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

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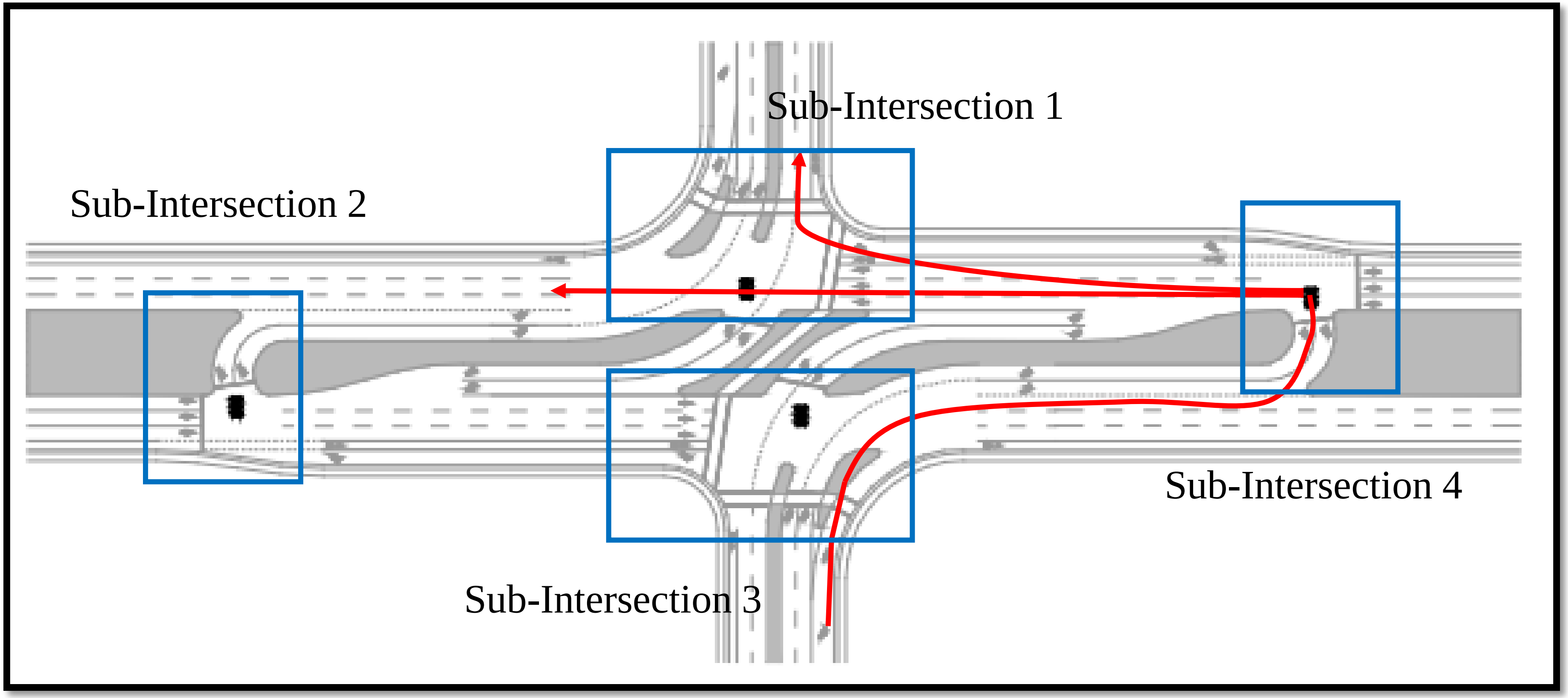
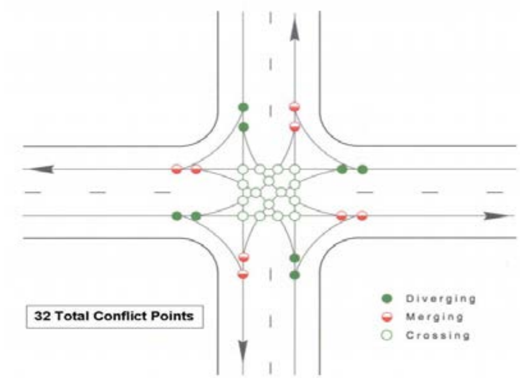
# Superstreet



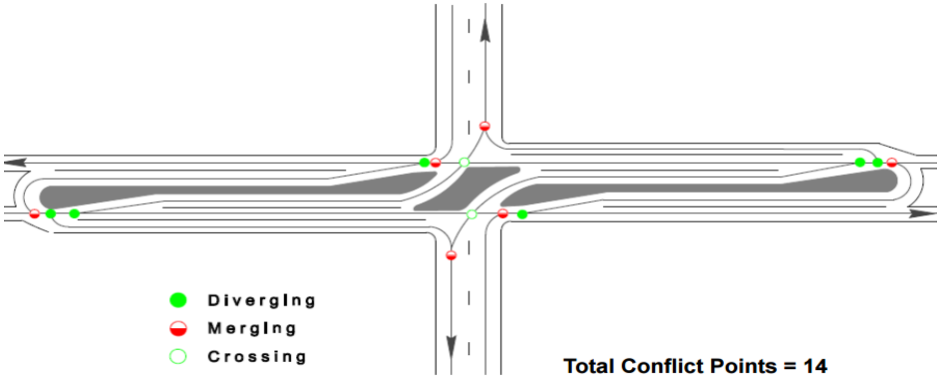
# Superstreet

## ❑ BENEFITS:

- Economical Benefits: *Less expensive than an interchange;*
- Safety Benefits: *Reduction in number & severity of the collisions;*
- Operation Benefits: *Provide un-interrupted flows 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).
- Only limited studies (Olarte, 2011) have attempted to address the design and operational issues associated with Superstreet.
- A newly published report (FHWA, 2014) also has indicated the lack of sufficient information in the area of designing a Superstreet.

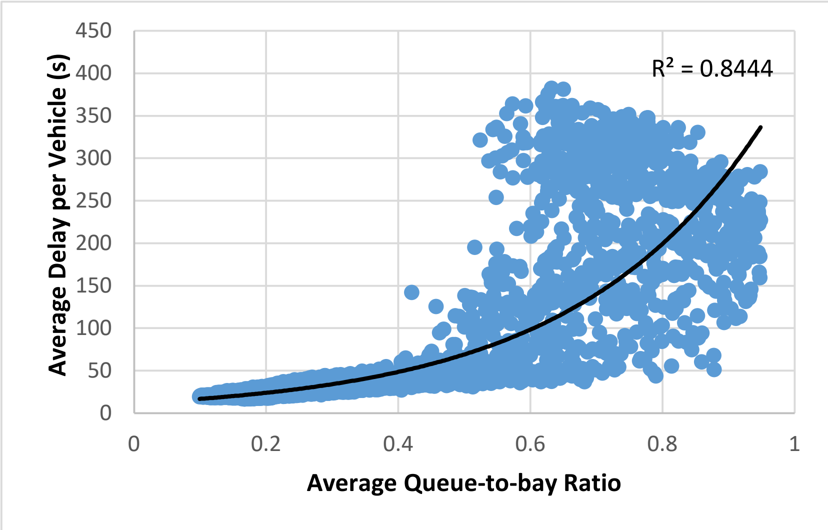
***Existing Literature fall short on the subjects of Design and Evaluation of Superstreets.***

# Operation Analysis

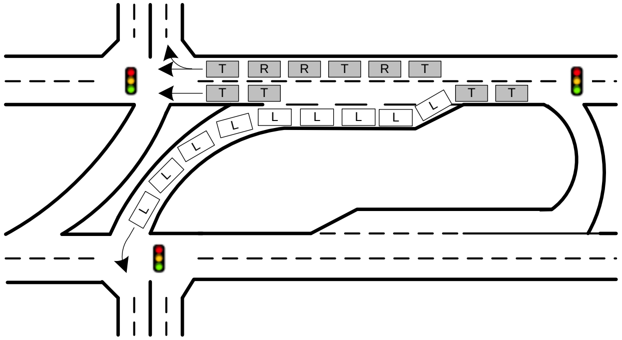
## Field Survey and VISSIM Calibration

- 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.

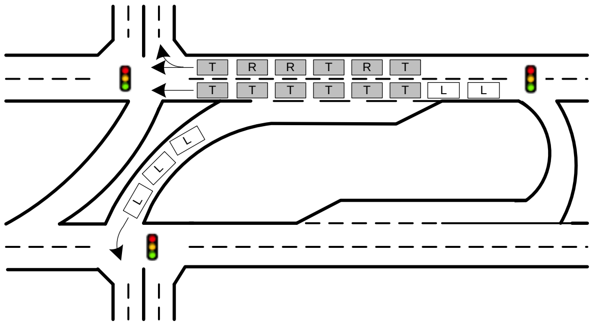
**Figure 1. Scatter plot of average delay v.s. average QL ratio**



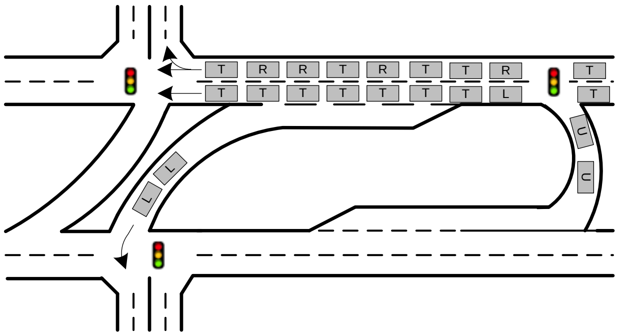

Possible blockages among a Superstreet are shown below:



(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

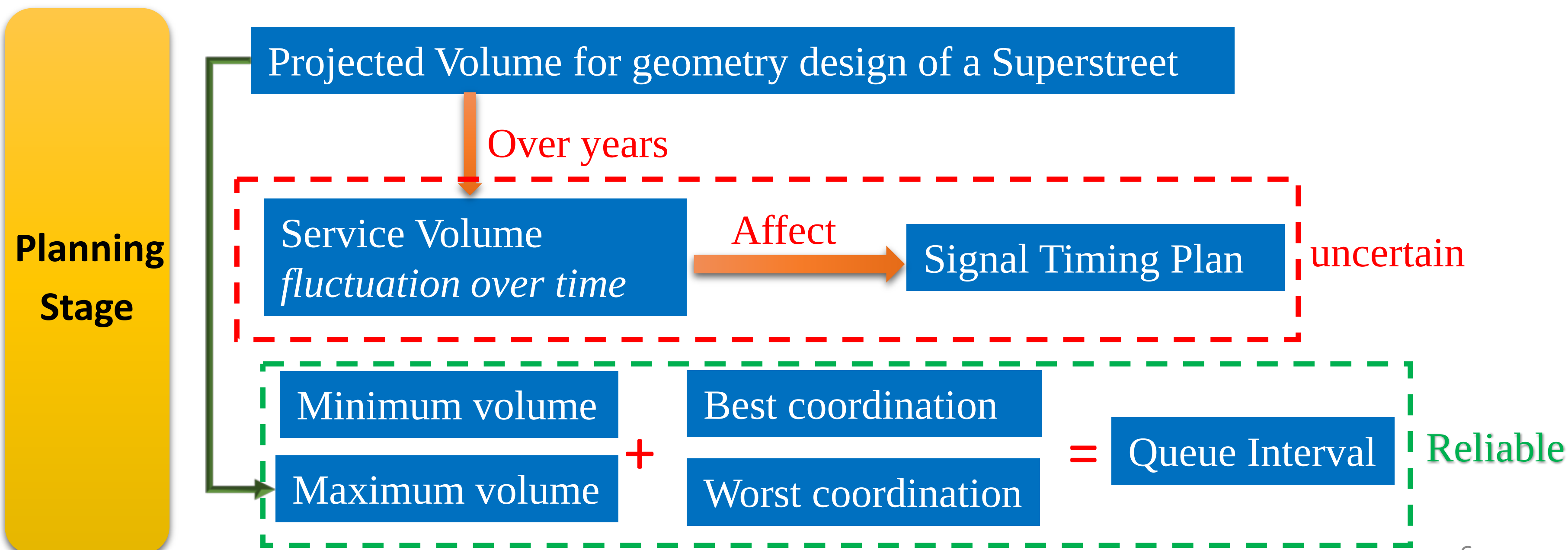
## Interval-based queue estimation models

- Both Traffic volume and signal design may contribute to the formation of queues in a superstreet

1. **Incoming traffic fluctuates over time**
2. **Signal coordination**

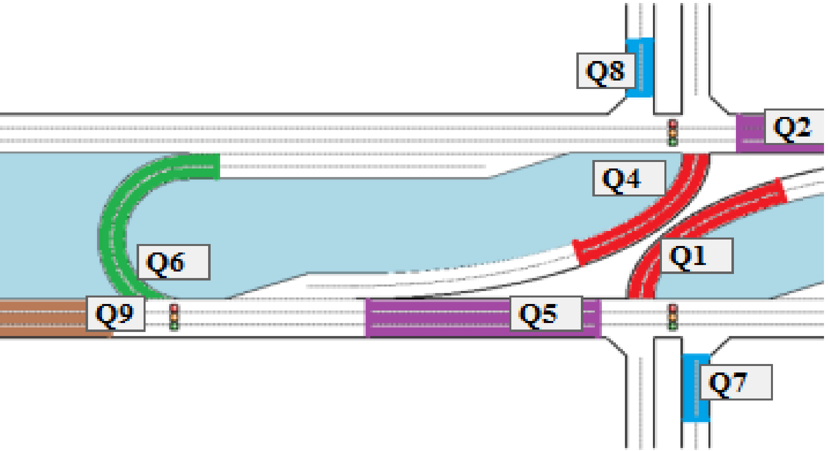
***Queue interval takes into both uncertainties***

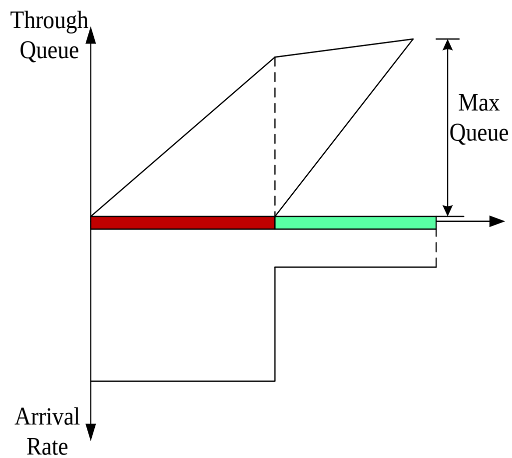
### Why interval-based queue estimation?

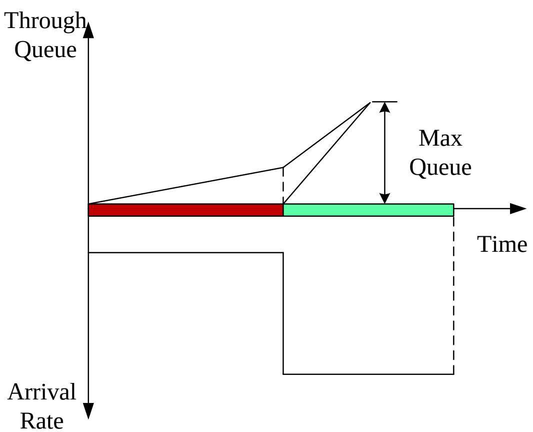


# Queue Length under different signal coordination plans

- **For the main intersection through Q: *Q5*, from both Q6 and Q9**
- **1) through and right-turn movements from Q9;**
- **2) departures from Q6**



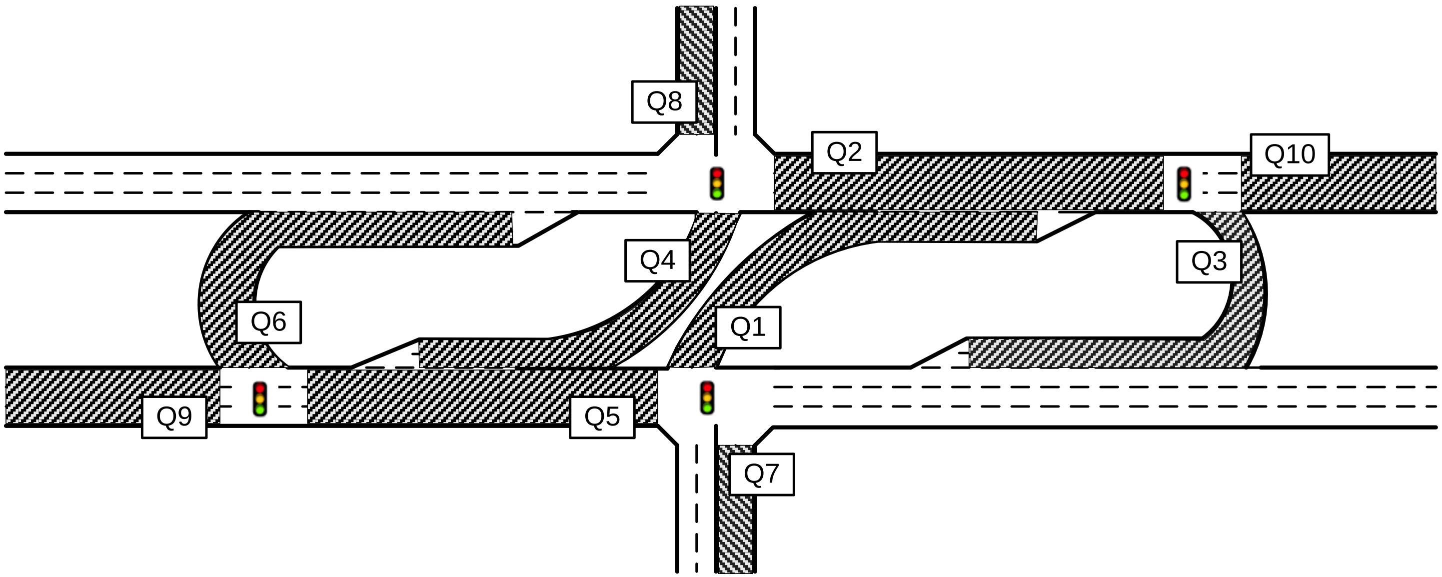




$Q_5^{max}$: **Worst Case=**
*Largest arrival rate*+
*worst signal coordination*

$Q_5^{min}$: **Best Case=**
*Smallest arrival rate*+
*Best signal coordination*

# Model Development

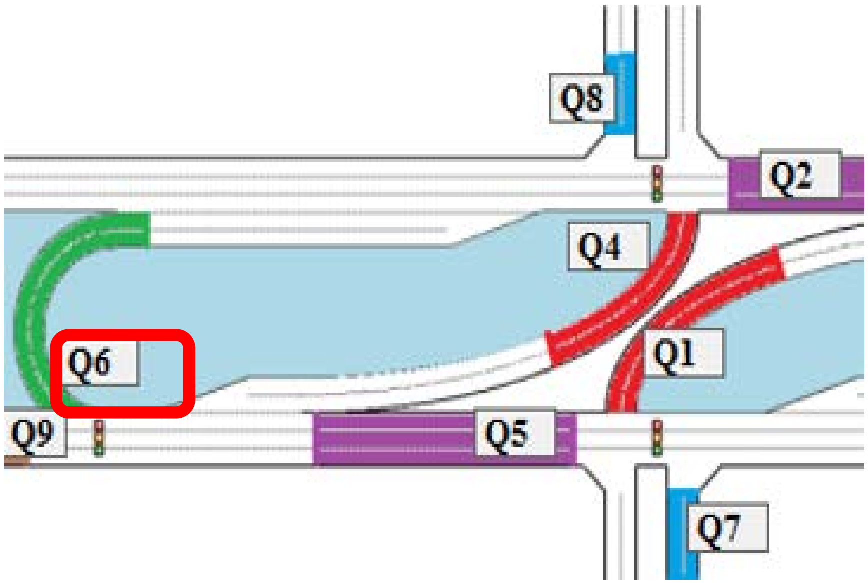
❑ **Spatial distributions of all potential queues among a Signalized Superstreet**




1) **External Queues:** only influenced by flow fluctuations
   - Type-1 (Q7, Q8, Q9,Q10): Through queues at major & minor road
2) **Internal Queues:** influenced by both flow fluctuations and signal coordination
   - 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




At any time point k, the departures from Q6 to Q5 can be expressed as:

**Departure from Q6:**

$$D_6^k = \begin{cases} 0 & \text{During Red Time} \\ \min(s, A_6^k + q_6^k) & \text{During Green Time} \end{cases}$$

where :

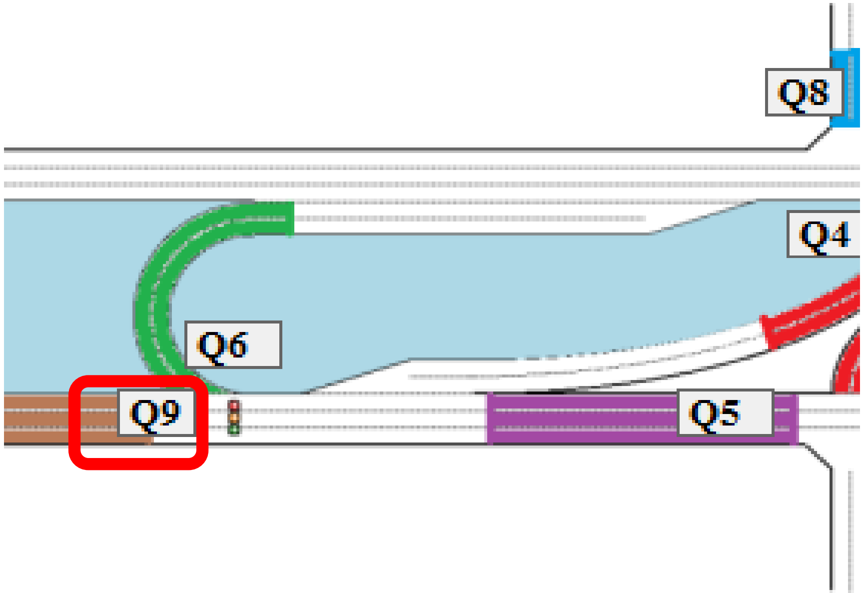
$s$ is the saturation flow rate for link 6;

$A_6^k$ is the arrived vehicle in Q6 at time point k;

$q_6^k$ is the vehicles in Q6 at time point k.

# Interval-based Queue Model

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




**Departure 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 :

$s_9$ is the saturation flow rate for link 9;

$\beta_{9TR}$ 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.

**Arrivals at Q5:**

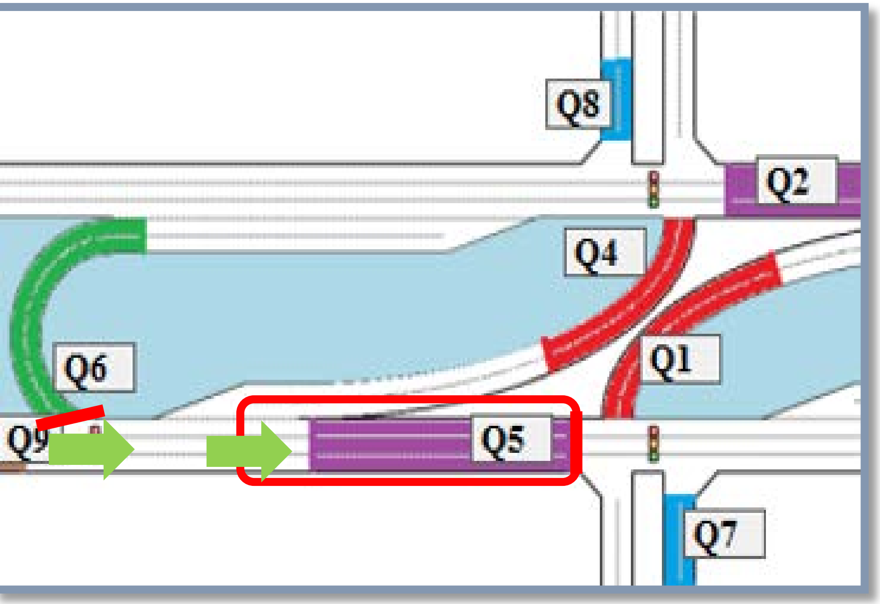
Conflicting movements

$$A_5^k=\alpha D_{9TR}^{k-\sigma}+(1-\alpha)D_6^{k-\tau}, \alpha=0,1$$

*where* : $\sigma$ *is* the travel time from Q9 to Q5;

$\tau$ is the travel time from Q6 toQ5.

# Interval-based Queue Model




**Initial Queue dissipating time $t^*$**

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

Accumulated Q during red

Queue discharging during the initial green

where:

$\alpha = 0 \ or \ 1$;

$t_0$ is the start of red phase for Q5;

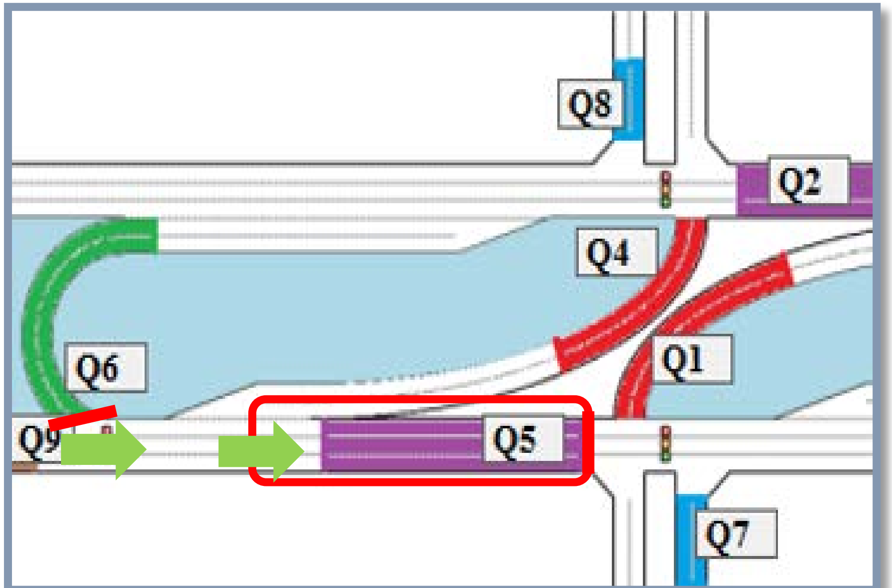
$t_1$ is the start of green phase for Q5;

$t^*$ is time to dissipate initial queue;

$s$ is the saturation flow rate.

## Queue length under worst signal coordination

When Q5's red and Q9's green is concurrent,




Under different signal timing plans, the maximum Q5 will be

1) $if \;\; R^5 + t^* \le g^9,$

$$\bar{Q}_5 = \int_{t_0}^{t_0+R_5} D_{9TR}^{t-\sigma} dt + \int_{t_1}^{t_1+t^*} D_{9TR}^{t-\sigma} dt$$

during red — during initial green

2) $if \;\; R^5 + t^* > g^9 > R^5,$

$$\bar{Q}_5 = \int_{t_0}^{t_0+R_5} D_{9TR}^{t-\sigma} dt + \int_{t_1}^{t_1+t^*} A_5^t dt$$

3) $if \;\; R^5 > g^9,$

$$\bar{Q}_5 = \int_{t_0}^{t_0+g_9} D_{9TR}^{t-\sigma} dt + \int_{t_0+g_9}^{t_0+R_5} D_6^{t-\tau} dt + \int_{t_1}^{t_1+t^*} D_6^{t-\tau} dt$$

Apply same method to model the queue length under best coordination.

## Input the minimum and maximum flow:

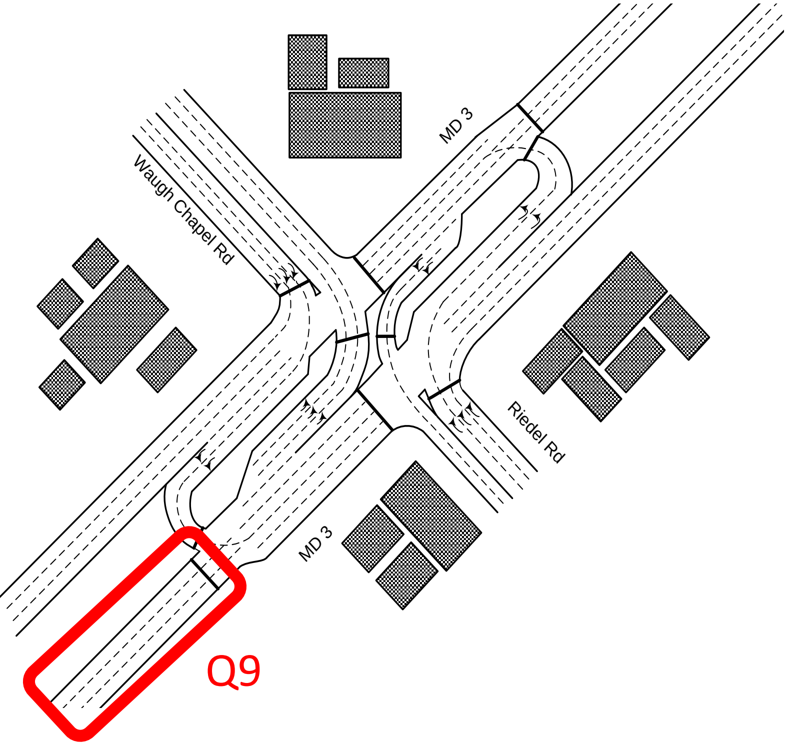
By taking into consideration of incoming traffic fluctuation, **Queue Interval** as:

$$[Q_5^{\max}, Q_5^{\min}] = [\bar{Q}(A_5^{\max}), \underline{Q}(A_5^{\min})]$$

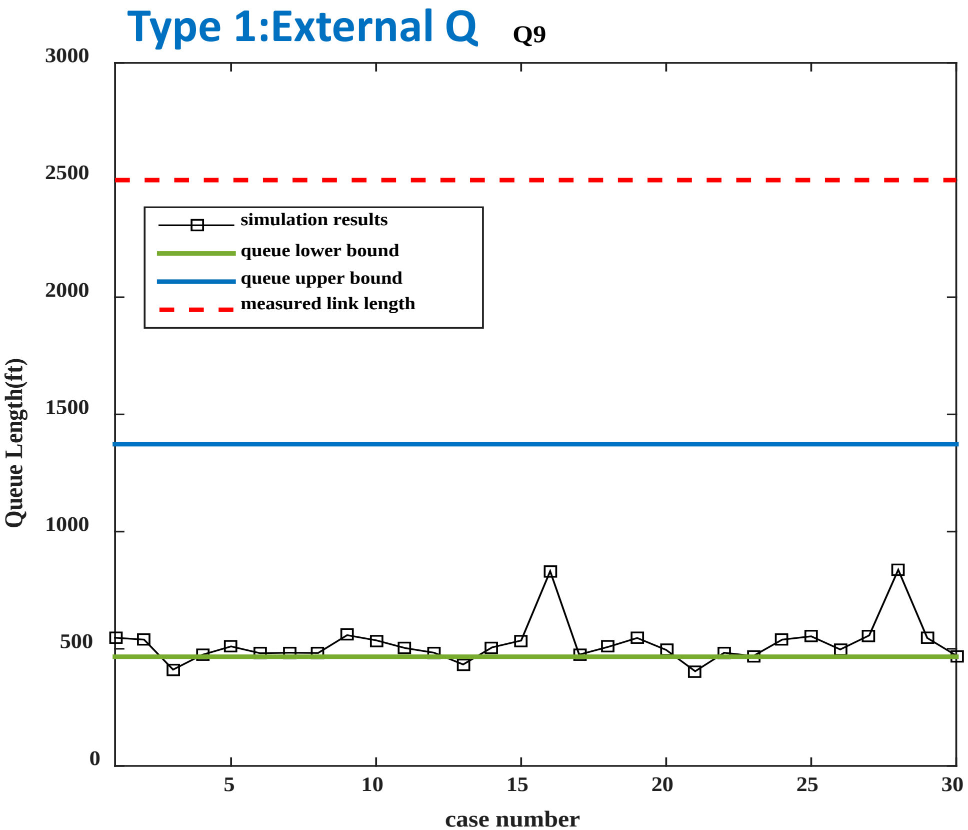
# Model Validation

- Field Collected peak hour traffic data were 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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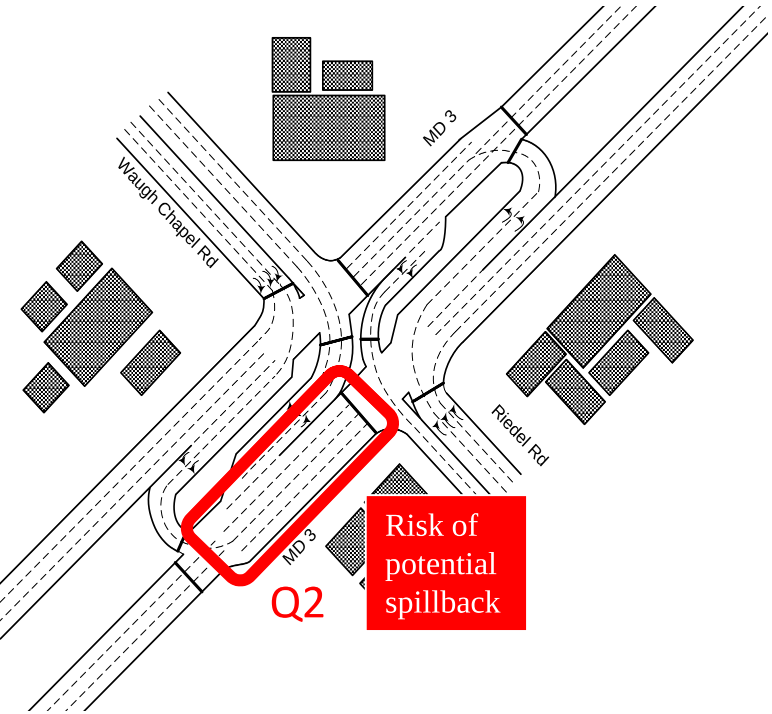
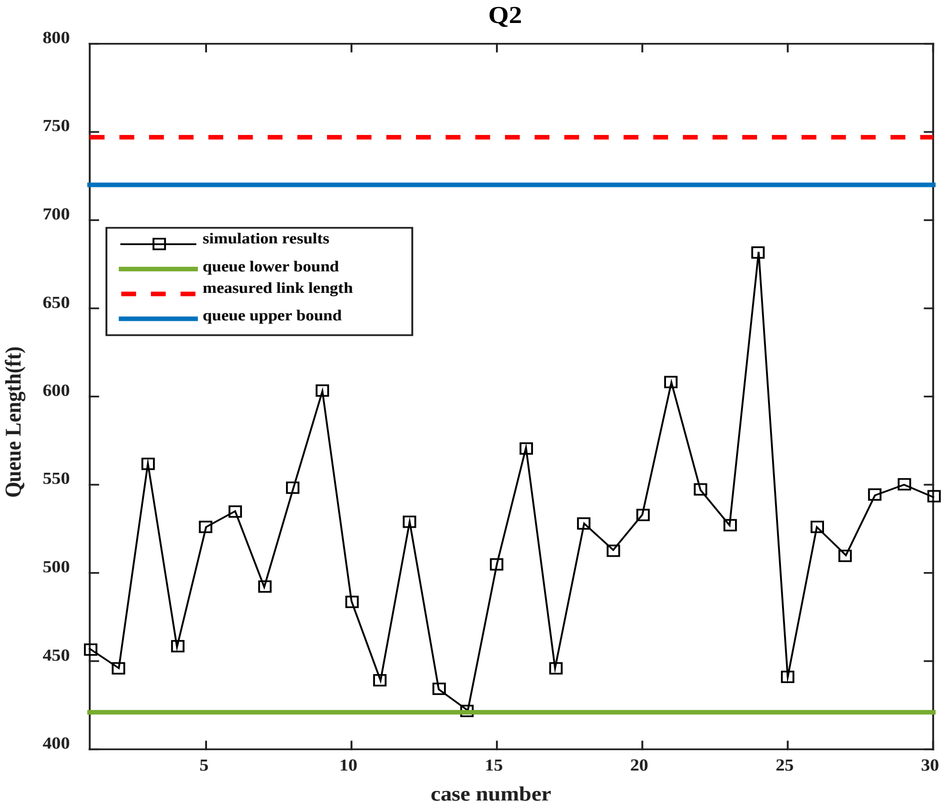



MD 3 @ Waugh Chapel Rd

## ❑ Type-4(Q2): Main through queue




**The distribution of simulated maximal queue length (ft)**

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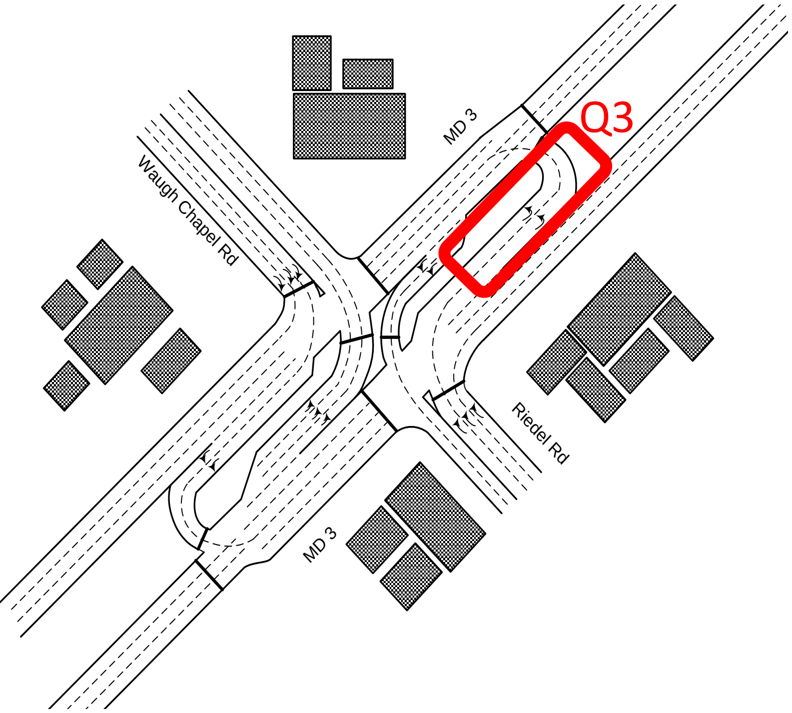
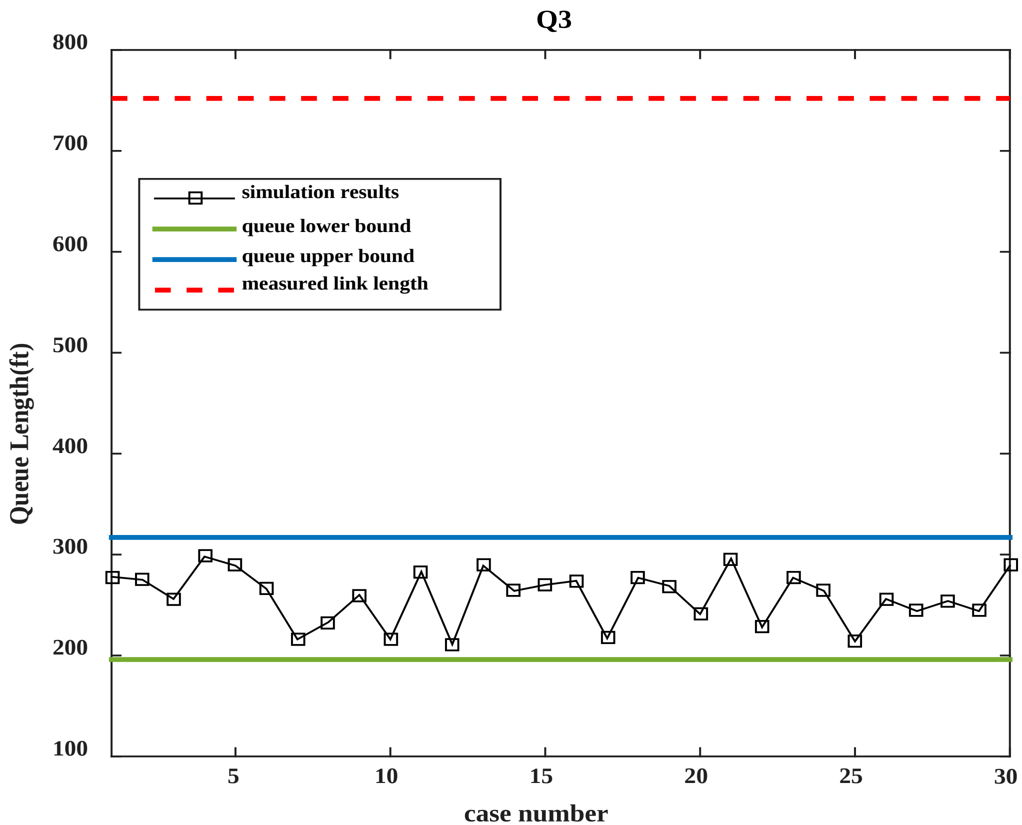



MD 3 @ Waugh Chapel Rd

## ❑ Type-2(Q3): U-turn queue




**The distribution of simulated maximal queue length (ft)**

# Model Validation

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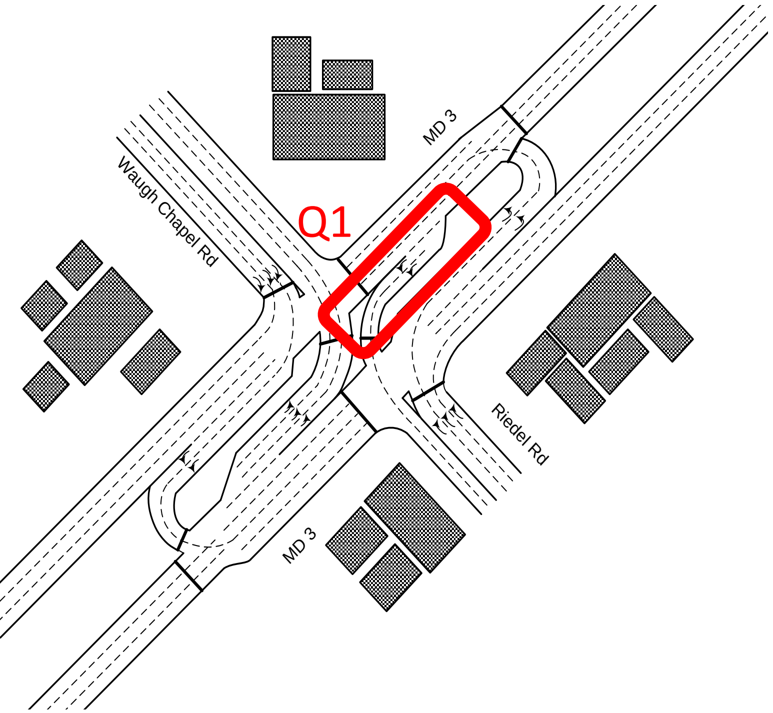
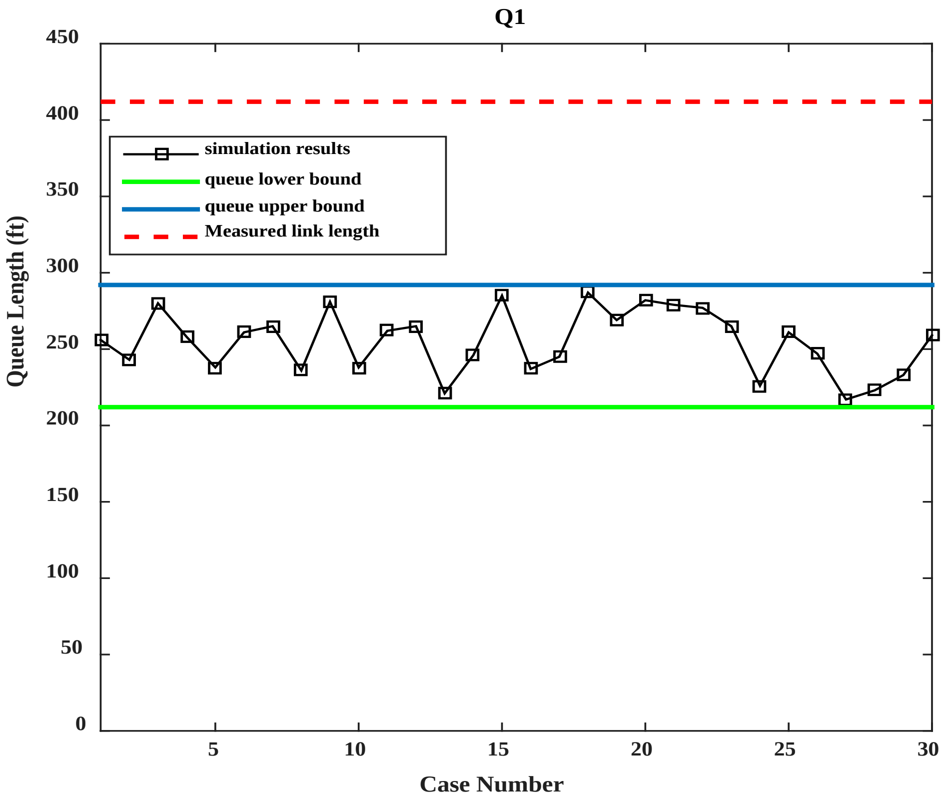



MD 3 @ Waugh Chapel Rd

## ❑ Type-3(Q1):Main left-turn queue




**The distribution of simulated maximal queue length (ft)**

# Closure

## ❑Evaluation Purpose

- **Design engineers can *use the comparison results* between the *estimated queue size* and designed *link length* for evaluation:**

i. **If the estimated lower bound of the queue length exceeds the available link length, then the geometric design needs to be changed; or**

ii. **The signal plan and offsets may need to be revised to achieve better coordination and to reduce the queue length.**

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