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

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Superstreet

Sub-Intersection 1

Sub-Intersection 2

Sub-Intersection 3

Sub-Intersection 4
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.
Research Background

**Literature Review**


- 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.

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?

Projected Volume for geometry design of a Superstreet

Over years

Service Volume fluctuation over time

Signal Timing Plan

Affect

uncertain

Planning Stage

Minimum volume

Maximum volume

Best coordination

Worst coordination

Queue Interval

Reliable
Queue Length under different signal coordination plans

- For the main intersection through Q: $Q_5$, from both Q6 and Q9
  - 1) through and right-turn movements from Q9;
  - 2) departures from Q6

$Q^\text{max}_5$: Worst Case=
Largest arrival rate +
worst signal coordination

$Q^\text{min}_5$: 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:

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

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:
- \(s\) 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:**

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

where:
- \(\sigma\) is the travel time from Q9 to Q5;
- \(\tau\) is the travel time from Q6 to Q5.
Interval-based Queue Model

Initial Queue dissipating time $t^*$

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

where:

$\alpha = 0 \text{ or } 1$;

$t_0$ 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.

Accumulated Q during red

Queue discharging during the initial green
When Q5’s red and Q9’s green is concurrent, Under different signal timing plans, the maximum Q5 will be

1) If \( R^5 + t^* \leq g^9 \),
\[
\bar{Q}_5 = \int_{t_0}^{t_0 + R_5} D_{9TR}^{t-\sigma} dt + \int_{t_1}^{t_1 + t^*} D_{9TR}^{t-\sigma} dt
\]
during red

during initial green

2) If \( R^5 + t^* > g^9 > R^5 \),
\[
\bar{Q}_5 = \int_{t_0}^{t_0 + R_5} D_{9TR}^{t-\sigma} dt + \int_{t_1}^{t_1 + t^*} A_s^t dt
\]

3) If \( R^5 > g^9 \),
\[
\bar{Q}_5 = \int_{t_0}^{t_0 + g_9} D_{9TR}^{t-\sigma} dt + \int_{t_0 + g_9}^{t_0 + R_5} D_{6-\tau}^{t-\sigma} dt + \int_{t_1}^{t_1 + t^*} D_{6-\tau}^{t-\sigma} dt
\]

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:

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

The distribution of simulated maximal queue length (ft)
Model Validation

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☐ Type-4(Q2): Main through queue

The distribution of simulated maximal queue length (ft)
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**Type-2(Q3): U-turn queue**

The distribution of simulated maximal queue length (ft)
Model Validation

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The distribution of simulated maximal queue length (ft)
Closure

- 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.
References

• FHWA, US. Department of Transportation, Restricted Crossing U-turn Informational Guide, Publication No. FHWA-SA-14-070, August 2014.


• 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.
