Capacity Characteristics of Long-Term Work Zones on Signalized Intersection Approaches

By

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Presentation Outline

Study Background

- The big-picture of traffic congestion problem in GTA
- Study motivation and background
- Study sites and traffic data

Results & Recommendations

- Work zone capacity models
- The impact of heavy vehicles
- The impact of weather conditions
- The impact of turning movements
- Closing remarks

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TORONTO STAR
are you losing stuck
the roads during rush
Rush hour was bad before COVID-19, it could be worse as restrictions ease
MATT BUBBERS
TORONTO
SPECIAL TO THE GLOBE AND MAIL
PUBLISHED JUNE 30, 2021
A new study by TomTom has
amount of time spent stuck in
TomTom is Dutch multinational developer
electronics such as GPS mapping units for

WHY traffic congestion and work zones are especially important in Toronto?

Toronto is the North America **fastest growing city.**

Toronto is the **most congested** Canadian city.

Congestion is very costly!

How much is the annual cost of traffic congestion in the GTHA area (in CAD)?

WHY traffic congestion and work zones are especially important in Toronto?

- The cost of congestion in the GTHA is forecasted to increase to **$15 billion per year** by 2031. This is equivalent to:

$41.1 million / day

$1.713 million / hour

$29,000 / minute

- Construction sites and work zones cause around **10% of the total road delay, i.e.,:**

$1.5 billion/year ~ $4.1 million / day ~ $0.1713 million / hour ~ $2,900 / minute

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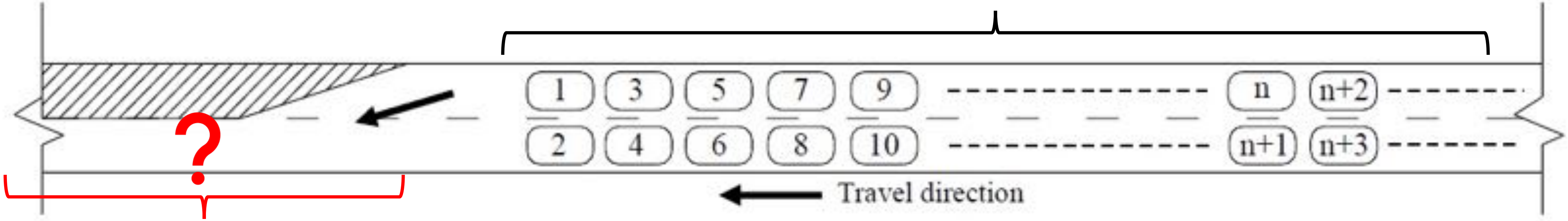
WHY we have traffic congestion?

- Because we have traffic capacity (highways or lanes) less than the demand (number of vehicles/travellers)

Traffic Demand



How much capacity we have?
Is capacity > Demand?

- ***we need an accurate estimation of work zone traffic capacity to have efficient traffic management plans (TMPs) and avoid congestion.***

Work Zone Capacity Model in the Highway Capacity Manual

In Chapter 31: Signalized Intersection - Supplemental (Equations 31-89 to 31-91), a work zone capacity adjustment factor is calculated as:

$\boldsymbol{f_{wz} = 0.858 \times f_{wid} \times f_{\text{reduce}} \leq 1.0}$; where:

f_{wid} = adjustment factor for approach width

f_{reduce} = adjustment factor for reducing lanes during work zone presence

Model limitations:

> Only relies on the total approach width & the number of lanes closed/opened.

> No considerations given to specific geometric conditions (e.g., long taper, right vs left closure, median cross-over, etc)

> No considerations are given to the impact of: degree-of-saturation (queue length), light condition, late-merge, heavy vehicles, weather conditions, etc.

Why this study?

> Work zone (WZ) traffic **capacity is vitally needed** to prepare efficient traffic management plans.

> The existing WZ capacity guidelines at signalized intersections **are very limited.**

> This leaves transportation agencies, contractors, and consultants with **many challenges** when they attempt to reliably manage work zone traffic.

The Study Objectives and Contributions

This study aimed to **transform** available work zone capacity models by:

> Examining ***unconventional geometric configurations*** (e.g., excessively long closure, median crossover, etc).

> Focusing on ***long-term WZs -*** lasting impact for weeks/months.

> Incorporating ***reliability and stochasticity***.

> Evaluating ***factors that have not been addressed before.***

> ***Advise the industry*** accordingly.

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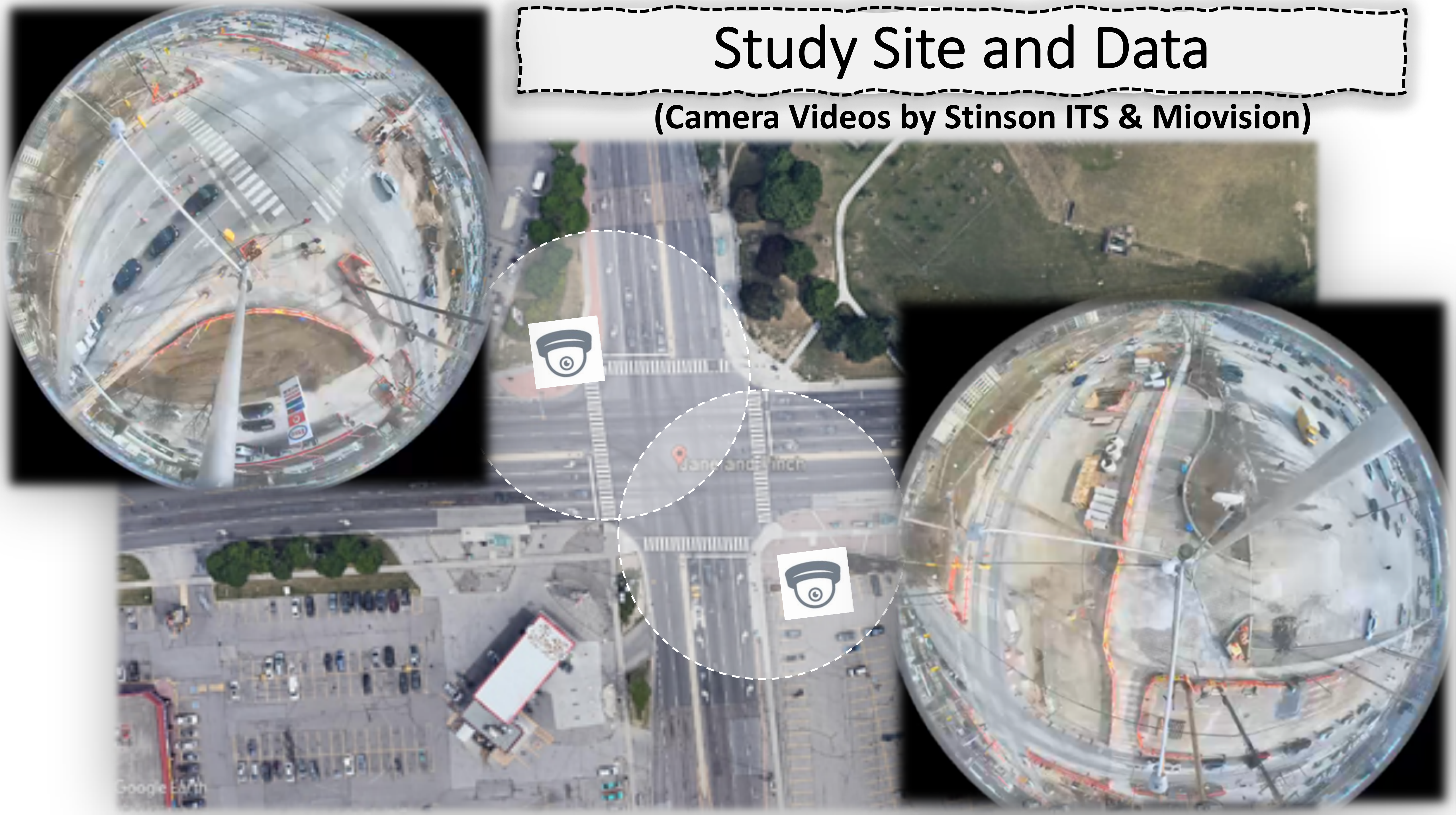
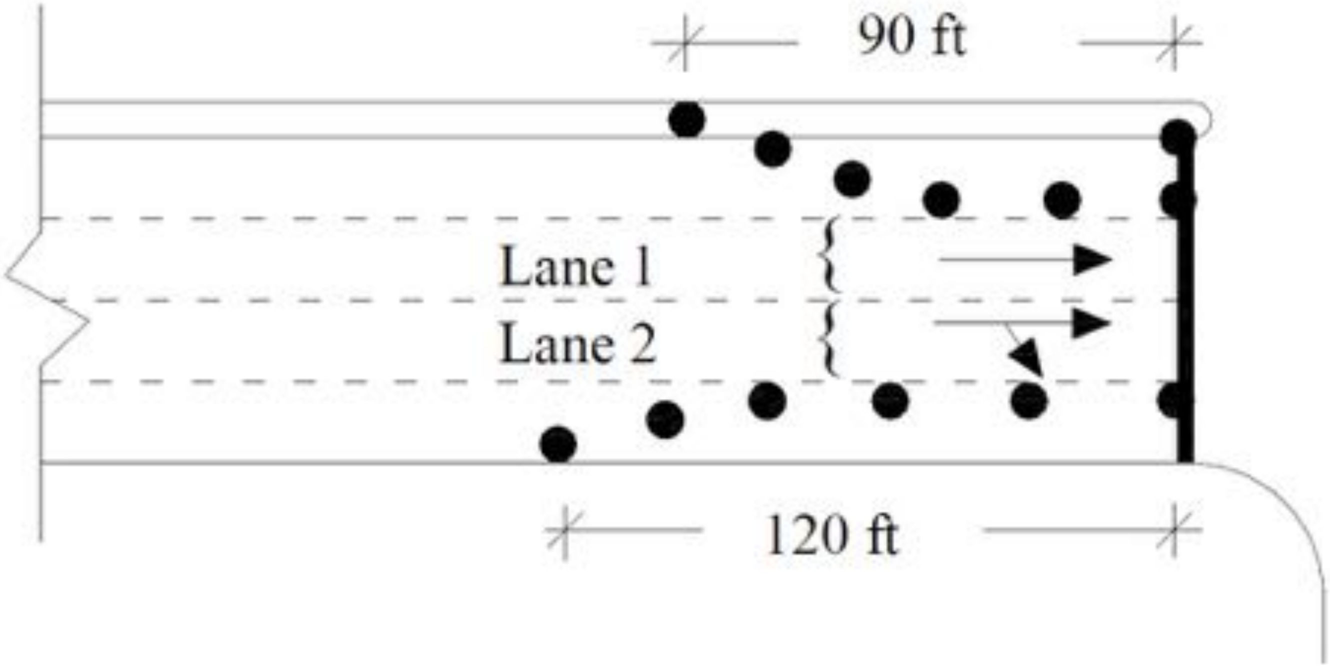
Jane and Finch Area – Aerial Image

Study Site and Data

(Camera Videos by Stinson ITS & Miovision)

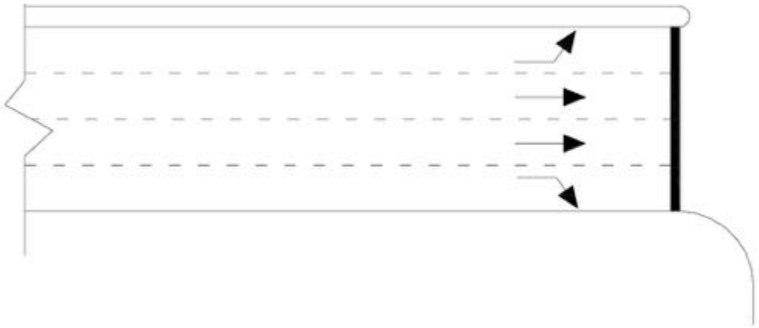


Work Zone Configurations Tested

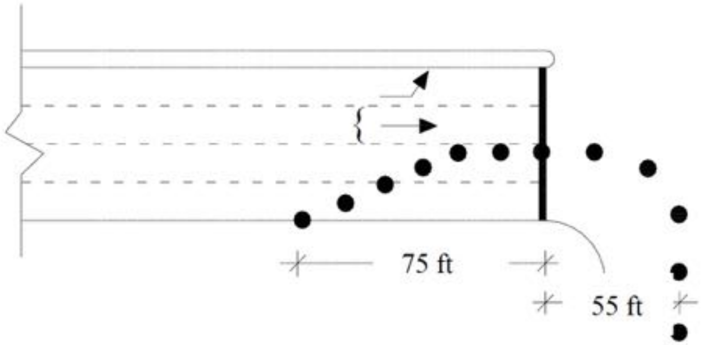


Site 5 (Southbound)

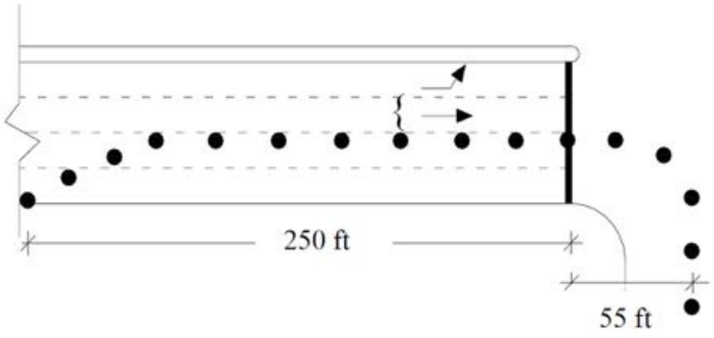
Work Zone Configurations Tested



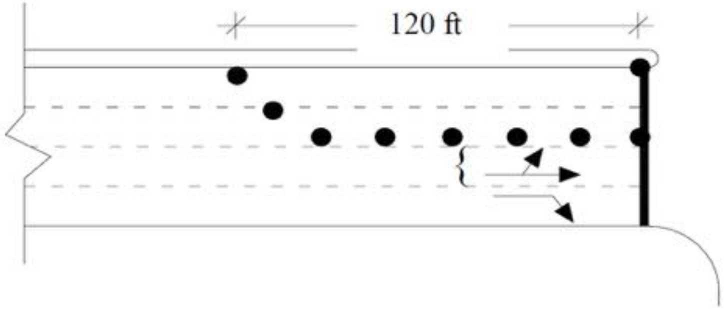
Normal “non-WZ” configuration (all sites)



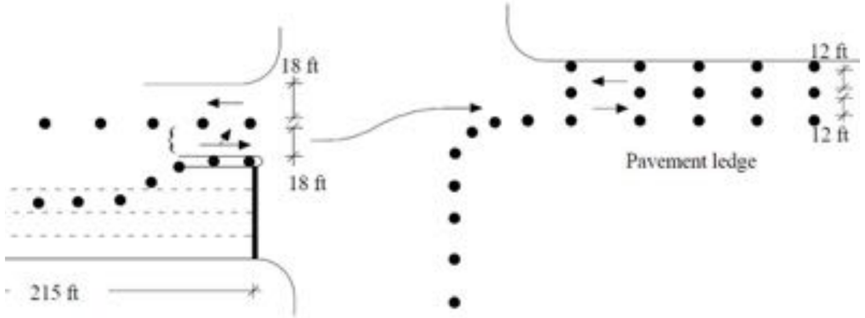
Site 1 (Northbound)



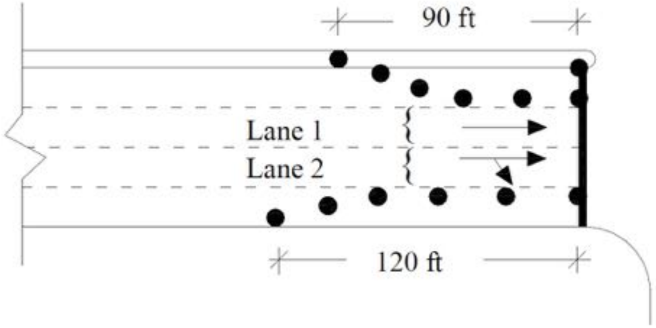
Site 2 (Northbound)



Site 3 (Southbound)



Site 4 (Southbound)



Site 5 (Southbound)

Traffic Database

In Total:

140 hrs of video recordings were analyzed & visually inspected

1,766 of traffic signal cycles were analyzed

23,823 per-vehicle headways (timestamps in milliseconds)

The largest sample size in the literature so far!

Traffic Data

> Cycle-level data included:

Cycle and phasing intervals, light condition (daylight or nighttime), degree-of-saturation (over- or undersaturated traffic), total number of vehicles, HVs, and right- and left-turns.

> Per-vehicle-level data included:

Time headway, vehicle classification including the four HV subclasses, vehicle origin (merging late from the closed lanes or approaching from the open lane), and vehicle direction (through, left-turn, or right-turn).

Study Database Structure

Overall Study Database

1,766 per-lane cycles, 23,823 vehicles, and 22,057 inter-vehicle headway observations

Subset One
467 cycles,
7,008 vehicles,
6,541 headways

- Dry-and-clear weather conditions.
- Cycles having only PCs (zero HV%) and no turning movements (zero left- or right-turns).
- **Used to derive the base saturation flow for through traffic.**

Subset Two
523 cycles,
7,451 vehicles,
6,928 headways

- Dry-and-clear weather conditions.
- Cycles having HV% > 0 and no turning movements.
- **Used to analyze the impact of HVs on through traffic.**

Subset Three
208 cycles,
2,618 vehicles,
2,410 headways

- Dry-and-clear weather conditions.
- Cycles with left- or right-turn movements regardless of the HV%.
- **Used to assess the impact of turning movements.**

Subset Four
568 cycles,
6,746 vehicles,
6,178 headways

- Snow-impacted weather conditions.
- Cycles having HV% > 0 and no turning movements.
- **Used to assess the impact of several snow conditions.**

Data Analysis

Putting microscopic traffic data (per-vehicle time headway) under the microscope!!

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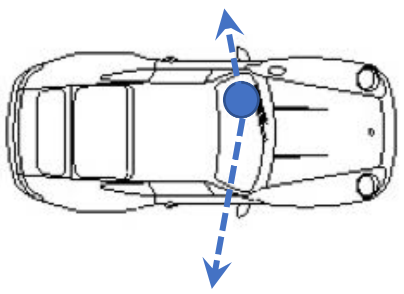
Work Zone Capacity Models

Saturation Flow Characteristics at The Study Sites

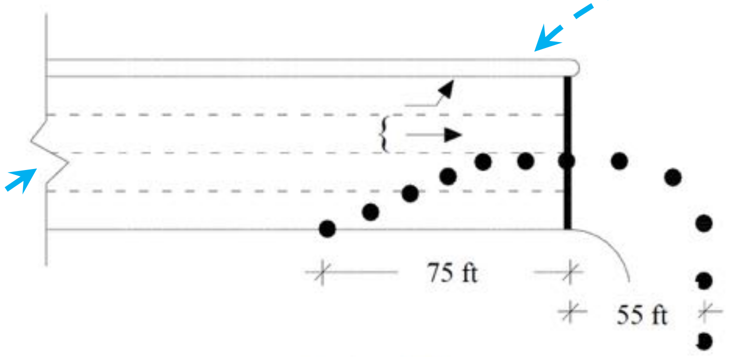
Site ID	Oversaturated Conditions			Undersaturated Conditions		
	Ave Saturation Headway (sec) [SD]	**Hourly Saturation Flow (pc/hr/ln)**	No of Cycles & [Headways]	Ave Saturation Headway (sec) [SD]	**Hourly Saturation Flow (pc/hr/ln)**	No of Cycles & [Headways]
Site 1	2.037 [0.5158]	**1,767.3**	86 [1283]	2.290 [0.5570]	**1,572.1**	30 [240]
Site 2	2.250 [0.6069]	**1,600**	31 [406]	2.447 [0.6173]	**1,471.2**	67 [459]
Site 3	2.175 [0.5414]	**1,655.2**	42 [566]	2.317 [0.5577]	**1,553.7**	21 [118]
Site 4	2.730 [0.6722]	**1,318.7**	60 [623]	2.882 [0.7591]	**1,249.1**	18 [107]
Site 5 Lane 1	2.315 [0.7063]	**1,555.1**	79 [967]	NA	**NA**	NA
Site 5 Lane 2	2.435 [0.7168]	**1,478.4**	33 [371]	NA	**NA**	NA

WZ Capacity: The impact of Geometrics

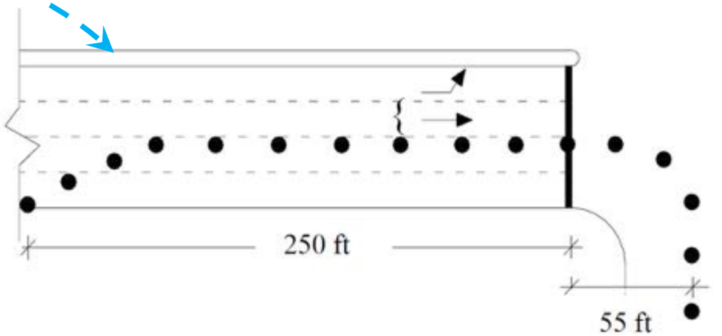


A very long WZ closure (250 ft) further reduced the flow by 9.5% as compared to moderate closure length (75 ft).

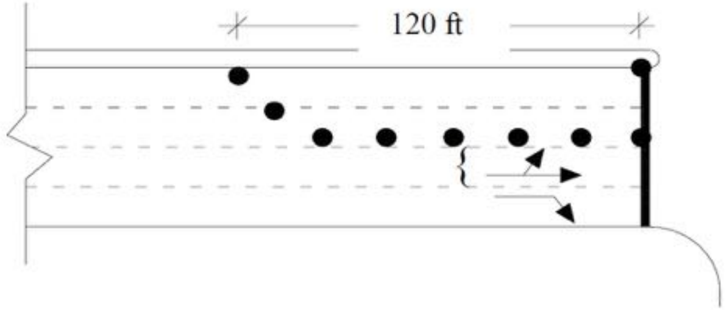
Left-side closure appeared to further reduce the saturation flow by 6.3% as compared to right-side closure.



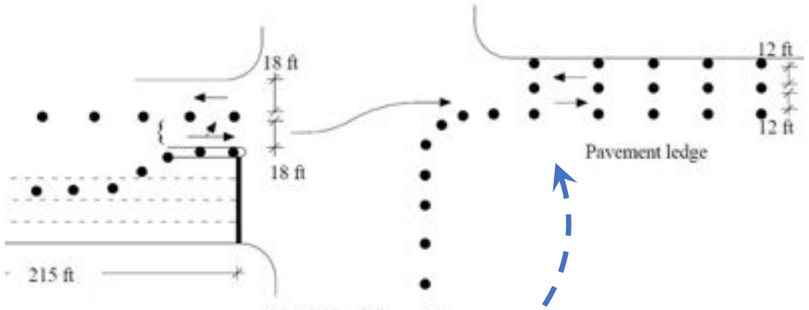
Site 1 (Northbound)



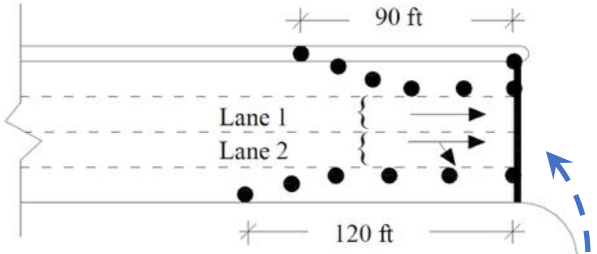
Site 2 (Northbound)



Site 3 (Southbound)



Site 4 (Southbound)



Site 5 (Southbound)

The configuration with a median crossover retrieved the lowest flow rate (1318 pc/hr/ln).

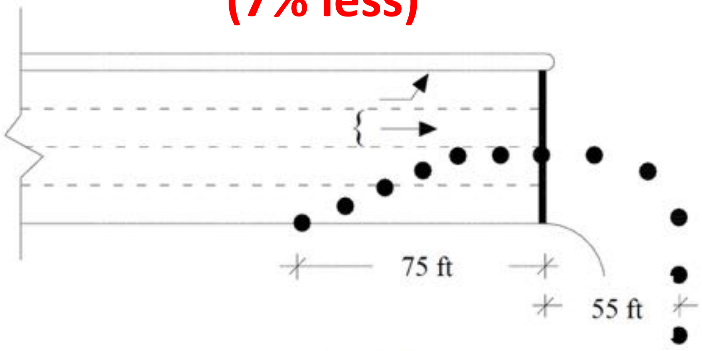
The two-lane WZ yielded lower per-lane capacity as compared to single-lane WZs.

WZ Capacity: Comparing the HCM WZ Model

Using the HCM WZ model, the derived fwz was always 1.0; therefore:
The HCM-based WZ flow was 1900 pcphpl for all examined cases.

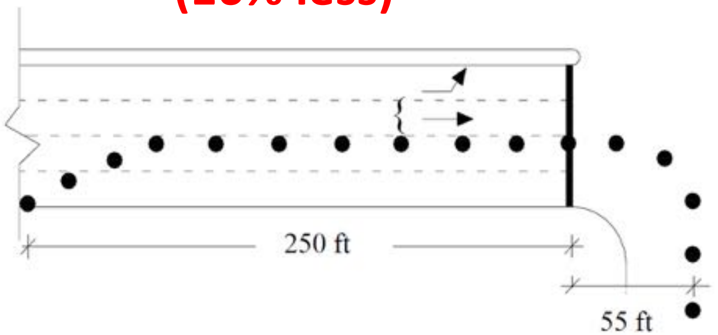
Clearly, the HCM did not accurately capture the capacity (it overestimated the flows).

1767/1900 = 0.9302
(7% less)



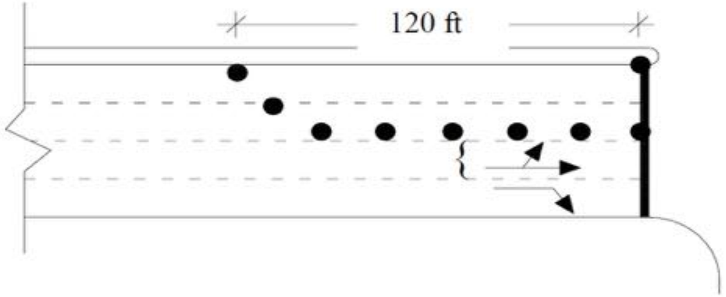
Site 1 (Northbound)

1600/1900 = 0.8421
(16% less)



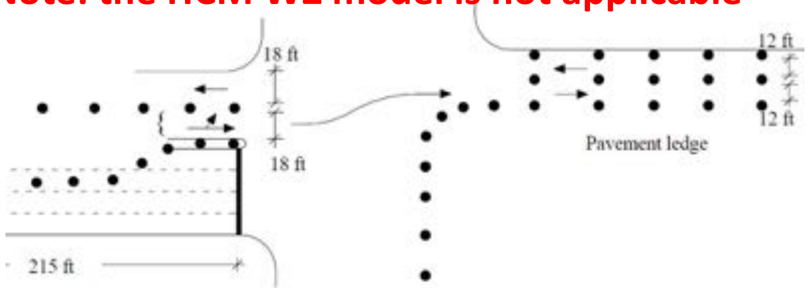
Site 2 (Northbound)

1655/1900 = 0.8712
(13% less)



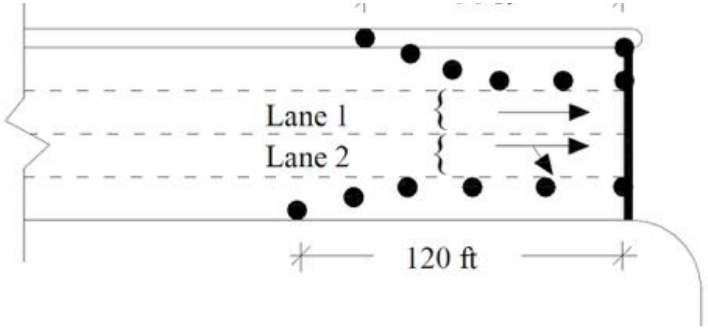
Site 3 (Southbound)

1318/1900 = 0.6941
(31% less)
Note: the HCM WZ model is not applicable



Site 4 (Southbound)

Lane 1: 1555/1900 = 0.8185 **(18% less)**
Lane 1: 1478/1900 = 0.7781 **(22% less)**



Site 5 (Southbound)

Work Zone Capacity Models: Other Influential Factors

$$H_o: \mu_{\text{headway, oversaturation}} = \mu_{\text{headway, undersaturation}}$$
$$H_a: \mu_{\text{headway, oversaturation}} < \mu_{\text{headway, undersaturation}}$$

Capacity flow during oversaturated conditions was **higher by 5 to 11%** across the study sites as compared to undersaturated conditions.

$$H_o: \mu_{\text{headway, daylight}} = \mu_{\text{headway, nighttime}}$$
$$H_a: \mu_{\text{headway, daylight}} < \mu_{\text{headway, nighttime}}$$

Capacity flow under nighttime conditions was **lower by 3 to 6%** as compared to daylight conditions.

$$H_o: \mu_{\text{Late Merge-On Lane}} = \mu_{\text{On Lane-On Lane}}$$
$$H_a: \mu_{\text{Late Merge-On Lane}} < \mu_{\text{On Lane-On Lane}}$$

Vehicles merging late from the closed lanes had a shorter headway as compared to vehicles approaching from the open lane (**by 8 to 10%).**

Takeaways and Recommendations

> ***WZ capacity cannot be estimated accurately based solely on the number of closed and open lanes*** and additional attention must be given to each site and its particular geometry (e.g., WZ length, right versus left closure, presence of median crossover, etc).

> Generalizing the HCM WZ model may result in ***significant inaccuracy***.

> ***Capacity models are better to be based on oversaturated conditions***.

> ***More attention for nighttime WZ activities.***

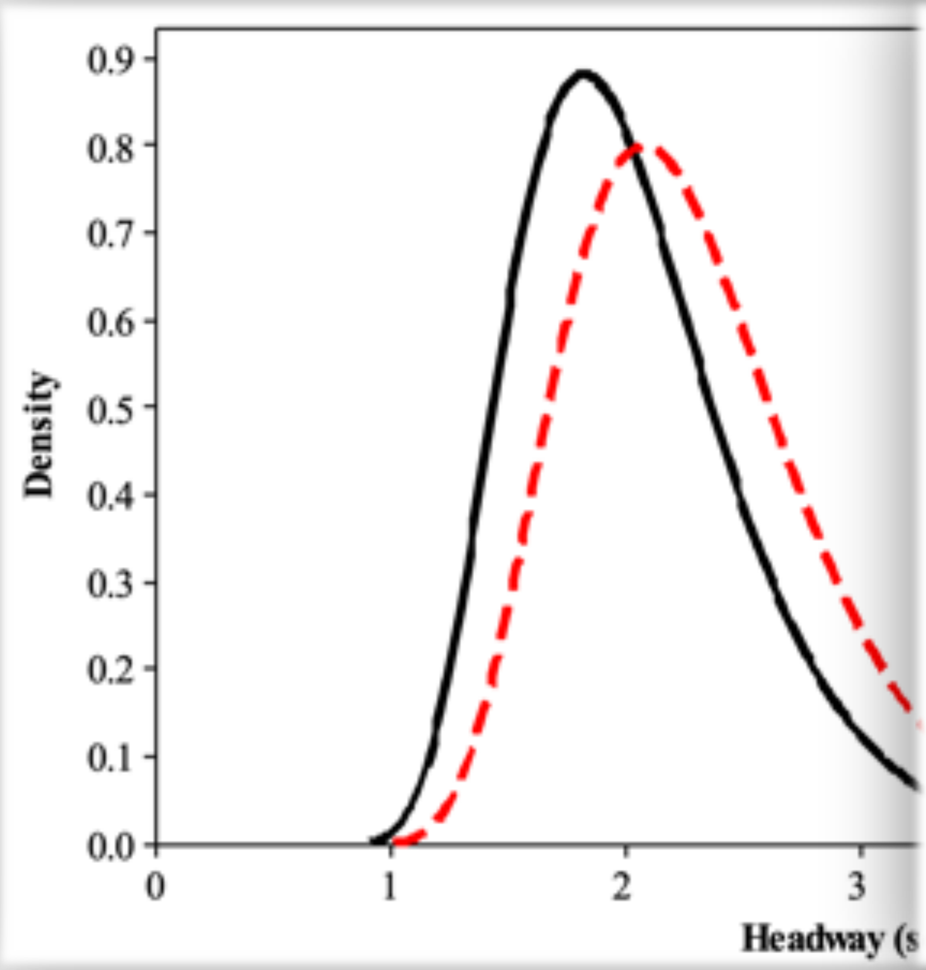
Takeaways and Recommendations

> ***Late-merging further compressed the time headway*** and consequently increased capacity and the throughput.

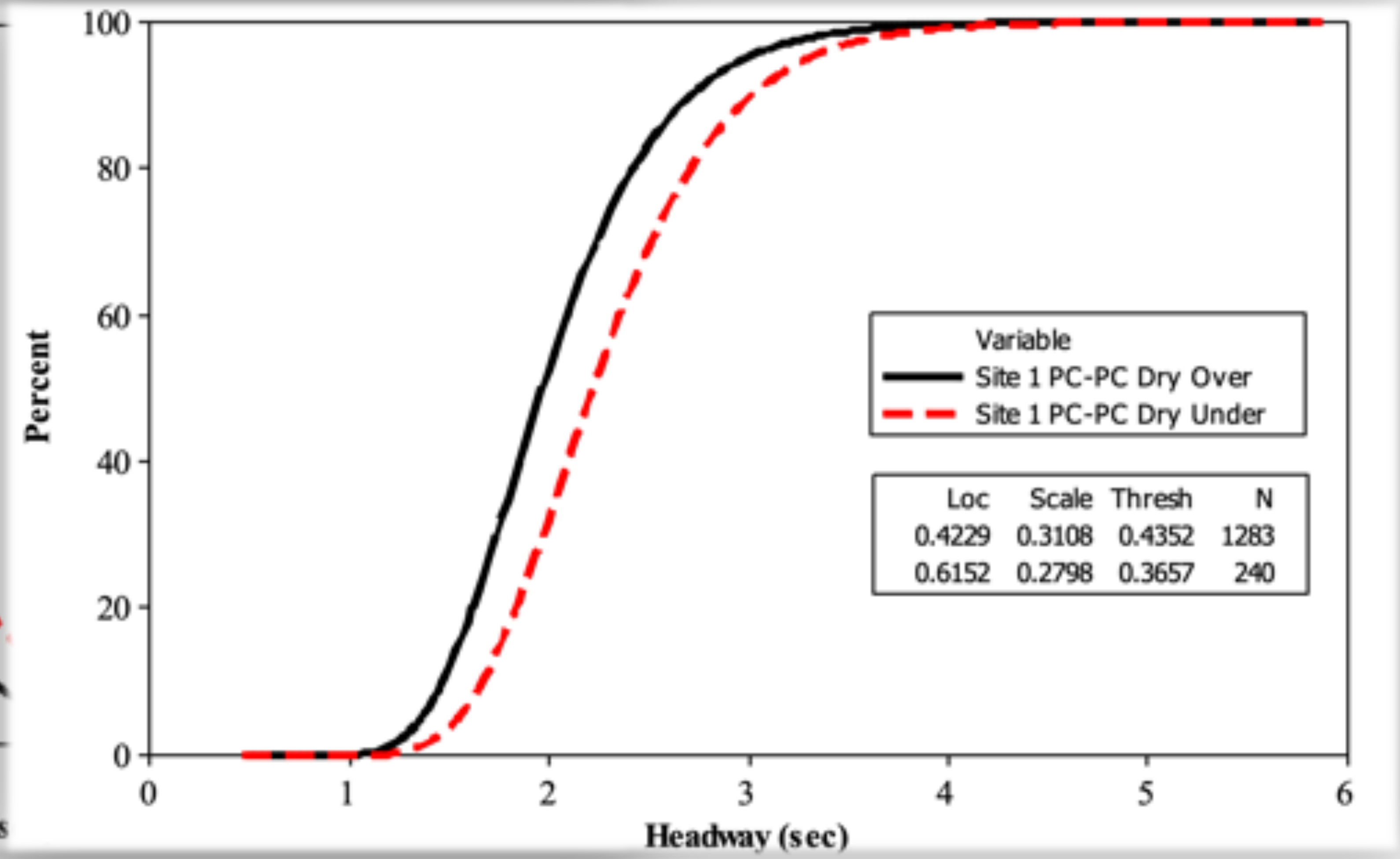
> Therefore, **from capacity perspectives, imposing an early-merge system upstream may not be an efficient strategy**.

> This may not only reduce the flow but it may also reduce the available queue storage space. Nevertheless, safety implications should also be considered.

Work Zone Capacity Models: Reliability and Stochastic Approach

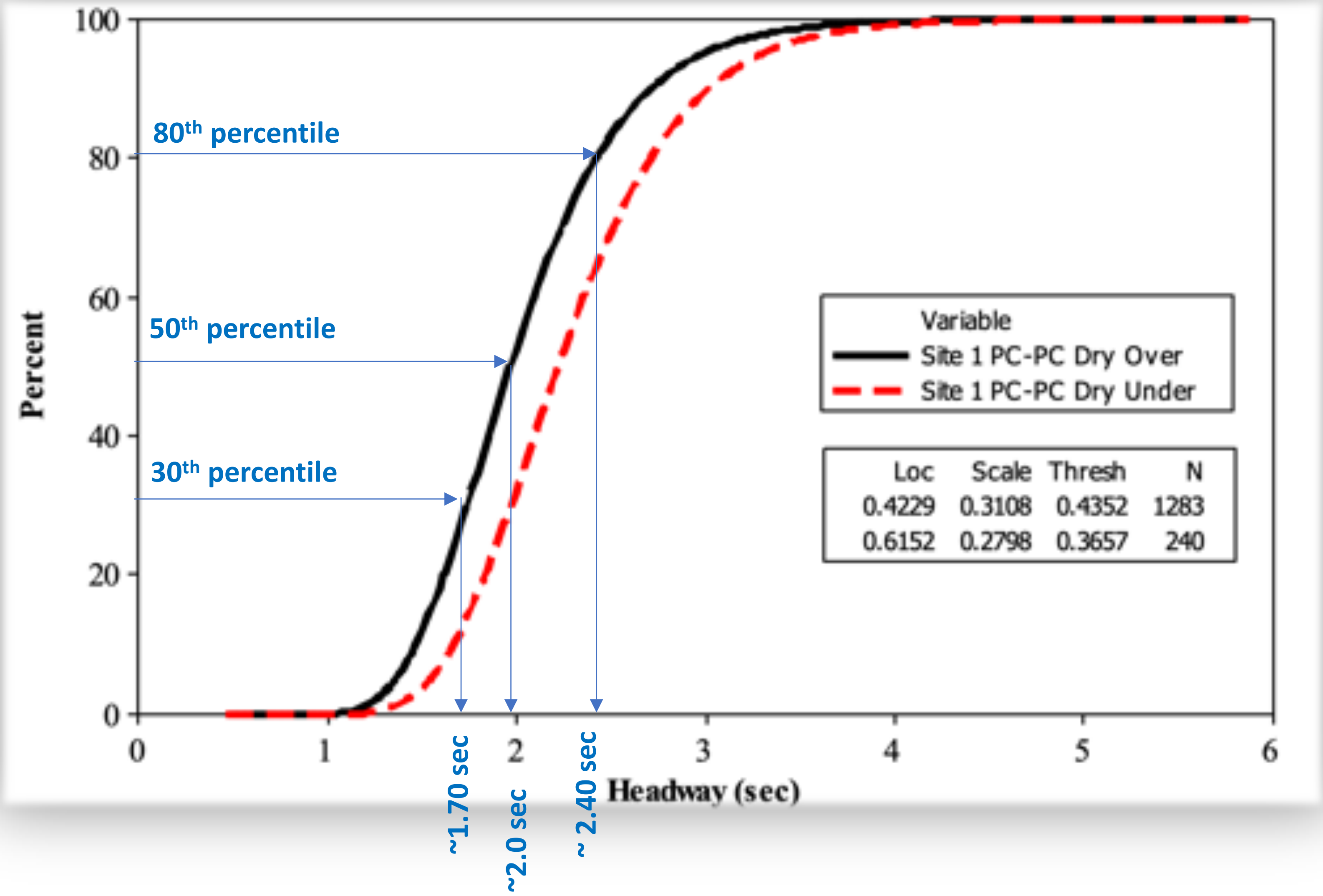


Probability Density Function – Site 1



Cumulative Distribution Function – Site 1

Work Zone Capacity Models: Reliability and Stochastic Approach



Cumulative Distribution Function

Stochastic and Reliability Modelling

50th percentile flow = 1800 pcphpl
(average case for practical applications)

80th percentile flow = 1500 pcphpl
(conservative case for highly congested, unpredictable, and important corridors)

30th percentile flow = 2118 pcphpl
(non-conservative value, never used it in planning, just to evaluate the probability of queuing, e.g., if the demand is fixed at 2118 pcphpl then the probability of queuing is 70%, in other words, only 30% of time the capacity is approximately sufficient to serve the demand)

(capacity flow = saturation flow =3600/headway)

Takeaways and Recommendations

> Stochastic capacity models can assist in preparing more reliable traffic management plans.

> Higher headway percentiles, e.g., the 80th percentile, can yield a conservative capacity estimation (i.e., capacity=3600/headway) which ***can better suit WZ operations on important junctions and streets,*** e.g., junctions connected to major corridors which may create influential queue spillage or streets leading to universities, transit stations, airports, and other travel-time sensitive destinations.

> Central percentiles, e.g., the 50th, can be used ***for common streets located in moderately congested areas*****.**

> Using ***lower percentiles should be avoided*** for all planning studies/purposes. ***Only useful for estimating the chance/probability of queuing*** when congestion becomes inevitable.

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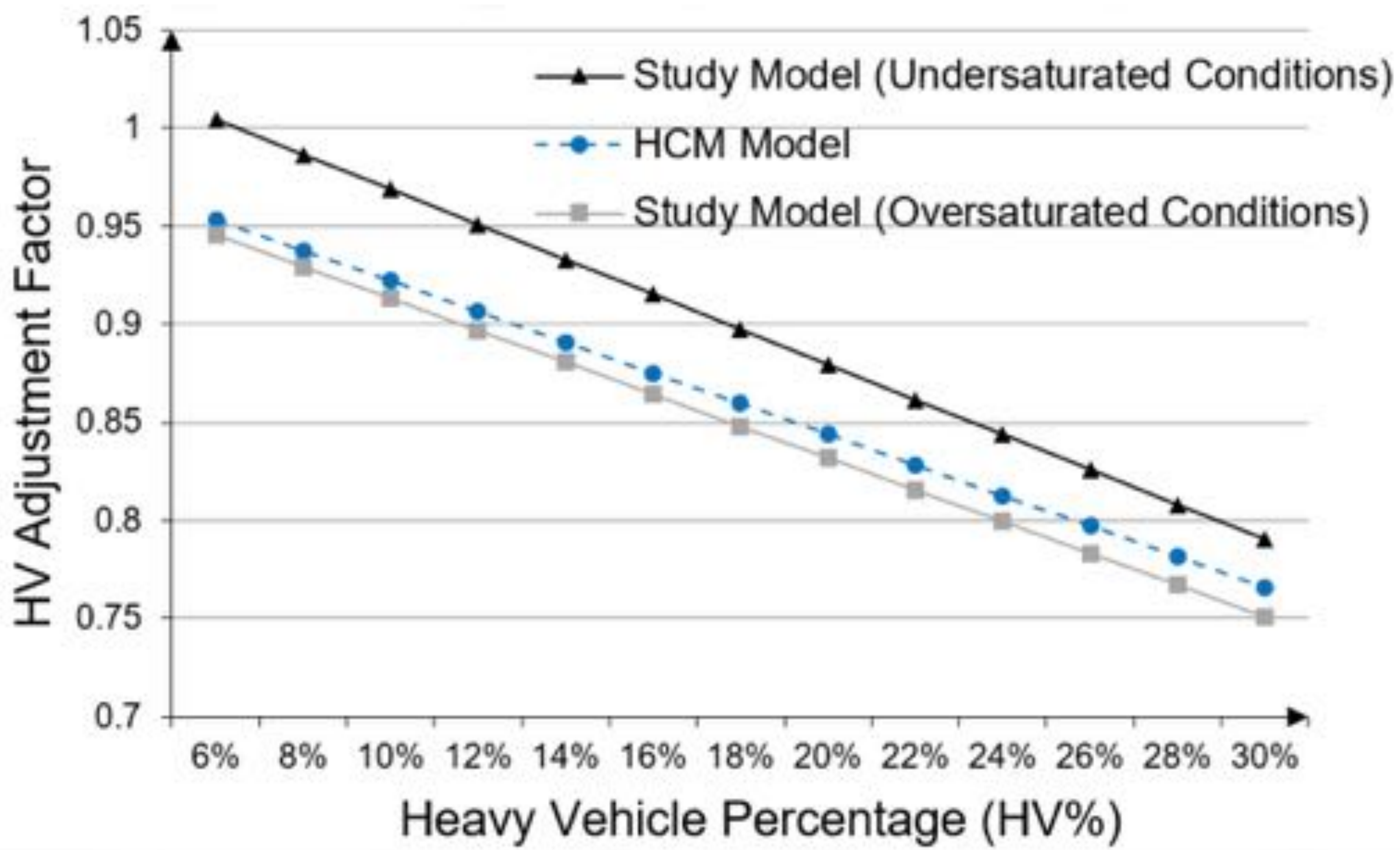
Impact of Heavy Vehicles on Capacity

Model	Predictors	Resulting Equation	Regression Statistics
Model One	HV% for all degrees of saturation	HV Factor = 1.008-0.792 HV%	WLS regression R-sq = 0.539, Adjusted R-sq= 0.535 Significance of the coefficients = 0.000 Sample = 106 bins
Model Two	HV% for only oversaturated conditions	HV Factor = 0.994-0.810 HV%	WLS regression R-sq = 0.573, Adjusted R-sq= 0.567 Significance of the coefficients = 0.000 Sample = 75 bins
Model Three	HV% for only undersaturated conditions	HV Factor = 1.058-0.892 HV%	Standard regression R-sq = 0.655, Adjusted R-sq= 0.643 Significance of the coefficients = 0.000 Sample = 31 bins
Model Four	HV%, degree-of-Saturation	HV Factor = 1.003 -0.890 HV% + 0.054 Undersaturation Undersaturation: dummy variable, 1 if the operations are undersaturated and 0 otherwise.	WLS regression R-sq = 0.680, Adjusted R-sq= 0.674 Significance of the coefficients = 0.000 Sample = 106 bins
Model Five	Transit Bus%, Light Truck%, Large Truck%, Articulated Bus%, degree-of-saturation	HV Factor = 1.010 -1.013 TTC% - 0.423 Light Truck% -2.839 Large Truck% -3.106 Artic Bus %+ 0.054 Undersaturation	WLS regression R-sq = 0.680, Adjusted R-sq= 0.664 Significance of the coefficients = 0.000 Sample = 106 bins

Impact of Heavy Vehicles on WZ Capacity



Impact of Heavy Vehicles on WZ Capacity

Average headway by different vehicle classes and following modes

Following Mode	Average Headway (sec)	Number of Observations	Standard Deviation
Articulated Bus-Passenger Car	5.936	19	1.732
Passenger Car-Articulated Bus	2.550	22	0.63420
Large Truck-Passenger Car	7.421	27	2.4353
Passenger Car-Large Truck	2.535	28	0.7663
Light Truck-Passenger Car	3.494	227	1.2022
Passenger Car-Light Truck	2.433	227	0.6427
Transit Bus-Passenger Car	4.630	358	1.3433
Passenger Car-Transit Bus	2.514	369	0.6378
Passenger Car-Passenger Car	2.367	12,160	0.6684

Different subclasses of heavy vehicles yield significantly different headways and impacts on capacity. But, heavy vehicles are predominantly composed of lights trucks and normal buses. The R-square did not improve significantly when splitting the blanket HV% into subclasses.

Takeaways and Recommendations – HV Impact

>On average, ***oversaturated conditions yielded a 5.4% additional HV-induced flow reduction*** as compared to undersaturated conditions.

>***The HCM HV model appears to be applicable at oversaturated WZs*** for practical reasons, although this study model, which is WZ-induced, appears to be more conservative.

> There was ***no need to over-complicate the HV model*** (no need to consider different HV subclasses).

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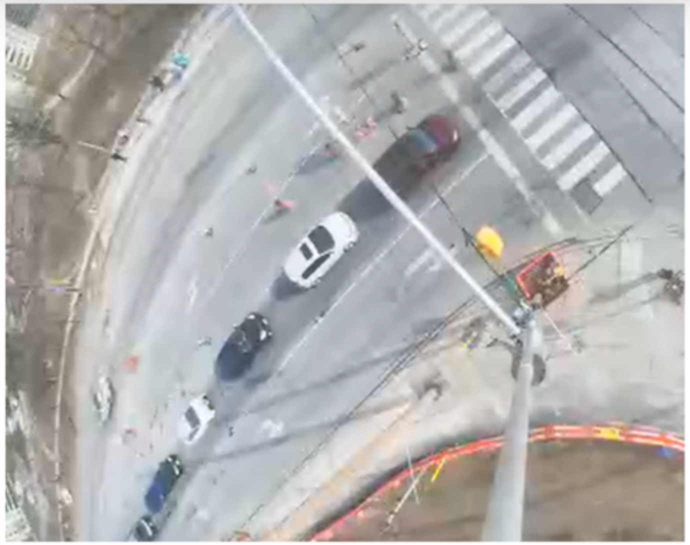
Impact of Snow Conditions on Capacity

Impact of Snow Conditions on Capacity

Fully Slushy

Partly Slushy

Bare and wet pavement (post-snow)



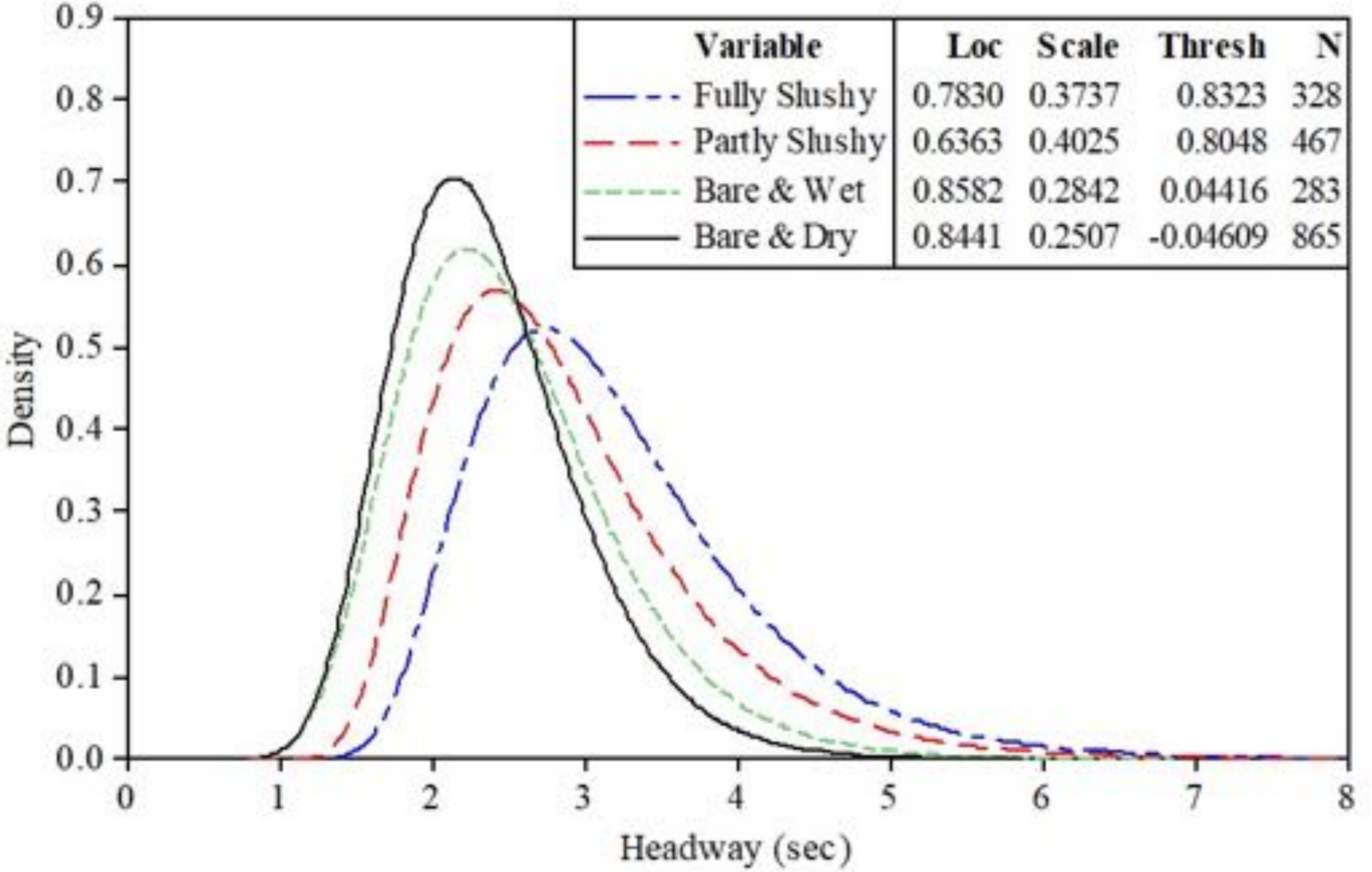
Bare and dry pavement (base conditions)

Impact of Snow Conditions on Capacity

Impact of Weather Variables on Headways (%increase) and Capacity (%decrease)

Following Mode	Statistics	Fully Slushy	Partly Slushy	Bare & Wet
PC-PC	Ratio to Bare & Dry (percent increase in headway)	+35.1% to +42.0%	+21.2% to +23.4%	+6.20% to +12.6%
PC-HV	Ratio to Bare & Dry (percent increase in headway)	+32.5% to +44.6%	+20.7% to +17.3%	+6.93% to +12.3%
HV-PC	Ratio to Bare & Dry (percent increase in headway)	+7.9% to +27.2	+2.4% to +17.4%	+1.8% to +9.85%

Impact of Snow Conditions on Capacity



Probability Density Functions for Several Weather and Snow Variables

> The presence of snow on the pavement increased the average headway ***and also the standard deviation***.

> ***Drivers' skills and capabilities were more heterogeneous*** under snow conditions as compared to dry-and clear condition.

Takeaways and Recommendations – Snow Impact

>Transportation agencies should consider ***restricting WZ activities under snow conditions.***

> ***WZ restriction may also extend for several hours after the snow event*** at important or congested corridors.

>Such a policy may be directed ***more towards short-term or intermediate-term activities.*.**

>Long-term WZs may however ***consider reopening lanes if the barriers and work equipment can be flexibly shifted***.

Takeaways and Recommendations – Snow Impact

> If a WZ cannot be avoided under snow conditions, then a ***refined traffic management plan*** that considers snow-specific capacity changes is needed.

> HVs appeared less sensitive and more resistant to snow conditions as compared to PCs.

> ***Restricting HV operations during such events may be less important*** as compared to dry-and-clear conditions.

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Impact of Turning Movements

>The low volume of turning movements (Data Subset Three) did not allow to prepare a detailed analysis of their impact (e.g., not enough to establish detailed adjustment factors by turning traffic and conflicting traffic volumes and pedestrians volume).

>High-level analysis using car-following modes for only PC-PC:

Following Mode	Average Headway (sec)	Ratio-to-Through-Through
Through-Through	2.762	1.0
Right Turn-Through	3.792	1.373
Through-Right Turn	4.085	1.479

At Site 5

Following Mode	Average Headway (sec)	Ratio-to-Through-Through
Through-Through	2.958	1.0
Left Turn-Through	3.841	1.298
Through-Left Turn	3.296	1.114

At Site 4

Impact of Turning Movements

> ***The impact of turning movements (right and left) on capacity is substantial and important.***

> Traffic agencies should ***consider prohibiting turning movements at WZs,*** when capacity becomes a concern and when the volume of turning traffic is high.

> Such prohibition should also reduce the WZ overall traffic demand and promote rerouting strategies especially at long-term WZs.

> Feasible ***alternate routing schemes*** should be arranged and accommodated.

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Results & Recommendations

All-In-All Closing Remarks and Advices

>This study highlights that many ***geometric, traffic, weather, and environment factors*** can dynamically and significantly impact WZ capacity.

>Transportation agencies may consider adopting ***an adaptive traffic management plan*** at long-term WZs where conditions may vary considerably over the WZ lifetime.

>Nevertheless, this study provided ***the basic tools to estimate WZ capacity*** and each jurisdiction may adopt its own TMP change/update warrants based on its road standards and socio-economic factors.

Study Limitations

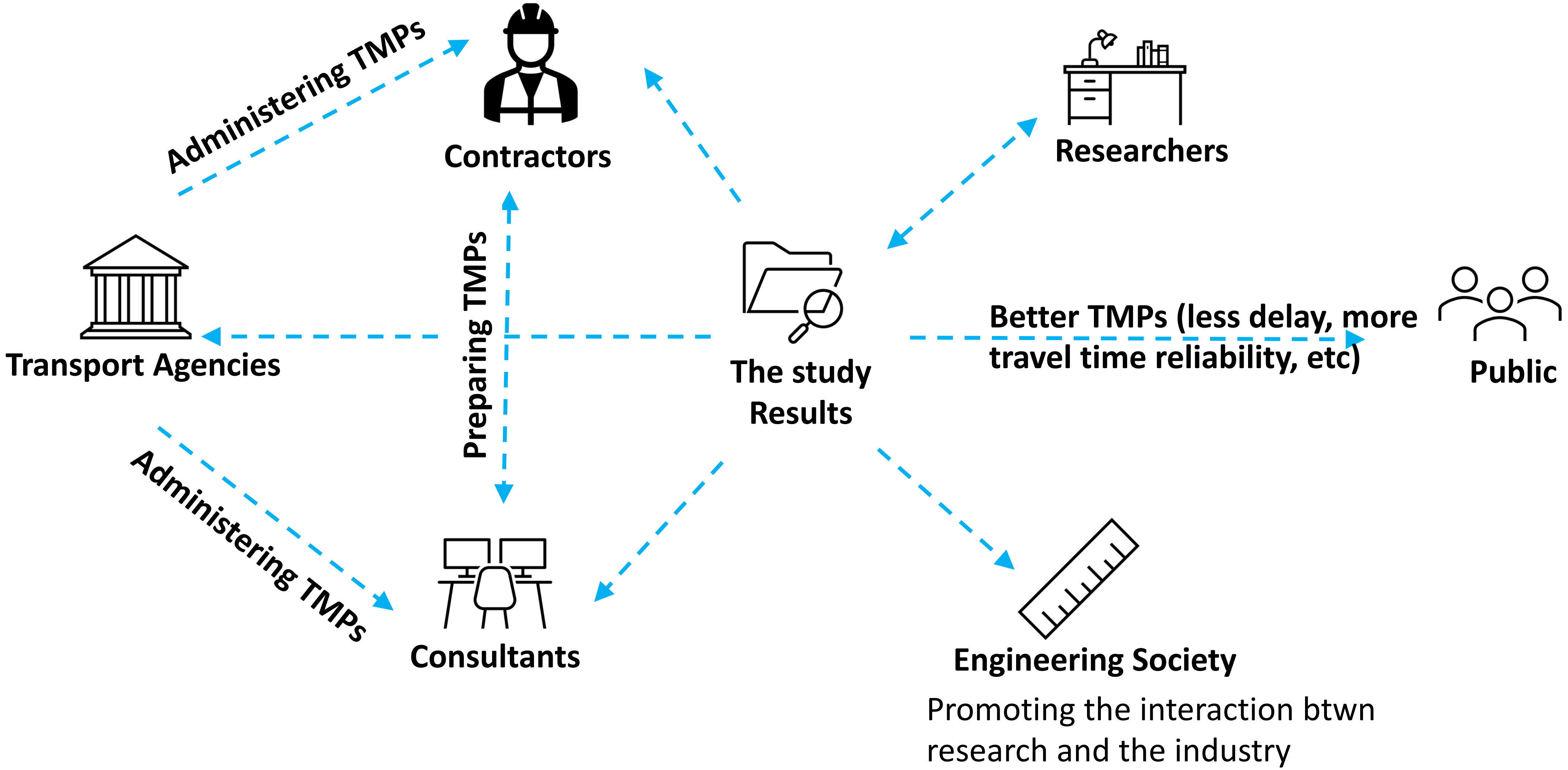
This study evaluated several popular and basic WZ configurations, so the results can be transferred into many similar WZ sites. However, additional efforts are needed *to examine:*

> more specific configurations.

> ***the impact of rain and fog.***

> ***demand estimation and modelling also deserve attention in future work.***

Work Zone Activities as Eco-System



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Thank You

Questions?