Variable Speed Limit Control To Increase Discharge Rates At Freeway Incident Bottlenecks

Danjue Chen

Soyoung Ahn

8/11/2014

Background

- Variable Speed Limit (VSL)
  - Safety (harmonized speed, smooth queue transition)
  - Freeway efficiency (defer congestion onset, increase BN discharge rate).

Background

- VSL – efficiency focus
  - SPECIALIST – resolve moving jams (implemented) (Hegyi et al., 2008; 2009).
  - MTFC– prevent/defer congestion onset (simulation) (Carlson et al., 2010a, b).
  - Chen et al. – resolve BN queue and then resume high discharge flow (analytical study) (2014).

Background

- Key characteristics of incident BNs
  - Moderate to severe congestion
  - Sharp transition at the tail of queue
  - Significant capacity drop (Knoop et al., 2008; 2009a; 2009b)
    - ✓ Road blockage
    - ✓ Rubbernecking
    - ✓ Change in driving behavior
    - ✓ **Disruptive LCs.**

Background

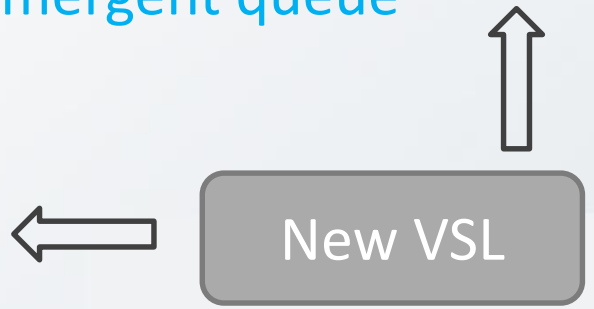
- Key characteristics of incident BNs
  - Moderate to severe congestion
  - Sharp transition at the tail of queue
  - Significant capacity drop
    - ✓ Road blockage
    - ✓ Rubbernecking
    - ✓ Change in driving behavior
    - ✓ **Disruptive LCs. → Potentials of discharge improvement**

New VSL

Background

- Key characteristics of incident BNs
  - Moderate to severe congestion → Need less restrictive speed limit
  - Sharp transition at the tail of queue → Need smoother queue management
  - Significant capacity drop
    - ✓ Road blockage
    - ✓ Rubbernecking
    - ✓ Change in driving behavior

    → Need to address re-emergent queue
    - ✓ **Disruptive LCs. → Potentials of discharge improvement**



Background

- What our new VSL strategy will do?
  - Reduce delay – by increasing BN discharge flow
  - Enhance safety – by smoothing upstream queue transition

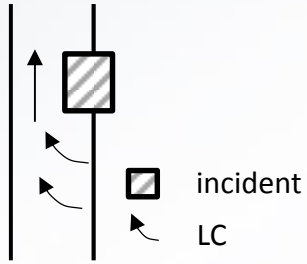
Outline

- Baseline case
- Basic VSL control
  - Procedure
  - Parameter analysis
- VSL for re-emergent queue
  - Procedure
  - Parameter analysis
- Conclusions

Baseline Case

- Traffic scenario
  - KW theory
  - Demand: A (constant)
  - Breakdown state: H

(a)



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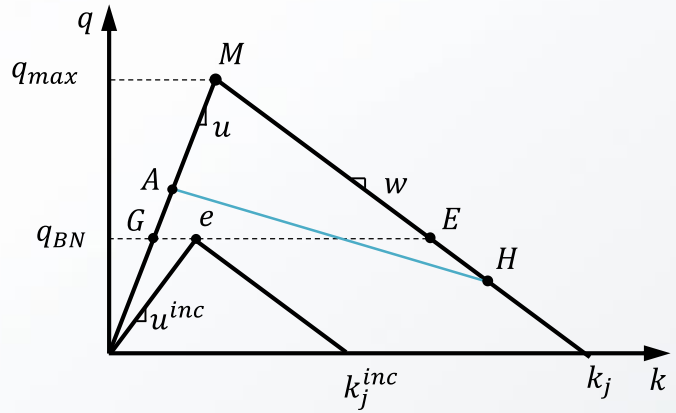

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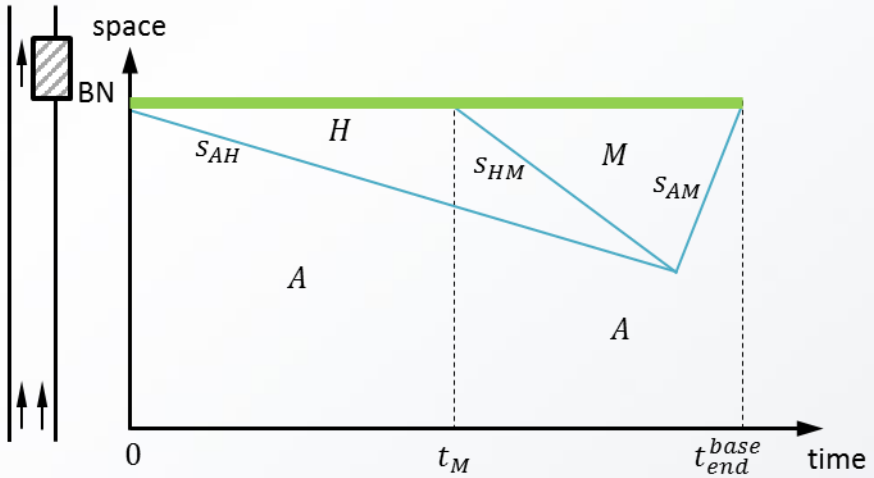
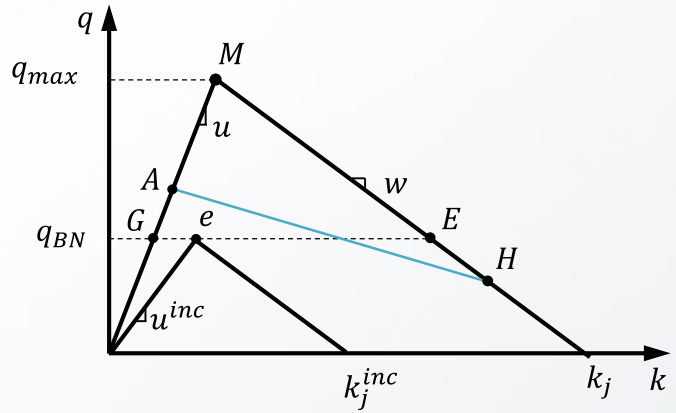


Baseline Case

- Basic assumptions
  - Lower FD: $u^{inc} < u$: rubbernecking + other effects
  - Stable max state: e
    - $q_{BN} = q_e; q_E = q_G = q_e$
    - $q_H < q_{BN}$



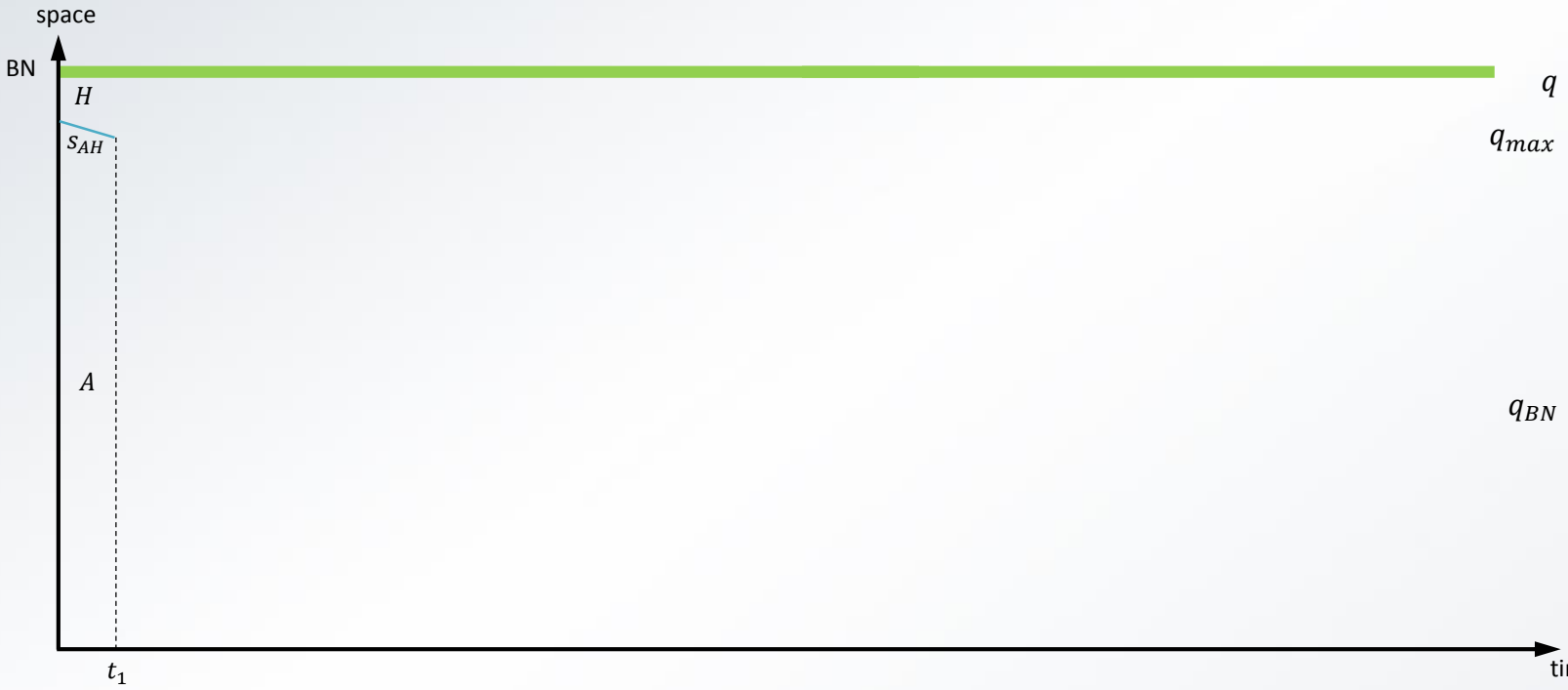
Basic VSL Control Strategy

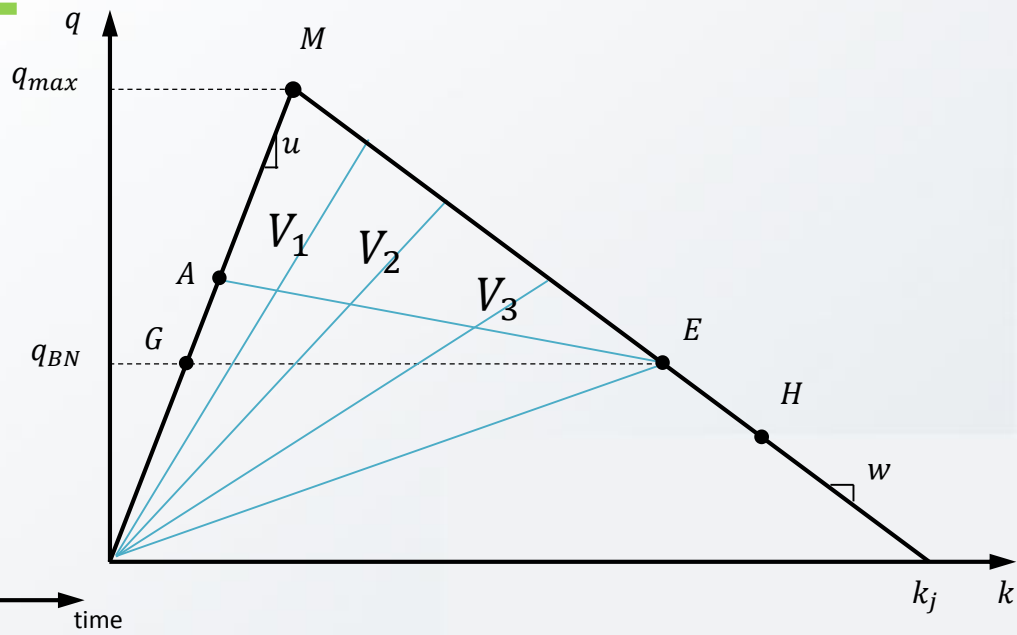
- Procedure
  - Step 1: control demand progressively to clear queue at BN.
  - Step 2: regulate inflow at stable max flow.

Basic VSL Control Strategy

- Step 1: control demand progressively to clear queue at BN

  Demand in A → state E : $u \rightarrow V_1 \rightarrow V_2 \rightarrow V_3 \rightarrow v_E$

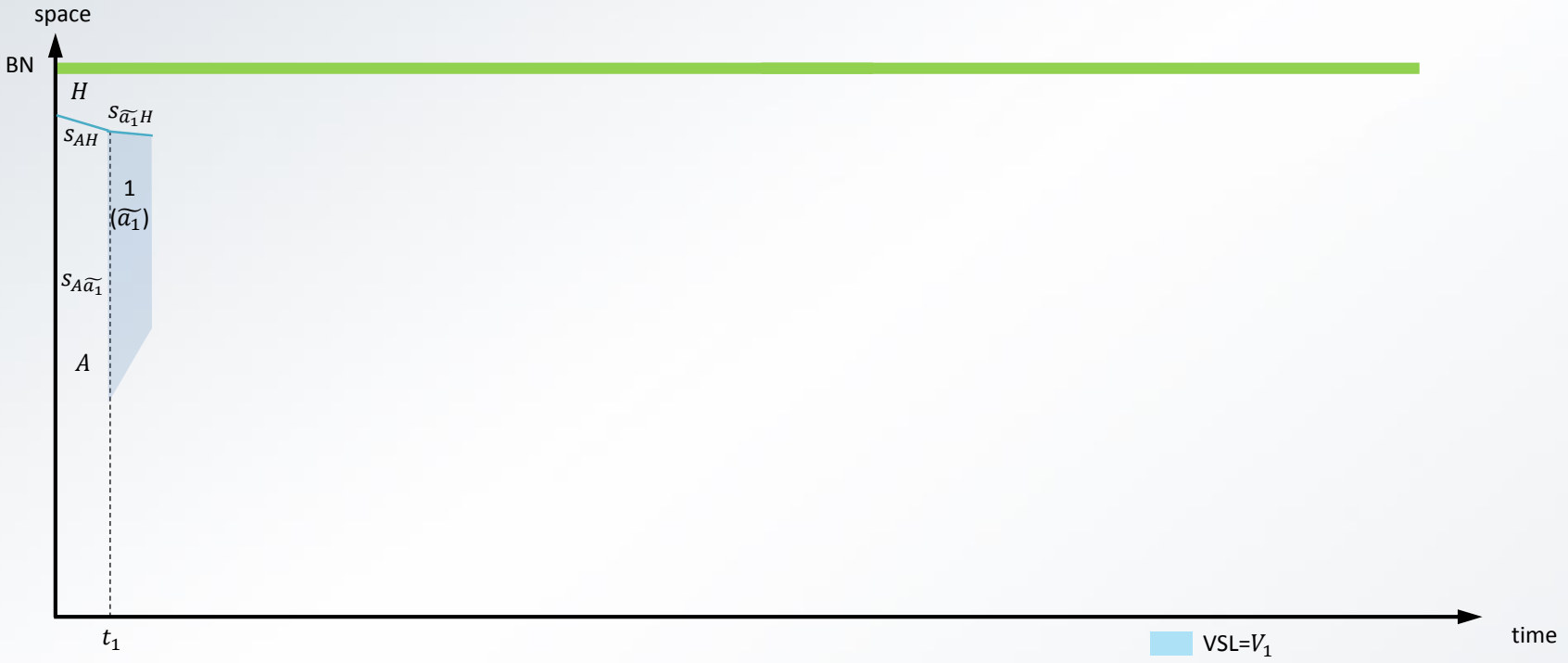


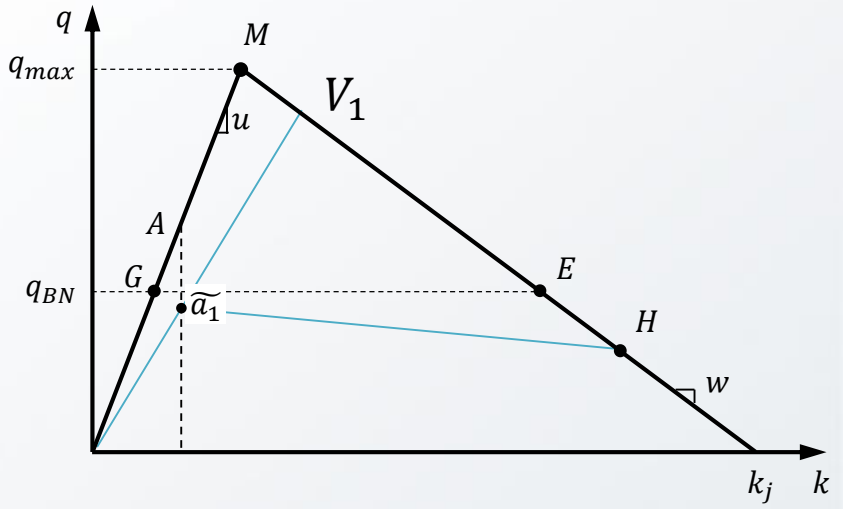


Basic VSL Control Strategy

- Step 1: control demand progressively to clear queue at BN

  1-1: Impose VSL=V_1 simultaneously over an extended segment upstream of queue

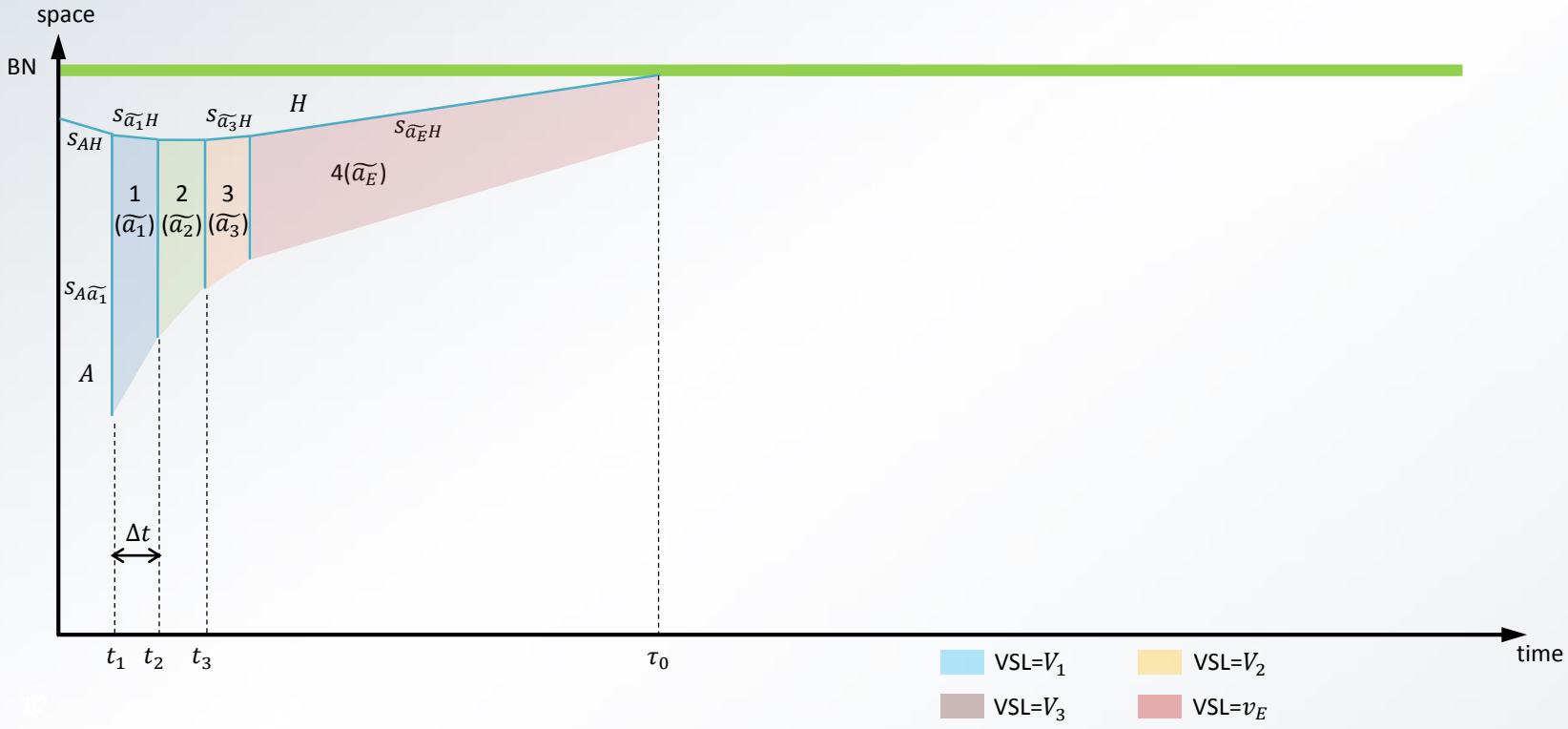


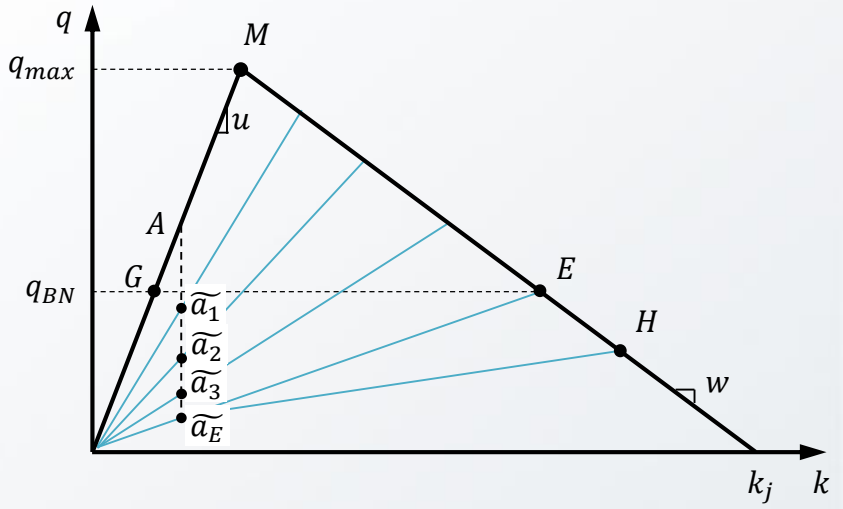


Basic VSL Control Strategy

- Step 1: control demand progressively to clear queue at BN

  1-2: Impose V_2, V_3, and v_E in sequence.

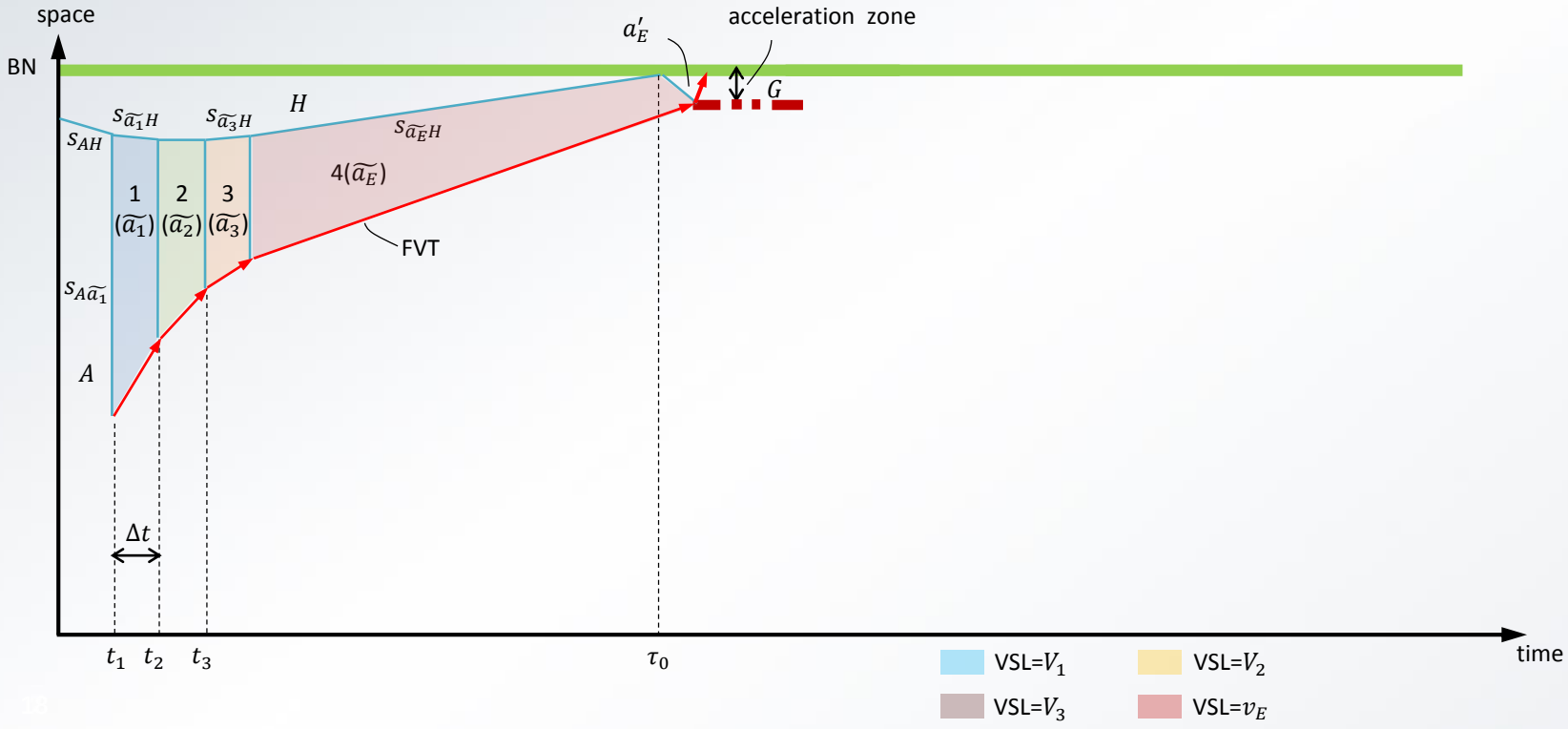


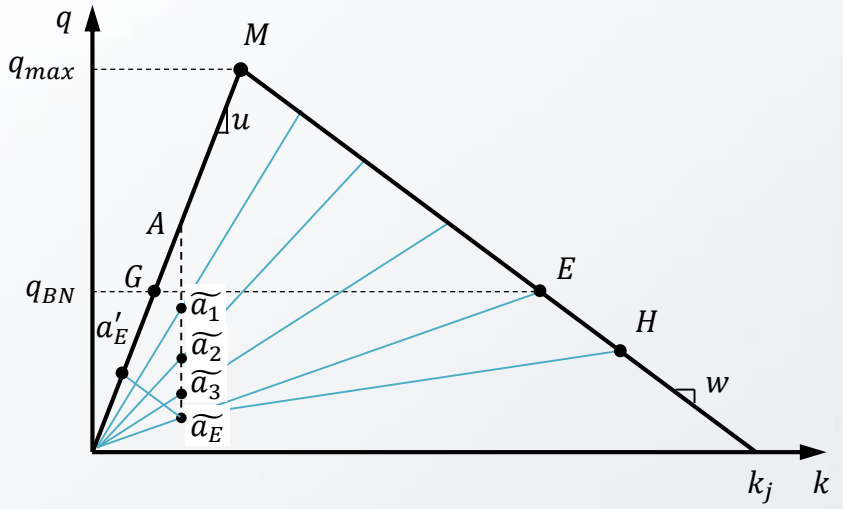


Basic VSL Control Strategy

- Step 2: regulate inflow at stable max flow

  2-1: Deactivate v_E to enable free-flow traffic at the acceleration zone

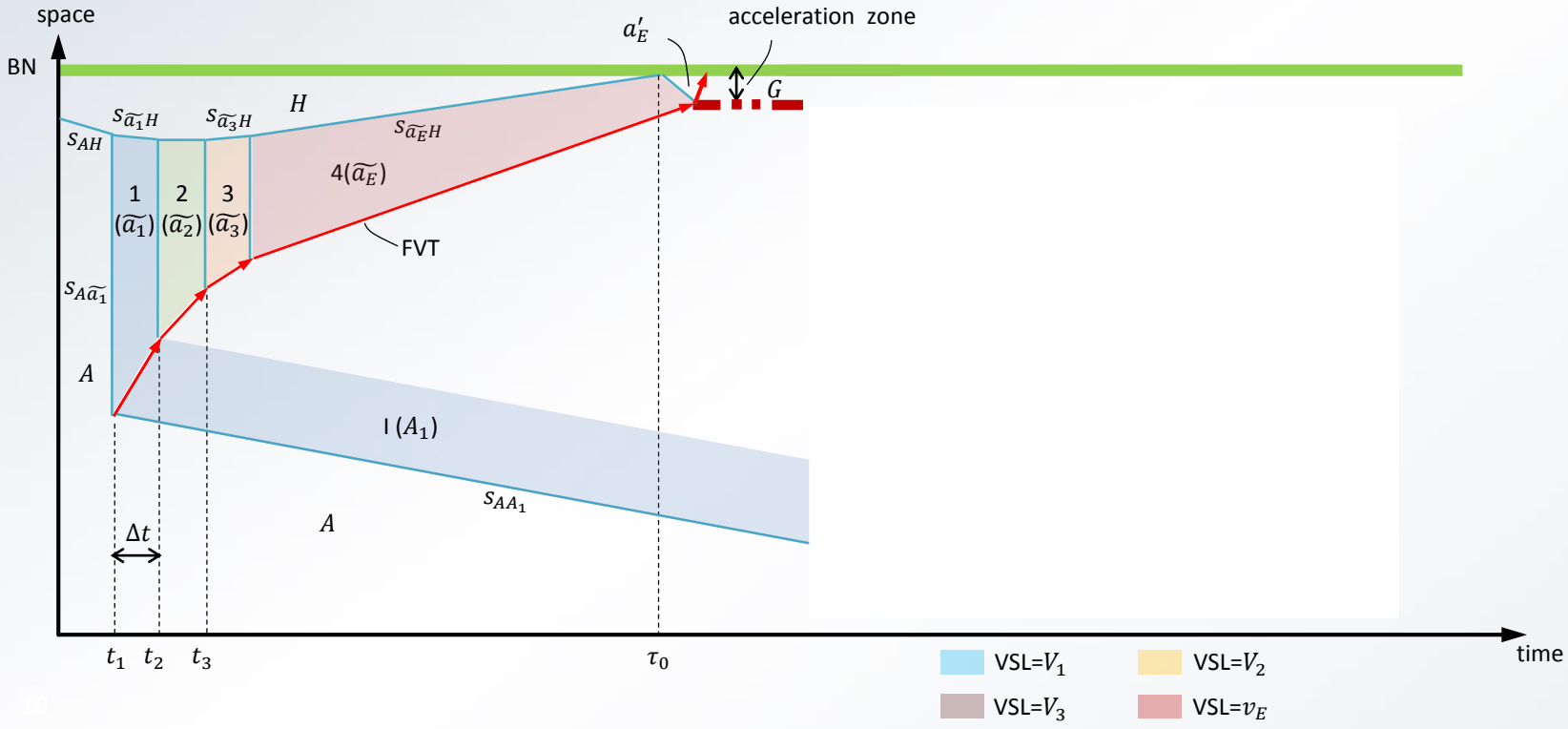


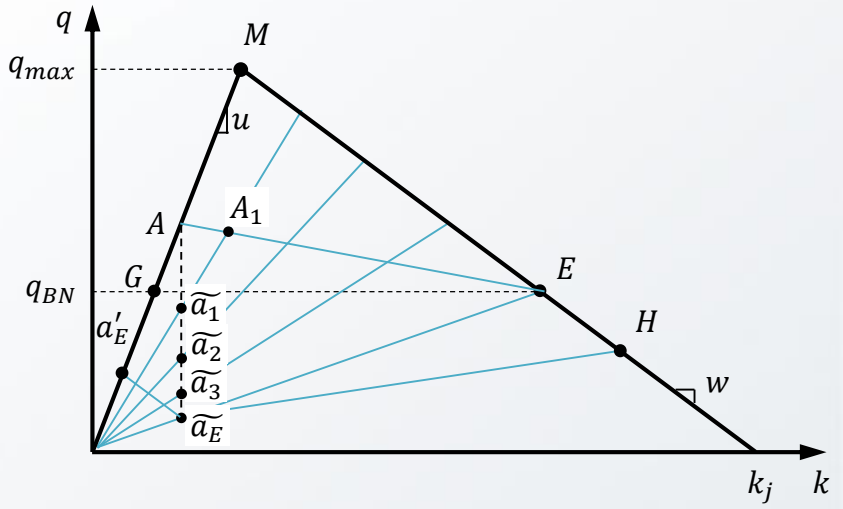


Basic VSL Control Strategy

- Step 2: regulate inflow at stable max flow

  2-2: Impose V_1 at the rate of s_{AA_1} $(= s_{AE})$

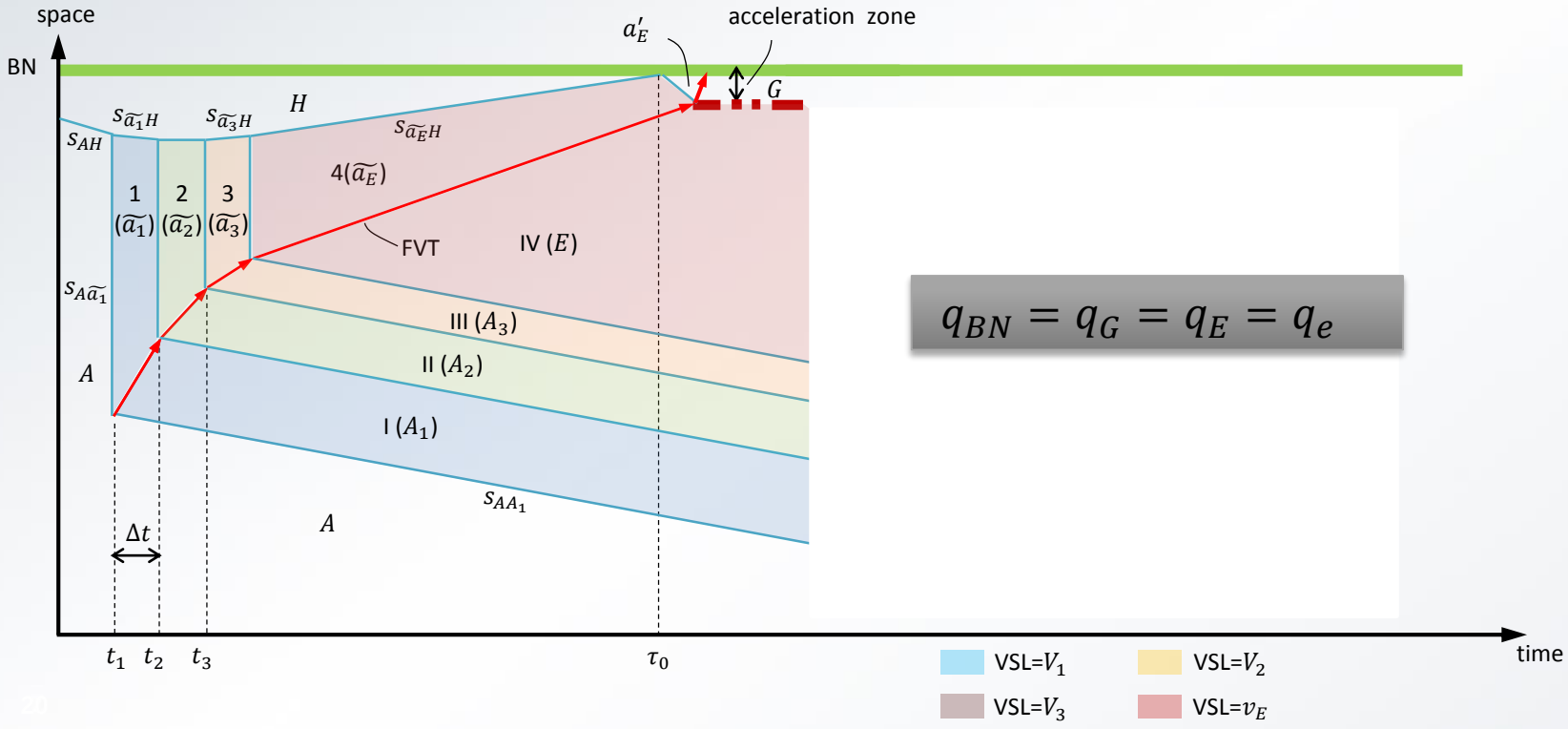




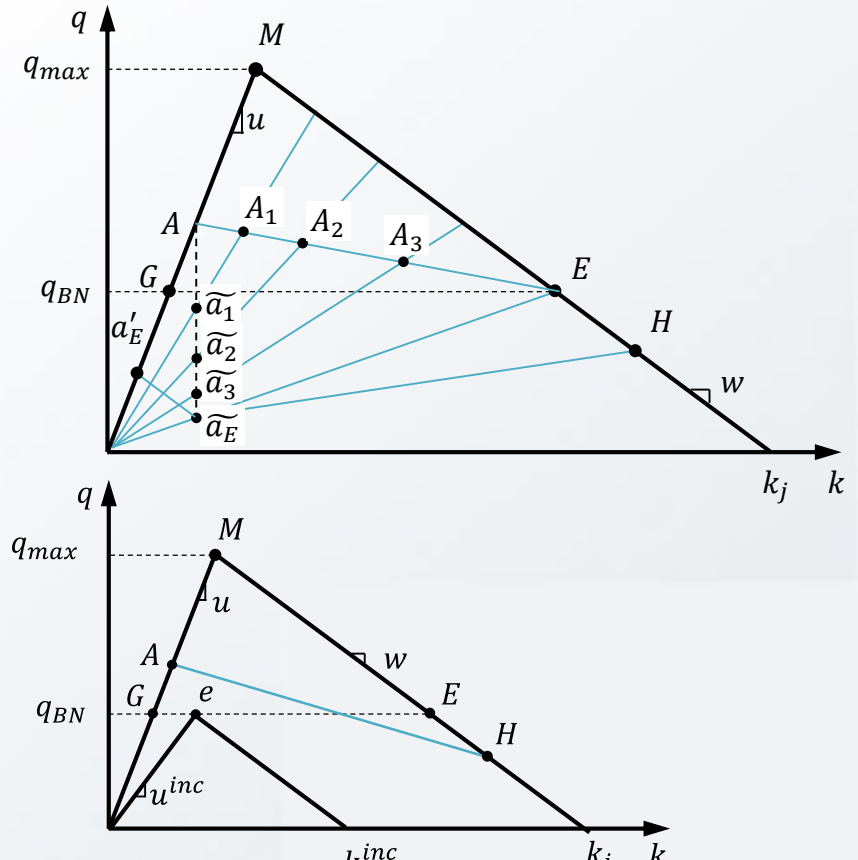
Basic VSL Control Strategy

- Step 2: regulate inflow at stable max flow

  2-2: Impose V_2, V_3, and v_E in similar way. v_E is extended to the entrance.



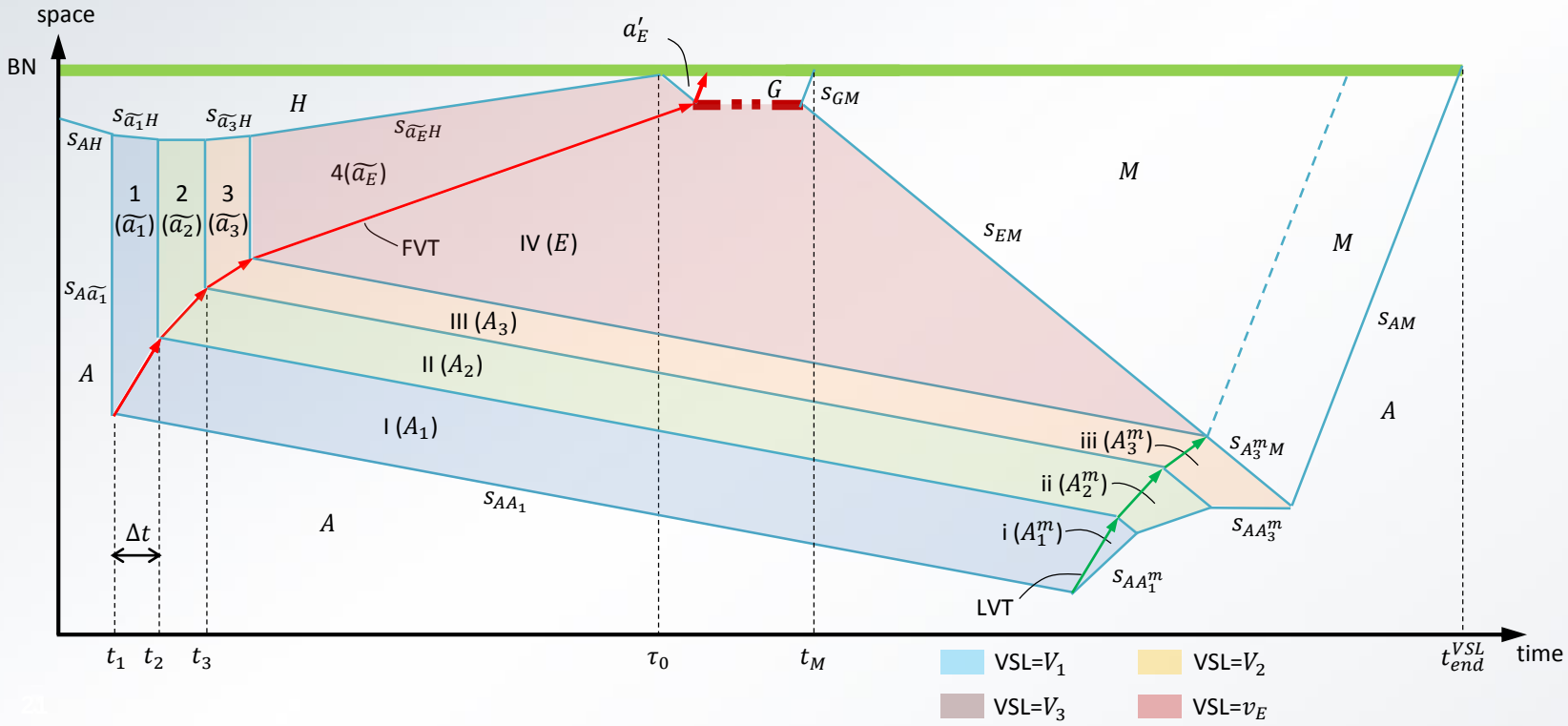
$$q_{BN} = q_G = q_E = q_e$$

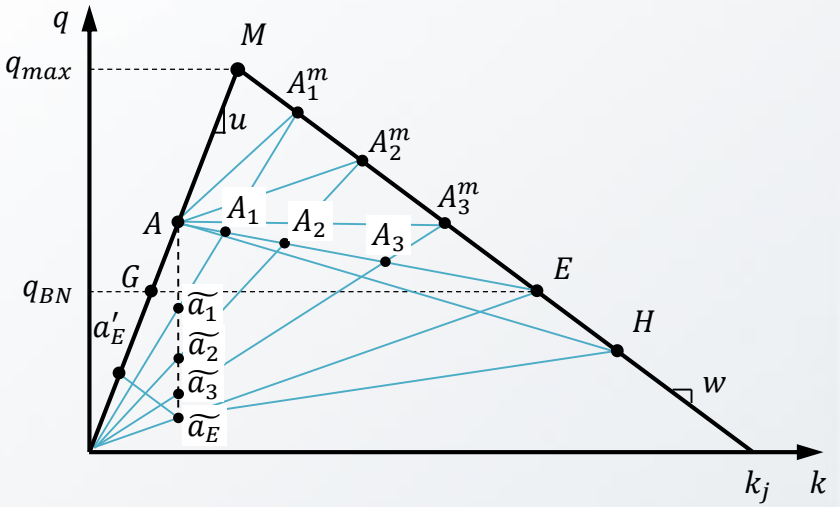


Basic VSL Control Strategy

- Step 2: regulate inflow at stable max flow

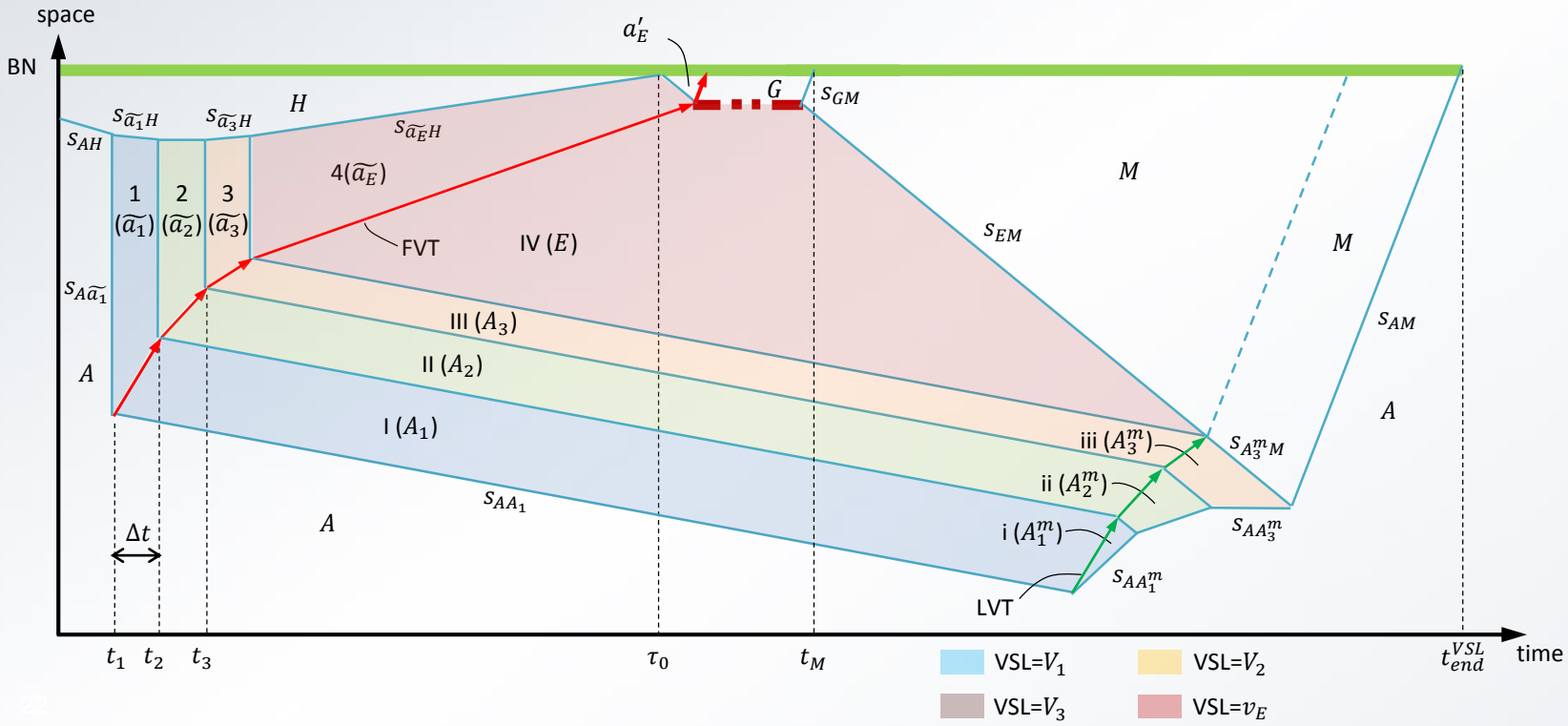
  2-3: De-activate V_1, V_2, and V_3 along LVT to end VSL control.

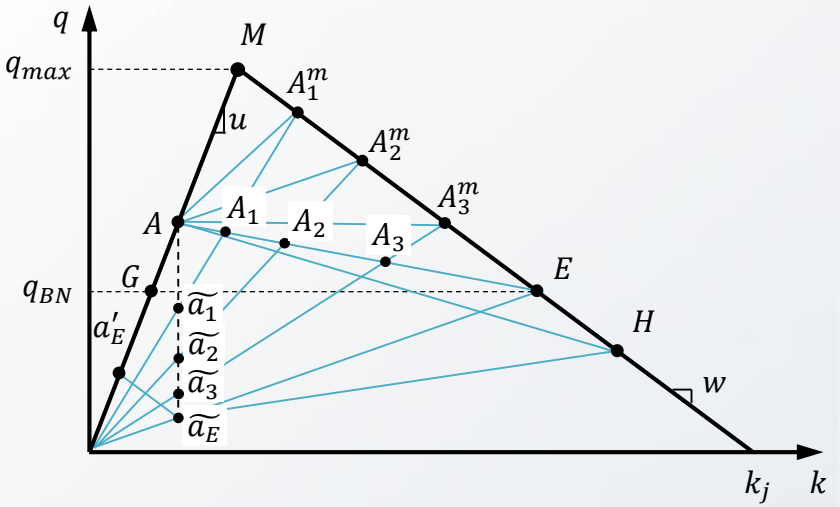




Basic VSL Control Strategy

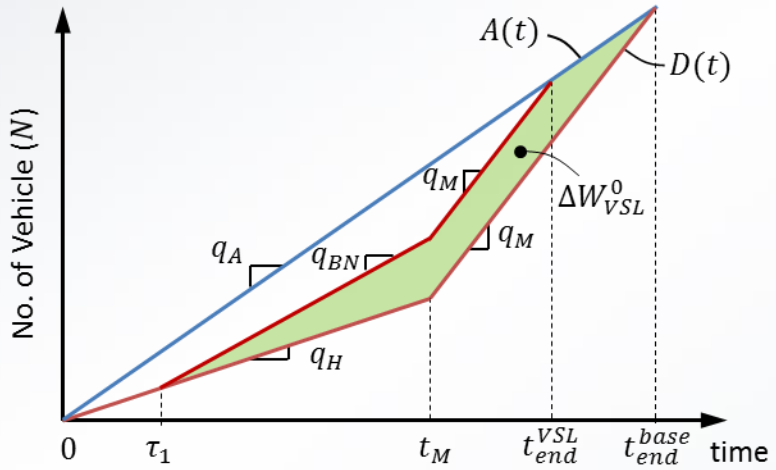
- Step 1: control demand progressively to clear queue at BN.
- Step 2: regulate inflow at stable max flow.

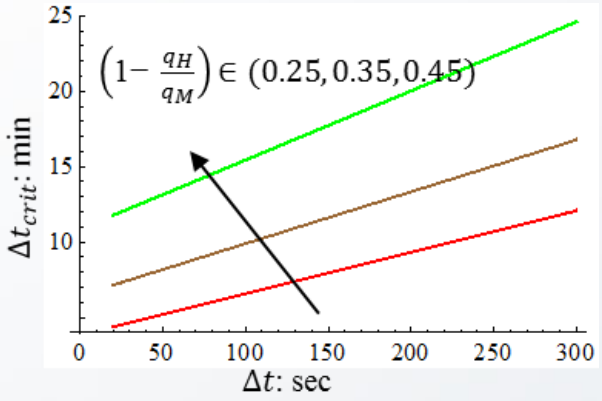




Basic VSL Control Strategy

- Parameter analysis
  - Delay saving ΔW_{VSL}^{0}
    - Queue clearance time: shorter time → more saving
    - Capacity drop ($1 - q_H/q_M$): larger drop → more saving

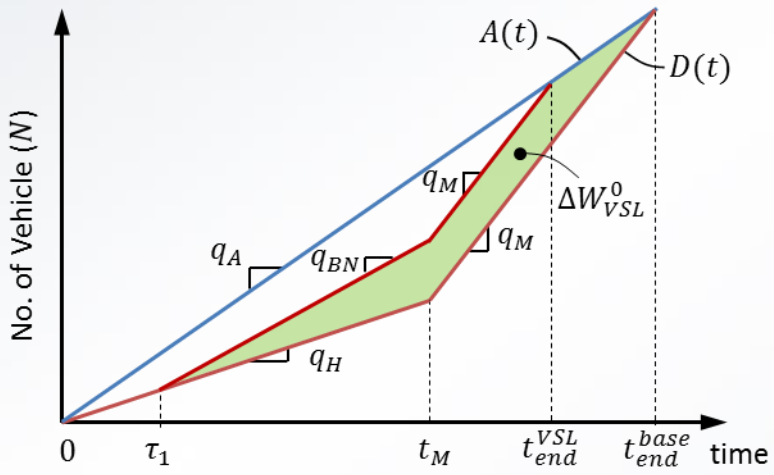


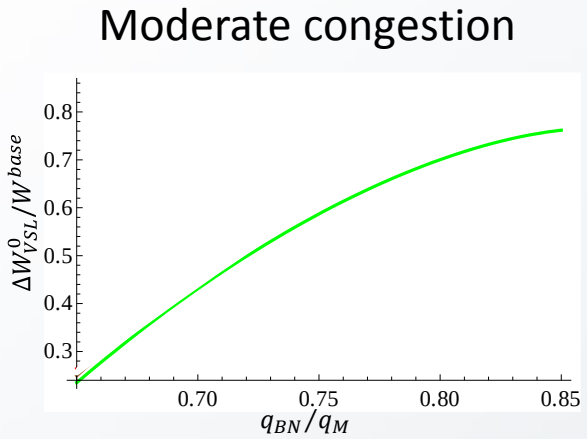


Δt: duration of intermediate zones 1, 2, 3

Basic VSL Control Strategy

- Parameter analysis
  - Delay saving ΔW_{VSL}^{0}
    - q_{BN}: positive (moderate congestion)

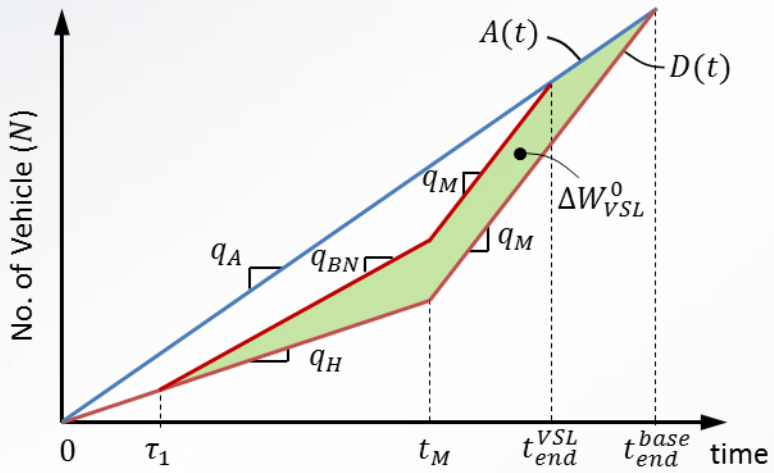




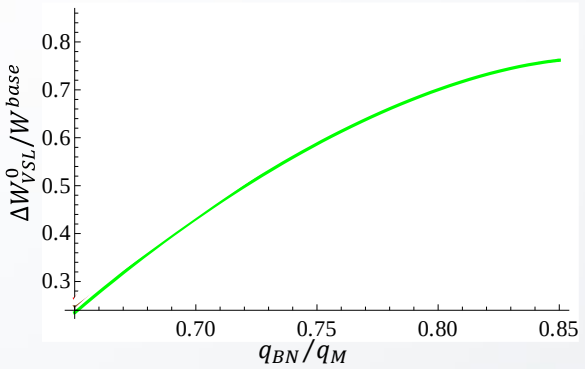
Basic VSL Control Strategy

- Parameter analysis
  - Delay saving ΔW_{VSL}^{0}
    - q_{BN}: positive (moderate congestion)
    - q_{BN}: positive →negative (severe congestion)

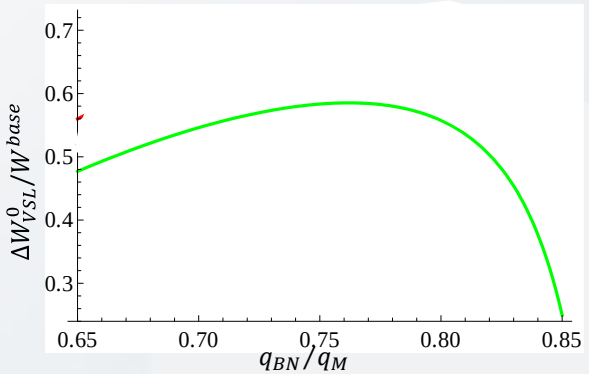
Higher q_{BN} → higher v_E (less restrictive)



Moderate congestion

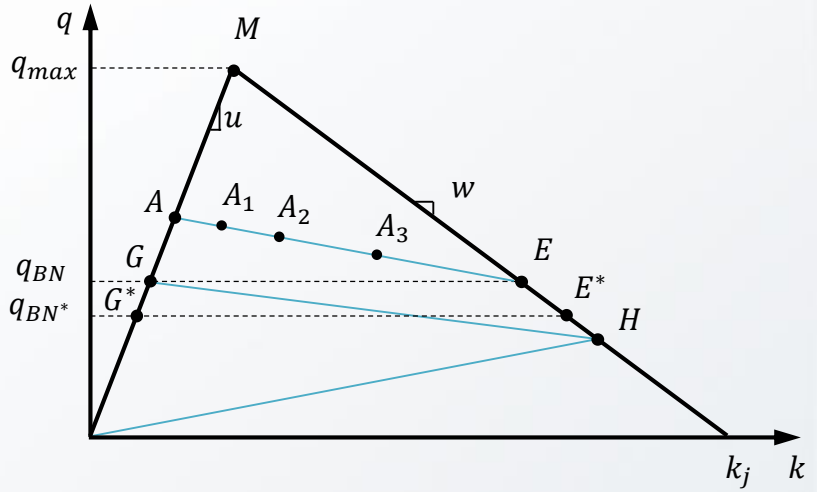


Severe congestion



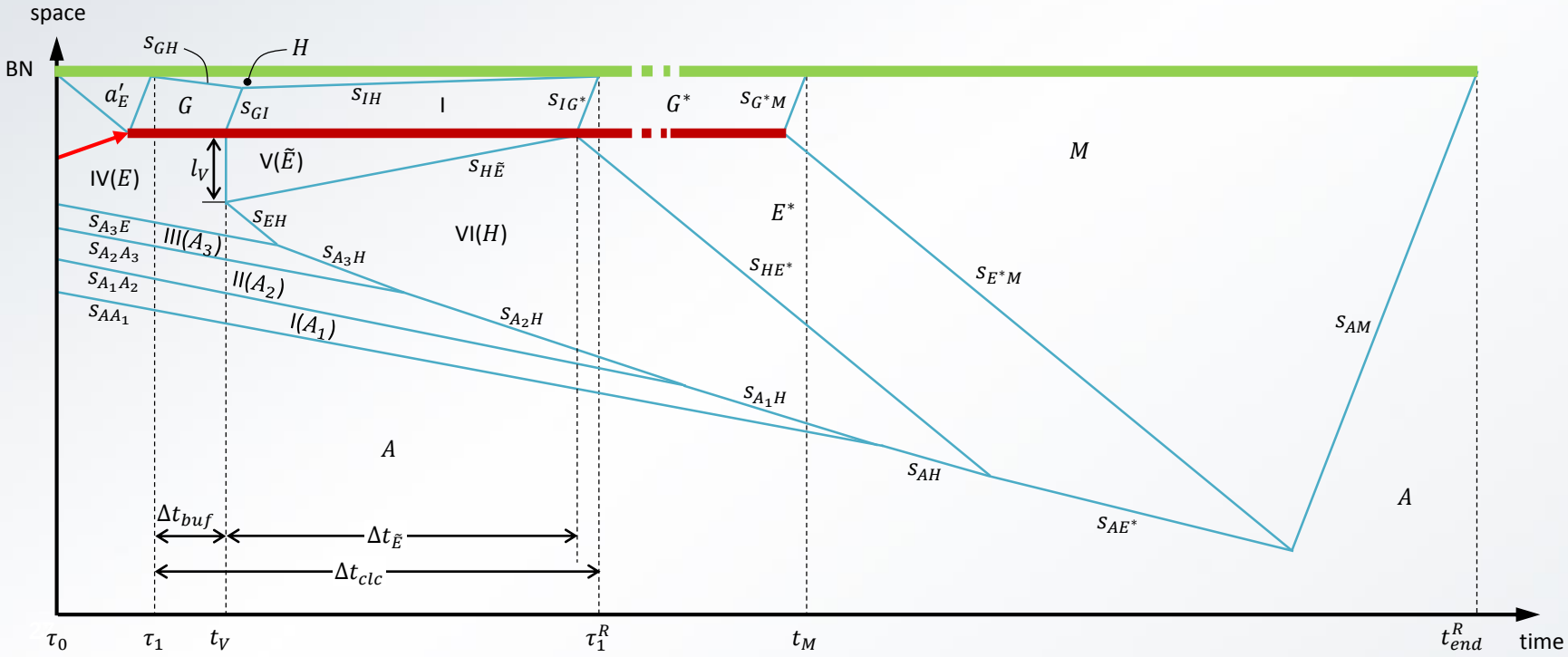
Re-emergent Queue

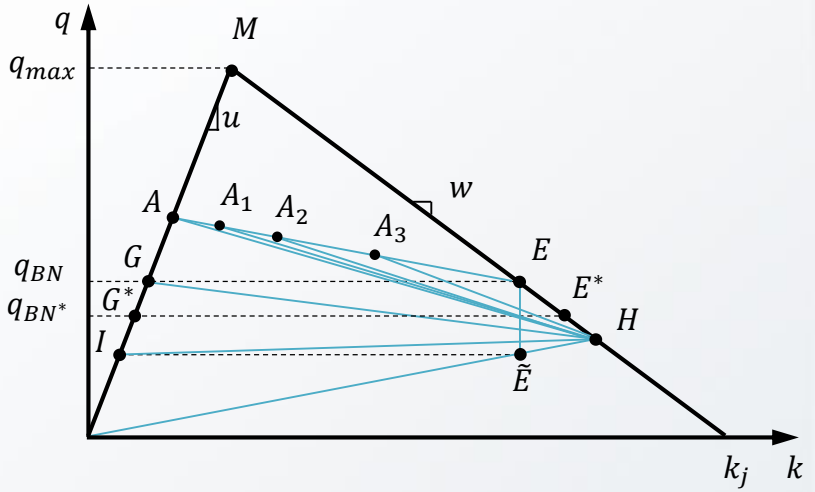
- Potential cause: overestimated stable max flow
- Control procedure
  - Impose a restrictive VSL to clear new queue
  - Regulate BN discharge rate at q_{E^*}



Re-emergent Queue

- Full image for traffic evolution
  - Impose a restrictive VSL (v_H) to clear new queue
  - Regulate BN discharge rate at q_{E^*}





Conclusions

- VSL control can achieve significant delay savings at freeway incident BNs and also smooth traffic transition at the tail of the queue.
- Re-emergent queue can be remedied. Delay saving will be smaller but still substantial.