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# Speed Limit and Control Studies and Practices

TOPL Meeting  
02/22/08





# Outlines

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- Objectives for Speed Regulation
- Speed Regulation Studies & Practices
- Combination of VSL and Ramp Metering





## Objectives Speed Regulation

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- **Safety Improvement by reduce accident/incident**
- **Emission Reduction**
- **Traffic management and Control**





# Objectives Speed Regulation

- **Safety Improvement by reduce accident/incident**
  - To reduce speed variation vs. distance means speed
  - To reduce inter-vehicle interaction
    - **Relative speed**
    - **Relative acceleration**
  - To directly reduce accident/incident → indirectly reduce non-recurrent bottleneck → improves capacity and throughput
- **Traffic and Highway situations considered**
  - Work zone
  - Where weather changes are significant
  - Where traffic demand is high
  - Where truck is heavy





# Objectives Speed Regulation

- **Approaches**
  - Fuzzy logics used to determine based on
    - Road geometric situation
    - Weather: road surface condition, windy, ...
    - Illumination
    - Road capacity
  - Empirical data for time of day and day of a week statistics
- **Feedback to the driver**
  - Variable Message Sign (VMS)
- **Regulation type**
  - Advisory (part time, all times)
  - Enforced





# Objectives Speed Regulation

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- **Emission reduction through**
  - Reducing stop and go
  - Reducing traffic pileups
  - Homogenizing traffic
- **Noise reduction through**
  - Reduced speed variation
  - Reduced acceleration





# Objectives Speed Regulation

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- **Traffic management and Control**
  - Reduce shock wave or traffic accumulation upstream of bottleneck
  - Smoothing traffic by reducing traffic dispersion (speed and distance variation) including *Stop&Go*





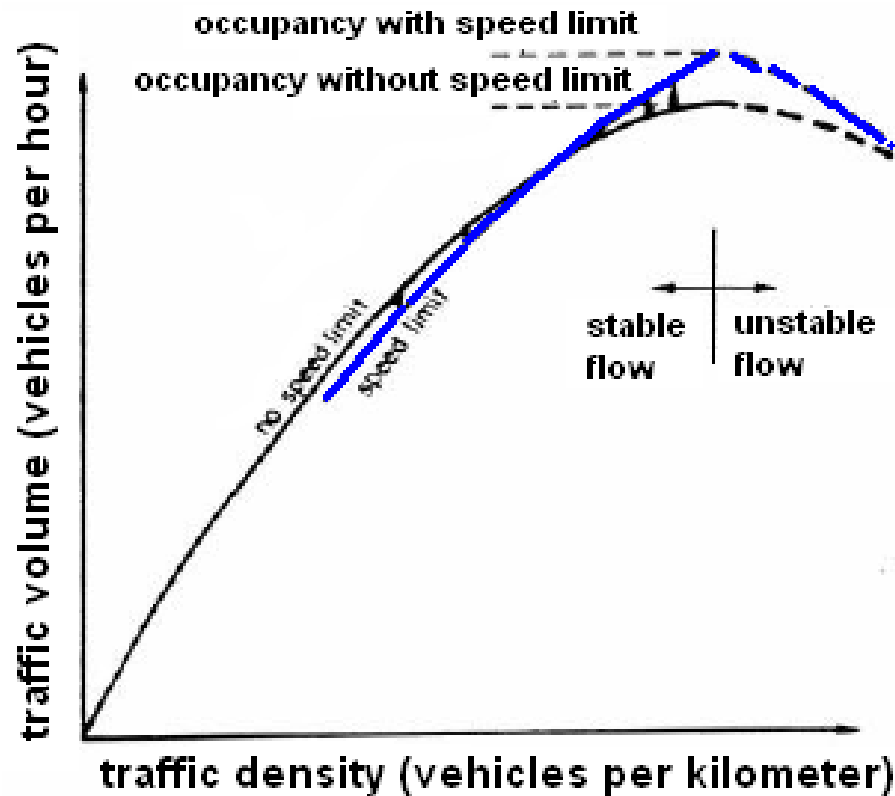
## Speed Regulation Studies & Practices - Zackor

- **Zackor:** Speed Limitation on Freeways: Traffic-Responsive Strategies. In Concise Encyclopedia of Traffic and Transportation Systems, M. Papageorgiou, Editor, Oxford, UK, 1991, pp. 507–511.



# Speed Regulation Studies & Practices - Zackor

- Change of FD due to speed limit; Zackor's results





## Speed Regulation Studies & Practice - Zackor

- **at lower or mean traffic volumes:** the mean speed is lower due to the reduction effect;
- **at higher volumes:** an increase is detected due to the stabilizing effect; both capacity and speed rise by about 5% to 10% at the same time





## Speed Regulation Studies & Practices - Bertni

- **Robert Bertni et al:** Dynamics of a Variable Speed Limit System Surrounding a Bottleneck on a German Autobahn, *84th TRB*, 2005
- **Location:** Germany, 18 km freeway known recurring bottleneck
- **Feedback: VMS with and start/end time/location**
  - (a) speed limit (piecewise constant with 12km/h increment);
  - (b) start/end time and location;
  - (c) warning information (attention, congestion, slippery).
- **Outcome:**
  - speed was regulated to some extent
  - improve on traffic somehow
  - improvement on safety was more significant, up to 20%~30%.





# Speed Regulation Studies & Practices - Papageorgiou

- **Papageorgiou et al:** Effects of Variable Speed Limits on motorway traffic, 87th *TRB Annual Meeting*, Jan. 14-18, 2008
- **Objective**
  - To investigate VSL impact on aggregate traffic flow behavior: flow-occupancy diagram (equivalent to FD flow-density diagram)
- **Control strategy**
  - Rule based algorithm depending on flow, occupancy and speed
  - Not designed for traffic flow optimization
- **Feedback strategy**
  - VMS, advisory
  - NSL, 60mph, 50mph, 40mph





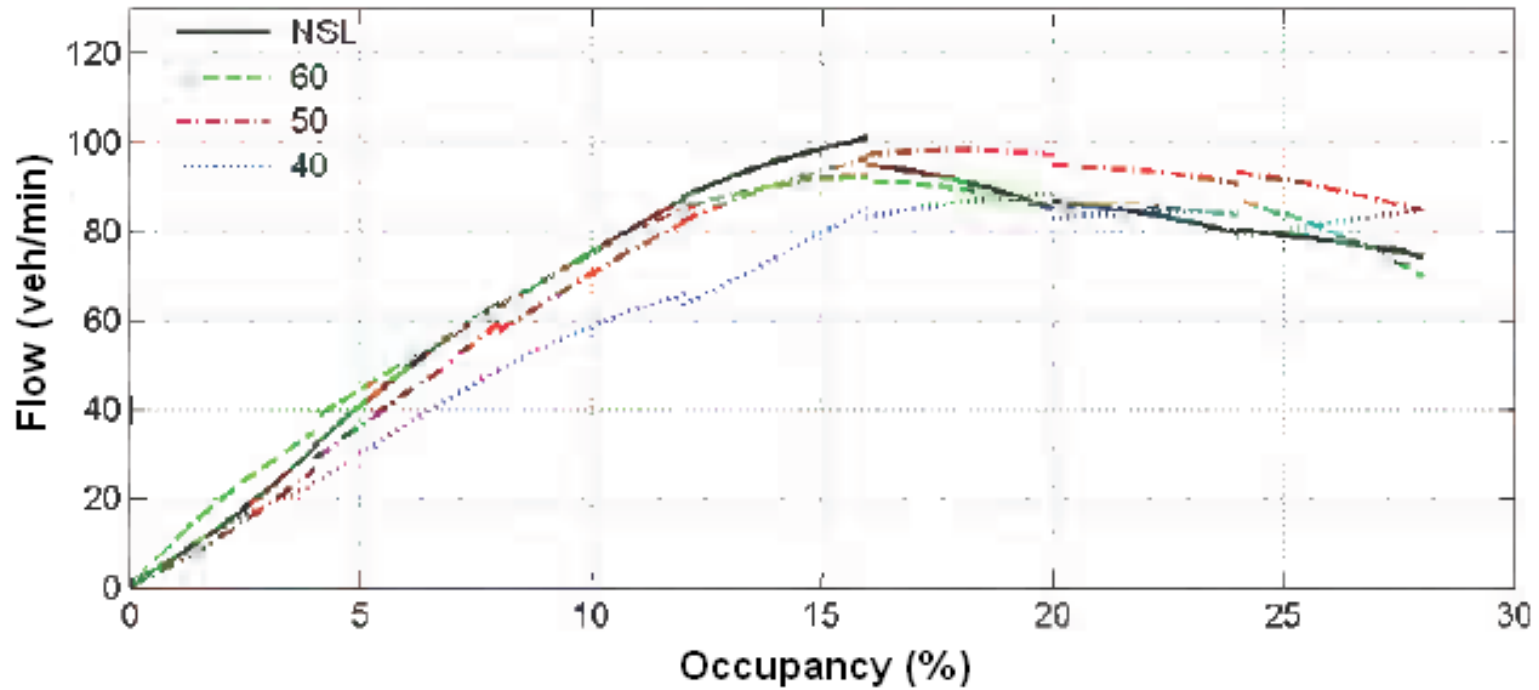
# Speed Regulation Studies & Practices - Papageorgiou

- **Methodology**
  - Aggregation: (a) over *all* 27 days; (b) over *clear* and *rainy* days;
  - Curve fitting to obtain FD
- **Data source**
  - Both direction of freeway (3 lanes each side);
  - Loop detection, stations 500m apart;
  - Providing point measured occupancy, flow and speeds;
  - Implemented in 2005; fine tuned in 2006; both data were used;
  - Only effective data used; faulty data discarded; no data cleansing/correction/imputation conducted;
  - Weekends and incident also removed;
  - Randomly selected 27 days and classified according to
    - **Weather**
    - **Peak or off-peak hours**



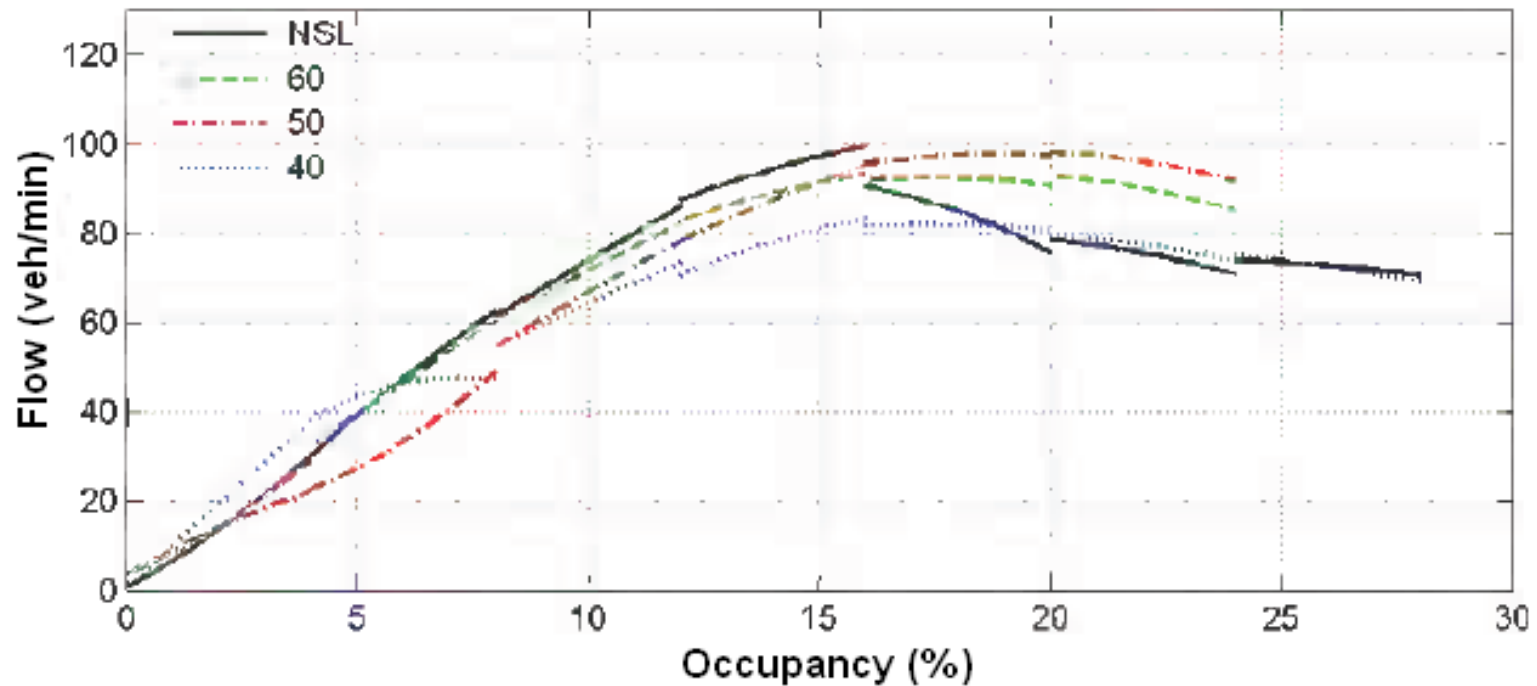


# Speed Regulation Studies & Practices - Papageorgiou





# Speed Regulation Studies & Practices - Papageorgiou





# Speed Regulation Studies & Practices- Papageorgiou

- **Reducing Mean Speed at Under-critical Occupancies →**
  - Considering upstream only (locally)
    - Occupancy increasing
    - Speed decreasing
    - May increase travel times → deteriorate traffic flow efficiency
  - Considering a stretch of fwy upstream of bottleneck (semi-globally)
    - Delay bottleneck activation
    - Delay congestion building up
- **The cross-points (if any) characteristics:**
  - lie at increasing occupancy values for decreasing VSL due to the decreasing slope of the under-critical VSL-affected curves;
  - may be no cross-point for very low VSL.





# Speed Regulation Studies & Practices - Papageorgiou

- **Cross-points of NSL FD and FD with VSL from data analysis:**
  - VSL=60 → not significant for both clear and rainy days
  - VSL=50, 40 → significant on both clear and rainy days
    - *Critical occupancy increased: 15%(NVSL) → 20%(VSL)*
    - *Corresponding flow increased*
  - Conclusion: control efficiency improved
  - Impact on *Capacity* is visible for some but not for others → unclear yet





# Speed Regulation Studies & Practices - Papageorgiou

- **Results**

- reduced mean speed at under-critical conditions
- Homogenization of speeds - reduce speed variation: relative distance/speed/acceleration
- decrease the slope of the flow-occupancy diagram at under-critical conditions: shift the critical occupancy to higher values;
- enable higher flows at the same occupancy values in overcritical conditions.





## Speed Regulation Studies & Practices - Papageorgiou

- **Global rules for efficient switching of VSL:**
  - (a) VSL-activation at occupancies lower than the crosspoint of the VSL and non-VSL flow-occupancy diagrams decreases the traffic flow efficiency (increases travel times), unless it is used to address a downstream bottleneck.
  - (b) VSL-activation at the cross-point occupancy or (the latest) at the non-VSL critical occupancy is likely to improve the traffic flow efficiency due to avoidance or delay of congestion as well as improved traffic flow stability which might allow for higher flows under overcritical occupancies.





# Speed Regulation Studies & Practices - Papageorgiou

- **Implementation techniques:**

- Proper selection of thresholds based on measured occupancy, flow, and speed;
- Avoiding switching oscillation considering the response delay of traffic;
- Activation at proper time – not too early nor too late;
- Thresholds variable from location to location:
  - Needs elaborate calibration
  - Location-specific cross-points of the various flow-occupancy curves

- **Comments:**

- For fully evaluate the impact of VSL on traffic flow, the VSL should be judicially designed and feedback to the driver for advisory and/or enforcement;
- Speed Control should be tightly coupled with Ramp Metering





## Speed Regulation Studies & Practices - Juan et al

- **Juan Z. et al**, Simulation research and implemented effect analysis of variable speed limits on freeway, *Proc. the 7th IEEE ITS*, 3-6 Oct. 2004 p.894 - 898
- **Freeway congestions classified in two types:**
  - demand driven: due to the increase of traffic volume;
  - supply driven: due to the road geometric condition, weather or traffic accident.
- **Simulation conducted in view of the cause of congestion with several factors leading to the traffic flow instability taken into consideration:**
  - small time headway
  - large speed variance
  - frequent disturbances





## Speed Regulation Studies & Practices - Juan et al

- Many scenarios of VSL are simulated. The results indicated that the VSL benefits are obvious  $\geq$  when the traffic volume is equal to or greater than 2800 veh/h (double lane) volume 2000veh/h (double lane).
  - (a) for demand driven congestion, which is shown as:
    - increase of the served traffic volume
    - saving of travel time
    - reduction of speed deviation
  - (b) For supply driven congestion
    - reduce the queue time and stops
    - avoid happening of congestion
    - save travel time

when the traffic volume is equal to or greater than 2000veh/h (double lane).





## Speed Regulation Studies & Practices - Juan et al

- **Performance of VSL is limited if traffic volume > capability:**
  - Only delays the occurrence of congestion
  - Unable to avoiding it
- **Suggestion:**
  - VSL need to combine with Ramp Metering for high traffic volume





## Speed Regulation Studies & Practices – New Mexico

- **Status:** Inactive (activated 1989, dismantled 1997 due to road widening)
- **Objective – Safety oriented:**
  - to provide a US test bed for VSL equipment and algorithms
  - to post speed limits that reflect traffic conditions (to minimize accident risk and advise motorists of hazards)
- **Setting:** Urban – I-40 Eastbound in Albuquerque
- **Size:**
  - 4.8 km (3miles)
  - 3 variable speed sign locations





# Speed Regulation Studies & Practices – New Mexico

- **Control & Feedback Strategies**
  - Fully automated - updated every minute
  - Smoothed Average Speed + Environmental Constant
  - Posted speeds ranged from 30-55 mph
  - Also displayed minimum speed limit
  - Enforced

Environmental Condition	Constant
Light	+7.5 mph
Dark	+ 5.0 mph
Light and Precipitating	+ 2.5 mph
Dark and Precipitating	+ 0.0 mph





## Speed Regulation Studies & Practices – New Mexico

- **Results:**

- Overall, the equipment and algorithm were a success.
- There was a slight reduction in accidents.
- The effectiveness evaluation was hindered by high average speeds, sign visibility, and sun glare.
- The maximum speed limit that could be posted was the National Maximum Speed Limit (55 MPH). Because smoothed average speeds regularly exceeded this maximum, the ability of the system to post speed limits that reflected traffic conditions was hindered.





# Speed Regulation Studies & Practices –UK London Orbital M25

- **Status: Active (extended 1995)**
- **Objective – Primarily Safety:**
  - to smooth traffic flows by reducing stop-start driving
  - to demonstrate control of traffic speeds which might be used on wide motorways (dual 5/6 lane).
- **Setting:**
  - Urban - M 25 London Orbital
  - 22.6 + km (14+ miles) with variable speed display stations spaced at 1 km (0.6 mile) intervals
  - loop detectors at 500 m (0.3 mile) intervals
  - CCTV





# Speed Regulation Studies & Practices –UK London Orbital M25

- **Displayed Speed Logic:**
  - Speed limits are changed according to detected vehicle volumes.
    - The displayed speed changes from 70 mph to 60 mph when volume exceeds 1,650 veh/h/l.
    - The displayed speed is lowered to 50 mph when volumes exceed 2,050 veh/h/l.
  - The system also monitors traffic speeds and stationary traffic to slow vehicles down that are approaching a queue, and has additional logic to stop speed limit settings fluctuating too often.
- **Advisory/Enforceable/Enforced:**
  - Enforced - photo radar (uses 35mm photos)





# Speed Regulation Studies & Practices –UK London Orbital M25

- **Results:**

- Very high driver compliance with the VSL signs
- Police impressed with the system.
- Drivers also impressed – 68%, would like to be extended
- There has been a 10-15% reduction in accidents
- No evaluation on traffic improvement reported





## Combination of VSL and Ramp Metering - Hegyi

- **Hegyi et al:** Optimal coordination of ramp metering and variable speed control-an MPC approach, 2002 ACC, p.3600 – 3605
- **Objectives:** Suppressing shockwaves
- **Model, 2<sup>nd</sup> order:**

$$\rho_{m,i}(k+1) = \rho_{m,i}(k) + \frac{T}{L_m \lambda_m} (q_{m,i-1}(k) - q_{m,i}(k))$$

$$v_i(k+1) = v_i(k) + \frac{T}{\tau} (V(\rho_i(k)) - v_i(k))$$

$$- \frac{T}{L} v_i(k) (v_{i-1}(k) - v_i(k)) -$$

$$\frac{vT}{\tau L} \frac{\rho_{i+1}(k) - \rho_i(k)}{\rho_i(k) + \kappa}$$





## Combination of VSL and Ramp Metering - Hegyi

- The driver desired speed:

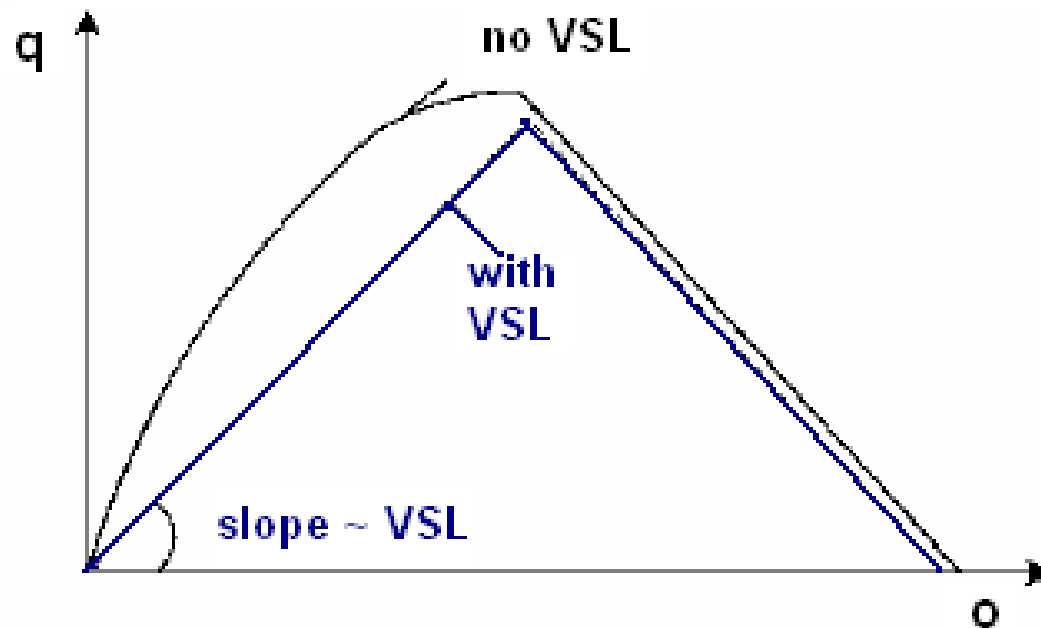
$$V(\rho_i(k)) = v_{free} \exp\left(-\frac{1}{a} \left(\frac{\rho_i(k)}{\rho_{crit}}\right)^a\right)$$

- $v_{free}$  – free-flow speed;
- $a$  – model parameter; from the expression, should be a quite large number.
- $\rho_{crit}$  – critical density, which should be a constant or can be a function related to environmental conditions (road geometry, weather, road conditions, etc)



# Combination of VSL and Ramp Metering - Hegyi

- Model for VSL impact on FD





## Combination of VSL and Ramp Metering - Hegyi

- **Control Design method:** Finite Horizon Model Predictive Control
- **Simulation conducted for different scenarios:**
  - M. Lu, A. Hegyi, K. Wevers, Perspective of Mitigating Shock Waves by Temporary In-Vehicle Dynamic Speed Control, *85th TRB Annual Meeting*, Washington D. C., Jan. 2006





## Speed Regulation Studies & Practices – Servin and Barth

- **O. Servin and M. Barth:** A Preliminary Design of Speed Control Strategies in Dynamic Intelligent Speed Adaptation System for Freeways  
87th *TRB Annual Meeting*, Jan. 14-18, 2008
- **Goal:** Energy/emission reduction through speed control strategy with *travel time* penalty minimization
- **Method of Speed Control (Finite Horizon MPC of Hegyi)**
- **Simulation with PARAMICS to show energy/emission reduction**

