DEVELOPMENT OF INTERVAL-BASED PLANNING MODELS FOR EVALUATING THE BAY LENGTH IN A SIGNALIZED SUPERSTREET

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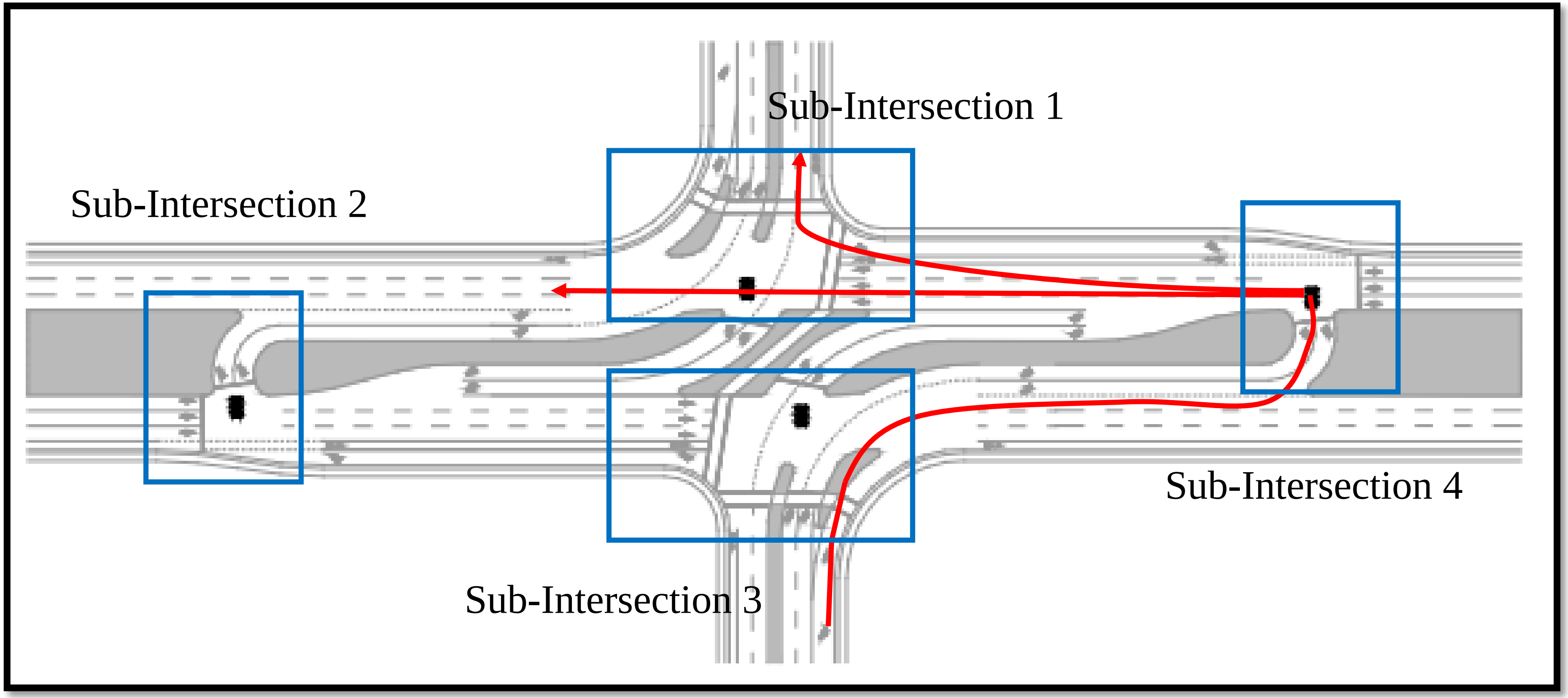
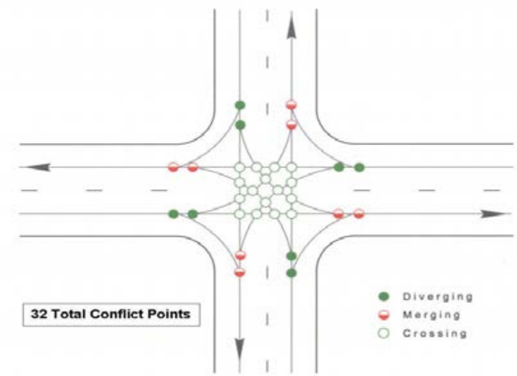
Superstreet



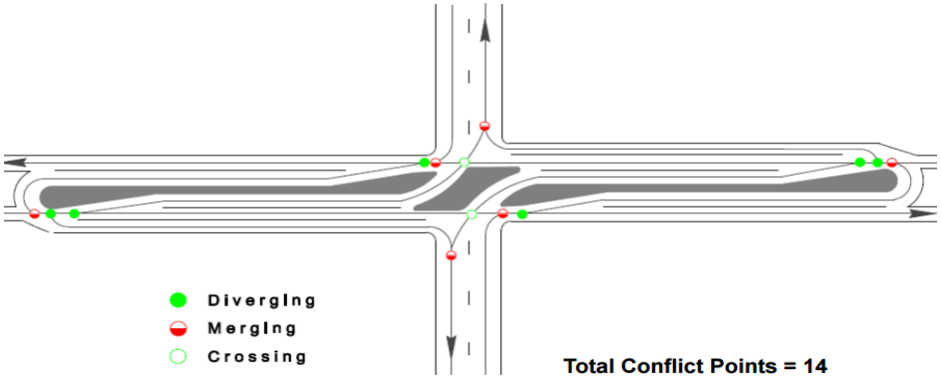
Superstreet

❑ **BENEFITS:** → ***Increased Popularity of un-signalized Superstreets.***

- Economical Benefits: *Less expensive than an interchange;*
- Safety Benefits: *Reduction in number & severity of the collisions;*
- Operation Benefits: *Provide un-interrupted flow along the corridor.*



Conventional Intersection



Superstreet

Research Background

❑Literature Review

- A number of studies in the literature have confirmed its safety benefits. (Hummer, 2001, 2008, 2010, 2012; Kim, 2007).
- In fact, over the past decades, only limited studies (Olarte, 2011) have attempted to address the issues of design and operations of a Superstreet.
- A newly published report (FHWA, 2014) also indicated the lack of sufficient information in the area of designing a Superstreet.

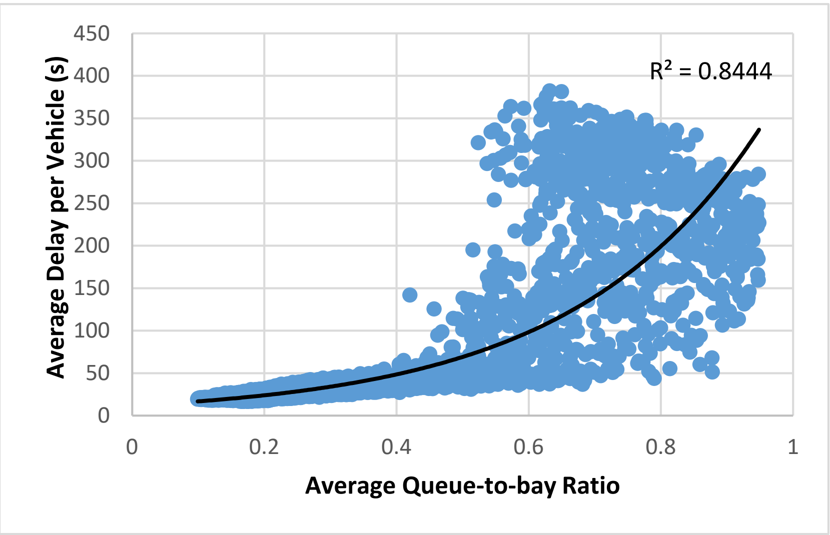
Existing Literature fall short on the subjects of Design and Evaluation of Superstreets.

Operation Analysis

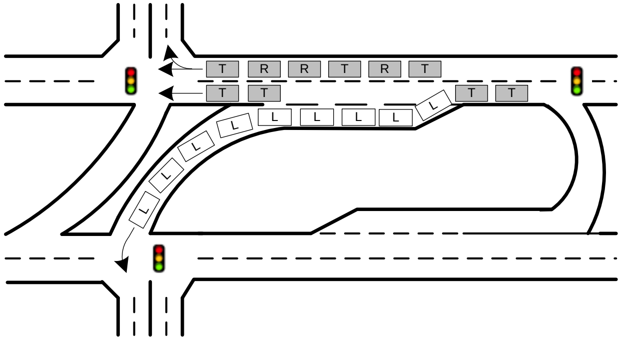
Field Survey and VISSIM Calibration

- This study has conducted a field survey at a signalized Superstreet Intersection **(MD3 & Waugh Chapel Rd)** to calibrate key parameters in VISSIM;
- The collected data include queue lengths, signal plan and traffic flow rates.
- Extensive simulation results reveal that the exponentially increased delay when Q/L ratio approaches to 1.

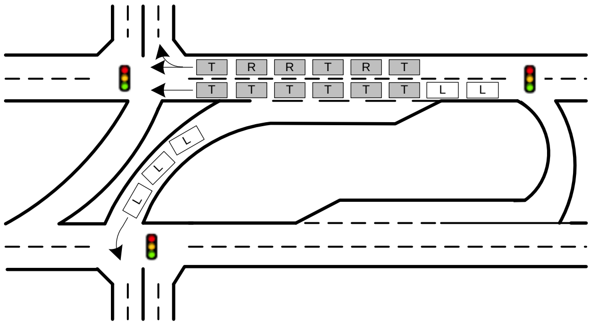
Figure 1. Scatter plot of average delay v.s. average QL ratio



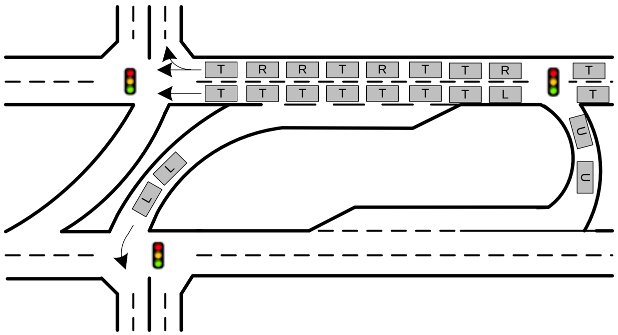
Possible blockages among a Superstreet are shown below:



(A) Left-turn lane group partially blocks the right-through lane group



(B) Right-through lane group completely blocks the left-turn lane group



(C) Through lane group completely blocks the upstream lane groups

Critical Issues

Interval-based queue estimation models

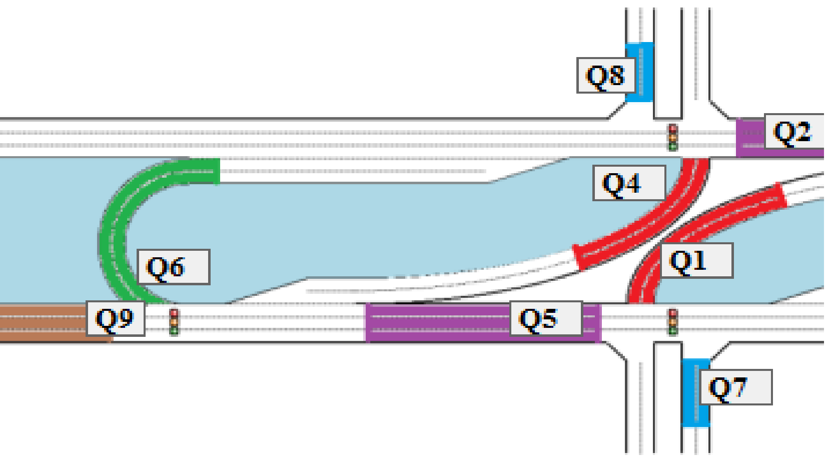
- Traffic flow and signal design can both contribute to the formation of queues in a superstreet
- ➢ *Incoming traffic fluctuates over time*
- ➢ *Signal coordination plan is another key factor to determine queue length*
- ➢ *Develop interval-based queue estimation models to take into account of the both uncertainties*.

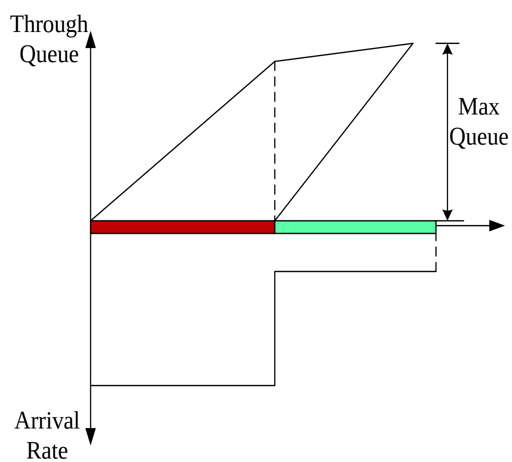
- Two types of queues:

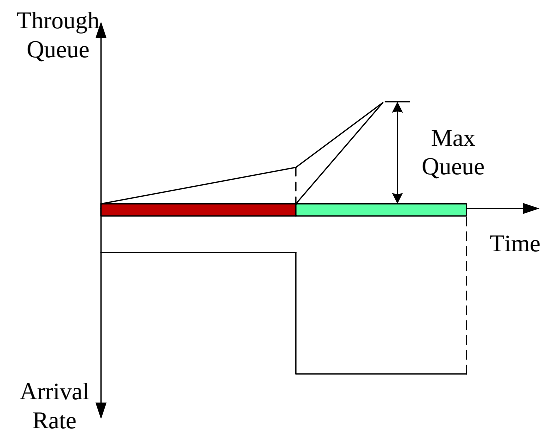
1) **External Queues:** only influenced by flow fluctuation
2) **Internal Queues:** influenced by both flow fluctuation and signal coordination

Queue lengths under different signal coordination plan

- For main intersection through Q: ***Q5***, departures from Q6 and Q9 are two sources for it's incoming flow.
- 1) through and right-turn movements from Q9;
- 2) departures from Q6





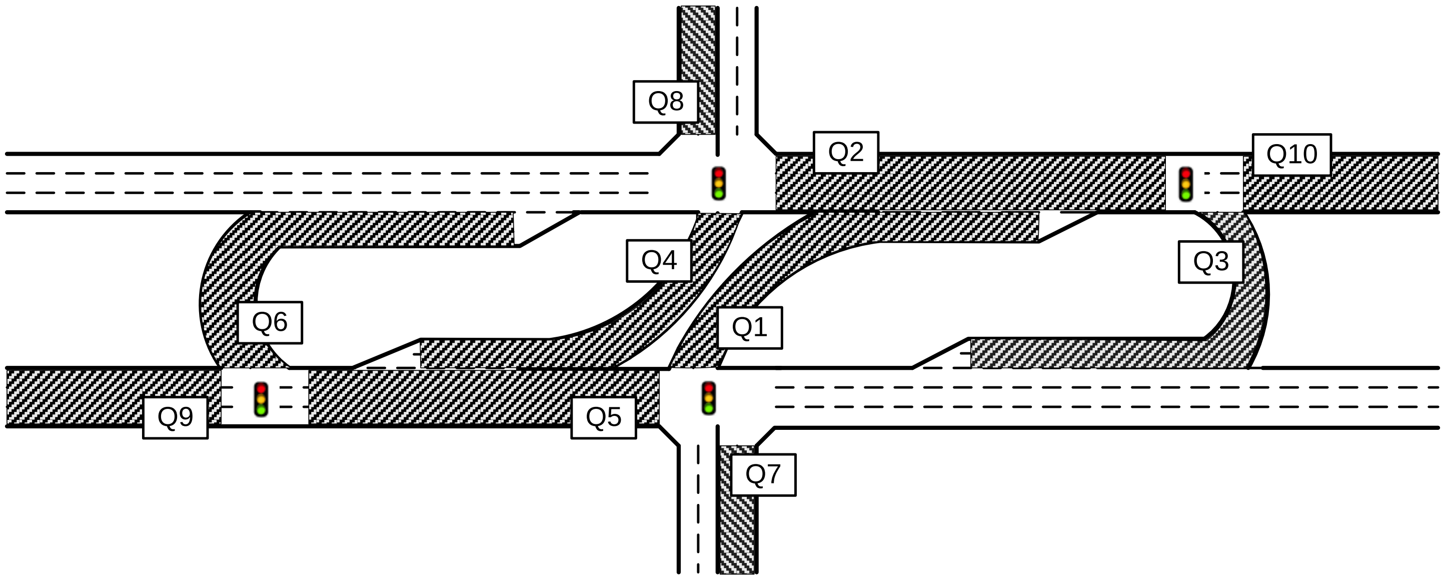


Worst Case=
Largest arrival rate+
worst signal coordination

Best Case=
Smallest arrival rate+
Best signal coordination

Model Development

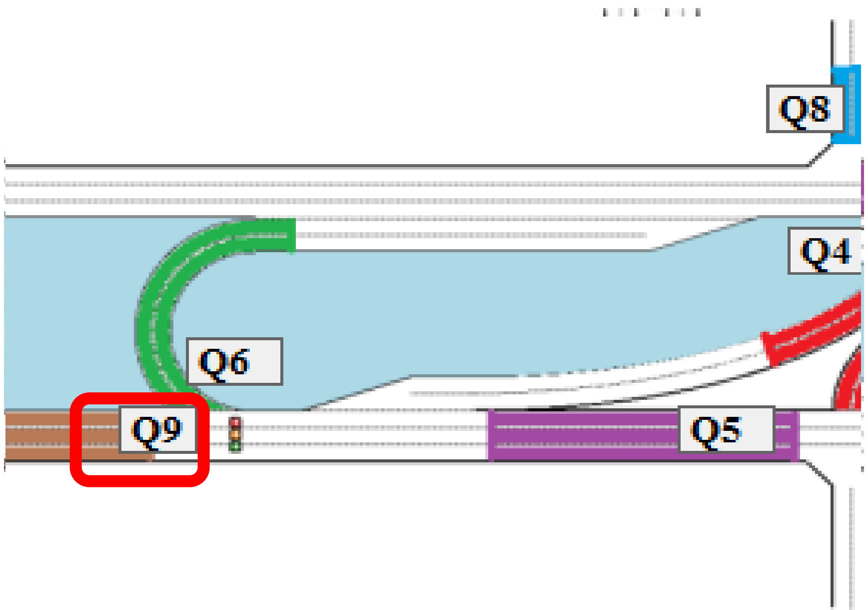
❑ **Spatial distributions of all potential queues among a Signalized Superstreet**



- Type-1 (Q7, Q8, Q9,Q10): Through queues at major & minor road
- Type-2 (Q3, Q6): U-turn queues at the crossover intersection
- Type-3 (Q1, Q4): Left-turn queues at main intersection
- Type-4(Q2, Q5): Through queues at main intersection

Interval-based Queue Model

- **Q5: Through queues at the main intersection**
  - Departures from Q6
  - Through and Right-turn departures from Q9



$$D_{9TR}^{k} = \begin{cases} 0 & \text{During Red Time} \\ \min(s, A_{9TR}^{k} + q_{9TR}^{k}) & \text{During Green Time} \end{cases}$$

where : s is the saturation flow rate for link 9;

β_{9TR} is the through and right-turning ratio for Q9;

A_{9TR}^{k} is the arrived vehicle for through and right-turn movements in Q9 at time k;

q_{9TR}^{k} is the queued through and right-turning vehicles in Q9 at time k.

For Q6, all the departures from it should merging into Q5, so at any time point k, the departures from Q6 to Q5 can be expressed as:

$$D_{6}^{k} = \begin{cases} 0 & \text{During Red Time} \\ \min(s, A_{6}^{k} + q_{6}^{k}) & \text{During Green Time} \end{cases}$$

where : s is the saturation flow rate for link 6;

A_{6}^{k} is the arrived vehicle in Q6 at time point k;

q_{6}^{k} is the vehicles in Q6 at time point k.

Arrivals at Q5:

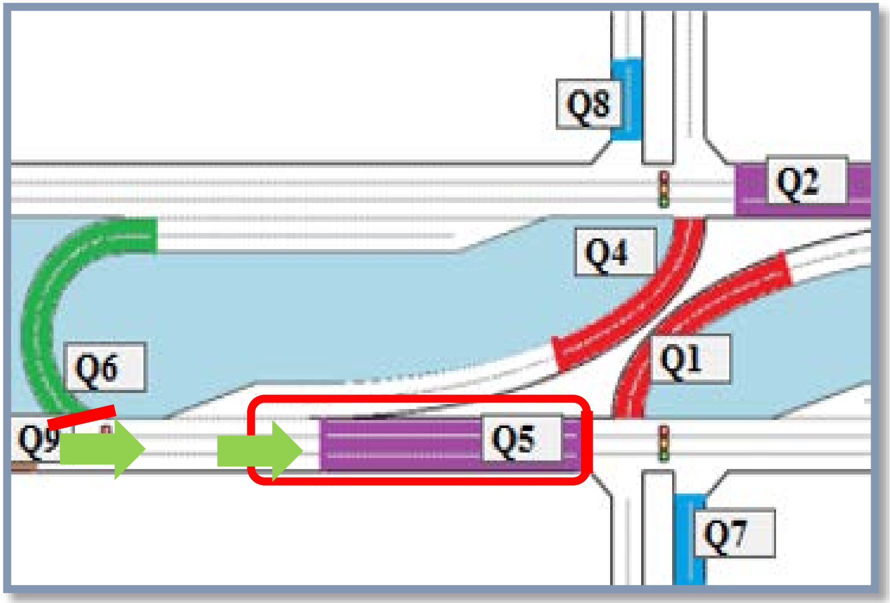
$$A_{5}^{k} = \alpha D_{9TR}^{k-\sigma} + (1-\alpha) D_{6}^{k-\tau}, \alpha = 0,1$$

where : σ *is* the travel time from Q9 to Q5

τ is the travel time from Q6 toQ5;

while α is a binary variable.

Interval-based Queue Model



- When Q5's red and Q9's green is concurrent, we could find the queue as:

$$\bar{Q}_5 = \begin{cases} \int_{t_0}^{t_0+R_5} D_{9TR}^{t-\sigma}\,dt + \int_{t_1}^{t_1+t*} D_{9TR}^{t-\sigma}\,dt, if R^5 + t* \le g^9 \\ \int_{t_0}^{t_0+R_5} D_{9TR}^{t-\sigma}\,dt + \int_{t_1}^{t_1+t*} A_5^t\,dt, if R^5 + t* > g^9 > R^5 \\ \int_{t_0}^{t_0+g_9} D_{9TR}^{t-\sigma}\,dt + \int_{t_0+g_9}^{t_0+R_5} D_6^{t-\tau}\,dt + \int_{t_1}^{t_1+t*} D_6^{t-\tau}\,dt, if R^5 > g^9 \end{cases}$$

- The queue dissipate time $t*$ can be derived using:

$$\int_{t_0}^{t_0+R_5} A_5^k\,dt = \int_{t_1}^{t_1+t*} (s_5 - [\alpha D_{9TR}^{k-\sigma} + (1-\alpha) D_6^{k-\tau}])\,dt$$

$\alpha = 0$ or 1;

where t_1 is the intial time of green phase of Q5

t* is time to dissipate initial queue

s is the saturation flow rate.

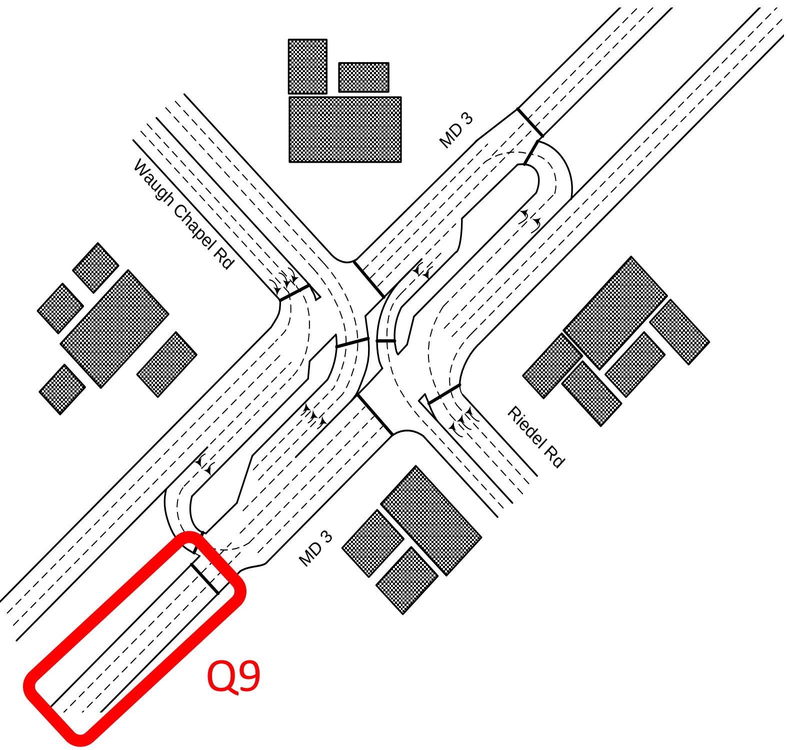
By taking into consideration of incoming traffic fluctuation, we can have the maximum queue interval as:

$$Q_5^{\max} = \bar{Q}(A_5^{\max})$$

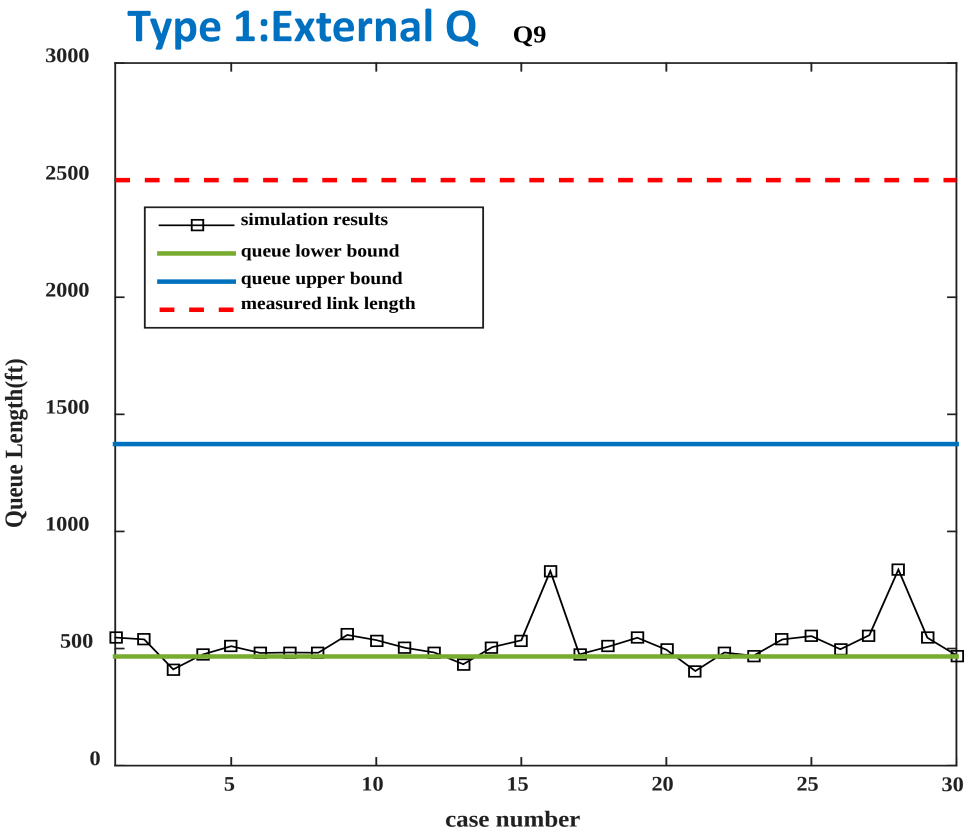
$$Q_5^{\min} = \underline{Q}(A_5^{\min})$$

Model Validation

- Field Collected peak hour traffic data are used for the case study
- ➢ Most of the simulated maximum queues fall within the estimated intervals.



MD 3 @ Waugh Chapel Rd



The distribution of simulated maximal queue length (ft)

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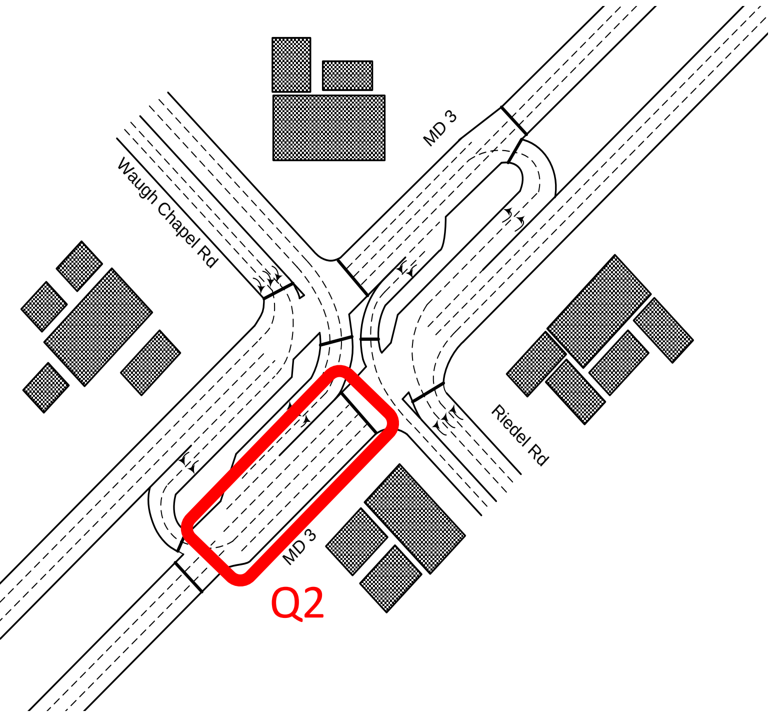
❑ Type-4(Q2): Main through queue



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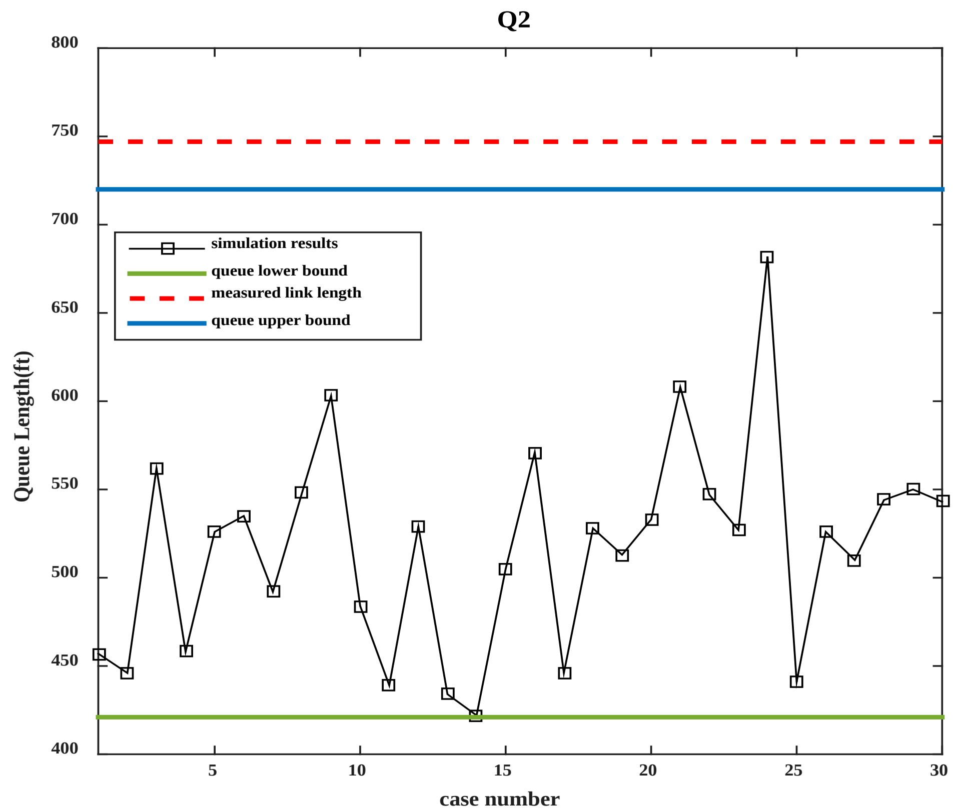

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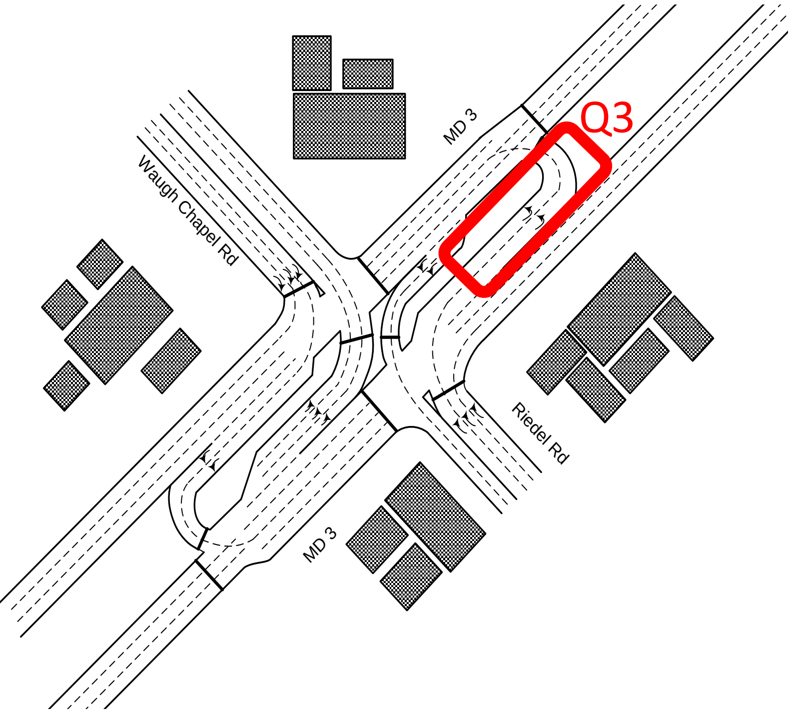
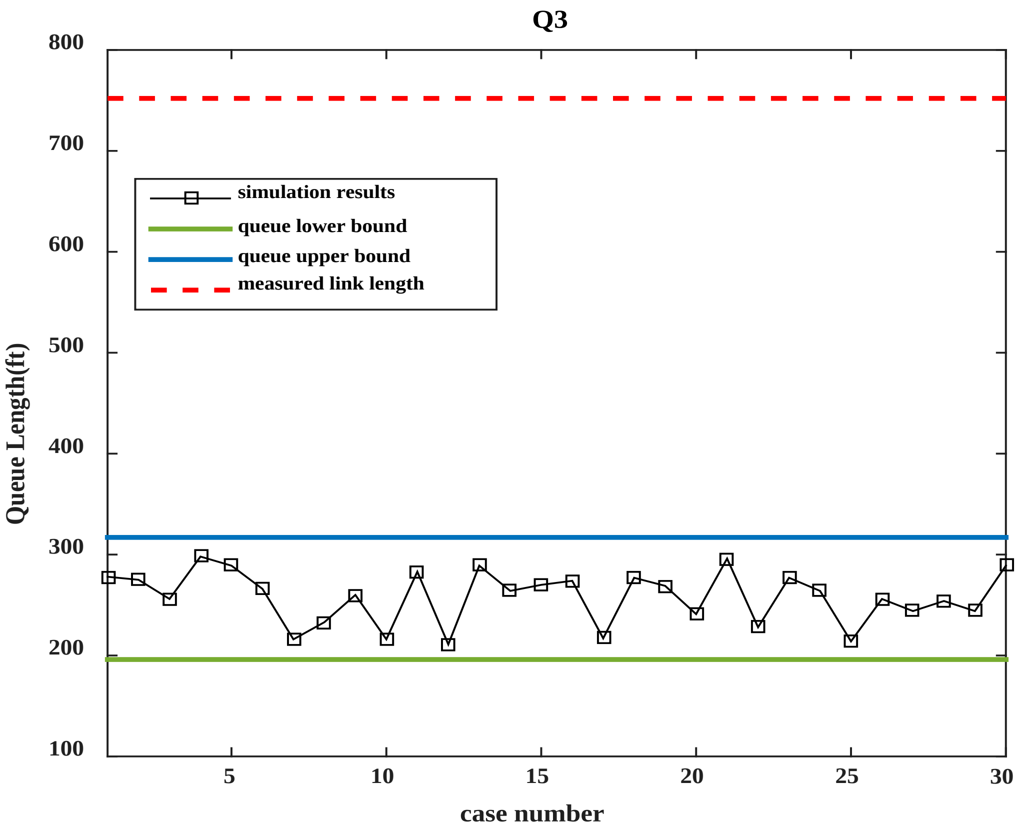


MD 3 @ Waugh Chapel Rd

❑ **Type-2(Q3): U-turn queue**



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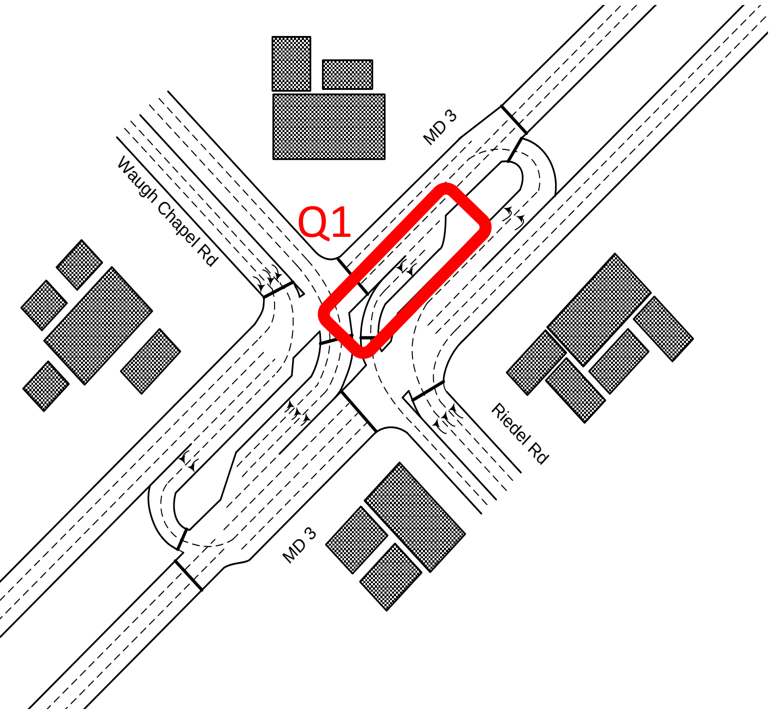
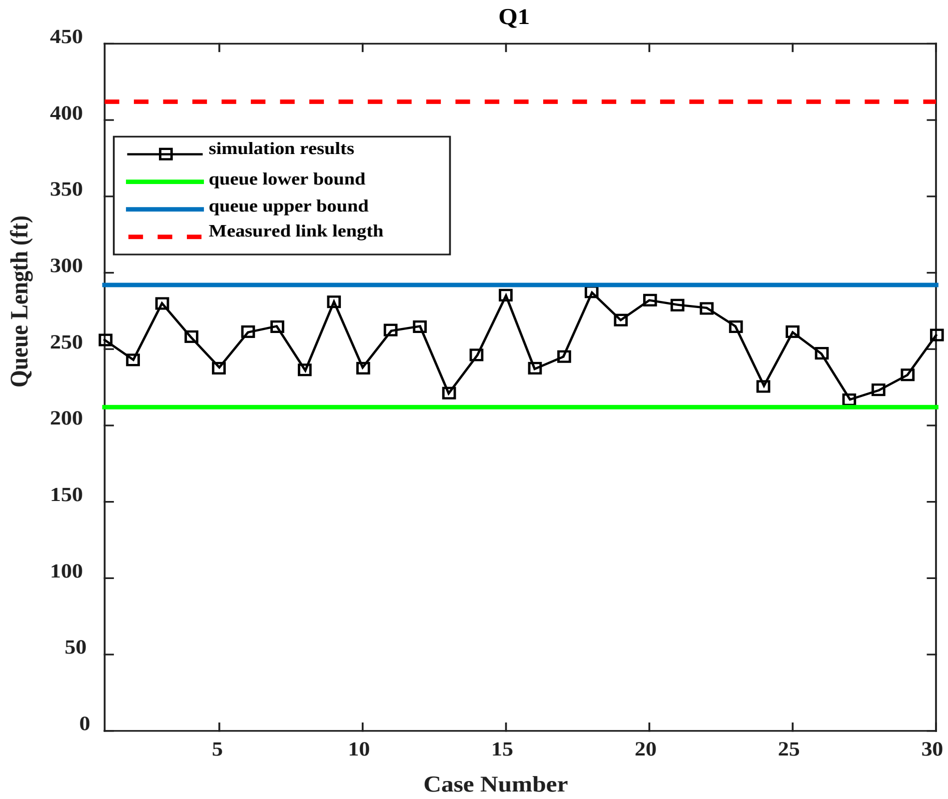


MD 3 @ Waugh Chapel Rd

❑ **Type-3(Q1):Main left-turn queue**



The distribution of simulated maximal queue length (ft)

References

- FHWA, US. Department of Transportation, Restricted Crossing U-turn Informational Guide, Publication No. FHWA-SA-14-070, August 2014.
- Hummer, Joseph E., and Ram Jagannathan. "An update on superstreet implementation and research." In Eighth National Conference on Access Management, Transportation Research Board, Baltimore, Md. 2008.
- Hummer, J. E., Haley, R. L., Ott, S. E., Foyle, R. S., & Cunningham, C. M. (2010). Superstreet Benefits and Capacities (No. FHWA/NC/2009-06).
- Thompson, Cipriana D., and Joseph E. Hummer. Guidance on the Safe Implementation of Unconventional Arterial Designs. No. Draft Final Report. 2001.
- Hummer, J. E., & Blue, V. J. (2012). Taking Advantage of the Flexibility Offered by Unconventional Arterial Designs. Institute of Transportation Engineers. ITE Journal, 82(9), 38.
- Kim, T., Edara, P. K., & Bared, J. G. (2007). Operational and safety performance of a nontraditional intersection design: The superstreet. In Transportation Research Board 86th Annual Meeting (No. 07-0312).
- Olarte, Rafael, Joe G. Bared, Larry F. Sutherland, and Anand Asokan. "Density Models and Safety Analysis for Rural Unsignalised Restricted Crossing U-turn Intersections." Procedia-Social and Behavioral Sciences 16 (2011): 718-728.