Speed Harmonization and Peak Period Shoulder Use Workshop

Tools for Managing Urban Freeway Congestion

Month Day, 20XX
Texas DOT Workshop

Workshop Overview

- **Introduction to Speed Harmonization and Peak Period Shoulder Use**
- Discuss Completed Research
- Introduction to Project Handbook
- Introduction to Multi-Resolution Analysis
- Summary

First we will cover a brief introduction to speed harmonization and peak period shoulder use.

Introduction to Speed Harmonization and Peak Period Shoulder Use

- What is speed harmonization and peak period shoulder use?
- Where have these strategies been applied in the past?
- Why consider implementing these strategies?

The following slides will address these questions three topics.

Introduction: What is speed harmonization and peak period shoulder use?

- Speed harmonization is a DTM strategy used to set speed limits in real-time on freeway sections based on prevailing roadway and traffic conditions. It has been implemented in the past with various objectives.

- Temporary shoulder use is primarily a congestion management tool where freeway shoulders are opened to motorists and used as an additional travel lane.

Introduction:
Where have these strategies been used?

- Examples in the U.S.:

Year	Location	Primary Objective
1989	Albuquerque, New Mexico	Safety Improvement
1990	Washington State	Reduce winter accidents
2000	Minnesota	Improve work zone safety
2001	Austin, TX	Delay reduced by half

Introduction:
Where have these strategies been used?

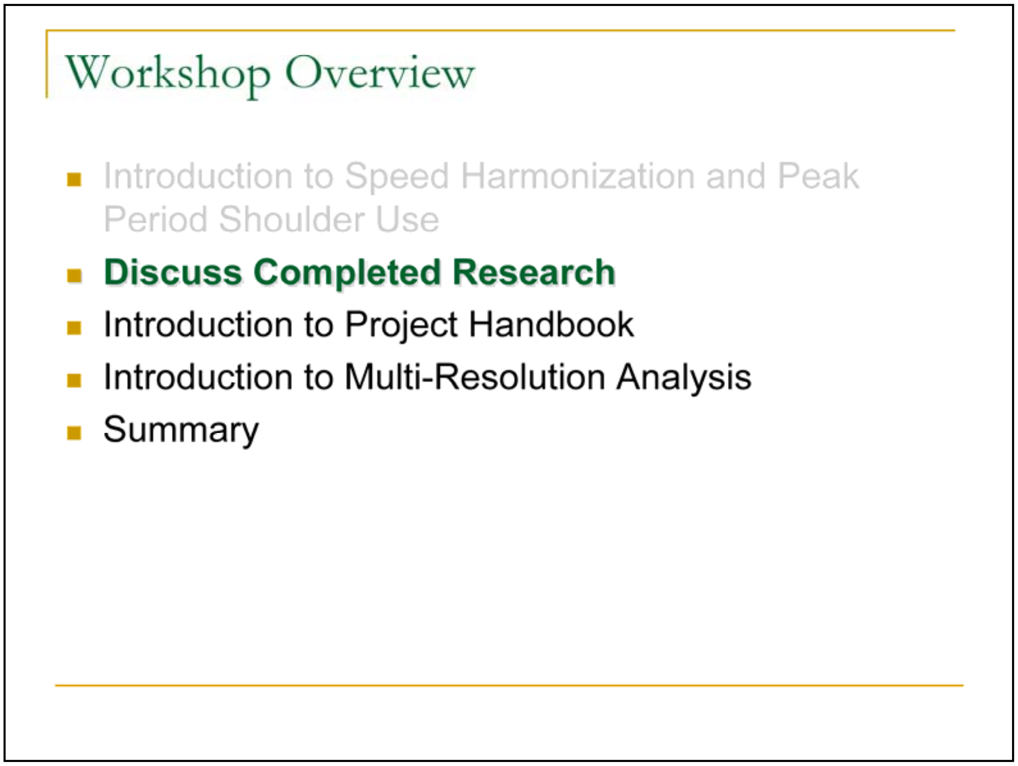
- Examples outside of the U.S.:

Locations	Active Traffic Management Strategy	
	Speed Harmonization	Temporary Shoulder Use
Germany	◆	◆
Netherlands	◆	◆
United Kingdom	◆	◆
Australia	◆	
France	◆	◆
Finland	◆	
Belgium	◆	
Denmark	◆	
Sweden	◆	
Italy		◆

Introduction:
Why implement these strategies?

Potential Benefits	Active Traffic Management Strategy	
	Speed Harmonization	Temporary Shoulder Use
Increased Throughput	◆	◆
Increased Capacity		◆
Decrease in Primary Incidents	◆	
Decrease in Secondary Incidents		
Decrease in Incident Severity	◆	
More Uniform Speeds	◆	
Decreased Headways	◆	
More Uniform Driver Behavior	◆	
Increased Trip Reliability	◆	◆
Delay Onset of Freeway Breakdown	◆	◆
Reduction in Traffic Noise	◆	
Reduction in Emissions	◆	
Reduction in Fuel Consumption	◆	

Benefits and motivations for implementing speed harmonization and peak period shoulder use are shown in the table above. The information presented is based on a trip sponsored by FHWA to visit European countries using these technologies.



Why discuss the completed research…..

1) It is the foundation for the content in the project handbook.
2) It provide valuable background information for understanding the material in the project handbook.

Overview of Completed Research

- TxDOT Research Project 0-5913
- Work plan included
  - **Synthesis of Past Experiences**
  - Selecting and Analyzing Candidate Corridors
  - Conducting Simulation Analyses
  - Developing and Testing Control Strategies (Offline and Online Algorithms)
  - Assessing Safety Implications
  - Recommending Geometric Design Guidelines
  - Recommending ITS Infrastructure
  - Highlighting Enforcement Considerations
  - Developing a Cost Benefit Analysis Framework
  - Producing an Operational and Deployment Plan

First we’ll discuss the synthesis of past experiences.

Completed Research: Synthesizing Past Experiences

- Example findings of the FHWA:
  - In Germany, using speed harmonization, a 27% reduction in crashes with heavy material damage, 30% reduction in personal injury damage
  - In the Netherlands, using speed harmonization, the number of collisions reduced by 16%, the throughput increased by 3 to 5%. The use of the shoulder increased the capacity by 7 to 22%.
  - In the UK, speed harmonization resulted in 18% reduction in incidents.

Completed Research: Synthesizing Past Experiences

- The FHWA recommendations regarding speed harmonization:
  - Sufficient sensor deployment for traffic and weather monitoring to support the strategy.
  - Adequate sign gantries to ensure at least one speed limit sign is in sight at all times.
  - Place speed limit signs over each travel lane.
  - Implement a system that deploys the strategy based on prevailing roadway conditions without requiring operator intervention. It is critical this system is reliable and accurate to gain public trust and acceptance.
  - Connect the system to a traffic management center to serve as the focal point for the system.

Completed Research: Synthesizing Past Experiences

- FHWA recommendations continued…
  - Pass enabling legislation and related laws to allow for dynamic speed limits.
  - Use uniform signing related to speed harmonization and its components.
  - Apply modeling tools to assess the impacts of speed harmonization on overall network operations.
  - Install closed-circuit television cameras to support the monitoring of the system.
  - Install dynamic message signs to provide traveler information and regulatory signs as appropriate.
  - Use automated speed enforcement to deter violations.

Continued from the previous slide (harmonization)

Completed Research: Synthesizing Past Experiences

- FHWA recommendations for temporary shoulder use:
  - Deploy in conjunction with speed harmonization.
  - Pass enabling legislation and related laws to allow the shoulder to be used as a travel lane.
  - Develop a policy for uniformly applying the strategy through entrance and exit ramps and at interchanges.
  - Install adequate sign gantries to provide operational information and to ensure operational information is in sight at all times.
  - Place lane control signals over each travel lane.
  - Use uniform signing and markings.

Completed Research: Synthesizing Past Experiences

- FHWA recommendations continued….
  - Install closed-circuit television cameras to verify the clearance of the shoulder before deployment.
  - Provide pullouts at regular intervals with automatic vehicle detection and emergency call boxes to provide refuge areas for minor incidents.
  - Install lighting to enhance visibility of the shoulder.
  - Install advanced incident detection capabilities as well as a comprehensive incident management program.
  - Connect the system to a traffic management center to serve as the focal point for the system.
  - Use dynamic message signs to provide guide sign information and regulatory signs to adapt to the shoulder as a travel lane.

Continued from the previous slide (shoulder use)

Completed Research: Synthesizing Past Experiences

- These solutions require a dense deployment of Intelligent Transportation Systems (ITS) infrastructure.
- Given the large price tag of these investments, it is crucial to understand the potential benefits of such a system before deployment.
- In particular, we have to account for driver behavior, road characteristics, weather conditions and so on *specific to Texas* if these DTM strategies are to be successful in Texas.

Overview of Completed Research

- TxDOT Research Project 0-5913
- Work plan included
  - Synthesis of Past Experiences
  - **Selecting and Analyzing Candidate Corridors**
  - Conducting Simulation Analyses
  - Developing and Testing Control Strategies (Offline and Online Algorithms)
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Completed Research: Selecting Candidate Freeway Corridors

- Several freeway corridors were examined as a test bed for speed harmonization.

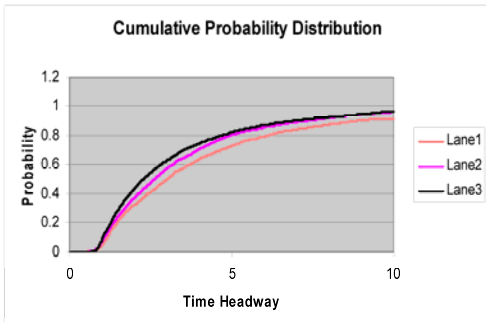
- Two corridors were the most promising based on criteria such as congestion pattern, data availability:
  - South Padre Island Dr., Corpus Christi, TX
  - Mopac, Austin, TX

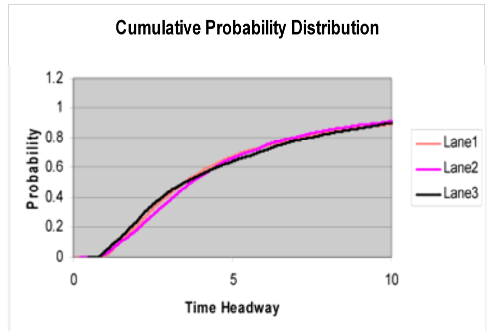
Completed Research: Selecting Candidate Freeway Corridors

- South Padre Island Dr, Corpus Christi, TX.
- AADT = 139 000

Completed Research: Selecting Candidate Freeway Corridors

- Preliminary simulation results with speed harmonization for this corridor shows that the time headway decreases:



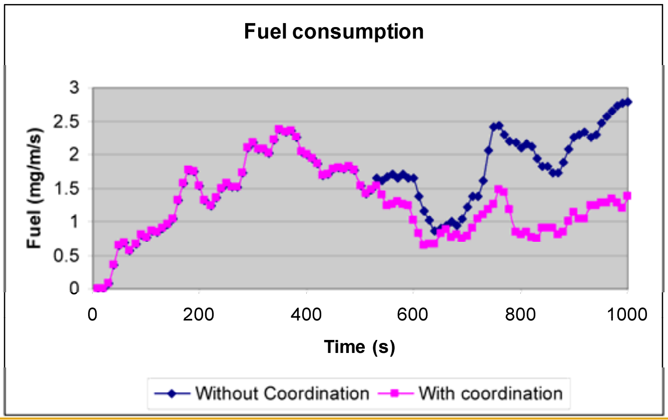


-The control strategy here was to reduce speed from 60 mph to 35 mph once the occupancy reached 0.35.

- Left: before speed harmonization. Right: after speed harm.

Completed Research:
Selecting Candidate Freeway Corridors

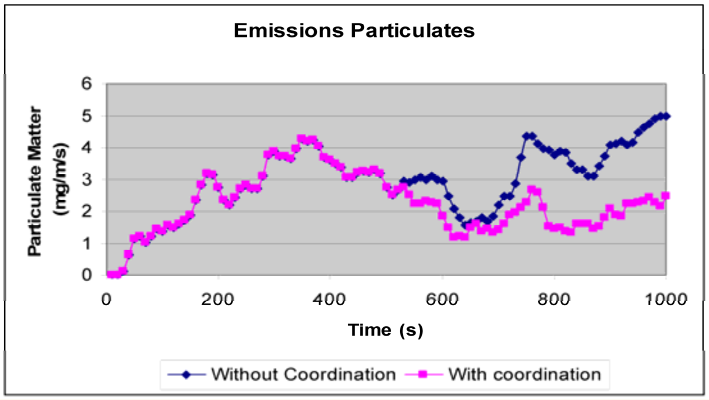
- Preliminary simulation results with speed harmonization for this corridor also shows that the fuel consumption declines:



-The control strategy here was to reduce speed from 60 mph to 35 mph once the occupancy reached 0.35.

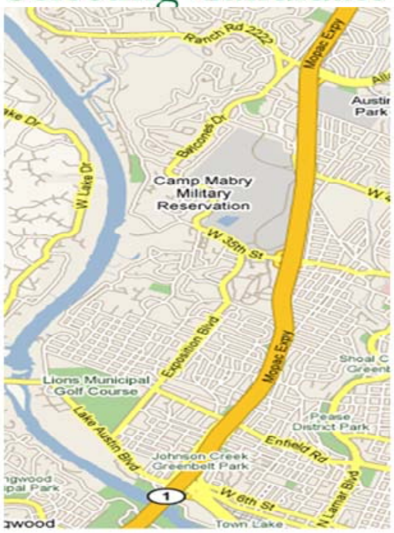
Completed Research:
Selecting Candidate Freeway Corridors

- Finally, preliminary simulation results with speed harmonization for this corridor shows beneficiary impacts on the emission.



-The control strategy here was to reduce speed from 60 mph to 35 mph once the occupancy reached 0.35.

Completed Research:
Selecting Candidate Freeway Corridors



- Mopac between Enfield Rd and 45th Street, Austin,TX.
- Motivation for Selection:
  - Calibrated model to measure network impacts
  - Data availability
  - Recurrent congestion
- Both freeways were equally suitable. Finally, we decided to use Mopac.
- Simulation results are presented later in this presentation

Overview of Completed Research

- TxDOT Research Project 0-5913
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  - Synthesis of Past Experiences
  - Selecting and Analyzing Candidate Corridors
  - **Conducting Simulation Analyses**
  - Developing and Testing Control Strategies (Offline and Online Algorithms)
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Completed Research: Conducting Simulation Analyses

- Simulation Model Framework
  - The implementation of advanced traffic management strategies requires a careful feasibility study prior to the actual deployment.
  - Traffic simulation provides a feasible and cost-effective option to perform such analysis.
  - Microscopic vs. Mesoscopic simulation
  - Hybrid Model -> multi-resolution analysis

Completed Research: Conducting Simulation Analyses

- Main Benefit of Microsimulation:
  - High degree of realism (e.g. lane changing, car-following, gap acceptance)
- Main Drawbacks of Microsimulation:
  - Many parameters to calibrate
  - Results sensitive to model parameters
  - Computationally intensive
- Examples:
  - CORSIM, VISSIM, PARAMICS

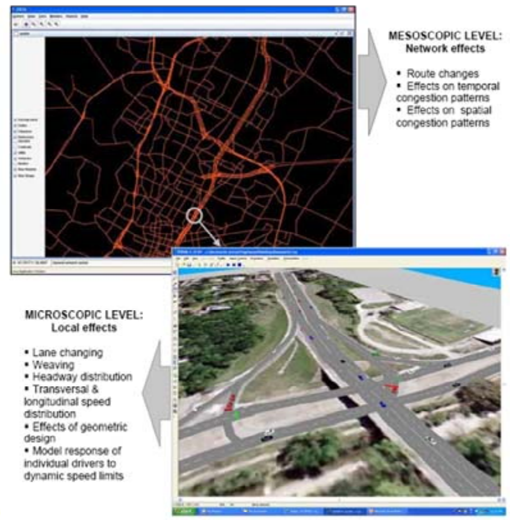
Completed Research: Conducting Simulation Analyses

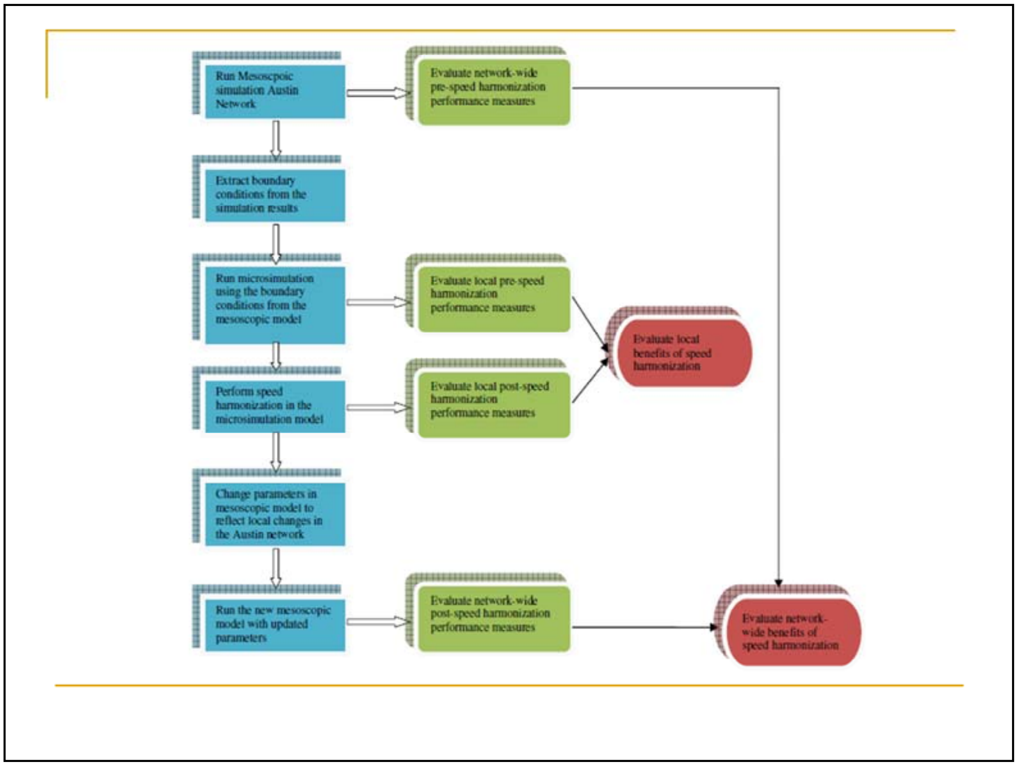
- Main Benefits of Mesoscopic Simulation:
  - Less parameters to calibrate
  - Computationally less intensive
- Main Drawbacks of Mesoscopic Simulation:
  - Less detailed driving behavior
- Examples:
  - Dynasmart, DynaMIT, VISTA

Are these software names ok?

Completed Research: Conducting Simulation Analyses

- Microscopic as well as mesoscopic simulation has advantages and disadvantages.
- Hence we need a multi-resolution approach.





Shown above is the overall framework for the multi-resolution approach.

Completed Research: Conducting Simulation Analyses

- Examples of local performance measures:
  - Change in average speed, average density, throughput
- Examples of network-wide performance measures:
  - Total travel time, OD travel time

Overview of Completed Research

- TxDOT Research Project 0-5913
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  - Selecting and Analyzing Candidate Corridors
  - Conducting Simulation Analyses
  - **Developing and Testing Control Strategies (Offline and Online Algorithms)**
  - Assessing Safety Implications
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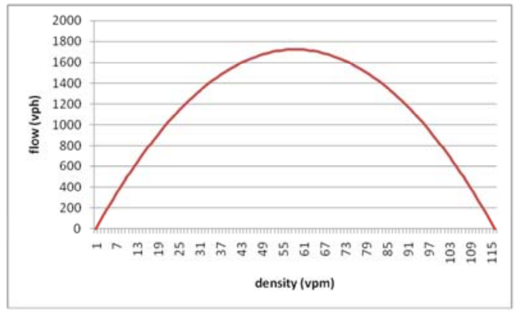
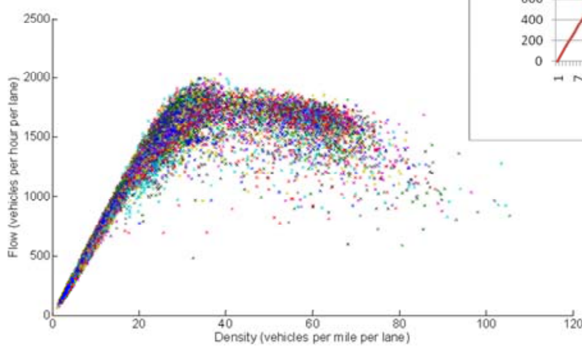
Completed Research: Developing and Testing Control Strategies Offline Model for Speed Harmonization

- One key element of whether or not speed harmonization is successful is the underlying control algorithm.
- It is more beneficial to account for real-time traffic information in speed harmonization. This requires the presence of ITS (loop detectors, gantries, VMS etc).
- Offline control algorithms are used when a corridor is lacking sufficient ITS for an online strategy.

Completed Research: Offline Model Speed Harmonization

- Fundamental diagram:

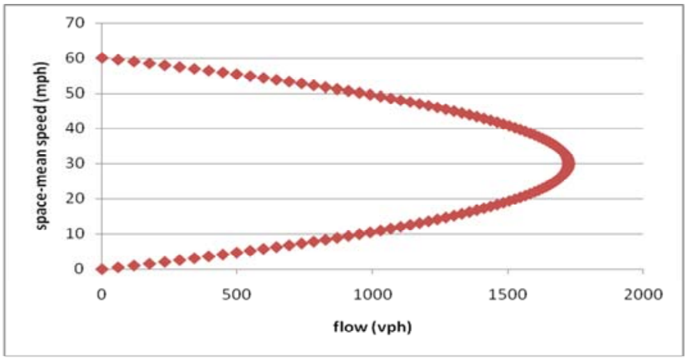




Mathematical and empirical flow-density curve for a section of the I-880S in California (adopted from Dervisoglu et al., 2009).

Completed Research:
Offline Model for Speed Harmonization

- Speed-flow curve:



Completed Research: Offline Model for Speed Harmonization

- **Offline algorithm Speed Harmonization**

Input speed-flow-curves for each of the *n* road segments

Output "Speed-harmonized road segments" at time *t*

Step 1 Pick the most downstream road segment *k* for which the flow is known to (almost) reach capacity.

Step 2 FOR all road segments $r = k-1, k-2, \ldots, 1$

DO select a speed for segment *r* such that $q(r)<c(r+1)$

set c(r)=q(r)

END DO

END FOR

Step 3 When flow reduces to normal, off-peak values, reinstall original speed limits.

-q(r) is the flow in segment r, c(r) is the capacity of segment r. Note that the selection of a speed for segment r induces a q(r).

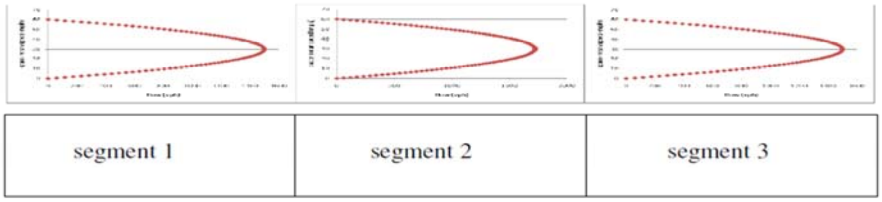
-In step 3, since the algorithm is offline, it is assumed to be known when the flows reduce to normal conditions (i.e. at a fixed time).

-The speed selection in Step 2 can be accomplished in various ways, both subjectively (e.g. based on engineering judgement) as well as objectively (e.g. via simulation). We used microsimulation.

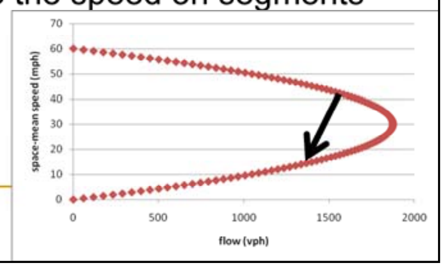
- Since model is offline, it is recommended that the operator at the TMC checks the new speed limits first before posting, to account for factors such as visibility, pavement conditions etc.

Completed Research: Offline Model for Speed Harmonization

- Consider the 3-segments freeway



- Suppose segment 3 is known to be a bottleneck during the peak-hour. Then we reduce the speed on segments 2 and 1 (in that order).



Example of offline algorithm. If section 3 is known to be bottleneck in the morning peak period, say, then every morning we reduce the speed on segments 1 and 2. For example, if the capacity of segment 3 (the bottleneck) is 1700 vph, then we choose a speed on segment 1 and 2 such that the flow into segment 3 is less than its capacity. The exact speed to choose is determined via simulation.

Completed Research: Offline Model Case Study

- Two micro-simulation models of Mopac were developed: Peak-period model and Uncongested model.
- Variable speed limits were implemented in a 2.5 mile corridor on Mopac NB (Enfield Rd – W 45th St).

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Offline Model Case Study Traffic Data

- 15-min interval loop detector data for 2007 were used for calibration.

STN_ID	LANE_QTY	STA_TIME	VOLUME	FLOWRATE	OCC	SPEED	TRUCKS	SPD_DAYS	VOL_DAYS	OCC_DAYS	TRK_DAYS	Year
164	2	0:00	99.989	199.98	0.94	61	1.2811	185	185	185	185	2007
164	2	0:15	85.622	171.24	0.76	61	1.4162	185	185	185	185	2007
164	2	0:30	72.822	145.64	0.62	61	1.1676	185	185	185	185	2007
164	2	0:45	61.848	123.7	0.49	61	1.0217	184	184	184	184	2007
164	2	1:00	53.005	106.01	0.4	61	1.1749	183	183	183	183	2007
164	2	1:15	44.978	89.956	0.31	61	1.0608	181	181	181	181	2007
164	2	1:30	39.783	79.567	0.26	61	1.3556	180	180	180	180	2007
164	2	1:45	36.654	73.307	0.24	61	1.4749	179	179	179	179	2007
164	2	2:00	32.514	65.028	0.22	61	1.3503	177	177	177	177	2007
164	2	2:15	32.282	64.565	0.2	61	1.2768	177	177	177	177	2007

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Offline Model Case Study Traffic Conditions

- Traffic condition on Mopac NB during evening.

	Density (veh/mi/ln)			Level of Service (LOS)		
Time	9 1/2 St	Westover Rd	45th St	9 1/2 St	Westover Rd	45th St
3 PM - 4 PM	33	36	33	D	E	D
4 PM - 5 PM	47	57	44	F	F	E
5 PM - 6 PM	52	61	50	F	F	F
6 PM - 7 PM	34	43	37	D	E	E

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Offline Model Case Study Calibration

Detectors on Mopac NB	Time	Observed Volume (veh/hr)	Simulated Volume (veh/hr)	% Difference	GEH*
9 1/2 St	4 PM - 5 PM	2448	2515	2.7	1.3
Westover Rd	4 PM - 5 PM	4605	4322	-6.1	4.2
45th St	4 PM - 5 PM	5176	5199	0.4	0.3
9 1/2 St	5 PM - 6 PM	1826	1767	-3.2	1.4
Westover Rd	5 PM - 6 PM	3717	3897	4.8	2.9
45th St	5 PM - 6 PM	4702	4742	0.9	0.6

$$*GEH = \sqrt{\frac{2(Observed - Simulated)^2}{(Observed + Simulated)}}$$

- Calibration guideline: GEH < 5 at 85% of the locations. (FHWA)

Some real-world examples of Speed harmonization. Copied this from the kick-off meeting

Completed Research: Offline Model Case Study - VSL Effect on Throughput (1)

- VSL resulted in a small increase in throughput for the peak-period model (Abdel-Aty et al., 2008; Papageorgiou et al., 2008).

Peak Period Model

Variable Speed Limit (mph)	Throughput (% change)	
	Westover Rd	W 40th St
Base Case (65 mph)	-	-
60 mph	1.3	0.9
55 mph	1.4	1.0
50 mph	1.6	1.2
45 mph	1.0	0.6

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Offline Model Case Study - VSL Effect on Throughput (2)

- VSL had negligible effect on throughput for the uncongested model.

Uncongested Model

Variable Speed Limit (mph)	Throughput (% change)	
	Westover Rd	W 40th St
Base Case (65 mph)	-	-
60 mph	0.0	0.0
55 mph	0.0	-0.1
50 mph	0.0	-0.1
45 mph	-0.1	-0.1

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Offline Model Case Study - VSL Effect on Delay (1)

- VSL consistently decreased delay for both the peak-hour and uncongested models.

Peak-period Model

Variable Speed Limit (mph)	Total Delay per Vehicle (% change)	Stopped Delay per Vehicle (% change)
Base Case (65 mph)	-	-
60 mph	-3.8	-2.3
55 mph	-3.6	-1.4
50 mph	-7.0	-3.3
45 mph	-7.1	-1.9

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Offline Model Case Study - VSL Effect on Delay (2)

- VSL consistently decreased delay for both the peak-hour and uncongested models.

Uncongested Model

Variable Speed Limit (mph)	Total Delay per Vehicle (% change)	Stopped Delay per Vehicle (% change)
Base Case (65 mph)	-	-
60 mph	-8.9	-18.5
55 mph	-12.0	-16.7
50 mph	-17.8	-24.6
45 mph	-18.0	-22.2

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Offline Model Case Study - VSL Effect on Delay (3)

- VSL decreased delay more if it was implemented early.

VSL Effect by the Time of Implementation

Variable Speed Limit Hours	Total Delay per Vehicle (% change)	
	Peak-period Model	*Uncongested* Model
No VSL	-	-
4:00-4:30 PM	-5.7	-16.9
4:30-5:00 PM	-6.8	-20.5
5:00-5:30 PM	-5.4	-8.9
5:30-6:00 PM	-3.6	-10.4

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Offline Model Case Study - VSL Effect on Traffic Homogenization

- VSL homogenized the traffic by reducing the number of lane changes and stops.
- Smoother traffic has fewer number of lane changes (compared to the total number of lane changes in the peak-period and uncongested models on next slide).
- It reduced stop-and-go traffic condition by moving the traffic more steadily.

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Offline Model Case Study - VSL Effect on Lane Change

- VSL reduced the number of lane changes in traffic.

VSL Effect on Lane Change

Variable Speed Limit (mph)	Peak-period Model		Uncongested Model	
	Number of Lane Changes	% Change	Number of Lane Changes	% Change
Base Case (65 mph)	68444	-	31388	-
60 mph	68312	-0.19	31411	0.07
55 mph	67297	-1.68	31045	-1.09
50 mph	67288	-1.69	30689	-2.23
45 mph	66245	-3.21	30474	-2.91

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Offline Model Case Study - VSL Effect on Stops

- VSL reduced the number of stops in traffic.

VSL Effect on Stops

Variable Speed Limit (mph)	Number of Stops per Vehicle (% change)	
	Peak-period Model	Uncongested Model
Base Case (65 mph)	-	-
60 mph	-4.3	-8.3
55 mph	-2.7	-8.9
50 mph	-4.2	-14.0
45 mph	-3.8	-11.0

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Offline Model Case Study - VSL Effect on Speed (1)

- VSL may have adverse effect on speed variability if applied late.

Peak-period Model

Variable Speed Limit (mph)	Speed Variability (% change)	
	Westover Rd	W 40th St
Base Case (65 mph)	-	-
60 mph	1.6	4.4
55 mph	2.5	3.2
50 mph	0.3	1.2
45 mph	1.2	-1.8

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Offline Model Case Study - VSL Effect on Speed (2)

- VSL reduced speed variability if applied before the onset of congestion.

Uncongested Model

Variable Speed Limit (mph)	Speed Variability (% change)	
	Westover Rd	W 40th St
Base Case (65 mph)	-	-
60 mph	-3.1	-4.0
55 mph	-5.3	-6.5
50 mph	-6.0	-8.5
45 mph	-5.0	-10.0

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Offline Model VSL Benefits – Summary (1)

- VSL does not have significant effect on capacity enhancement.
- VSL improves operating conditions by reducing total and stopped delays, lane changing, and number of stops.
- Smoother flow of traffic results in less emission, less fuel consumption, and less wear and tear for vehicles.

Completed Research: Off line Model VSL Benefits – Summary (2)

- If applied before onset of congestion, it reduces the speed variability.
- Reductions in speed variability, lane changing, and stop-and-go condition lead to safer driving conditions.

Completed Research: Online Model Speed Harmonization

- Online algorithms are expected to perform better than offline strategies. However, they require a dense deployment of ITS.

- In the literature, both simple (Washington State, Finland, UK,…) and advanced (Lee et al, 2004; Hegyi et al, 2005; Abdel-Aty et al, 2006) algorithms have been proposed.

Completed Research: Online Model Speed Harmonization

- After a carefully examining existing control strategies, we found that all instances report benefits (congestion, safety, etc).
- Moreover, the reported results do not indicate there is a single algorithm that is superior to the rest.
- This observation motivated us to consider simple online strategies since:
  - It has the potential to be as effective as involved algorithms;
  - Simple algorithms are easier to implement; and
  - Simpler algorithms are more transparent to the network operator at the TMC.

Here we try to argue that simple is as good as fancy algorithms. In this way, the algorithm will be much easier to implement in VISSIM.

Completed Research:
Online Model Speed Harmonization

- **Online algorithm Speed Harmonization**

Input

- speed flow curves for each of the n road segments.
- maximum road capacities $c_0(k)$, k = 1, 2, .., n
- Current speed limits $s_0(k)$, k = 1, 2, .., n
- The minimum intervention duration T_{min} , *i.e.* the minimum time interval in which the speed limit remains constant.

Output

A set of dynamically changing speed limits for each of the road segments.

INITIALIZATION $c(k)=c_0(k), s(k)=s_0(k)$

Completed Research:
Online Model Speed Harmonization

FOR $k = n, n\text{-}1,.., 2$

    IF q(k) ~= $c_0(k)$

        FOR all road segments $r = k\text{-}1, k\text{-}2,\ldots, 1$

            DO select a speed $u(r)$ for segment r such that

                q(r)< c(r+1) and u(r)<=s(r)

                set c(r) =q(r), s(r) = u (r)

            END DO

        END FOR

    END IF

    set c(k)=$c_0(k)$

END FOR

Display new speed limit vector $s(k)$

Wait for T_{min} time units, set and repeat the algorithm.

~= means “about equal”

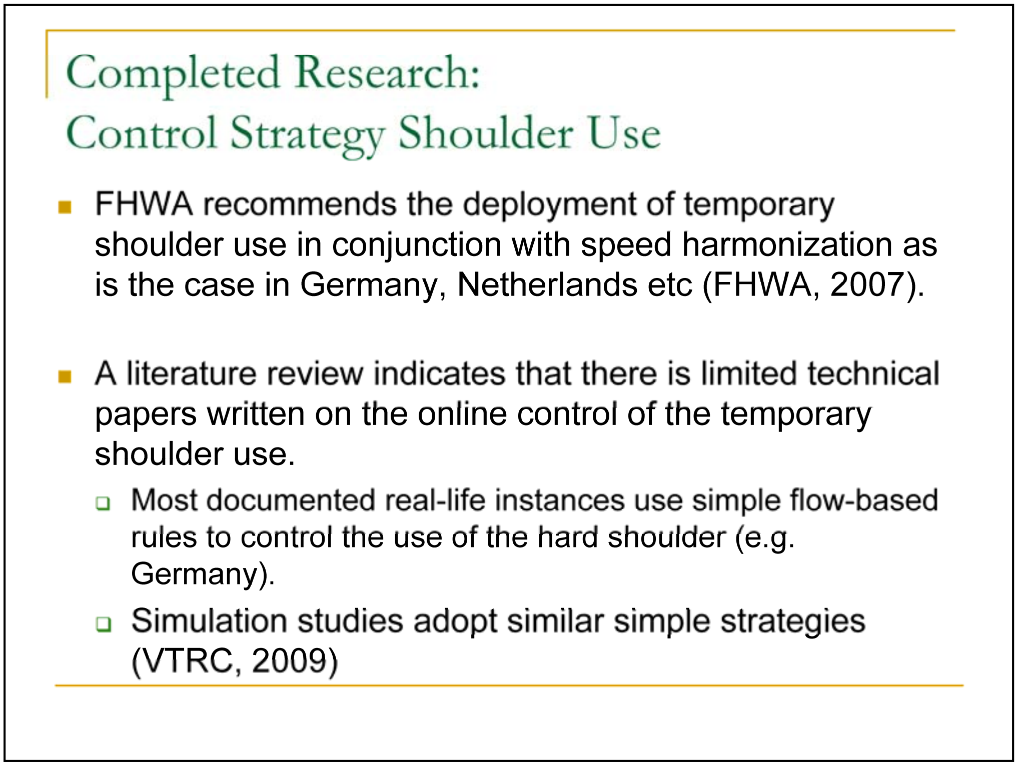
Remarks:

• Although it is possible to use reported values for T_{min} in the literature (e.g. Lee et al, 2004 suggest a value between 5 to 10 min; Abdel-Aty et al (2006) recommends a value of 10 min), we adopt micro-simulation to experimentally determine the optimal intervention duration as it is our believe that T_{min} is dependent on the specific configuration of the freeway (e.g. spacings between gantries).

• Note that when for a given iteration of the algorithm no segment satisfies the condition q(k) ~= $c_0(k)$, then the speed limit will be returned to its original value.

• As in the offline algorithm, the speed selection can be accomplished in various ways, both subjectively (e.g. based on engineering judgement) as well as objectively using the fundamental diagrams. We prefer the latter method. We use microsimulation to select “optimal” speed limits.

• Note that in a given iteration, $s(k)$ is a non-increasing sequence. That is, once the speed limit of a given section has been lowered, the algorithm ensures that (in the same iteration) subsequent speed limit modifications are such that the speed limit can only be further reduced on the section in question. This prevents that the lowering of speed limits in support of downstream bottleneck *i* are cancelled when we consider bottleneck *i-m*, where $0 < m < i$.



This is based on FHWA's European tour on ATM strategies.

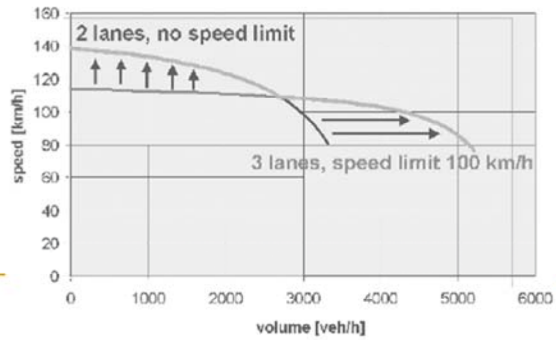
Completed Research: Control Strategy Shoulder Use

- Motivated by the above, we have investigated simple, flow-based rules to control the shoulder use during peak-periods.
- The generic pseudo-code (assume speed harmonization is active):
  - Step 1 Check if shoulder lane is free of objects (e.g. cars with mechanical problems, debris etc). If the shoulder lane is free, goto Step 2, otherwise, repeat step 1 after some time.
  - Step 2 Open shoulder lane for traffic.
  - Step 3 If the average flows on the lanes are less than a pre-specified value, then close the shoulder lane.

Specific values

Completed Research: Control Strategy Shoulder Use

- Some remarks:
  - Specific values in the above generic pseudo-code have to be determined.
  - We use micro-simulation to determine optimal values for these parameters
  - It is easy to see capacity will increase. Pictorially:



Source picture: FHWA (2007) European scan tour report.

Completed Research: Control Strategy Shoulder Use

- Peak-period shoulder use was implemented on Mopac NB between Enfield Rd and W 35th St.
- Left shoulder (8 ft.) was opened to traffic during peak-period 4 PM – 6 PM.
- Heavy vehicles were barred from using the shoulder.

Completed Research: Shoulder Use Effect on Throughput

- Peak-period shoulder use resulted in increased throughput in the corridor.

Peak-period Shoulder Use	Throughput (% change)	
	Westover Rd	W 40th St
No Shoulder Use	-	-
Shoulder Use	2.2	3.5

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Shoulder Use Effect on Speed

- Shoulder use improved traffic speed considerably where it was implemented.
- However, speed reduced at the end of shoulder use section due to bottleneck creation.

Peak-period Shoulder Use	Speed (mph)	
	Westover Rd	W 40th St
No Shoulder Use	25	34
Shoulder Use	51	25

- Note: Shoulder was opened to traffic between Enfield Rd and 35th St.

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Shoulder Use Effect on Delay

- Peak-period shoulder use reduced total delay and stopped delay by half.

Peak-period Shoulder Use	Total Delay per Vehicle (% change)	Stopped Delay per Vehicle (% change)
No Shoulder Use	-	-
Shoulder Use	-45.3	-50.9

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Shoulder Use Effect on Stops, Lane Change

- Peak-period shoulder use reduced number of stops per vehicle by half.
- It did not have effect on lane changing. Reduction in lane changes due to traffic homogenization was countered by lane changes to and from shoulder.

Peak-period Shoulder Use	Number of Stops per Vehicle (% change)	Number of Lane Changes (% change)
No Shoulder Use	-	-
Shoulder Use	-50.0	0.2

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Completed Research: Shoulder Use Benefits – Summary

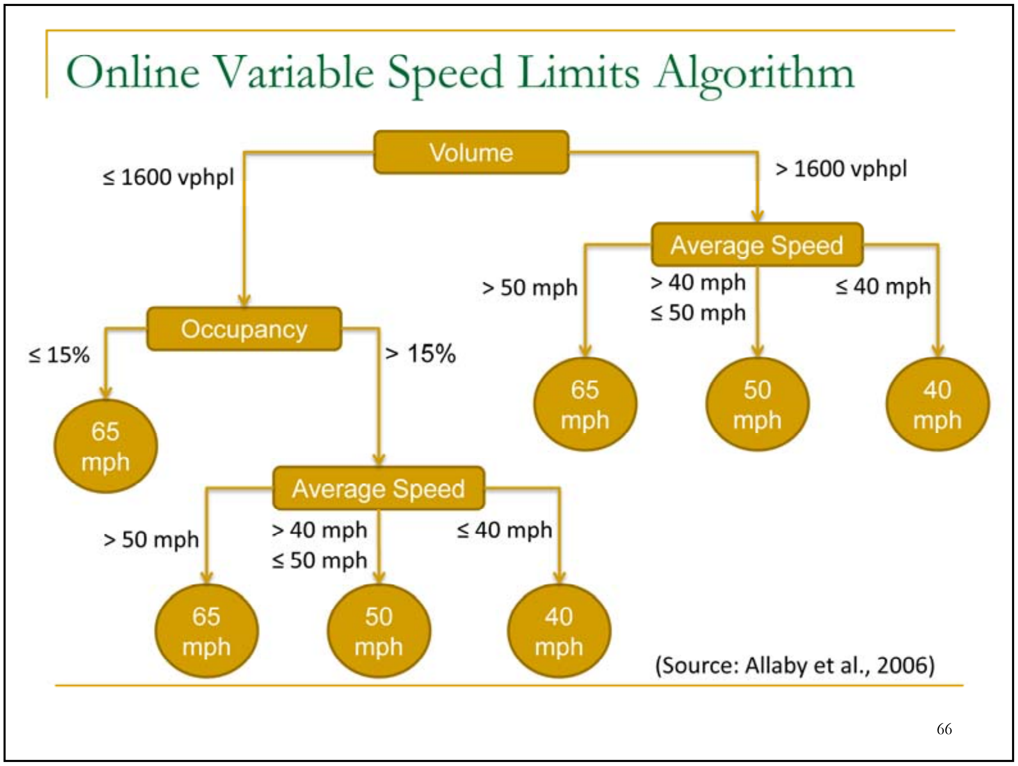
- Peak-period shoulder use increased throughput and speed in the implementation corridor.
- Increased throughput in the corridor created bottleneck at downstream. This resulted in speed reduction there.
- Shoulder use homogenized traffic flow considerably: number of stops and stopped delay reduced by half; total delay also reduced by half.

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Online Models

- Online variable speed limits were implemented using the algorithm show on next slide.
- Traffic conditions were checked every 5 minutes and speed limit was determined using the algorithm.
- Since level of service (LOS) of traffic is “F” during the study period (4:00-6:00pm), shoulder was opened to traffic for the entire duration of study.

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT



Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Online Models

- Three combinations of traffic management strategies were implemented, and their benefits were compared with the base case:
  - Online Variable Speed Limit (VSL)
  - Shoulder Use
  - VSL and Shoulder Use (simultaneously)
- Ten simulation runs were conducted to test the difference between cases using two-sample T-test. Cells highlighted in the last column indicate that the difference is not significant at 90% confidence level.

Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Variable Speed Limits: Operational Effects

	Base	VSL	(VSL-Base)%	T-Test p-value
Throughput -mid (veh)	8458	8190	-3%	8.3E-05
Throughput -end (veh)	10406	10104	-3%	1.4E-04
Speed -mid (mph)	25	20	-18%	7.6E-06
Speed -end (mph)	33	27	-18%	2.1E-06
# Stop/Vehicle	17	17	-1%	7.2E-01
Delay-network(sec/veh)	72	77	7%	6.1E-02
Delay-corridor(sec/veh)	363	260	-28%	8.2E-07

- Online VSL did not have significant effect on throughput.
- Operating speed further decreased (speed limit = 65mph).
- Delay decreased for the VSL corridor; it increased at network level.

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Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Shoulder Use: Operational Effects

	Base	Shoulder Use	(Shoulder use-Base)%	T-Test p-value
Throughput -mid (veh)	8458	8661	2%	2.9E-05
Throughput -end (veh)	10406	10706	3%	1.4E-05
Speed -mid (mph)	25	49	98%	5.3E-09
Speed -end (mph)	33	26	-22%	5.6E-05
# Stop/Vehicle	17	15	-11%	6.1E-02
Delay-network(sec/veh)	72	56	-22%	8.6E-04
Delay-corridor(sec/veh)	363	193	-47%	5.4E-07

- Shoulder use did not have significant effect on throughput.
- Speed increased in the middle; bottleneck creation at the end.
- Delay time decreased everywhere.

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Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

VSL & Shoulder Use: Operational Effects

	Base	VSL & SU	(VSL & SU -Base)%	T-Test p-value
Throughput -mid (veh)	8458	8591	2%	6.2E-04
Throughput -end (veh)	10406	10556	1%	6.4E-03
Speed -mid (mph)	25	26	3%	1.1E-01
Speed -end (mph)	33	21	-36%	3.6E-07
# Stop/Vehicle	17	15	-13%	2.2E-02
Delay-network(sec/veh)	72	57	-21%	3.7E-04
Delay-corridor(sec/veh)	363	152	-58%	7.8E-09

- VSL & shoulder use did not have significant effect on throughput.
- Speed unchanged in the middle; bottleneck creation at the end.
- Delay decreased everywhere.

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Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

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  - Developing and Testing Control Strategies (Offline and Online Algorithms)
  - **Assessing Safety Implications**
  - Recommending Geometric Design Guidelines
  - Recommending ITS Infrastructure
  - Highlighting Enforcement Considerations
  - Developing a Cost Benefit Analysis Framework
  - Producing an Operational and Deployment Plan

Completed Research: Safety Analysis

- To perform safety analysis, ideally a statistical model of crash prediction/accident potential is developed using multiyear crash database.
- Such a crash databases was not available for the section of Mopac studied in this project.
- However, researchers have identified several key crash precursors for freeways. Speed variability is the most important among them.

Completed Research: Safety Analysis

- Three crash precursors were found suitable for the purpose of this study and were adapted from Lee et al. (2002).
  - Coefficient of variation (c.o.v) of speed (within lane)
  - Coefficient of variation (c.o.v) of speed (across lanes)
  - Traffic density

- A higher value of any of these variables indicates higher crash potential for the prevailing traffic condition.

Completed Research: Safety Analysis

- These precursors are calculated during the 5-minute period before reported accident times and compared with the non-accident case.
- Since, a crash database was not available, safety was evaluated at a fixed time during the evening peak-period(4:40pm) in the middle of the test section.
- Crash precursors for the VSL, Shoulder Use, and VSL & Shoulder Use cases were compared with the base case.

Variable Speed Limits (VSL): Safety Effects

	Base	VSL	(VSL-Base)%	T-Test p-value
Speed c.o.v (within lane)	0.54	0.49	-10%	4.0E-02
Speed c.o.v (across lanes)	0.52	0.44	-17%	4.4E-02
Density (veh/mi)	91	87	-4%	6.4E-01

- Results are based on ten simulation runs for each case. A cell highlighted in the last column indicates that the result is not significant at 90% confidence level.
- Variable speed limits (VSL) reduced both types of speed variability and it lead to safer driving condition. Reduction in traffic density was insignificant.

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Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

Shoulder Use (SU): Safety Effects

	Base	SU	(SU -Base)%	T-Test p-value
Speed c.o.v (within lane)	0.54	0.14	-74%	1.5E-07
Speed c.o.v (across lanes)	0.52	0.27	-48%	2.9E-03
Density (veh/mi)	91	27	-70%	1.4E-05

- Shoulder use reduced both the speed variability and traffic density significantly and lead to much safer driving condition in the middle of test section.
- However other factors should be considered to evaluate overall safety: merging behavior at the end of shoulder use section, suitability of shoulder as a running lane for traffic.

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Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

VSL & Shoulder Use: Safety Effects

	Base	VSL & SU	(VSL & SU -Base)%	T-Test p-value
Speed c.o.v (within lane)	0.54	0.05	-91%	2.7E-07
Speed c.o.v (across lanes)	0.52	0.83	58%	2.5E-02
Density (veh/mi)	91	59	-35%	3.5E-03

- Simultaneous use of VSL & SU had mixed effect on safety.
- Speed variability decreased within lane, but it increased across lanes. VSL & SU also decreased traffic density.

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Some examples shoulder use. Again, the table has been copied from kick-off meeting PPT

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Completed Research: Geometric Design Guidelines

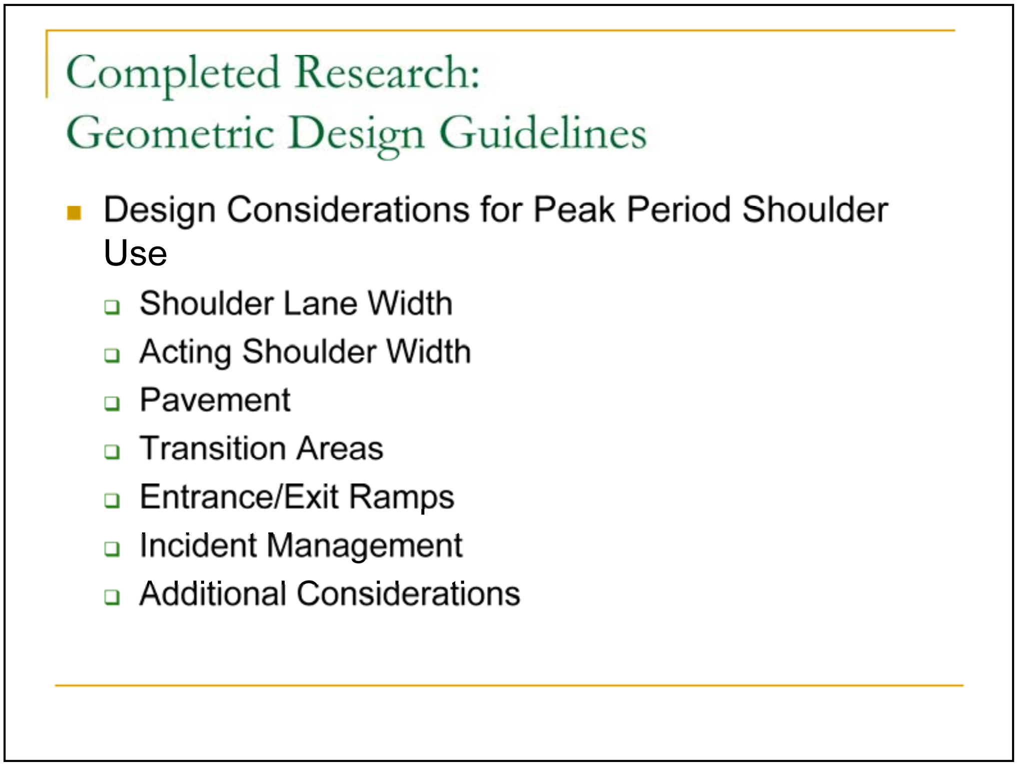
- Provided design guidelines for shoulder travel lanes.
- Resources for Developing the Guidelines
  - TxDOT Roadway Design Manual
  - AASHTO Policy on Geometric Design
  - Manual on Uniform Traffic Control Devices
- Key Assumptions
  - Shoulder use under congested periods implemented with speed harmonization.
  - Operating speeds 35 mph or less
  - Each candidate corridor considered individually

The resources listed are self explanatory.

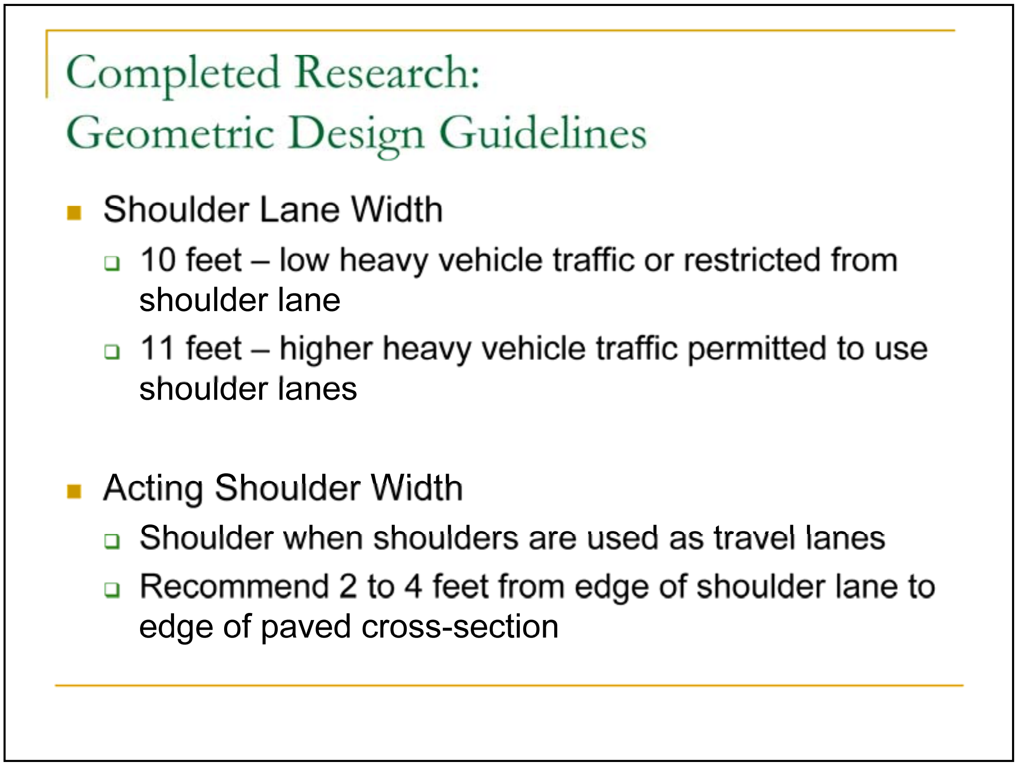
Key Assumptions –

•The peak period shoulder under congested conditions and operating speeds are critical to allowing for a less than 12-foot wide lane width for the shoulder lane. Higher operating speeds would likely require a wider shoulder lane.

•Each candidate corridor needs to be considered individually – every corridor will have existing design nuances and unique characteristics that will require specific design plans. **Design plans specific to each corridor** should be developed to ensure the freeway geometry when the shoulders are used as travel lanes remains **consistent with driver expectations** and fits into the **self-explaining roadway design**.



Each of these were covered in the tech memo. The following set of slides highlights the important features regarding each topic.



Shoulder Lane Width:

Based on TxDOT Roadway Design Manual for urban and suburban arterials (Chapter 3, Sections 2 and 3) and the assumed operating conditions (i.e. speeds 35 mph or less), a minimum lane width of 10 feet could be considered permissible for the shoulder lanes, if heavy vehicle volumes are low or heavy vehicles are restricted from using the shoulder lanes. To allow heavy vehicles to use the shoulder lanes, a width of at least 11 feet is desirable. A width of 11 feet for the shoulder lanes would provide approximately a 15-inch lateral distance on both sides of a typical heavy vehicle (width of 8.5 feet) between the vehicle and the edge of the shoulder travel lane.

Acting Shoulder:

The 2- to 4-foot acting shoulder will provide lateral support to the shoulder lane as well as a shy distance or lateral buffer zone for vehicles to avoid medians, drainage facilities, and other roadside features beyond the paved cross-section.

Completed Research:
Geometric Design Guidelines

- Pavement
  - Upgrade structural integrity, as necessary
  - Shoulder pavement should be full depth
  - Cross slope 1.5% to 2%
- Transition Areas
  - Areas in which shoulders are added or dropped as travel lanes
  - Adding shoulder lane: Taper rate of 10 to 1
  - Dropping shoulder lane: Taper rate of 50 to 1

Pavement:

•We recommend upgrading the structural composition of the pavement for the shoulder lanes to be consistent with the mainline lanes particularly if the shoulder lanes will be used during peak hours each weekday (i.e. shoulder pavement should be full depth).

•In highly congested areas, this could be as frequent as 4 to 6 hours per day, five days per week.

•At most this would account for 65 days in one year or 1/5th of the calendar year; therefore, upgrading the structural integrity of the shoulder lanes could be accomplished through an existing freeway maintenance schedule.

•The slope of shoulders should be 2% or less for driver comfort.

Transition Areas:

•Transition areas are the areas in which the shoulders are added (i.e. opened to vehicles for use) as travel lanes and dropped as travel lanes.

•Adding at 10 to 1 rate – Effectively open the shoulder for use over a distance of 100 feet.

•Dropping at 50 to 1 rate –

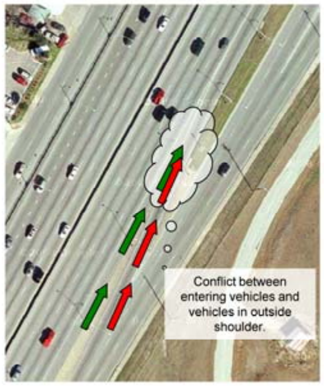
  •Consistent with the taper rates cited in the TxDOT Roadway Design Manual, Chapter 3, Section 6 for merging traffic from entrance ramps with the freeway mainlines.

  •Sufficient time for drivers to merge back into mainline traffic as congested periods dissipate and operating speeds exceed 35 mph.

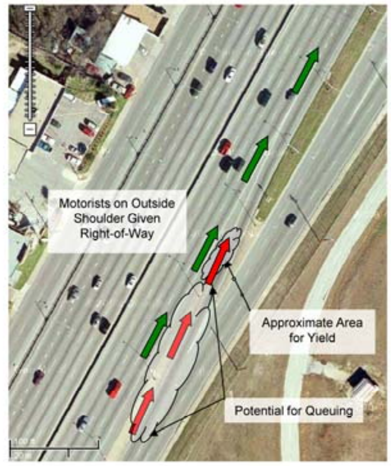
  •Provides a reasonable transition when shoulder lanes must be dropped due to

Completed Research: Geometric Design Guidelines

- Entrance/Exit Ramps



Potential Conflict



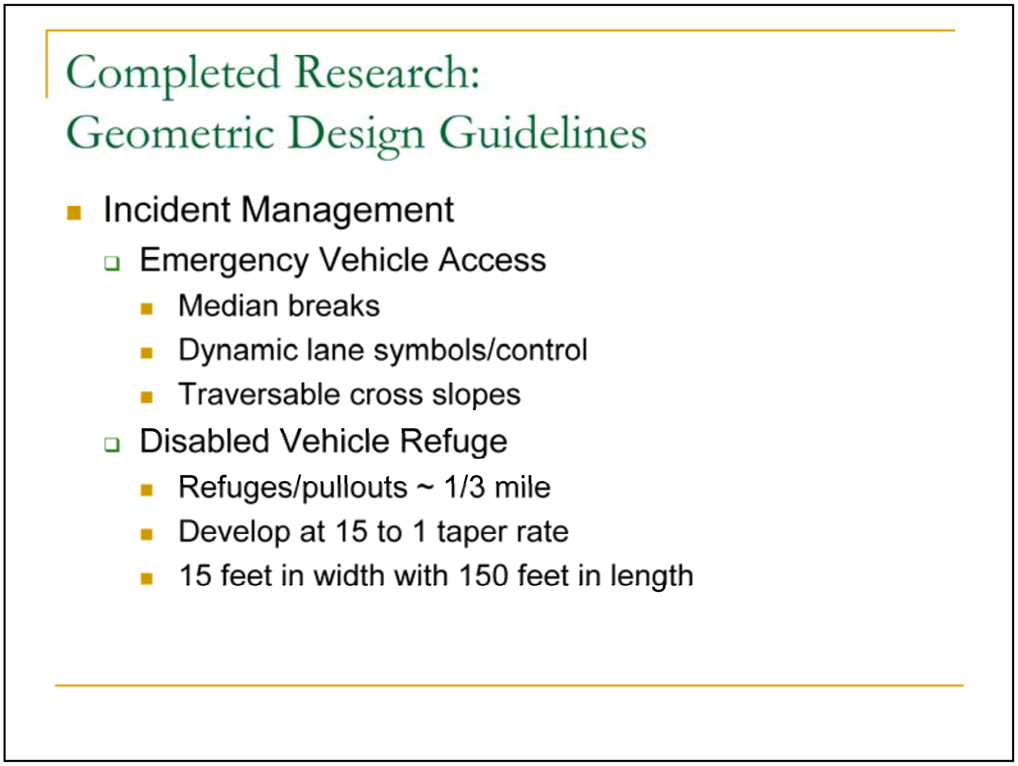
Mitigation

Potential Conflict Occurs between vehicles in the shoulder lane and vehicles entering. Only a concern when outside shoulder is used as travel lane and/or if the inside shoulder is used and there are left-hand side on and off ramps.

Mitigation – Vehicles in the shoulder lane have the right of way. Entering vehicles yield

Considerations for implementing mitigation

- Communicating and enforcing expected operations to motorists
  - Signing – changeable message signs on the freeway mainline and on-ramp
  - Ramp meters on the freeway on-ramps
  - Enforcement and education
- Sight Distance and Acceleration
  - Location of yield based on anticipated operating speeds
  - Adequate sight distance to identify gaps



Emergency Vehicle Access:

•Reviewed on case-by-case basis – these are ideas/potential solutions.

•In the presence of monitoring equipment, **dynamic lane assignment symbols** and changeable message symbols a lane or set of lanes can be closed to vehicles at the time of an incident clearing a travel way for emergency vehicles.

•Freeways with **breaks in the center median** would allow emergency vehicles to access an incident by traveling on the freeway section designated for the opposite direction crossing over to access the incident.

•In the absence of the above unique characteristics, emergency vehicle access can be provided by **ensuring slopes adjacent to the freeway** (i.e. just beyond the edge of travel way) are rounded and **change at a rate of 1 vertical foot to every 6 horizontal foot (1V:6H) or flatter**. This slope is negotiable by vehicles and could be used by emergency vehicles as a travel way.

Disable Vehicle Refuge:

Vehicle refuges provide a location for disabled vehicles to exit the travel way, call for service via a call box, and wait for service or help to arrive. Previous instances where shoulders are used as travel lanes during peak periods, were accompanied by refuge areas approximately every 1/3 of a mile. A refuge area of 15 feet in width

Completed Research: Geometric Design Guidelines

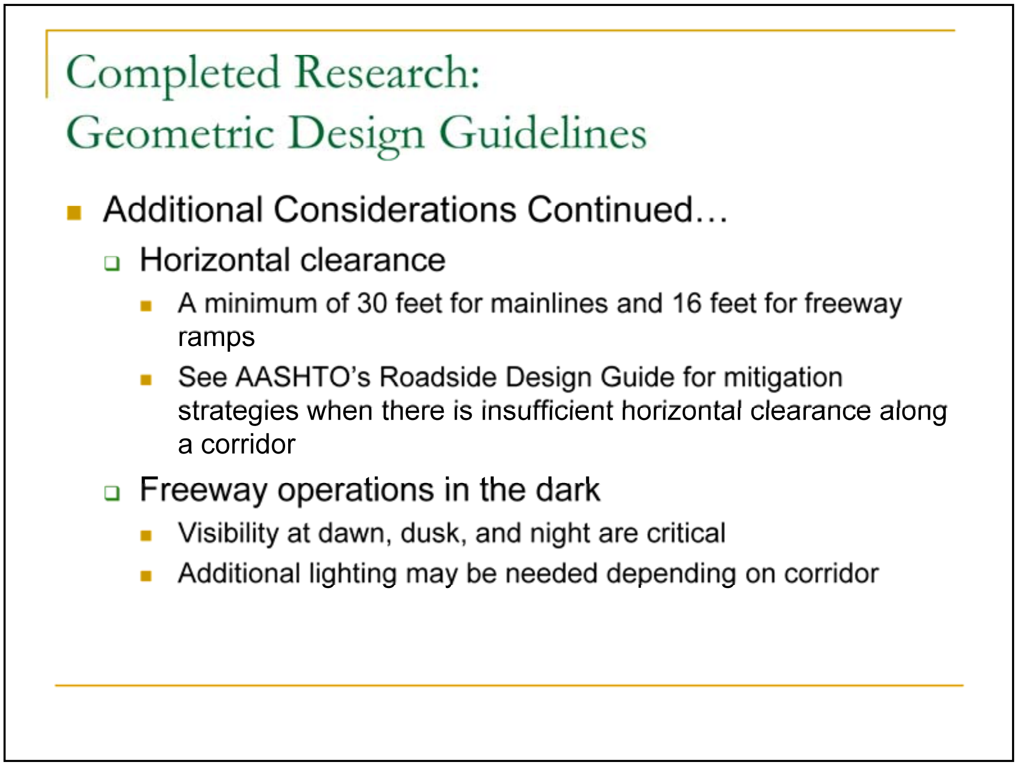
- Additional Considerations
  - Horizontal curves
    - Review and modify superelevation on the shoulder
    - Ensure shoulder remains sufficiently wide through curve
  - Vertical clearance
    - TxDOT Roadway Design Manual specifies a minimum clearance of 16.5 feet
    - Review and modify as necessary per site

Horizontal Curves

Candidate freeway corridors with frequent or long horizontal curves may require additional reconstruction compared to tangent stretches of freeway to accommodate use of shoulder lanes as travel lanes. Depending on the design speed of the facility and the radius of the horizontal curve the **superelevation** of the inside or outside shoulder may be too steep to safely serve as a travel lane or may not **be sufficiently wide** to serve as a travel lane. Horizontal curves will need to be reviewed on a case-by-case basis to ensure the superelevation and cross slopes for the shoulders (in addition to the other characteristics discussed above) are suitable for carrying traffic.

Vertical Clearance

Each bridge, gantry, or other structure passing overtop of a freeway will need to be reviewed to ensure sufficient vertical clearance exists over the shoulder lanes if they are to be used as travel lanes. TxDOT Roadway Design Manual specifies a **minimum vertical clearance of 16.5 feet** over the useable roadway. To use the shoulders as travel lanes, this clearance will need to be confirmed for each piece of overhead infrastructure.



Horizontal Clearance

Horizontal clearance is the distance from the edge of travel way to the nearest fixed object. When the shoulders are used as travel lanes, the horizontal clearance from the edge of the shoulder lane to the nearest fixed object should be reviewed to ensure the distance meets standards. If the distance does not meet standards, the fixed object may be moved or mitigations (e.g. crash cushions) may be identified and implemented to lessen the severity of a vehicle hitting the fixed object. TxDOT Roadway Design Manual cites a **minimum horizontal clearance of 30 feet** for **freeway mainlines** and **16 feet for freeway ramps** in the absence of a barrier or other treatment of safety appurtenances (Chapter 2, Section 6). **AASHTO's Roadside Design Guide** presents potential roadside barriers and other safety appurtenances treatments to **mitigate instances of insufficient horizontal clearance**.

Freeway Operations in the Dark

During winter months, the traditional commuting peak hours do not occur in full daylight; therefore it is conceivable that the use of shoulder lanes will occur at times when drivers' visibility is relatively limited. The traffic control devices used to communicate the modified operations while peak shoulders are in use should **meet night-time visibility standards as outlined by the MUTCD**. Candidate sites should also be reviewed to ensure sufficient lighting is providing along the freeway corridor; adjustments, maintenance or upgrades may be needed depending on the site.

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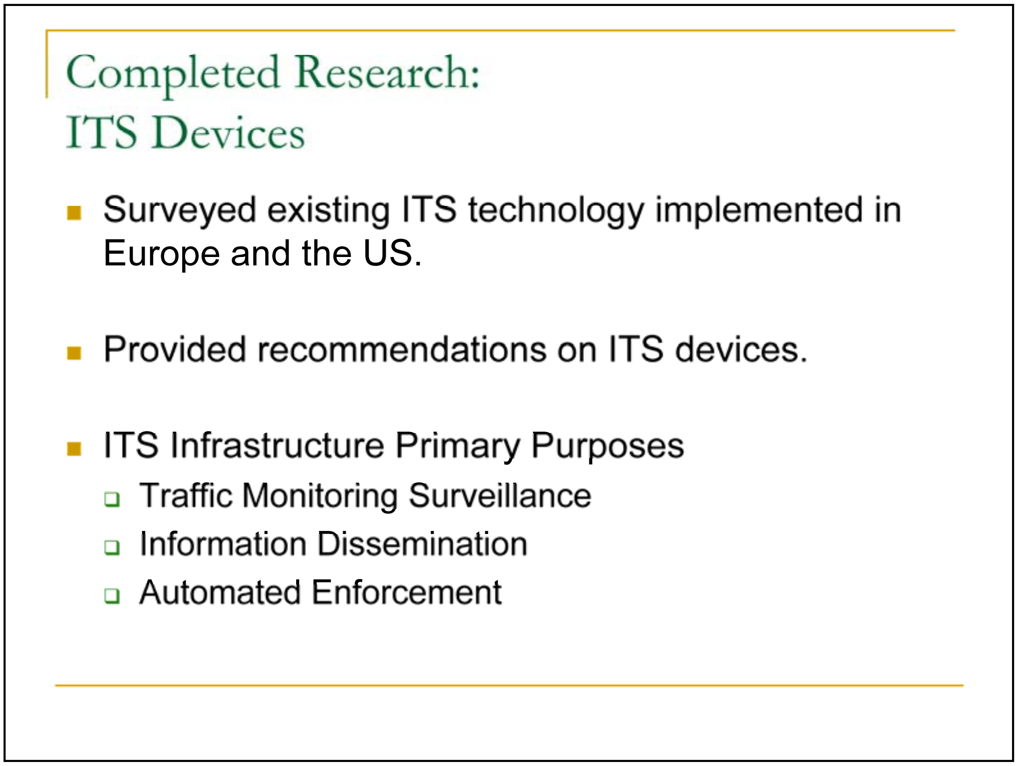

Reviewed ITS for speed control and temporary shoulder use in the following locations:

UK, M25

Netherlands, A2 Motorway

Washington State, I-90

Germany, Bavaria A7

New Mexico, I-40

The following slides discuss the considerations identified above in more detail. Follows tech memo content.

Completed Research:
ITS Devices

- Traffic Monitoring Surveillance
  - Speed Harmonization Traffic Detection

Location	Detector
United Kingdom	Automatic Number Plate Recognition (ANPR) cameras
Netherlands	Loop detectors spaced at 0.5 km
Germany	Inductive loops or radar sensors.
Washington	Wide aperture radar tracks speeds for feedback to the control system.
New Mexico	Three roadside stations, each consisting of a pair of loop detectors in each lane

Completed Research: ITS Devices

- Traffic Monitoring Surveillance
  - Tracking Shoulder Conditions
    - Close circuit cameras
    - Loop detectors

Location: United Kingdom, M25

Related Recommendations:

Based on the previous review, the monitoring surveillance system is recommended for the Speed Harmonization and Peak-Period Shoulder Use to Manage Urban Freeway Congestion. For monitoring purposes, camera detectors are placed at an average of 1 mile, at most, for incident detection purpose. Loop detectors were used along with closed circuit camera detection in case of bad weather like fog, heavy rain, etc. The integration information of camera and loop detectors software is also recommended for the whole system for better performance.

Completed Research: ITS Devices

- Information Dissemination
  - Dynamic Message Signs

Location: United Kingdom, M25

Location: Washington State, I-90

Recommendations:

Since the project of ‘Speed Harmonization and Peak-Period Shoulder Use’ has potential for improvement. The combination of VMS and PCMS system is recommended for the information dissemination. The sign is recommended to be displayed on overhead gantries, located each mile.

Completed Research: ITS Devices

- Information Dissemination

Location	Analyze Information	Output Information
United Kingdom	Journey Time Management System (JTMS) built with Talon Journey Time Analysis (JTA) and Average Speed (AS) software	Roadside portable Variable Message Signs (VMS)
Netherlands	The posted speed is determined by a system control algorithm based on one-minute averages of speed and volume across all lanes.	VSL signs spaced approximately every one km
Germany	The control and the switching of all traffic relevant systems normally take place out of the sub centre LCS A7. If there is an emergency, the switching instructions will be generated by the OCT and will be transmitted via the sub centre to the control units of the LCS for execution.	The system includes altogether 14 display gantries, four variable direction signs and 26 measurement sites outside the tunnels.
Washington	All of collected information goes to a central computer, which processes the data and determines the "safe speed" for the roadway. Currently, a computer recommends the speed limit and an operator confirmation implements it.	VSL (Variable Speed Limit) signs including hazard warning
New Mexico	After obtaining inputs (which have a broad range of criteria), the system used a look-up table to generate the posted speed limit.	VSL (Variable Speed Limit) signs and hazard warning sign

Recommendations:

Since the project of 'Speed Harmonization and Peak-Period Shoulder Use' has potential for improvement. The combination of VMS and PCMS system is recommended for the information dissemination. The sign is recommended to be displayed on overhead gantries, located each mile.

Completed Research: ITS Devices

- Automated Enforcement
  - Photo radar systems commonly used in Europe
  - Recommend placing enforcement devices on overhead gantries

Completed Research: ITS Devices

- Enforcement Techniques (continued)

Location	Tolerance/Enforcement
The Netherlands	Fine for driving 4 km/h over the speed limit, after applying a 3 or 4 km/h correction factor to compensate for measuring errors. Discretion by police officers not allowed during automated enforcement.
United Kingdom	Tolerance level of the speed limit "+10% +2 mph" (e.g. a tolerance level in a 30 mph (50 km/h) zone of 35 mph). Police force or safety camera partnership has ability to use discretion to set levels at which drivers will be prosecuted.

Additional enforcement considerations discussed in Task 10 Technical Memorandum.

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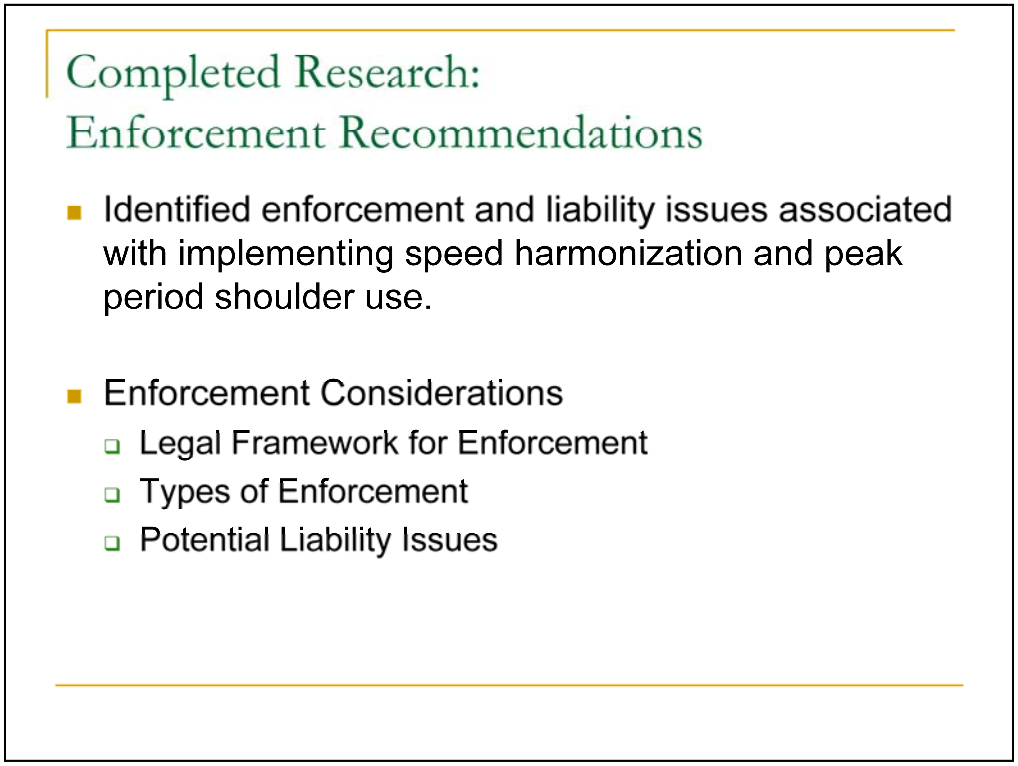

Follows draft tech memo for the most part.

Completed Research: Enforcement Recommendations

- Important Elements in Legal Framework for Enforcing Variable Speed Limits
  - Allow agency to change the speed limit to protect public safety.
  - Change in speed limit should be based on traffic engineering investigation.
  - Require advance warning of change in speed limit and clear posting of speed limit.
  - Prohibit automatic enforcement within a certain distance of the changed speed limit.

Above are key points from Hines et al., 2002 outlining key legal framework to be able to be able to set and enforce variable speed limits.

Additional points are contained in the tech memo.

The spirit of the guidelines are to make the VSL open, honest and transparent to the public – therefore, in the event of a lawsuit/challenge in court, the agency comes across as having fully disclosed the limit and reasonably enforced it.

Completed Research: Enforcement Recommendations

- Types of Enforcement
  - Manual Enforcement
    - Expensive in man power and time
    - Difficult to implement in poor weather and/or high congestion
  - Automated Enforcement
    - Increasing in popularity particularly for red-light running
    - Automated speed enforcement is more common in European countries

Manual Enforcement:

•Stationary marked or unmarked vehicles by side of the road with radar or vascar technology or a stationary officer with detectors located across the road enabling the officer to be farther from the road.

•Other variations are a stationary police car plus a chase car (one officer operates the radar and the other chases down the violator), moving police vehicle using moving radar, and air patrol with an air observer and police chase cars on the ground. These strategies can be challenging to operate in periods approaching high congestion and/or adverse weather conditions.

•Both of these situations make it difficult for officers to chase down the vehicles and find a location to the pull them over safely.

•In periods approaching high congestion, a traffic stop can create the traffic flow disturbance and shockwaves the variable speed limit program is trying to eliminate thereby being counter productive.

Automated Enforcement:

More effective but key issues that need to be addressed in legal framework.

Key issues are:

Criminal vs. civil offense – speeding needs to be setup as a civil offense to make things easier

Completed Research: Enforcement Recommendations

- Potential Liability Issues
  - Primarily concerned with respect to VSL rather than temporary shoulder use.
  - Potential for VSL to transfer the responsibility for choosing a safe speed from driver to engineers.
  - VSL is not widely used enough in the US to indicate whether this concern is valid.
  - Review of current literature did not bring to attention any specific cases related to liability.

Overview of Completed Research

- TxDOT Research Project 0-5913
- Work plan included
  - Synthesis of Past Experiences
  - Selecting and Analyzing Candidate Corridors
  - Conducting Simulation Analyses
  - Developing and Testing Control Strategies (Offline and Online Algorithms)
  - Assessing Safety Implications
  - Recommending Geometric Design Guidelines
  - Recommending ITS Infrastructure
  - Highlighting Enforcement Considerations
  - **Developing a Cost Benefit Analysis Framework**
  - Producing an Operational and Deployment Plan

Completed Research: Cost Benefit Analysis

- Developed a framework to identify and quantify the costs and benefits of speed harmonization and peak period shoulder use.
- Considerations for Cost Benefit Analysis
  - Benefits
  - Costs
  - Uniform Evaluation Process
- A key resource for Handbook content.

Completed Research: Cost Benefit Analysis

- Benefits
  - Identify performance measures
    - Travel Time
    - Travel Time Reliability
    - Safety
  - Convert to monetary values
    - Unit costs of travel time
    - Unit costs of travel time reliability
    - Unit costs of crashes by severity and/or type

These are covered in more detail in the project handbook.

Completed Research: Cost Benefit Analysis

- Costs
  - Identify primary sources of costs
    - Right-of-Way Acquisition (peak period shoulder use)
    - Changes in Roadway Geometry
      - Vertical Alignment
      - Horizontal Alignment
    - ITS Infrastructure Investment
    - Reoccurring Operational Costs
      - Monitoring System
      - Enforcement
      - ITS Maintenance

These are covered in more detail in the project handbook.

Completed Research: Cost Benefit Analysis

- Uniform Evaluation Process
  - Provided Overarching Framework
  - Outlined Procedure and Considerations

Covered in more detail in the handbook and on the handbook slides.

Overview of Completed Research

- TxDOT Research Project 0-5913
- Work plan included
  - Synthesis of Past Experiences
  - Selecting and Analyzing Candidate Corridors
  - Conducting Simulation Analyses
  - Developing and Testing Control Strategies (Offline and Online Algorithms)
  - Assessing Safety Implications
  - Recommending Geometric Design Guidelines
  - Recommending ITS Infrastructure
  - Highlighting Enforcement Considerations
  - Developing a Cost Benefit Analysis Framework
  - **Producing an Operational and Deployment Plan**

Completed Research: Operational and Deployment Plan

- Produced guidelines to assess the feasibility of applying speed harmonization and peak period shoulder use.
- Considerations
  - Consistent Process
  - Effective Screening of Candidate Sites
- A key resource for Handbook content.

Completed Research: Operational and Deployment Plan

- Consistent Process
  - Provide guidelines on assessing key attributes at candidate sites
  - Key attributes for consideration
    - Existing freeway geometry and potential conflicts with shoulder use and/or speed harmonization
    - Existing ITS infrastructure compared to necessary ITS infrastructure
    - Enforcement resources and corresponding feasible enforcement plan
    - Opportunities and plan for public education

Completed Research: Operational and Deployment Plan

- Effective Screening of Candidate Sites
  - Develop strategies for assessing key attributes
  - Produce comprehensive framework for effective screening
  - Components of framework
    - Results from Cost/Benefit Analysis
    - Qualitative Benefits and/or Disbenefits to Surrounding Communities
    - Community Support for Project

Workshop Overview

- Introduction to Speed Harmonization and Peak Period Shoulder Use
- Completed Research
- **Introduction to Project Handbook**
- Introduction to Multi-Resolution Analysis
- Summary

Introduction to Project Handbook

- **Purpose and Overview of Handbook**
- Introduce Content of the Handbook
  - Identify Candidate Sites
  - Construct and Run Simulation Analysis
  - Identify Infrastructure Improvements
  - Develop Enforcement and Education Plan
  - Applying Benefit Cost Analysis
  - Consider Qualitative Impacts
- Approach for Using the Handbook

Purpose and Overview of Handbook

- Purpose
  Provide guidance in determining whether or not speed harmonization and peak period shoulder is feasible for a given corridor or set of corridors.

- Overview
  - Integrates the cost benefit analysis and operational and deployment strategy from the research project.
  - Uses the steps and analysis in the research project as a foundation for determining the degree to which speed harmonization and shoulder use are feasible.

Purpose and Overview of Handbook

- Guidance is organized into six components:
  - Identify candidate sites;
  - Construct and run microscopic and mesoscopic simulation;
  - Identify infrastructure improvements;
  - Develop an enforcement strategy and public education plan;
  - Apply cost benefit analysis framework; and
  - Consider potential qualitative impacts.

Introduction to Project Handbook

- Purpose and Overview of Handbook
- Introduce Content of the Handbook
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Handbook Content: Identify Candidate Sites

- Considerations for selecting candidate sites (or corridors):
  - Does the site illustrate potential to benefit from speed harmonization and temporary shoulder use?
  - Is there recurring traffic congestion? How severe?
  - Are there inclement weather patterns that warrant lower speeds or pose safety concerns on a recurring basis?
  - Is this corridor part of an evacuation route?
- Existing TxDOT and local agency data and monitoring systems can be used to answer these and similar questions.

Potential characteristics in identifying initial candidate sites.

Introduction to Project Handbook

- Purpose and Overview of Handbook
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Handbook Content: Construct and Run Simulation Analysis

- Recommended Simulation…
  - Microscopic: The preferred tool to study the effect of traffic management strategies on a specific roadway section in detail.
  - Mesoscopic: The simulation tool used to study the effect at the network level.

Handbook Content: Construct and Run Simulation Analysis

- Data Requirements for Simulation

Microscopic Model	Mesoscopic Model
Network topology for the candidate freeway: Geometry, number of lanes, on-ramps, off-ramps	Network topology for the study area: All major freeways and arterial network
Demand: volume counts on mainline and ramps; or origin-destination travel demand data	Demand: Origin-destination travel demand data
Speed limits on mainline and ramps	Capacity and free flow speed for all roadways

Handbook Content: Construct and Run Simulation Analysis

- As discussed above, there are two ways to implement speed harmonization and shoulder use….
  - Online in real-time (preferred, requires relatively dense ITS technology in the field)
  - Offline
- The following slides serve as a reminder of the recommended online and offline algorithms.

Handbook Content: Construct and Run Simulation Analysis

- Online algorithm Speed Harmonization

Input

- speed flow curves for each of the n road segments.
- maximum road capacities $c_0(k)$, k = 1, 2, .., n
- Current speed limits $s_0(k)$, k = 1, 2, .., n
- The minimum intervention duration T_{min} , *i.e.* the minimum time interval in which the speed limit remains constant.

Output

A set of dynamically changing speed limits for each of the road segments.

INITIALIZATION c(k)=$c_0(k)$,s(k)=$s_0(k)$

Handbook Content:
Construct and Run Simulation Analysis

- Online Speed Harmonization Algorithm

FOR *k* = *n*, *n*-1,.., 2
  IF q(k) ~= *c0*(*k*)
    FOR all road segments *r* = *k*-1, *k*-2,…, 1
      DO select a speed *u*(*r*) for segment *r* such that
        q(r)< c(r+1) and u(r)<=s(r)
        set c(r) =q(r), s(r) = u (r)
      END DO
    END FOR
  END IF
  set c(k)=*c0*(*k*)
END FOR
Display new speed limit vector *s*(*k*)
Wait for *Tmin* time units, set and repeat the algorithm.

Handbook Content: Construct and Run Simulation Analysis

- Online Shoulder Use Generic Pseudo-Code (assume speed harmonization is active):
  - Step 1 Check if shoulder lane is free of objects (e.g. cars with mechanical problems, debris etc). If the shoulder lane is free, goto Step 2, otherwise, repeat step 1 after some time.
  - Step 2 Open shoulder lane for traffic.
  - Step 3 If the average flows on the lanes are less than a pre-specified value, then close the shoulder lane.

Handbook Content:
Construct and Run Simulation Analysis

- Offline algorithm Speed Harmonization

Input speed-flow-curves for each of the *n* road segments

Output "Speed-harmonized road segments" at time *t*

Step 1 Pick the most downstream road segment *k* for which the flow is known to (almost) reach capacity.

Step 2 FOR all road segments *r* = *k*-1, *k*-2,…, 1

DO select a speed for segment *r* such that *q*(*r*)<*c*(*r*+1)

set c(r)=q(r)

END DO

END FOR

Step 3 When flow reduces to normal, off-peak values, reinstall original speed limits.

To state the offline algorithm, let us first introduce some notation. In the following, let

= space mean speed

n = the number of segments the selected test corridor is to be divided (parameter that can be experimentally determined with microsimulation)

q(k) = flow at road segment *k* in vehicle per hour

c(k) = capacity of road segment *k*

Handbook Content: Construct and Run Simulation Analysis

- After simulations have been run for a “do-nothing” scenario and a scenario with speed harmonization and shoulder use, performance measures can be quantified.

- These performance measures are used later in the cost benefit analysis.

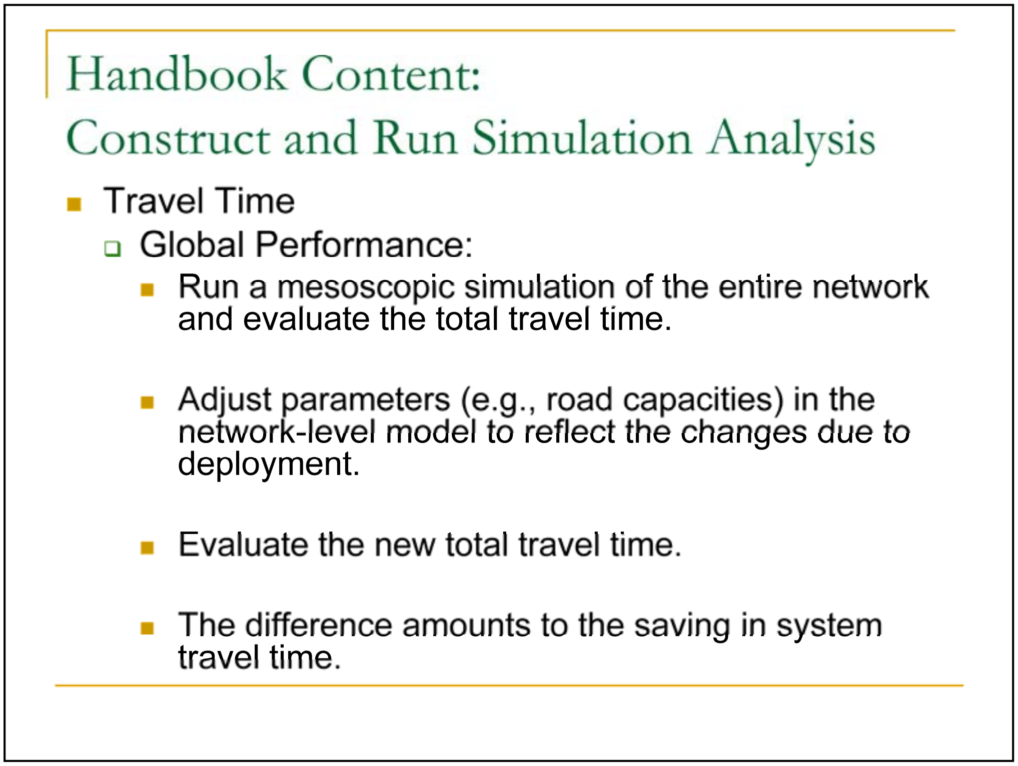
- Performance measures include….
  - Travel Time
  - Travel Time Reliability
  - Safety
  - Emissions and Fuel Consumption

Handbook Content: Construct and Run Simulation Analysis

- Quantifying the performance measures listed previously….
  - Able to quantify local performance measures; those experienced on the corridor.
  - Also able to quantify network performance measures; those experienced for origin-destination pairs on the network.
- The following slides highlight how for each measure.

Handbook Content: Construct and Run Simulation Analysis

- Travel Time
  - Local Performance:
    - Run microsimulation to evaluate the total travel time before and after deployment.
    - Travel time savings can be computed for the (microscopic) network as a whole, or for the (average) individual traveler on the corridor under consideration.



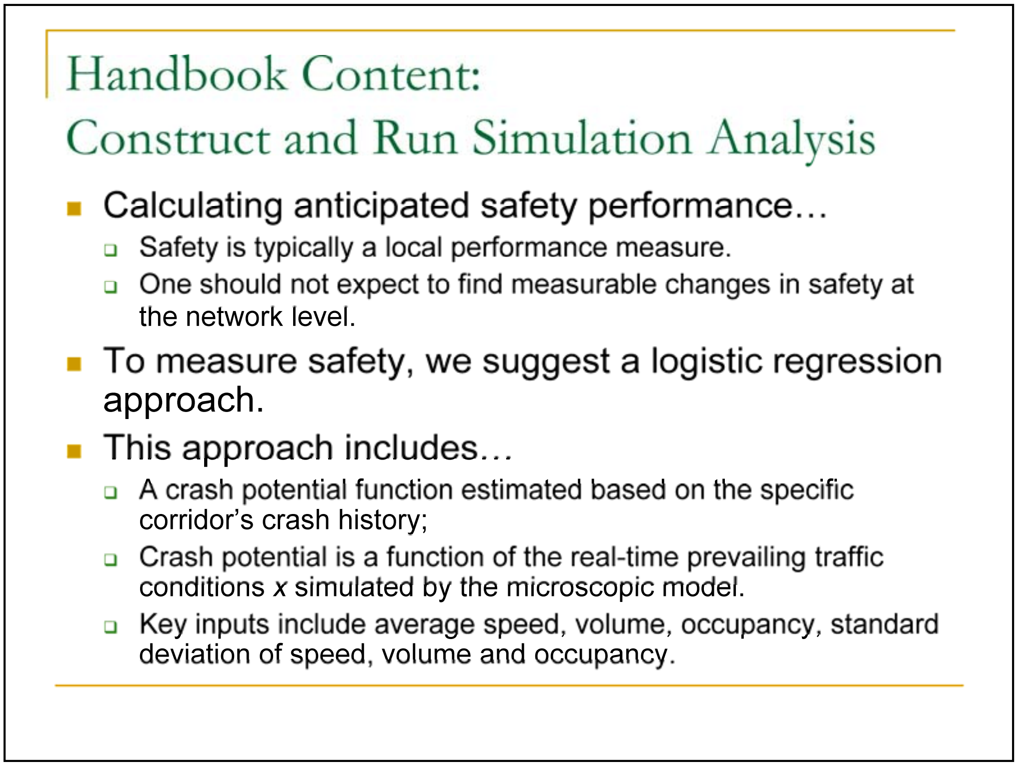
Note: By restricting our attention to specific origin-destination pairs, the travel time saving per origin-destination pair can be obtained.

Handbook Content: Construct and Run Simulation Analysis

- Travel Time Reliability
  - Local Performance:
    - Run microsimulation as done for travel time; only run multiple times for the same scenario.
    - Evaluate the variability of the travel time by calculate the sample variance of the travel time before and after the implementation of the traffic management strategies.
    - Use the multiple runs of the before and after scenarios as the travel time samples for the sample variance calculation.
    - Sample variance calculation is typically done manually; not included in many software programs.

Handbook Content: Construct and Run Simulation Analysis

- Travel Time Reliability
  - Global Performance:
    - Same as procedure as for the local performance of travel time reliability.
    - However, now use the travel time data obtained from the mesoscopic simulation model to estimate the variance of travel time.
    - Again, this step is typically performed manually.



More details in Technical Memo for Task 7.

Handbook Content: Construct and Run Simulation Analysis

- Measuring Emissions and Vehicle Fuel Consumption…
  - Often included in simulation software packages as output parameters.
  - Tools from the Environmental Protection Agency (EPA) are also available for supplemental emissions analysis.
    - MOBILE and MOVES are EPA programs available for download online.
    - Inputs to these are often outputs generated by the simulation software.

Introduction to Project Handbook

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  - Construct and Run Simulation Analysis
  - **Identify Infrastructure Improvements**
  - Develop Enforcement and Education Plan
  - Applying Benefit Cost Analysis
  - Consider Qualitative Impacts
- Approach for Using the Handbook

Handbook Content:
Identify Infrastructure Improvements

- Two key areas related to infrastructure improvements:
  - ITS Infrastructure
  - Roadway Geometry
- The handbook contains a synopsis of key requirements for ITS infrastructure and roadway geometry.
- The more a site's characteristics match the ITS infrastructure and roadway geometry guidelines, the more attractive it becomes as a deployment location.

Handbook Content:
Identify Infrastructure Improvements

- ITS Infrastructure Recommendations

ITS Function	Recommendation
Traffic Surveillance	• Place camera detectors at 1-mile intervals to detect incidents on the main line and shoulders. • Place loop detectors at 1500 to 2000 foot intervals to gather data regarding traffic flow characteristics.
Information Dissemination	• Place variable message signs at 1-mile intervals preferably on overhead gantries.
Enforcement	• Place photo radar sensors and cameras at approximately 1-mile intervals. Take care to provide enable the system motorists with ample time to respond to changes in the posted speed limit before enforcing it.

Handbook Content: Identify Infrastructure Improvements

- Roadway Geometry Recommendations

Roadway Characteristic	Guidance
Shoulder Lane Width	10 feet with low to no heavy vehicles in shoulder lane. 11 feet to allow for more extensive use of shoulder lane by heavy vehicles.
Acting Shoulder Width	2 feet to 4 feet to provide shy distance and lateral support to pavement.
Pavement	Structural composition consistent with mainline. Cross slope 2.5% or less; maintain driver comfort, control and ample drainage.
Horizontal Curves	Verify superelevation and width are adequate/appropriate for vehicle use.

Handbook Content: Identify Infrastructure Improvements

- Roadway Geometry Recommendations (Cont'd.)

Roadway Characteristic	Guidance
Vertical Clearance	Verify 16.5 feet of vertical clearance across shoulder lanes; mitigate discrepancies as specified in TxDOT Roadway Design Manual.
Horizontal Clearance	Verify appropriate horizontal clearance of 30 feet for mainline travel and 16 feet for freeway ramps. Mitigate discrepancies via appropriate treatments identified in the TxDOT Roadway Design Manual and/or AASHTO's Roadside Design Guide.
Transition Areas (Closed to Open Shoulder and vice versa)	Open shoulder at a 10 to 1 taper (one lateral foot for every 10 feet traveled). Close shoulder at a 50 to 1 taper.

Handbook Content: Identify Infrastructure Improvements

- Roadway Geometry Recommendations (Cont'd.)

Roadway Characteristic	Guidance
Entrance/Exit Ramps	Implement yield control for traffic entering freeway on an auxiliary lane (see figures in Task 8 Technical Memorandum for details).
Incident Management	Provide emergency vehicle access via a case-by-case review of each site. Options include managing lanes via lane assignment controls, providing median breaks, and/or recoverable areas adjacent to freeway. Provide vehicle refuge areas every 1/3rd of a mile; areas of 15 feet in width and 150 feet in length.
Freeway Operations in Dark	Verify traffic control devices in use meet night-time visibility standards outlined in MUTCD.

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Handbook Content: Enforcement Considerations

- Manual vs. Automated
  - Automated is preferred due to consistency and effectiveness.
  - Manual can be difficult in congested traffic conditions and may erode traffic conditions due to “rubber necking” by other travelers.
- Legal Framework Necessary
  - Need solid framework for enforcing variable speed limits (applies to manual and automated enforcement).
  - Need solid framework for using automated technology to enforce variable speed limits (only applies to automated enforcement).

Handbook Content: Education Considerations

- Purpose of public education
  - Inform motorists of new operating strategy.
  - Explain how they are expected to respond with the new strategy.
  - Provide information about why these strategies will be beneficial to freeway operations.
  - Collectively, intended to make the strategies more effective.

- Potential Education Forums
  - Public meetings, flyers, TV commercials, radio public announcements

Introduction to Project Handbook

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  - **Applying Cost Benefit Analysis**
  - Consider Qualitative Impacts
- Approach for Using the Handbook

Handbook Content: Applying Benefit Cost Analysis

- Cost benefit analyses are a useful for determining whether or not a project is economically valid (i.e., whether or not the monetary benefits out weigh on the investment).
- The Handbook contains a framework for conducting a cost benefit analysis (CBA). This is supplemented by information provided in the Task 12 Technical Memorandum.
- The following slides outline the framework and present key pieces of information regarding the CBA.

Handbook Content: Applying Benefit Cost Analysis

- CBA Framework

1. Identify candidate corridors.
2. Conduct preliminary analyses for “do-nothing” and implementation scenarios per corridor.
3. Identify design life to be considered in CBA.
4. Identify discount rate (minimum rate of return) to use for CBA.
5. Identify CBA comparison methodology or methodologies (e.g., NPV, B/C ratio).

Step 2 achieved via the constructing and running simulation step.

Handbook Content: Applying Benefit Cost Analysis

- CBA Framework (cont'd)

6. Identify benefits to quantify (i.e., identify the performance measures to be considered).
7. Conduct more focused analyses for "do-nothing" and implementation scenarios per site to quantify annual potential benefits over the course of the design life.
8. Use outputs for "do-nothing" and implementation scenarios per site to quantify difference in performance per year of design life.

Handbook Content: Applying Benefit Cost Analysis

- CBA Framework (cont'd)

9. Convert anticipated difference in performance per year to monetary values per year of the design life and convert annual monetary benefits to a total present value.
10. Estimate difference in costs for "do-nothing" and implementation scenario per year of design life and convert annual costs to a total present value.
11. Compare present value monetary benefits and costs via chosen methodology.

Supplemental CBA Information

- CBA Methodology
  - Goal: Assess the relative difference in benefits and costs for a given transportation project or initiative.
  - Key Components of CBA
    - Time Period of Analysis and Proposed Improvement's Design Life
    - Identify Benefits
    - Identify Costs
    - Convert to Monetary Values
    - Compare Costs and Benefits

Supplemental CBA Information

- Time Period of Analysis and Project Design Life
  - These are two initial considerations and key parameters.
  - The CBA will consider the total annual benefits and costs for the time periods within each year of the anticipated design life.
- For speed harmonization and peak period shoulder use:
  - Time period will likely be the daily peak commuting periods.
  - The design life will depend on how far into the future speed harmonization and peak period shoulder use will be employed.

Supplemental CBA Information

- Following slides identify potential benefits and costs to consider in a CBA.
- The benefits are based on performance measures for the corridor.
- These performance measures are quantified by running the simulation discussed earlier.
- Soon we will see how to convert these quantities to monetary values.

Supplemental CBA Information

- Potential Benefits Related to Speed Harmonization and Shoulder Use

Measure	Description
Travel Time	Changes in travel time for network users due to speed harmonization and peak period shoulder use.
Travel Time Reliability	Change in travel time reliability due to speed harmonization and peak period shoulder use.
Emissions	Change in emissions due to speed harmonization and peak period shoulder use..
Safety	Change in crash potential due to speed harmonization and peak period shoulder use.
Fuel Consumption	Change in fuel consumption for system users due to speed harmonization and peak period shoulder use.

Supplemental CBA Information

- Potential Capital Costs Related to Speed Harmonization and Shoulder Use

Item	Description
Right-of-Way Acquisition	Costs incurred while acquiring additional right-of-way (if necessary).
Geometric Changes to Facility	Design and construction costs associated with changes to the horizontal and vertical geometry of the facility.
Signing and Pavement Marking Modifications	Design and implementation costs for modifications to upgrade or change existing signing and/or pavement markings.
ITS Infrastructure	Costs incurred to design ITS layout, purchase ITS components, and install ITS system.

Supplemental CBA Information

- Other Potential Initial Costs

Item	Description
Initial Education Public Education Program	Includes costs for initial public information campaign to inform motorists of new operating procedures during congested periods.
Initial Enforcement Campaign	Costs incurred to ensure consistent, effective enforcement at on set of new operations.

Supplemental CBA Information

- Potential Operations and Maintenance Costs

Item	Description
Monitoring ITS System Operations	Cost of monitoring system performance in real-time (while under operation).
Evaluating System Effectiveness	Cost incurred to evaluate the effectiveness of the system on a routine basis and to identify potential improvements.
Maintaining ITS Components	Includes costs for routinely maintaining and as necessary, replacing ITS components.
Maintaining Integrity of Physical Road Structure, Signs, Pavement Markings	Cost incurred to maintain the physical integrity of the facility including pavement structure, overhead structures, bridges, signs, and pavement markings.
Continuing Enforcement	Costs incurred to ensure a consistent, effective level of enforcement.

Supplemental CBA Information

- Once benefits and costs have been identified and quantified in their respective units, it is time to convert the benefit (or disbenefits if performance worsened) to monetary values.

- Basic procedure for converting benefits and disbenefits to monetary values….
  - Use unit costs and time period to calculate an annual value.
  - Convert annual value to a total value for the chosen design life and discount rate.

Supplemental CBA Information

- Potential Unit Cost Values for Performance Measures
  - Travel Time: $7.44/hour (Levison and Tilahun, 2006)
  - Travel Time Reliability: $7.11/hour (Levison and Tilahun, 2006)

  Note: The values shown above are cited as examples. Monetary values for travel time and travel time reliability vary based on travelers' socio-demographics and trip characteristics. If the analyst has access to travel time unit cost values specific to the proposed project area those values can be used.

References

Levinson, D. and N. Tilahun (2006) A Moment of Time: Reliability in Route Choice using Stated Preference, Paper presented at the 11th International Conference on Travel Behavior Research. Kyoto, Japan. Available at: http://nexus.umn.edu/Papers/MomentOfTime.pdf.

This study was chosen because the value is based on travelers' route choice decisions depending on route performance – this is how speed harmonization and peak period shoulder use would influence travelers' choices – by route choice.

Supplemental CBA Information

- Potential Unit Cost Values (Cont'd)
  - Emissions Cost per Pollutant

Pollutant (tons)	Cost Estimate (per ton)	In 2009 dollars	Source
VOC	$4,400	$5,504	Ozbay and Berechman (2001)
NOx	$10,300	$12,884	Ozbay and Berechman (2001)
CO	$15	$19	Ozbay and Berechman (2001)
PM10	$133,000	$166,366	Ozbay and Berechman (2001)
CO_2	$50	$53	Fischer et al. (2007)

Notes for Table:

Ozbay and Berechman's work is cited as the most relevant for the unit cost per pollutant because it is the most recent study found available and is cited via the Bureau of Transportation Statistics website (available at: http://www.bts.gov/publications/journal_of_transportation_and_statistics/volume_04_number_01/paper_06/html/table7.html)

References:

Fischer, C., W. Harrington, and I.W.H. Parry. (2007) Should automobile fuel economy standards be tightened?. *The Energy Journal*, 28 (4), pp. 1-29.

Ozbay, K. and Berechman, J. (2001) Estimation and evaluation of full marginal costs of highway transportation in New Jersey. *Journal of Transportation Statistics*, 4(1), 81-103.

Supplemental CBA Information

- Potential Unit Cost Values (Cont'd)
  - Crash Cost per Crash Severity

Severity	In 2009 Dollars	Unit Cost	Source
Fatality	$4,259,339.64	$4,100,000	NSC (2009)
Incapacitating Injury	$216,603.00	$208,500	NSC (2009)
Non-incapacitating Evident Injury	$55,267.53	$53,200	NSC (2009)
Possible Injury	$26,283.24	$25,300	NSC (2009)
PDO	$2,389.39	$2,300	NSC (2009)

Table Notes:

1 All unit costs are comprehensive costs rounded to the nearest hundred dollars. Comprehensive costs incorporate the loss of quality of life and are considered the most appropriate unit costs for calculating the value of reducing crash occurrence in the future.

Reference:

National Safety Council (NSC). (2009) Estimating the cost of unintentional injuries, 2007. Available at: http://www.nsc.org/resources/issues/estcost.aspx. Last Accessed: April 1, 2009.

Supplemental CBA Information

- Potential Unit Cost Values (Cont'd)
  - Fuel Consumption Rates

Average Speed (mph)	Fuel Consumption Rate (miles per gallon)	
	Light Duty Vehicle	Heavy Truck (FHWA Class 8)
25	30.5	4.41
30	31.7	4.40
35	31.2	4.75
40	31.0	5.06
45	31.6	5.43
50	32.4	5.77
55	32.4	6.26
60	31.4	6.63
65	29.2	7.01

***More speed values are available for fuel consumption in table provided in Tech Memo #12. Truncated here due to space limitations.

Table Notes:

1Source: Davis et al. (2008)

2Light-duty vehicles include passenger cars, sports utility vehicles, pickup trucks and minivans.

3Fuel consumption is for dual tires on a tractor and trailer. Fuel economy improves when singlewide tires are used instead (Davis et al., 2008).

4Class 8 Heavy Duty Trucks are over 33,000 pounds (15,000 kg) as defined by the Federal Highway Administration.

Supplemental CBA Information

- Convert Annual Benefits and Costs to Total Benefit and Total Cost for the Design Life
  - Annual benefits and costs are unlikely to be uniform over the design life; therefore converting non-uniform annual values.
  - Recommended equation for conversion:
  - $PV = \sum_{y=1}^{n} [A_y*(1+i)^{-y}]$

    Where, PV = present value, A = annual benefit or cost, i = discount rate, y = index for year in design life of alternative, and n = total number of years in design life.

Supplemental CBA Information

- Final part of CBA is comparing costs and benefits.
- Three common methods for comparison are:
  - Net Present Value
  - Benefit Cost Ratio
  - Cost Effectiveness
- The following slide provides equations for these three methods.

Supplemental CBA Information

- Net Present Value
  - NPV = PVB=PVC
  - NPV = net present value, PVB = present value of benefits, and PVC = present value of costs.
  - NPV > 0 indicates economically justified
- Benefit Cost Ratio
  - BCR = PVB/PVC
  - BCR = benefit cost ratio, PVB = present value benefits, and PVC = present value cost.
  - BCR > 1.0 indicates economically justified

Up to engineer or analyst to decide which method(s) to use for comparison. Can use the ones above or another method consistent with TxDOT procedures.

Supplemental CBA Information

- Cost Effectiveness
  - Cost Effectiveness = PVC/(TTp,y – TTo,y)
  - PVC = present value of cost, TTp,y = travel time for proposed alternative in year y, and TTo,y = travel time for "do-nothing" scenario in year y.
- At the engineer or analysts discretion as to which comparison method to use.
- Can use one of three presented here or another consistent with TxDOT procedures.

Up to engineer or analyst to decide which method(s) to use for comparison. Can use the ones above or another method consistent with TxDOT procedures.

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- Approach for Using the Handbook

Handbook Content: Considering Qualitative Impacts

- Not all project impacts can be quantified, particularly at a screening level analysis or when determining project feasibility in preliminary analysis.
- Remains worthwhile to consider these qualitative impacts per candidate site or corridor.
- The handbook contains a table of potential qualitative impacts to consider.

Handbook Content:
Considering Qualitative Impacts

- Potential Qualitative Impacts

Measure	Description
Noise	Anticipated change in noise pollution due to change in traffic volume and/or mix to traffic.
Accessibility	Ability to access basic services (e.g., schools), employers, quality of life destinations (e.g., shopping), and local access (e.g., sidewalks).
Community Cohesion	The degree to which existing neighborhoods, communities, and recreational areas remain intact. Considers residents and local businesses necessary to relocate and/or residents and local businesses isolated from the community.

Handbook Content: Considering Qualitative Impacts

- Potential Qualitative Impacts

Measure	***Description***
Equity	Distributive effect of the proposed project; what is the investment's impact across societal groups?
Environmental Considerations	Impacts on water resources, wetlands, habitats of endangered/threatened species, and other similar considerations.
Regional Development/Economic Effects	Assessment of whether proposed project would attract new development or employers to the region.
Aesthetics	Visual impact of proposed project compared to "do-nothing" scenario.

Introduction to Project Handbook

- Purpose and Overview of Handbook
- Introduce Content of the Handbook
  - Identify Candidate Sites
  - Construct and Run Simulation Analysis
  - Identify Infrastructure Improvements
  - Develop Enforcement and Education Plan
  - Applying Benefit Cost Analysis
  - Consider Qualitative Impacts
- **Approach for Using the Handbook**

Using the Handbook

- Intended to be a reference guide to assist in consistently evaluating candidate corridors.
- Also, useful for developing preliminary deployment strategies for candidate corridors.
- Technical Memorandums and Final Report for Project 0-5913 are useful supplemental resources.

Workshop Overview

- Introduction to Speed Harmonization and Peak Period Shoulder Use
- Completed Research
- Introduction to Project Handbook
- **Introduction to Multi-Resolution Analysis**
- Summary

Multi-Resolution Analysis

- VSL and Shoulder Use have immediate effect on traffic condition in the test section. These effects are captured by a microsimulation model, and quantified by performance measures mentioned above.
- Due to VSL and Shoulder Use, the capacity of the test section changes. Change in freeway capacity affects route choice of users, and thus VSL and Shoulder Use have a larger network-wide impact.

Multi-Resolution Analysis

- Therefore, it is important to study impact of these traffic management strategies at both the corridor level and network level (i.e., multi-resolution analysis).
- Network level effects are studied by mesoscopic models, which are better suited for large scale network analysis and are less computationally intensive.

Multi-Resolution Analysis

- The mesoscopic model used in this project is a cell-transmission based model, and it takes three inputs to perform network analysis:
  - Travel demand data
  - Roadway capacity
  - Free-flow speed

- Network level impact of VSL and Shoulder Use have been quantified by making an equivalent change in roadway capacity of the test section in the bigger network in mesoscopic model.

Workshop Overview

- Introduction to Speed Harmonization and Peak Period Shoulder Use
- Completed Research
- Introduction to Project Handbook
- Introduction to Multi-Resolution Analysis
- **Summary**

Workshop Summary

- Discussed the basics of what speed harmonization is, where it has been used, and why it is beneficial.
- Covered the research findings and recommendations regarding speed harmonization and shoulder use on Texas Freeways.
- Introduced the content in the project handbook for assessing the feasibility of speed harmonization and shoulder use.
- Explained the basic concepts involved in multi-resolution analysis.