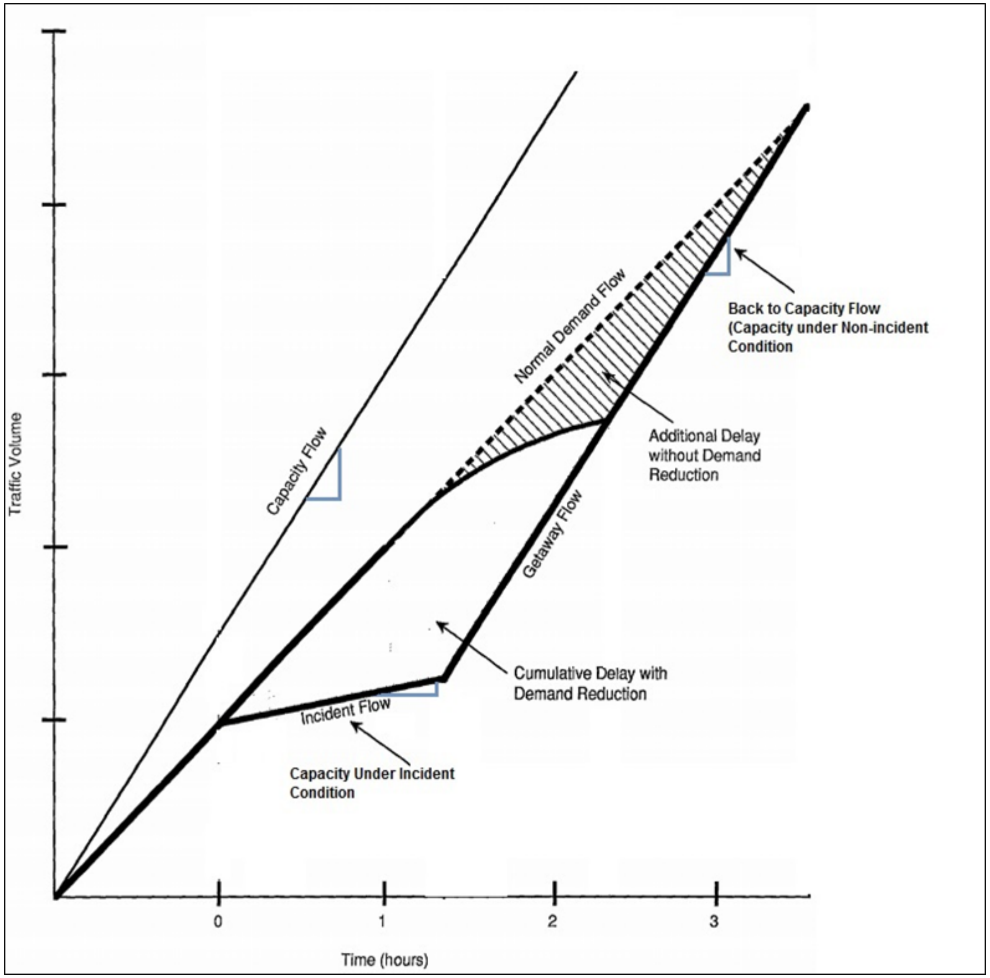
Bottleneck Identification

- Speed of 50 mph uncongested
- Maximum speed of 45 mph as congested
- Corresponding occupancies 14% and 17%
- Challenge of finding incident with active bottleneck
- At I-495 Inner Loop Past Exit 31 MD 97 Georgia Avenue on April 22, 2014



Capacity Estimation Proposed Method

- The relationship of the cumulative traffic volume and time (delay measurement)
- Capacity under incident condition is the slope of cumulative curve (duration of 10 minutes)
- The graph for cumulative flow over time was drawn for every incident case
- Cumulative curve varying slopes makes it difficult to establish a unique capacity estimate
- Next step, fit appropriate number of breakpoints to the data set to establish time periods during which the slope



Fitting Breakpoints To a Dataset

- An optimization problem
- Broken Stick Regression Function in MATLAB
- Mixed Integer Non-Linear Programming (MINLP) optimization model
- The objective was to minimize the sum of squared difference between the actual and fitted curves
- Inputs: ordered pair (x_i, y_i) points, vehicle cumulative counts (y_i) and their corresponding time stamps (x_i) in the form,$(i = 1, \dots, m)$ & 2) the desired number of breakpoints(p)
- The output is based on the number of breakpoints(p), thus, the next step was finding an efficient number of breakpoints for each data set (incident)

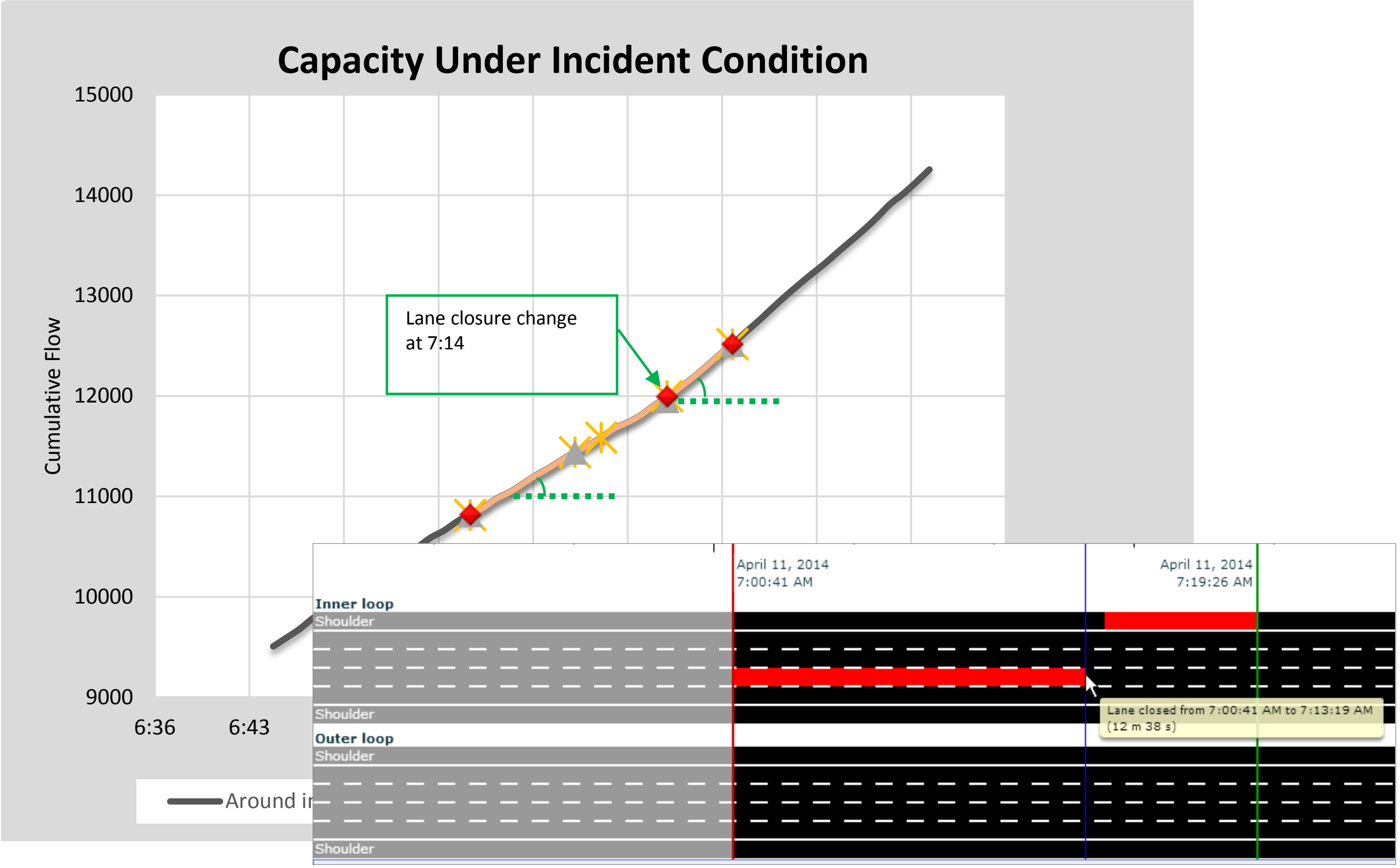
Incrementing the number of breakpoints

Starting with one breakpoint (two sections)

Ending when there is no section with duration higher than 10 min

If all increments identified a point as a breakpoints consider critical point (possibility of either change in lane closure or some other major changes)

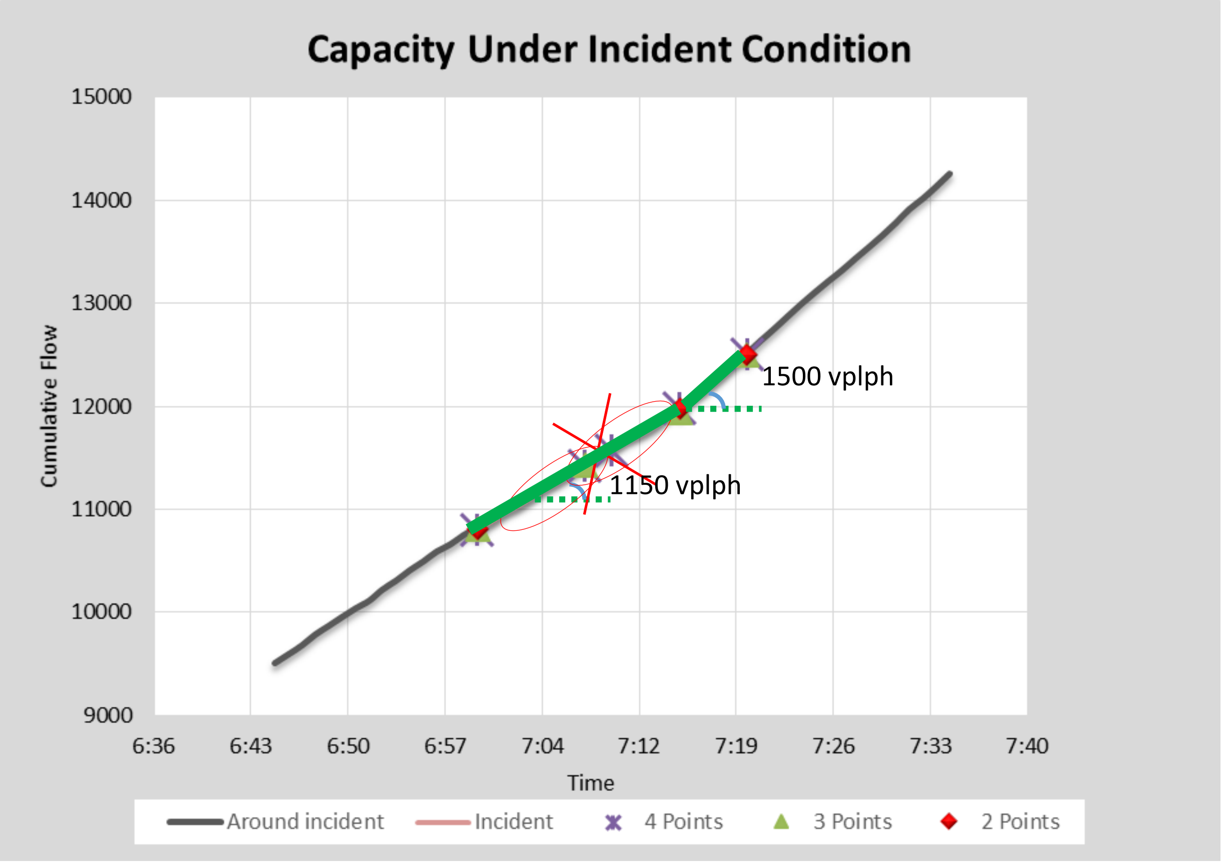
Stable breakpoints are compared to what RITIS reports on the incident lane closure detail



Slope Report

A unique slope for each section (between two critical breakpoints)

Any slope between two points with the duration less than 10 minutes is disregarded, unless both breakpoints are critical points (to ensure sustained flow)



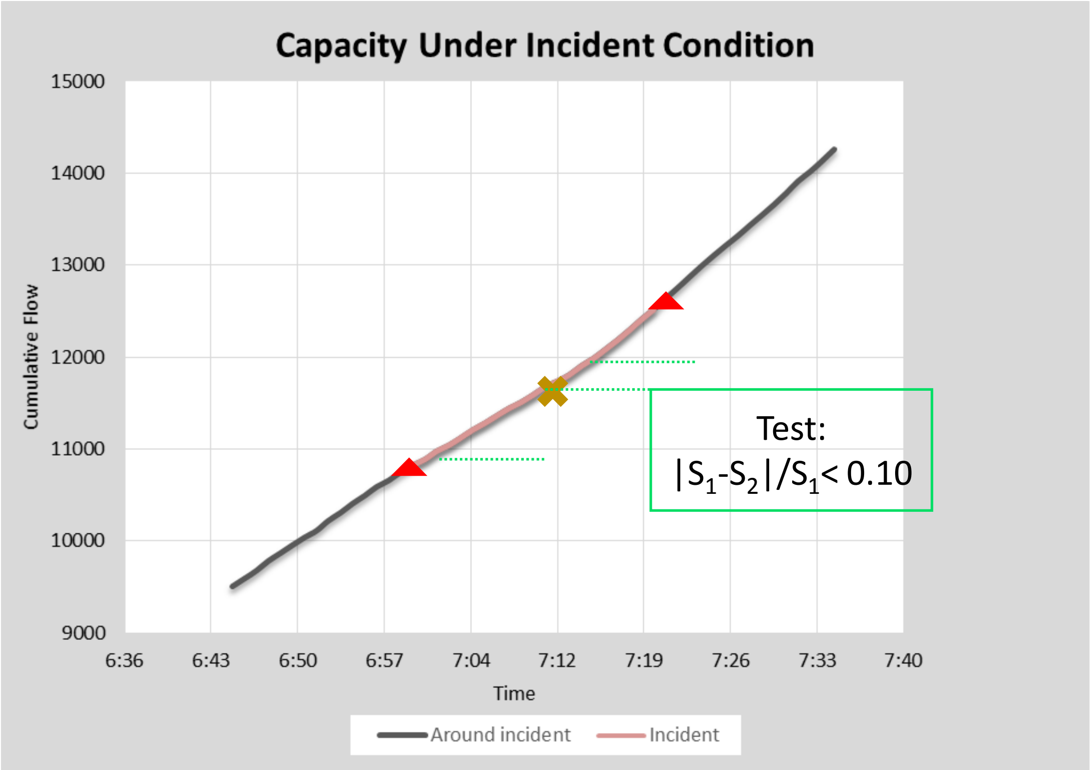
Slope Report

If breakpoints between two critical points (duration above 10 minutes)

Test to see if case there was a difference (above 10% significant)

The minimum slope was reported if there is a difference

The average of the slopes was reported if there is not a difference



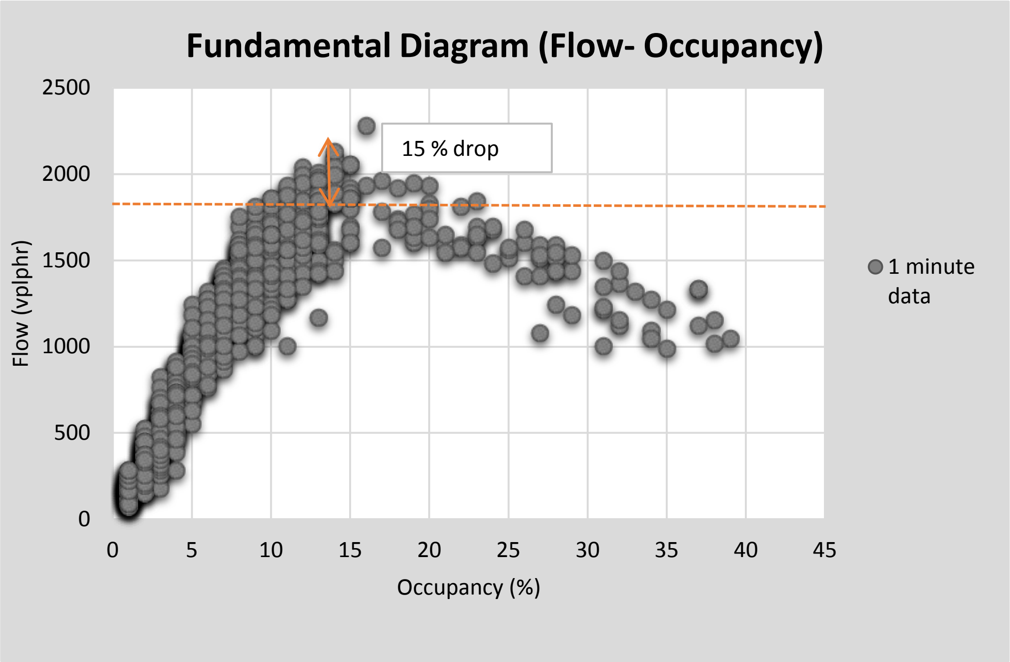
Capacity Under Non-incident Condition

Two different methods were used

In cases which the bottleneck condition exists after an incident, the slope of cumulative curve and maximum sustainable slope considered as the capacity under non-incident condition

For cases the bottleneck condition did not exist, fundamental diagram and flow at the 15% reduction of the maximum flow of the fundamental diagram

Available capacity= capacity under incident/ capacity under non-incident condition



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Data

INTRODUCTION

LITERATURE REVIEW

METHODOLOGY

RESULTS

CONCLUSION

- Traffic data (occupancy, speed, and vehicle count) accessed through detector query tools in RITIS
- Incident information (location, duration, affected lanes, etc.)
- Challenge: 1. both traffic data & incident data available 2. incident happen in the active bottleneck situation 3. enough of each lane closure configuration for the analysis
- Case Studies: the minimum sample size in each using the acceptable error using equation

$$N = \left(\frac{Z_{\alpha/2} \times \sigma}{E}\right)^2$$

- Sites: are I-495 at 0.31 Mile West of Sligo Creek Parkway and I-495 East of New Hampshire Ave/SR-650

Descriptive Statics

INTRODUCTION

LITERATURE REVIEW

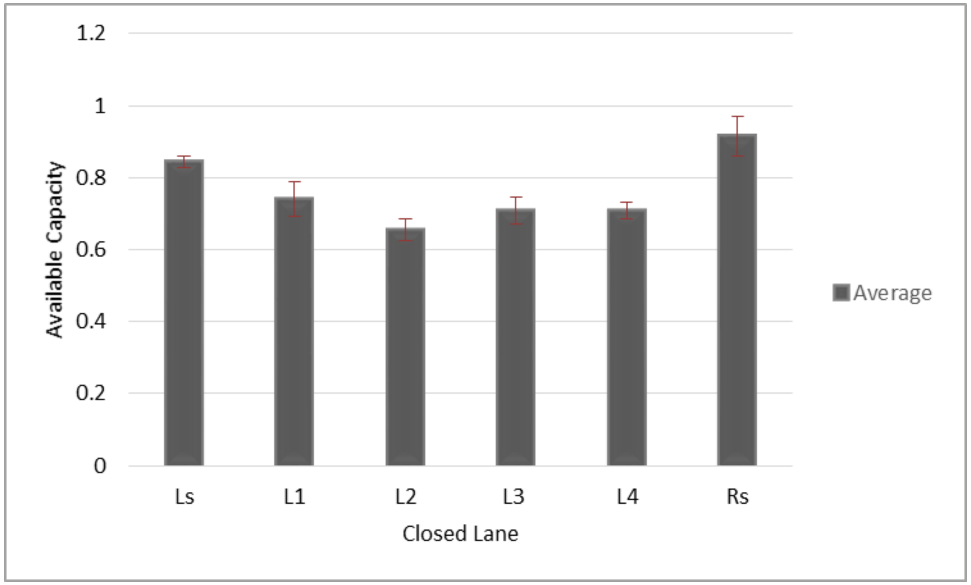
METHODOLOGY

RESULTS

CONCLUSION

Available Capacity Descriptive Statistics

Lane	N	Mean	Std. Deviation	Minimum	Maximum
Ls	3	0.834	0.015	0.820	0.850
L1	6	0.741	0.049	0.675	0.800
L2	4	0.654	0.034	0.607	0.683
L3	2	0.713	0.029	0.692	0.733
L4	2	0.709	0.023	0.692	0.725
Rs	7	0.920	0.047	0.858	1.000
Total	24	0.785	0.108	0.607	1.000



Regression Model

- The variable "location of lanes affected" was treated as a categorical variable
- Available Capacity Ratio = $\alpha_0 + b_1L_1 + b_2L_2 + b_3L_3 + b_4L_4 + b_5L_s$
- R-squared of the model is 0.93. Meaning 93% of the variation in available capacity is explained by the location of the closed lane
- All the dummy variables are significant at 95% confidence interval
- α_0 is the mean available capacity of right shoulder closure and the "B" values show how much more each of the other lane closure scenarios reduce the available capacity in comparison to the right shoulder
- Available Capacity Ratio = $0.914 - 0.173L_1 - 0.260L_2 - 0.181L_3 - 0.205L_4 - 0.070L_s$

Regression Model Coefficients

	B	Std. Error	Beta	t	Sig.
(Constant)	0.914	0.018		52.198	0.000
L1	-0.173	0.026	-0.717	-6.703	0.000
L2	-0.260	0.029	-0.932	-8.956	0.000
L3	-0.181	0.050	-0.348	-3.650	0.002
L4	-0.205	0.037	-0.547	-5.526	0.000
Ls	-0.070	0.032	-0.224	-2.202	0.042

Available Capacity Means Comparison

- Analysis of variance test (ANOVA) was conducted to test whether all the means are equal or not
- H0: $\mu_1 = \mu_2 = \ldots = \mu_i$
- H1: two or more means are different from the others

- The test result shows that H0 is rejected and thus available capacity means are not the same
- Honestly Significant Difference (Tukey's HSD Process) is used to determine which means are unequal and by how much they are different

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Available Capacity Means Comparison

- Right shoulder & left shoulder statistically different impact: closing the left shoulder reduces the capacity more
- Closing the second lane from left (L2) and left lane (L1) has different impacts: Closure of middle lane reduces the capacity more than the closure of left lane:
- The mean of available capacity for right lane closure is less than mean of available capacity for left lane closure (the test does not show the difference as significant)

		L1 (0.74)	L2 (0.65)	L3 (0.71)	L4 (0.71)	Rs (0.92)
Ls	Mean Dif.	0.093	0.181	0.122	0.126	-0.085
	Std. Error	0.029	0.032	0.038	0.038	0.029
	Sig.	0.048**	0.000**	0.045**	0.036**	0.071*
L1	Mean Dif.		0.087	0.029	0.033	-0.179
	Std. Error		0.027	0.034	0.034	0.023
	Sig.		0.041**	0.955	0.924	0.000**
L2	Mean Dif.			-0.059	-0.055	-0.266
	Std. Error			0.036	0.036	0.026
	Sig.			0.583	0.650	0.000*
L3	Mean Dif.				0.004	-0.207
	Std. Error				0.041	0.033
	Sig.				1.000	0.000*
L4	Mean Dif.					-0.211
	Std. Error					0.033
	Sig.					0.000*

Comparison with HCM

- Comparing a sample with accepted value, t-test
- $t = \frac{\bar{x} - \mu_0}{s/\sqrt{n}}$
- Two-tailed test (direction not important)
- estimated value for available capacity due to one lane closure (higher) is significantly different from what reported HCM values
- Shoulder disablement (lower) are significantly different from what reported HCM values
- Shoulder crash not significantly different

	1 Lane Closure	Shoulder Crash	Shoulder Disablement
Estimated Available Capacity	0.71	0.89	0.91
HCM Available Capacity	0.58	0.85	0.99
d.f	13	5	2
Two tale t-value (α = 0.05)	2.16	2.57	4.3
Calculated t-value	9.29***	1.37	3.05*

Comparison between Shoulder Crash and Shoulder Disablement

- H0: $\bar{x}_1 = \bar{x}_2$
- H1: two means are different from each other
- $\boldsymbol{t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}}$
- No significant difference between available capacity in shoulder disablement and shoulder crash

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Conclusion & Recommendation

INTRODUCTION

LITERATURE REVIEW

METHODOLOGY

RESULTS

CONCLUSION

- ✓ Proposed method, can be used in identifying the start & end of incident & any shift in lane closures during the incident. Enforce minimum 10 minute flow rate (capacity levels can be sustained). No additional data
- ✓ The R-squared (93%). in one lane closure in 4-lane highway 93% of the variation in the capacity reduction could be defined by specifying the location of the affected lane.
- ✓ Further analysis to see how the model predicts the available capacity when more than one lane is closed and how interactions between different lanes can impact the outcomes.
- ✓ Right & left shoulder closure different effects on available capacity (more efficient incident management strategies, right shoulder preferred at the partial clearance in the incident responses)

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Conclusion & Recommendation

INTRODUCTION

LITERATURE REVIEW

METHODOLOGY

RESULTS

CONCLUSION

- ✓ Middle lane (L2) closure causes a relatively higher capacity reduction. TIM, such incidents should get the higher priority for receiving responses
- ✓ Additional cases will be included in the analysis to test whether there is any significant difference between a right lane closure and left lane closure or other lanes
- ✓ Estimated capacities for 1-lane closures in 4-lane freeway are significantly different (lower) from what HCM considers
- ✓ Estimated available capacity for shoulder disablement is significantly different from HCM values
- ✓ There is no significant difference between available capacity due to shoulder disablement and shoulder incidents.
- ✓ Scenarios involving multilane closures (two and more lanes closed) will be investigated to determine the interactions and synergies between different lanes in impacting the capacity