VTRC
Virginia Transportation
Research Council

We Bring Innovation to Transportation

Cost of Congestion Due to Incidents on Freeways

Chien-Lun Lan, Mo Zhao, Noah Goodall, James Gillespie
Virginia Transportation Research Council
Virginia Department of Transportation

Incident Congest Cost?

Research Needs and Purpose

- Provide a quick planning-level response to public requests (e.g., by CTB)
  - Cost-effectiveness analyses of incident response strategies
  - Answer the question: How much can be saved by reducing 1 minute of incident response time?

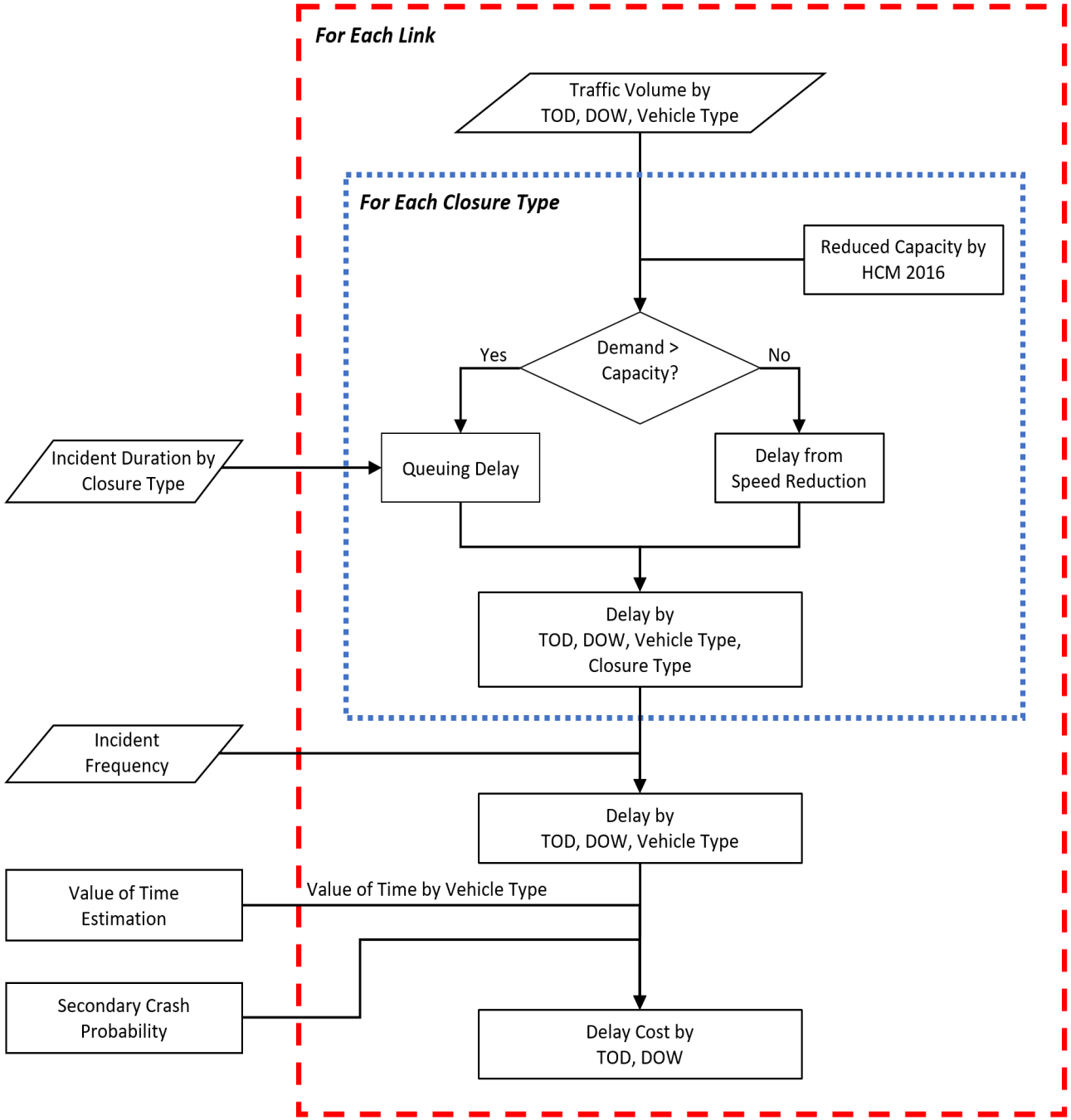
- Develop a method to estimate of congestion cost per incident-minute
  - Estimate the value-of-time for road users
  - Estimate the congestion caused by incidents
  - Planning-level estimates on Virginia Interstates

What other states do?

- Incident Costs
  - Washington DOT (2016*, 2011**)
    - Blocking incidents (1+ lane closed): $345 / min (814 vehicle-minute of delay per minute)
    - Non-blocking incidents: $244 / min (576 vehicle-minute of delay per minute)
    - VoT: $21.9 (Car), $57.4(Truck), assume 10% truck everywhere
    - WSDOT responded incidents, no nighttime hours, on 5 urban corridors
  - Oregon DOT (2019)
    - ATR-location based cost of delay, highway closure
    - Value of 1-hour of travel time for all vehicles: $900 ~ $332,600 (peak hours), as low as $100
    - VoT: $26.44 (Car), $31.89 (Med. Truck), $33.24 (Heavy Truck)

* WSDOT's Handbook for Corridor Capacity Evaluation, 2016 ($4.18 ~ $885.74 / min of incident)
** Incident Response Evaluation Phase 3, WSDOT Research Report 761.1 by Washington State Transportation Center, 2011

Flowchart



*TOD: Time-of-Day; DOW: Day-of-Week

Traveler's Value of Time

Regional Income Level Adjustment

$$VoT = (PL1/PL0) \times (INC1/INC0) \times \Sigma(Ri \times HEi \times AOi \times Fi),$$

Inflation Adjustment

Hourly earnings, HE/VoT ratio, vehicle occupancy, Fraction of trip purpose

where

PL1 = the prevailing price level at the time when the tool is applied,

PL0 = the baseline price level at the time when the value-of-time values were estimated,

INC1 = the prevailing income level at the time when the tool is applied,

INC0 = the baseline income level at the time when value-of-time values were estimated,

Ri = the ratio between the value of time for travelers in traffic category i and the hourly earnings for travelers in traffic category i,

HEi = the average hourly earnings of travelers in traffic category i,

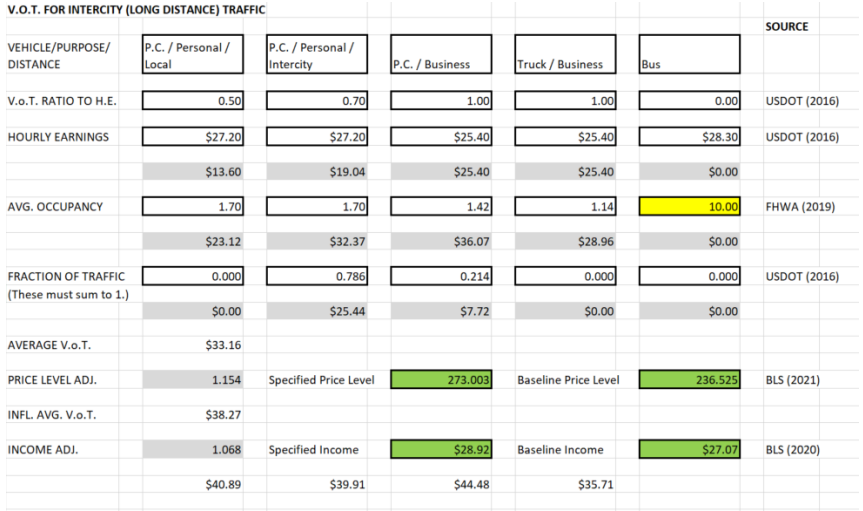
AOi = the average occupancy of vehicles in traffic category i

Fi = the fraction of traffic category i in the total traffic flow, and

i = a subscript that indexes the categories of traffic.

Sample VoT Computation

VoT (PC, business, VA, 2021) = (273.003/236.525)
× ($28.92/$27.07) × 1.00 × $25.40 × 1.42 = $44.48/hour.



V.O.T. FOR INTERCITY (LONG DISTANCE) TRAFFIC						SOURCE
VEHICLE/PURPOSE/ DISTANCE	P.C. / Personal / Local	P.C. / Personal / Intercity	P.C. / Business	Truck / Business	Bus	
V.o.T. RATIO TO H.E.	0.50	0.70	1.00	1.00	0.00	USDOT (2016)
HOURLY EARNINGS	$27.20	$27.20	$25.40	$25.40	$28.30	USDOT (2016)
	$13.60	$19.04	$25.40	$25.40	$0.00	
AVG. OCCUPANCY	1.70	1.70	1.42	1.14	10.00	FHWA (2019)
	$23.12	$32.37	$36.07	$28.96	$0.00	
FRACTION OF TRAFFIC (These must sum to 1.)	0.000	0.786	0.214	0.000	0.000	USDOT (2016)
	$0.00	$25.44	$7.72	$0.00	$0.00	
AVERAGE V.o.T.	$33.16					
PRICE LEVEL ADJ.	1.154	Specified Price Level	273.003	Baseline Price Level	236.525	BLS (2021)
INFL. AVG. V.o.T.	$38.27					
INCOME ADJ.	1.068	Specified Income	$28.92	Baseline Income	$27.07	BLS (2020)
	$40.89	$39.91	$44.48	$35.71		

273.003 = CPI-U as of July 2021.

236.525 = CPI-U as of December 2015.

$28.92 = mean hourly wage in Virginia, all occupations, as of May 2020.

$27.07 = mean hourly wage in U.S., all occupations, as of May 2020.

1.00 = the ratio between the value of time and hourly earnings for business traveler, surface mode.

$25.40 = average hourly earnings of business traveler, surface mode, in 2015 US$.

1.42 = average occupancy of passenger car in business travel.

Value of Time - Defaults

- ***Suggested values for Interstate from this study***:
  - **Passenger Car: $46.76 / hour** ($40.89 from Driver VoT; $5.87 from Operating Cost)
  - **Truck: $73.5 / hour** ($35.71 from Driver VoT; $37.79 from Truck Operating Cost)

- Data Source:
  - Average VoT: Ayala (2014), USDOT (2016)
  - VoT for specific vehicle classes: NHTS (FHWA 2019).
  - Adjustments for trip purpose, trip length: USDOT (2016).
  - Adjustments for local price level: BLS (2021), etc.
  - Adjustments for local income/wage level: BLS (2020), etc.
  - Truck Operation Cost: ATRI (2019)

Incident Distribution

- Data Source:
  - VaTraffic (2017 – 2020)
- No significant difference
  - Virginia vs. HCM
  - VDOT districts
  - Some difference when 3+ lane closed
- Suggest using HCM value

#. of Lanes Closed	Incident Probability					
	2017	2018	2019	2020	**Average**	**HCM**
0	0.750	0.755	0.748	0.734	**0.747**	**0.754**
1	0.162	0.162	0.168	0.168	**0.165**	**0.196**
2	0.070	0.066	0.066	0.075	**0.069**	**0.031**
3	0.013	0.012	0.013	0.016	**0.014**	**0.019**
4	0.004	0.004	0.004	0.006	**0.005**	**0**
5	0.001	0.001	0.001	0.001	**0.001**	**0**
6	0.000	0.000	0.000	0.000	**0.000**	**0**

#. of Lanes Closed	Incident Duration (min)					
	2017	2018	2019	2020	**Average**	**HCM**
0	26.7	30.9	37.2	33.6	**32.1**	**34**
1	35.2	37.7	37.7	40.9	**37.9**	**34.6**
2	47.7	52.5	50.2	51.8	**50.5**	**53.6**
3	77.8	74.1	71.0	78.0	**75.2**	**67.9**
4	90.5	94.1	84.8	87.8	**89.3**	**67.9**

Delay Calculation

- Delay caused by incident
  - ***Queue delay*: Traffic demand exceeding remaining capacity**
    - Capacity, AADT (2019), Hourly volume profile from TED
    - HCM 2016 "*Residual Freeway Capacity per Lane in Incident Zones*"
    - Calculated with typical queuing process, start of incident until queue fully dissipate
  - ***Slowdown delay*: Excessive travel time caused by speed reduction**
    - HCM 2016 Eq 25-1 (Zegeer et al., 2014)
    - $S = FFS \times SAF + \left[1 - e^{\ln((FFS \times SAF)+1-\frac{C \times CAF}{45}) \times \frac{v_p}{C \times CAF}}\right]$
    - Link free-flow speed calculated using 2019 INRIX data
- Detour operation: Volume adjustment factor

Probability of Secondary Crashes

- Method developed by Goodall (2017) based on I-66 data

$$P(s) = \frac{e^Y}{1+e^Y}$$

where

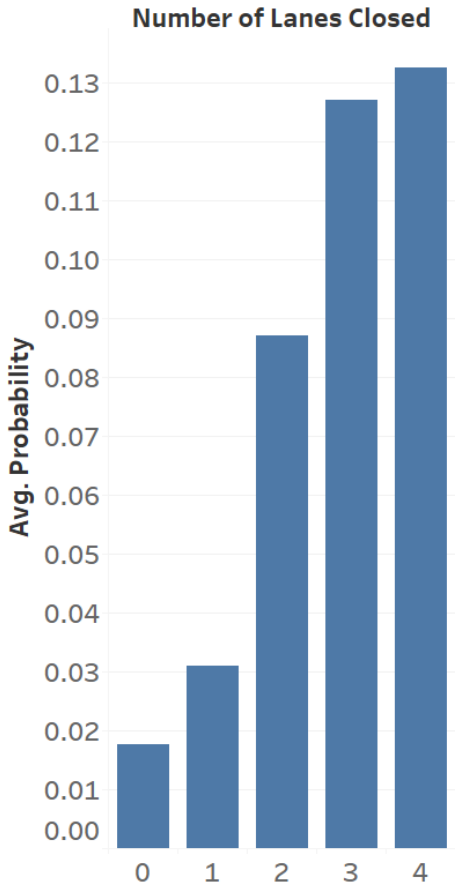
$P(s)$ = probability of a secondary crash occurring,

$$Y = \begin{cases} -4.459 + 0.006985t + 0.000162d & \text{for } C = 0 \\ -2.836 + 0.006985t + 0.000162d' & \text{for } C = 1 \end{cases}$$

C = 1 for congestion,

t = incident duration in minutes, and

d = total number of vehicles that encountered the incident or its queue.



Congestion Cost by VDOT District

Weekday, AM Peak (6AM – 10AM)
Lane-blocking incidents

District	Car Delay Cost	Truck Delay Cost	Secondary Crash Cost - Car	Secondary Crash Cost - Truck	Total Delay Cost
Bristol	60.09	10.73	0.53	0.12	71.47
Culpeper	157.44	14.46	2.09	0.23	174.21
Fredericksburg	675.09	95.76	15.95	2.44	789.24
Hampton Roads	536.41	69.68	14.85	2.06	622.99
Northern Virginia	1,150.13	120.33	67.39	9.16	1,347.01
Richmond	341.36	44.80	8.27	1.18	395.62
Salem	130.32	15.98	1.85	0.23	148.39
Staunton	105.89	11.10	1.20	0.13	118.32
Average	**382.76**	**46.53**	**15.79**	**2.18**	**447.26**

Weekday, AM Peak (6AM – 10AM)
Shoulder-close incidents

District	Car Delay Cost	Truck Delay Cost	Secondary Crash Cost - Car	Secondary Crash Cost - Truck	Total Delay Cost
Bristol	0.17	0.03	0.30	0.06	0.55
Culpeper	1.34	0.12	0.69	0.06	2.21
Fredericksburg	7.76	0.96	4.07	0.58	13.36
Hampton Roads	9.73	1.68	4.88	0.75	17.04
Northern Virginia	116.85	18.43	28.80	4.16	168.25
Richmond	3.23	0.87	2.55	0.41	7.06
Salem	0.78	0.07	0.73	0.08	1.67
Staunton	0.56	0.05	0.45	0.05	1.10
Average	**20.07**	**3.26**	**6.08**	**0.89**	**30.30**

Washington DOT Blocking incidents: $345 / min

Congestion Cost by VDOT District

Weekday, AM Peak (6AM – 10AM)
Lane-blocking incidents

District	Car Delay Cost	Truck Delay Cost	Secondary Crash Cost - Car	Secondary Crash Cost - Truck	Total Delay Cost
Bristol	60.09	10.73	0.53	0.12	71.47
Culpeper	157.44	14.46	2.09	0.23	174.21
Fredericksburg	675.09	95.76	15.95	2.44	789.24
Hampton Roads	536.41	69.68	14.85	2.06	622.99
Northern Virginia	1,150.13	120.33	67.39	9.16	1,347.01
Richmond	341.36	44.80	8.27	1.18	395.62
Salem	130.32	15.98	1.85	0.23	148.39
Staunton	105.89	11.10	1.20	0.13	118.32
Average	**382.76**	**46.53**	**15.79**	**2.18**	**447.26**

Weekday, Off Peak (10PM – 5AM)
Lane-blocking incidents

District	Car Delay Cost	Truck Delay Cost	Secondary Crash Cost - Car	Secondary Crash Cost - Truck	Total Delay Cost
Bristol	13.49	2.16	0.09	0.01	15.75
Culpeper	17.23	1.13	0.11	0.01	18.48
Fredericksburg	102.74	13.57	1.23	0.17	117.71
Hampton Roads	21.67	2.33	0.17	0.02	24.19
Northern Virginia	60.63	5.40	0.69	0.07	66.78
Richmond	19.32	1.91	0.15	0.02	21.39
Salem	18.71	2.37	0.12	0.01	21.22
Staunton	19.71	2.06	0.12	0.01	21.89
Average	**22.67**	**2.40**	**0.23**	**0.03**	**25.33**

Congestion Cost by # of closed lanes

Weekday, AM Peak

- The number of closed lanes have significant impact on congestion costs
  - Justify the need for quick incident response
  - Open lanes ASAP

Shoulder Closed

District	Total Delay Cost
Bristol	0.55
Culpeper	2.21
Fredericksburg	13.36
Hampton Roads	17.04
Northern Virginia	168.25
Richmond	7.06
Salem	1.67
Staunton	1.10
Average	**30.30**

2 Lanes Closed

District	Total Delay Cost
Bristol	326.66
Culpeper	702.81
Fredericksburg	1,456.75
Hampton Roads	1,538.78
Northern Virginia	2,385.48
Richmond	981.20
Salem	587.86
Staunton	539.14
Average	**1,135.20**

1 Lane Closed

District	Total Delay Cost
Bristol	3.90
Culpeper	44.70
Fredericksburg	157.49
Hampton Roads	256.53
Northern Virginia	547.76
Richmond	98.44
Salem	26.94
Staunton	15.22
Average	**168.10**

3 Lanes Closed

District	Total Delay Cost
Bristol	733.61
Fredericksburg	3,250.38
Hampton Roads	2,692.81
Northern Virginia	4,410.69
Richmond	2,705.08
Salem	1,306.86
Average	**3,074.88**

Congestion Cost by District-Route

- Urban/Rural areas
  - Significant impact on costs even on the same route
- A single average per incident-minute value is not representative of any of those costs

AM Peak Lane-blocking incidents

District	Route & Dir.	Car Delay Cost	Truck Delay Cost	Total Delay Cost
Northern Virginia	I-95N	3,960.00	525.93	4,901.02
Fredericksburg	I-95N	816.08	91.74	931.83
Richmond	I-95N	578.44	67.55	663.39
Hampton Roads	I-95N	62.86	8.67	71.99
Average		**1,309.55**	**168.44**	**1,591.08**

PM Peak Lane-blocking incidents

District	Route & Dir.	Car Delay Cost	Truck Delay Cost	Total Delay Cost
Staunton	I-81S	205.31	24.18	233.09
Salem	I-81S	182.42	19.60	205.23
Bristol	I-81S	99.51	26.88	127.99
Average		**163.13**	**23.78**	**189.74**

Conclusions

- The per incident-minute congestion cost varies across VDOT districts, routes, time-of-day, and day-of-week

- The appropriate corridor cost values should be used to evaluate projects across different locations or covering different time periods

Acknowledgement

Special thanks to:

Katie McCann, Robert Rabe, Sanhita Lahiri,

Sandy Wyrick, and Lance Dougald

Questions?

Chien-Lun Lan, chien-lun.lan@vdot.virginia.gov

Mo Zhao, mo.zhao@vdot.virginia.gov