NCHRP Synthesis 482
Work Zone Speed Management

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Scope of Work

- Work zone speed management for facilities with ordinary speed limits of 45 mph and up
- Summarize research and expert opinion on technique effectiveness
- Minimize duplication with NCHRP 746
Project Review and Oversight

Expert Task Group
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- Richard J. Porter (Univ of Utah)
- Larry Velasquez (Javel Engineering)
- John Wolford (MD SHA)
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Oversight & Liaisons
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- Daniel Grate (FHWA)
- Tanya Zwahlen (TRB)

Additional Reviewers
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- Milt Harmelink (Arges Consulting)
Information Sources

- Approximately 300 academic studies and related sources
- Two agency surveys
  - Engineering & Enforcement (n=50)
  - Public Outreach (n=42)
Report Organization

- Executive Summary
- Introduction
- Engineering Technologies (8 Techniques)
- Engineering Techniques (8 Techniques)
- Operational Techniques (4 Techniques)
- Enforcement: Traditional & Automated (5 Techniques)
- Public Outreach (3 Techniques)
- Combinations
- Conclusions
28 Techniques, No “Silver Bullet”

- Enforcement is limited by staffing, budget, and policy constraints.
- Some engineering techniques and technologies appear to lose effectiveness as drivers become accustomed to them.
- Operational techniques require staffing and logistics.
- Public outreach requires a sustained commitment to overcome pro-speeding attitudes.
What is the problem?
Work Zone Characteristics

Objective
- High cognitive workload for drivers
- Lack of space for traditional enforcement
- Increased safety risks due to physical and operational conditions

Subjective
- Worker concerns about safety
- Driver concerns about mobility
TZD National Strategy

- “Improve speed management and enforcement in work zones to reduce the risk of work zone fatalities.”
- “Improve work zone design and operations.”
- “Educate drivers on safer driving practices in work zones.”
- “Educate workers on safety practices.”
- “Educate judges, prosecutors and law enforcement on...risks related to work zones.”
- “Enact legislation...including pervasive automated speed enforcement and applications for school and work zones.”
Fatal Crashes in US Work Zones

- In 2012, 1.7% of fatal crashes occurred in work zones
  - 547 Crashes
  - 617 Deaths
- Speed cited as a factor in 35% of fatal WZ crashes

Source: NHTSA 2003-2012
Total Crashes in US Work Zones

- Fatalities 0.6%
- Injuries 30%
- Property Damage 69%

Perhaps 50 injuries for every death.

Source: NHTSA 2010
Worker Safety

- About 19 workers/year killed by traffic in US work zones.
- At least 20% of worker deaths involve flaggers.

Source: BLS/Pegula 2013
Speed vs Safety

Probability That a Work Zone Crash Results in Injury or Death

Probability of Death for a Pedestrian Struck by a Motor Vehicle

Source: Khattak and Targa 2004

Source: Interdisciplinary Working Group for Accident Mechanics (1986); Walz et al. (1983) and Swedish Ministry of Transport (2002).

- 20 mph: 90% chance of survival
- 30 mph: 20% chance of survival
- 45 mph: Almost no chance of survival
Speed Management

Free-Flowing Traffic

- Reduce speeds near workforce
- Avoid harsh/risky deceleration
- Encourage speed uniformity

Stop-And-Go Traffic

- Prevent/delay the onset of congestion
- Avoid abrupt deceleration at back-of-queue
- Prevent back-of-queue crashes

“[If] motorist safety is reduced in work zones, worker safety is also reduced, because the traffic crashes that occur often spill over into the work areas and put workers at risk.”

--Harmelink and Edwards 2005
"Over time...low-level speeding can become the accepted behavior... This results in the de facto speed limit becoming...over the posted limit. The increase in crash risk as a consequence can be quite large."

--Howard et al 2008
## Factors Affecting Work Zone Speeds

<table>
<thead>
<tr>
<th>Situation</th>
<th>Speed Limit (MPH)</th>
<th>85th Percentile Speed (MPH)</th>
<th>Difference</th>
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</thead>
<tbody>
<tr>
<td>Not in Work Zone</td>
<td>65</td>
<td>71.6</td>
<td>6.6</td>
</tr>
<tr>
<td>Work Zone: No Activity</td>
<td>55</td>
<td>67.7</td>
<td>12.7</td>
</tr>
<tr>
<td>Work Zone: Active, Typical Signs</td>
<td>55</td>
<td>62.8</td>
<td>7.8</td>
</tr>
<tr>
<td>Work Zone: Active, Double Fine Signs Only</td>
<td>55</td>
<td>62.2</td>
<td>7.2</td>
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<tr>
<td>Work Zone: Active, Double Fine Signs, Police</td>
<td>55</td>
<td>57.3</td>
<td>2.3</td>
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<tr>
<td>Work Zone: Active, Double Fine Signs, Radar Box, Police</td>
<td>55</td>
<td>56.2</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Source: Pigman et al. 2006
Speed Limit Reduction vs Actual Speed

Actual Speed Reduction as a Function of WZ Speed Limit Reduction

Percentage Increase in Speed Variance as a Function of WZ Speed Limit Reduction

Source: Migletz et al. 1999

Newer Studies: Possibly better compliance under reduced speed limit than under unchanged speed limit. (e.g. Hou et al. 2011)

Newer Studies: Complicated relationships between speed differential and other work zone factors, e.g. geometrics. (e.g. Porter & Mason 2008)
Methodological Challenges

- Adjusting for voluntary speed reduction
- Changing work zone conditions/configurations
- Aggregate vs individual vehicle speeds
- Measurement accuracy
- Speed profile through work zone
## Agency Speed Limit Setting Procedures

### Current Status

- No universal work zone speed limit setting procedure exists in US or internationally.
- State statutory work zone speed limits vary.
- Degree of discretion given to designers and field engineers varies.
- Ontario has detailed guideline updated in 2014.
- European Union research team working on a harmonized procedure for all 28 countries.

### Typical Decision-Making Factors

- Non-Construction Speed Limit
- Roadway Type
- Work Duration
- Worker Presence
- Proximity of Workers To Live Traffic
- Lane Width
- Traffic Volume
- Ability To Pass/Overtake
High Fines Not A Strong Deterrent

- Nearly all states have more severe penalties for work zone speeding.
- Some states have caveats:
  - Workers present
  - Advance notification signs
- A few studies have explored effects on driver speed behavior:
  - Modest increase in awareness of penalties and risk of citation.
  - Little evidence of measurable effect on driver speeds.

Sources: Ullman et al. 2000
Jones et al. 2002

Risk of Citation vs Risk of Collision
**Case Study 1: Flagger Fatality**

**Facts & Circumstances**
- Asphalt paving operation on two-lane rural highway about 50 miles north of US border
- Statutory 60 km/h (35 mph) work zone limit when workers are present
- Newly-trained 18 year old flagger struck from behind and killed by 44 year old driver
- Victim’s fiancée witnessed crash and interviewed by national media
- Driver told police he was distracted looking for a paper he dropped
- No prior violations, no evidence of alcohol/drug use
- Analysis showed 51-62 mph speed at time of impact
- Criminal justice process took 3½ years

**Legislative & Agency Response**
- Next-day media response from top officials
- Enforcement blitz using “Operation Hardhat” technique (400+ WZ speeding citations issued)
- Work zone speeding fines increased to 3X normal fine
- Truck safety officers authorized to issue work zone speeding tickets
- 5 year pilot program for automated speed enforcement authorized
- Work zone signage modified to more clearly indicate when 60 km/h limit is in force
- Work zone advance warning signs doubled up
- Specified use of temporary rumble strips
- Gateway treatments at work zone approaches
- Contractual emphasis on removing WZ speed limit signs when no longer applicable
- Public information campaign incorporating elements of the incident.
Engineering Technologies
Changeable Speed Limit Signs

- Faster changeover from workers-present to workers-not-present limits
- Possible slight reduction in average speeds, at least at night
- Possible slight reduction in speed variance

Sources: Rifkin et al. 2008
McMurtry et al. 2009
Edara et al. 2013
Variable Speed Limit Signs

- Real-time speed limit adjustment in response to traffic conditions
- Primary intent is to delay onset of congestion and prevent back-of-queue crashes
- Most work zones studies inconclusive, in part due to poor compliance

Sources: Lyles et al. 2004
Kwon et al. 2007
Fedula & Fontaine 2010
Edara et al. 2013
Case Study 2: VSL in Virginia

Facts & Circumstances
- Mega-project to reconstruct Woodrow Wilson Bridge on I-95/495 Capitol Beltway
- High volume multi-lane freeway with recurrent congestion
- VSL system implemented in two phases
- Concurrent deployment of additional ITS applications including delay warning
- $3.2 million

Results
- Difficult to assess objectively because before/after lane configurations differed
- No statistically significant changes in capacity or speed observed
- Anecdotal evidence suggested slight improvement in traffic flow
- Little feedback received from public after initial deployment
Dynamic Speed Feedback Signs

- Trailer- or post-mounted system comparing speed limit with observed speed
- Several studies show speed reductions ranging from 1 to 8 mph
- Practitioner interviews suggest effectiveness declines as drivers acclimate to the device
- Appears to be most effective if combined with enforcement

Sources: See Report
PCMS with Vehicle Activated Speed Messages

- Vehicle-activated messages with YOU ARE SPEEDING or similar messages resulted in speed reductions of 4-7 mph
- Displaying corresponding fine reduced the number of severe speeders
- Effect seems to be mainly near the sign

Sources: Fitzsimmons et al. 2009
Roberts & Smaglik 2012
PCMS with “Police” Lights

- California Highway Patrol uses blue and amber lights on police vehicles
- System activated when approaching vehicle was speeding by 5 mph or more
- With SLOW DOWN message only, speed reductions were about 5 mph
- With SLOW DOWN message plus flashing lights, an additional 3-7 mph reduction occurred
- Possible novelty effects

Source: Ravani 2012
Augmented Enforcement System

- Small-scale test of system that provided specific feedback on speed and associated license plate number
- 6% reduction in vehicles exceeding 60 mph
- 10% reduction in vehicles exceeding 65 mph

Source: Chan et al. 2013
Decoy Radar

- System emits simulated police radar signal, targeting drivers with radar detectors
- At least 11 studies since mid 1980s
- Typical reported reductions of about 2 mph for entire traffic stream and 5-8 mph for vehicles with radar detectors
- Radar detectors prohibited in heavy trucks since 1995
- Practitioners report that drivers quickly become aware of the ruse

Sources: See Report
Engineering Techniques
Lane Width Reduction

- Reducing lane width appears to have a moderate effect on traffic speeds
- Width vs speed relationship has not been extensively studied
- Capacity is also affected by lane width reduction
- Reduced width introduces challenges for accommodating over-width trucks

<table>
<thead>
<tr>
<th>Lane Width (feet)</th>
<th>Free-Flow Speed Reduction (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10.0</td>
</tr>
<tr>
<td>10.5</td>
<td>7.0</td>
</tr>
<tr>
<td>11</td>
<td>4.4</td>
</tr>
<tr>
<td>11.5</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Source: Chitturi & Benekohal (2005)
Chicane (Iowa Weave)

- Lateral shifts force speed reduction
- Mainly used in lower volume situations
- Sometimes simplifies construction staging
Chicane (Iowa Weave)

- Highly effective in reducing speeds
- Actual speeds depend on geometrics
  - Spain: 62 mph → 50 mph (single)
  - Sweden: 56 mph → 30 mph (double)
- 30% reduction in crashes in 2008 study of Arkansas work zones

Sources: Brewer 1972
Lorscheidler & Dixon 1995
Nygårdhs 2007
Schrock et al. 2008

Swedish Chicane from Nygårdhs 2007
Temporary Transverse Rumble Strips

- Dozens of studies have explored materials, thicknesses, colors, and spacing patterns
- Most reported applications are on 2-lane rural highways at flagger station approach
- Most studies report increased driver awareness
- Changes in approach speed profiles have been difficult to quantify (1-2mph?)
- Erratic maneuvers reported in some studies, especially if high color contrast
- High driver acceptance in Saskatchewan public opinion survey

Sources: See Report
Emergency Flasher Traffic Device (EFTD)

- Small-scale study at rural flagging operations in Kansas
- Each driver arriving at flagger station asked to turn on emergency flashers
- 2.5 to 5.5 mph upstream speed reduction

Source: Bai & Li 2009, 2011
Tractor-Trailer-Type Mobile Barriers

- Steel wall system pulled by semi-tractor to isolate workers from live traffic
- Mainly used for maintenance projects
- Two designs in service in US:
  - Balsi Beam
  - MBT-1
- Recent study showed speeds passing MBT-1 were higher than when workers were unprotected

Source: Gambatese & Zhang 2013
Gateway Assemblies (Freeway)

- Approach treatment currently used in two Canadian provinces
- Intended to create sense of entering a constrained area
- No effectiveness data was found
Gateway Assemblies (Two-Lane Rural)
Converging Optical Devices

- Transverse bars or chevrons painted on pavement
- *Peripheral* transverse bars approved in MUTCD
- Spacing between bars/chevrons decreases as vehicle moves downstream
- Only one study evaluated work zone applications:
  - Slight speed reduction
  - Confounded by poor color contrast
- Studies of permanent applications show contradictory results (−17 mph vs −1 mph)
- Primarily for approach to a point hazard

Sources: Meyer 1999, 2004
Drakopolous & Vergou 2003
Gates et al. 2008
Hunter et al. 2010

Milwaukee work zone installation based on Yokohama pattern.
Operational Techniques
Pilot Vehicles

- Discussed in US MUTCD
- Most often used in rugged terrain
- Pilot vehicle limits speed of platoon
- Recommended in British & Canadian guidance for high-risk situations:
  - Workers very close to live traffic
  - Steep drop-offs
- Recent Australian study showed high effectiveness as a speed control measure, if the pilot vehicle observes the work zone limit

Source: Debnath et al. 2014
Pace Vehicles

- Multi-lane version of the Pilot Vehicle
- Typically requires one vehicle per lane
- Recommended in Canadian guidance for situations where workers are close to traffic.
- Logistics of continuous pacing discussed in detail in Ontario Traffic Manual

Source: MTO 2014
Rolling Closures

- Special case of Pace Vehicle operations
- Pace vehicles reduce traffic speed to create a period of several minutes when all lanes are clear of traffic
- Preparation and logistics essential for safety
- Traffic volume must be low
- Might need to stop traffic completely if work is not completed timely
- Sources disagree about use of construction vs police vehicles.
- Sources disagree about minimum speed of pace vehicles (10 to 55 mph)

Sources: See Report
Flagging for Speed Reduction

- Mid 1980s research recommended measures to improve effectiveness of using flaggers to reduce speed of vehicles passing the work zone
  - Apparel
  - Hand Gestures
  - Position
- Correct combinations significantly reduced speeds:
  - Urban Interstate 4-5 mph
  - Rural Interstate 7-13 mph
  - Arterials and Two-Lane Rural Highways 10-16 mph
- Not used in some states due to safety concerns

Sources: See Report
Enforcement
Police Enforcement
Also See NCHRP 746

Advantages

- Effective at reducing work zone speeds
- Reduces speed variation and unsafe behavior
- Expedites response to work zone incidents

Disadvantages

- Diverts police resources from other duties
- Labor costs
- Limited space for enforcement activities
- Reduces work zone capacity by about 50 pcu/lane-hour
Active Enforcement

- Officer in vehicle with radar, often on shoulder
- Violators usually intercepted in work zone
- Maintains threat of being ticketed

- Space limitations can compromise safety
  - Officer close to live traffic
  - Deceleration and re-acceleration distances
- Limited deterrent effect while officer is issuing a citation

- Speed reduction near officers about 6 mph
- Most drivers accelerate after passing patrol
Circulating Enforcement

- Patrons loop through the work zone
- Patrons sometimes function as pace vehicles
- Reported speed reduction 2 to 4 mph
- Other pros & cons similar to Active Enforcement
Stationary Enforcement

- Officer positioned upstream of work zone
- Warning/deterrent effect
- Violators seldom pursued
- Little threat of being cited

- 5-9 mph reductions reported near officer
- If uncongested, drivers often accelerate after passing officer
- Advantageous for providing back-of-queue warning (perhaps facing upstream)
Enforcement Pack

- Upstream officer identifies violators
- Downstream officer(s) intercept violators
- Reduces safety risks
- Maintains threat of being cited for violations
- Requires additional personnel
Automated Enforcement

Photo Speed Enforcement

Photo Radar Speed Enforcement

Speed Photo Enforcement

Speed Cameras
Automated Enforcement Methods

SINGLE-POINT

- Currently used in Illinois, Maryland, Oregon, Washington work zones
- Citations based on speed while passing a single camera
- Driver deceleration approaching camera affects work zone capacity
- Limited downstream effect

POINT-TO-POINT (AVERAGE SPEED)

- So far, no deployments in US
- Two or more cameras
- Plate number timestamped at beginning of work zone.
- Camera at end of work zone used to determine average speed over entire distance
- Nearly 100% compliance in European deployments
- Uniform speeds throughout work zone
- Perceived as more equitable than single-point method in British and Australian surveys
Point-to-Point Enforcement in UK

Photo: Pierre Terre - Creative Commons

Photo: Martin Bodman - Creative Commons
Portable Speed Cameras
How Automated?

- Radar + License Plate Reader + Cameras
- Citation sent by mail
- No need to chase the violator
- Plate number requires human verification
- Policy issues:
  - Is citation against vehicle or driver? (How to verify driver ID?)
  - Who can issue the citation?
  - Collective bargaining provisions
Case Study 3: ASE in Illinois

- 2006: Illinois first in US to use Automated Speed Enforcement in work zones
- Components
  - Speed feedback display
  - Enforcement radar
  - Photo of license plate
  - Photo of driver’s face
- Operated by police officers
- Citation issued at officer’s discretion
- Officer verifies driver image against license photo for registered owner of vehicle
- Same fines as non-automated enforcement
- Judicial outreach prior to field deployment
- 2-4 mph reduction for cars
- 1-5 mph reduction for trucks
- 85% of drivers sped up downstream

Sources: Benekohal et al. 2008, 2009, 2010
Hajbabaie et al. 2008, 2011
Chitturi et al. 2010
Wang et al. 2011
Lodes & Benekohal 2013
# Automated Enforcement Controversy

**Benefits**
- Effectively reduces speeds
- European meta-study estimated 20-25% reduction in work zone injury crashes
- Compared to human enforcement, less risk for officers and violators

**Opposition**
- Statutorily prohibited in several states
- Criticized as “cash cow”
- “Vociferous” opposition though most US polls show majority support
Public Outreach
Introduction

- Public Service Announcements (PSAs) are highway agencies’ most direct effort to address social & behavioral factors that compromise work zone safety.
- Formal evaluations of campaign effectiveness are rare.
- Campaigns are typically produced for TV, but many agencies also post the PSAs on YouTube.
Methodology

- Found 43 work zone safety PSAs posted by agencies on YouTube (July 2008-May 2013)
- Inventoried PSA content
- Computed view rates
View Rate Computation

\[
\text{12,043 Views} \quad \div \quad \text{2487 Days} = 4.8 \text{ Views/day}
\]
Overall Results

- Max: 116.02 views/day*
- Median: 0.96 views/day
- Min: 0.09 views/day
- One seatbelt PSA >10,000/day
- No direct relationship between video length and view rate

*As of July 2014
Typical Work Zone PSA Messages

- Slow down
- No cell phones
- No texting
- Expect delays
- Be courteous
- Avoid distractions
Are We Trying to Say Too Much?

* Embrace the Orange - Illinois DOT – 0:33 - 1.79 views/day

- Be extra-careful driving through work zones
- Work zones dangerous even when workers aren’t present
- Cell phones illegal in Illinois work zones
- Over 90% of work zone victims are motorists like you
- Let’s make Zero Fatalities a reality
- Drive smart and Embrace the Orange

https://www.youtube.com/watch?v=db_xyjjpHuU

* As of 09-Jan-15
Highest View Rate

Vermont AOT Summer Work Zone Safety – Vermont AOT – 0:33 – 83.27 views/day*

- Do you know what it’s like to see your co-worker hit by a car..
- …and fly through the air?
- I do.
- I’ve worked on Vermont’s roads for years.
- I’m also...
- Please watch out for me:
  - Slow down
  - Put down cell phone
  - Pay attention
- Your safe driving makes the work zone safer for everyone.

https://www.youtube.com/watch?v=e9dwtp05C5s

* As of 09-Jan-15
Another Outlier

*Un Chatier Dans Tous Ses Etats* – Quebec  MOT – 2:43 – 76.09 views/day

https://www.youtube.com/watch?v=CwLWEJmTCSg

* As of 09-Jan-15
The Seatbelt Video

Embrace Life – Sussex Safer Roads Partnership – 1:28 – 10,411 views/day

https://www.youtube.com/watch?v=h-8PBx7isOM

* As of 09-Jan-15
Embrace Life
Always wear your seat belt

Sussex Safety Roads
Partnership
www.sussexsafetyroads.gov.uk
Film © 2010 SSSP. All Rights Reserved.
Common Features of Some Videos with Higher View Rates

- Positive tone
- Real workers doing their jobs and telling their story
- We’re in this together
Additional Observations

- Most PSAs released for WZ Safety Week
- Most agencies producing new content annually
- Very little content is state-specific
- Funding for paid advertising is scarce
- British research suggests radio is more salient to driving than TV
Additional Observations

- Most work zone PSAs say “Slow Down”...
- But not by a specific amount.
- Various studies indicate drivers usually slow down by about 5 mph...
- But still exceed the WZ speed limit.
- Perhaps drivers *think* they’re doing what the campaign asks them to do, when they’re not.
Combination Strategies
Florida Motorist Awareness System

- PCMS: Workers Present Ahead/Speed Reduced Next XX Miles
- Regulatory Speed Limit Signs with Flashers
- Radar Speed Feedback Signs
- Active Enforcement
- Public Information Campaign
Florida: Motorist Awareness System

- Approximately 1.5 mph speed reduction without enforcement
- 4-5 mph reduction with enforcement
- Reduction in speeders at downstream end of work zone
Illinois, Indiana & Vermont: Enforcement + Speed Feedback

- Various enforcement tactics tried in combination with feedback displays
- Significant reduction in speeds
- Severe violations substantially reduced
- Better than enforcement alone
- Better than speed feedback alone

Source: Benekohal et al. 2010
Hajibabaie et al. 2011
Chen & Tarko 2013
Lee et al. 2014
Oregon: Speed Feedback + Equipment-Mounted PCMS
Oregon: Speed Feedback + Equipment-Mounted PCMS

- 6 mph reduction in 85th percentile speed at end of taper
- No similar reduction when same treatments were used individually

Source: Gambatese & Zhang 2013
Sweden: Chicanes + Electronic Signage

Nygårdhs 2007
Sweden: Chicanes + Electronic Signage

- Electronic signage improved deceleration profile
- Novelty effect?

Source: Nygårdhs 2007
Conclusions
Current State of Practice

- “Voluntary” 5 mph speed reduction at work zone approach
- Additional reduction when workers/enforcement present
- General agreement on factors to consider in setting work zone speed limits, but no universal procedure
Mainstays

- **Enforcement**
  - Upstream Stationary Enforcement for back-of-queue warning
  - “Enforcement Packs”
  - Labor costs
  - Limited downstream effects

- Temporary Transverse Rumble Strips

- Electronic speed feedback systems
  - Modest speed reductions
  - Synergistic effect with enforcement
Infrequently Used But Probably Effective

- Pilot Vehicles (two-lane highways)
- Pace Vehicles (multi-lane highways)
- Chicane/Iowa Weave
- Lane Width Reduction
Promising Innovations

- Combination Strategies
- Speed Feedback with Plate Number
- Emergency Flasher Traffic Control Device
- Gateway Treatments
Public Outreach Campaigns

- Scope
- Worker focus
- In this together
- Specific information
- Thematic integration with project-level outreach
Automated Enforcement

- Point-to-point Automated Enforcement highly effective
- Sustained speed reduction throughout the work zone
- Implementation obstacles are mainly political:
  - Legitimate safety objective
  - Allocation of revenue to public benefit
  - Civil infraction vs misdemeanor
Matching Strategy With Location

- Pre-Trip Public Information
  - Explain Need for Speed Reduction
  - Request Public Cooperation

- Work Zone Approach
  - Gateway Treatments
  - Rumble Strips
  - Upstream Enforcement

- Buffer and Activity Areas
  - Enforcement Pack Observers
  - Automated Enforcement
  - Pace Vehicles
  - Lane Width Reduction

- Downstream
  - Enforcement Pack Interceptors
  - Thank non-violators for their cooperation
Thank You

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