Imposed vs. chosen change: A vision for the future of the pavement enterprise

Rasmus S. Nordal Lecture

John Harvey

University of California Pavement Research Center

10th Bearing Capacity of Roads, Railways and Airfields Conference, Athens, 28 June 2017
Outline

• Stationarity?
• Drivers of change
• Responses to change
• Takeaways and summary
Is Stationarity a Good Assumption?

• Stationarity
  – Assumption in time series data that mean, variance and autocorrelation structure do not change over time
  – Should we be designing, constructing and managing pavements assuming that the conditions under which they operate and the functionality desired by the public will be similar to now?

• An exploration of these questions for my state, which may have implications for others
What Causes Institutional Change?

• Changes in institutional choice set
  – Knowledge of ways to organize your enterprise
• Changes in technology
• Long-run changes in relative factor and product prices
• Changes in other institutional arrangements
  – Societal changes that interact with your enterprise
What is Chosen (Induced) vs. Imposed Change?

- Change that we choose because it benefits us
- Change that is imposed by others or circumstances
- We are instinctively opposed to making changes that we haven’t chosen for ourselves
- Hypothesis: pavement enterprise needs to proactively choose to change or it will be imposed, with negative consequences

Major Drivers of Change in the Pavement Enterprise:

• Population growth, changes in freight vehicle travel, vehicle ownership, urbanization and de-ruralization,
• Sustainability and population growth
  – Resource depletion, toxicity
  – Climate change, resilience
• Automation and vehicle technology, information technology
• Cost, financing and lack of confidence in government to deliver pavement efficiently
• Jobs, workforce
• The forgotten half
• Pavement values: what do our customers want? Are we communicating with them?
Truck traffic axle weights increasing?

- State-wide average axle loads (115 WIM stations) virtually unchanged in 10 years
- Gross vehicle weights slightly reduced

![Load Spectra (Single Axle)](image)

![Load Spectra (Tandem Axle)](image)
Freight Traffic is Increasing and Changing

• Freight is increasing
  – Economic growth, increasing population
  – Trade-driven economy, good jobs without college

• Changes in patterns of freight:
  – Last mile
    • Increasing household deliveries on local streets of purchases from internet
  – More short-haul delivery trucks in residential areas
  – Will be increasingly natural gas or electric
Freight growth: more trucks

- 62% increase in truck counts vs 14% growth in population
- Short-haul: 69% increase
- Long-haul: 59% increase

UCPRC/Caltrans WIM data
What kind of pavement will we need in the future?

Millennials driving the trend; may not just be recession

Less interested in cars; use of technology to connect instead of travel; more interested in walkable, bikeable cities

How much pavement will we need in the future? Annual travel per driver by age category


Millennials show longer term downward trend
Environmental impact =

Population * GDP / Person * Impact GDP

Increase in wealth and economic activity

Technological efficiency

Ehrlich and Holdren (1971) Impact of population growth. e.g. via LCA Science 171, 1211-1217
Slide adapted from R. Rosenbaum, Pavement LCA 2014 keynote address
Climate Change: are state goals achievable based on response to climate change law passed in 2006?

- Population growth:
  - 1990: 30 million
  - 2017: 39 million
  - 2055: 50 million
Climate Change: road transport related strategies planning to 2030 and 2050

- Vehicle fuel vehicle changes: Natural gas, Electric
- Complete streets

Air Resources Board Climate Scoping Plan
What Should be Done for Sustainability?

- Many alternatives to improve sustainability
- How to prioritize?
- Cost from Life Cycle Cost Analysis (LCCA)
- Environment from Life Cycle Assessment (LCA)

Bang for your buck metric: $/ton CO₂e vs CO₂e reduction

Life Cycle Cost = Initial Cost + Future Cost + Direct Energy Saving Benefits

Adapted from Lutsey, N (2008) Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-08-15
Maintaining competition in pavement
California Relative Asphalt and Concrete Costs
1978-2017

AC/PCC cost ratio

Year

Hauling our road materials damages the roads
Projected Growth in Freight Ton and Values 2012 to 2040

- Freight mass throughput +47%, value +95%
- Demolition, gasoline, gravel and crushed stone, crude oil

<table>
<thead>
<tr>
<th>Top 2012 Commodities</th>
<th>Weight (in ktons)</th>
<th>Share</th>
<th>Top 2040 Commodities</th>
<th>Weight (in ktons)</th>
<th>Share</th>
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</thead>
<tbody>
<tr>
<td>Waste and scrap</td>
<td>214,845</td>
<td>15.9%</td>
<td>Waste and scrap</td>
<td>275,456</td>
<td>13.9%</td>
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<td>Gasoline</td>
<td>147,106</td>
<td>10.9%</td>
<td>Nonmetallic mineral products</td>
<td>207,374</td>
<td>10.5%</td>
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<td>Nonmetallic mineral products</td>
<td>140,453</td>
<td>10.4%</td>
<td>Gravel and crushed stone</td>
<td>168,448</td>
<td>8.5%</td>
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<tr>
<td>Gravel and crushed stone</td>
<td>124,133</td>
<td>9.2%</td>
<td>Gasoline</td>
<td>138,305</td>
<td>7.0%</td>
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<td>Crude petroleum</td>
<td>86,022</td>
<td>6.4%</td>
<td>Other agriculture products</td>
<td>126,523</td>
<td>6.4%</td>
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<tr>
<td>Other agriculture products</td>
<td>63,217</td>
<td>4.7%</td>
<td>Crude petroleum</td>
<td>100,427</td>
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<td>Natural sands</td>
<td>54,886</td>
<td>4.1%</td>
<td>Other foodstuffs</td>
<td>82,896</td>
<td>4.2%</td>
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<tr>
<td><strong>2012 All Commodity Total</strong></td>
<td>1,351,574</td>
<td></td>
<td><strong>2040 All Commodity Total</strong></td>
<td>1,980,491</td>
<td></td>
</tr>
</tbody>
</table>

*Source: FHWA Freight Analysis Framework Summary Statistics*
How do Pavements Contribute to California GHG Emissions?

- Out of 459 MMT CO2e in 2013
  - On road vehicles 155 MMT
    - Optimizing smoothness, texture, deflection energy on state network reduces by 1% of this
  - Refineries 29 MMT
    - Paving asphalt about 1% of refinery production
  - Cement plants 7 MMT
    - Paving cement about 5% of cement plant production
  - Commercial gas use 13 MMT
    - Very small amounts for asphalt mixing plants
  - Mining 0.2 MMT
    - Large portion for aggregate mining

http://www.arb.ca.gov/cc/inventory/data/data.htm

Possible Pavement Reductions MMT/year

- Rolling resist to optimum 1.5
- Cement use 50% 0.2
- Asphalt use 50% 0.7
- Demo, oil, stone haul 10% 0.6

TOTAL 2.9
Air Pollution Toxicity

- Transportation related factor of most importance is air pollution, especially diesel trucks
  - Requiring changes in vehicle fuel sources

http://graphics.latimes.com/responsivemap-pollution-burdens/

Air Pollution Toxicity

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✓ Requiring changes in vehicle fuel sources

http://graphics.latimes.com/responsive.map-pollution-burdens/

Pavement Materials Resource Depletion and Replacement

• Aggregate:
  – Local future shortages and quality issues
  – Large quantities of aggregate moved on the roads, lots of fuel, high levels of damage

• Bitumen:
  – US: supply and demand balanced, because large amounts of asphalt are coked for liquid fuels
  – Europe: oversupply of asphalt?
  – If oil demand for transportation fuel diminishes, there is a nearly infinite future supply of asphalt
Pavement Materials Resource Depletion and Replacement

• Cement
  – Fly ash from coal burning reduces CO2 in concrete, reduces ASR
  – Main fly ash sources for California closing
  – Transportation distances long for other sources
  – Market is 0.7 to 1.1 MMT per year
  – Need natural pozzolans with low CaO

Caltrans/industry fly ash shortage report 2016
US Energy Information Agency
### Environmental Facts

<table>
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<tr>
<th>Environmental Impact</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Primary Energy Demand [MJ]</td>
<td>$4.0 \times 10^3$</td>
</tr>
<tr>
<td>Non-renewable [MJ]</td>
<td>$3.9 \times 10^3$</td>
</tr>
<tr>
<td>Renewable [MJ]</td>
<td>$3.5 \times 10^2$</td>
</tr>
<tr>
<td>Global Warming Potential [kg CO$_2$-eq]</td>
<td>79</td>
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<tr>
<td>Acidification Potential [kg SO$_2$-eq]</td>
<td>0.23</td>
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<tr>
<td>Eutrophication Potential [kg N-eq]</td>
<td>0.012</td>
</tr>
<tr>
<td>Ozone Depletion Potential [kg CFC-11-eq]</td>
<td>$7.3 \times 10^{-9}$</td>
</tr>
<tr>
<td>Smog Potential [kg O$_3$-eq]</td>
<td>4.4</td>
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**Boundaries:** Cradle-to-Gate  
**Company:** XYZ Asphalt  
**RAP:** 10%

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**Environmental Product Declaration (EPD)**

- Pilot Caltrans program for requiring EPDs for concrete, asphalt, steel expected in 2018; many issues to resolve
- Within 5 years expect materials producers will be competing on impact + cost, as in Netherlands, France and soon Sweden, UK

Adapted from N. Santero
Climate Change and Air Pollution: diesel to natural gas then electric vehicles

• Natural gas trucks as 20 year bridge to electric
  – Trucks: Increase vehicle weight by 250 to 750 kg depending on range

• Electric vehicles
  – Cars: currently about 30% heavier for about 30% of the range
  – Trucks: small trucks available, tractors for semi-trucks under development; likely heavier than diesel
**Electric vehicles and weight**

- Range and battery technology control weight
- Trucks use same technologies as cars, more range = add more batteries
- Fuel cells questionable

DeMorro, 2015,
https://cleantechnica.com/2015/03/17/lighter-batteries-may-prove-tipping-point-electric-vehicles/
Long-haul truck shown at Tesla shareholders meeting June 2017

Tesla Semi to reach ‘scale production’ in ’18 to 24 months’ and will be unveiled with something unannounced, says Elon Musk

Fred Lambert - Jun. 7th 2017 5:26 am ET  "@FredericLambert"
Autonomous Vehicle Technology

- List of companies with autonomous vehicle testing permits in California (15 June 2017):
  - Volkswagen Group of America,
  - Mercedes Benz,
  - Waymo
  - Delphi Automotive
  - Tesla Motors
  - Bosch
  - Nissan
  - GM Cruise LLC
  - BMW
  - Honda
  - Ford
  - Zoox, Inc.
  - Drive.ai, Inc.
  - Faraday & Future Inc.
  - Baidu USA LLC
  - Wheego Electric Cars Inc.
  - Valeo North America, Inc.
  - NextEV USA, Inc.
  - Telenav, Inc.
  - NVIDIA Corporation
  - AutoX Technologies Inc
  - Subaru
  - Udacity, Inc
  - Navya Inc.
  - Renovo.auto
  - UATC LLC (Uber)
  - PlusAi Inc
  - Nuro, Inc
  - CarOne LLC
  - Apple Inc.
  - Bauer’s Intelligent Transportation
  - Pony.AI
  - TuSimple
  - Jingchi Corp
Autonomous Vehicle Technology

• Automated Vehicles Symposium 2017
  – One presentation that mentions infrastructure
• Infrastructure focus on detection and guidance, not pavement condition
• Will cause increase in car travel?

AGENDA

5 ways driverless cars will change our roads and highways
Our entire transportation infrastructure needs to move away from a design focus on human drivers

Barbara E. Ossman | 915.857.0841 | barbara@ossman.com

Twitter: @BarbaraOssman

Autonomous Vehicle Technology: effects on pavements

• Fully automated truck platooning expected to deploy starting 2020 and broad implementation by 2030
  – 3 to 13% fuel savings

• Asphalt surfaced pavement
  – Channelized traffic if wander is not programmed into guidance, faster rutting and fatigue
  – Truck platooning will reduce thixotropic recovery times at high speeds, larger strains

• Concrete surfaced pavement
  – Can program trucks off of the slab edge, lower stresses
  – Difficulties discerning marking paint
Recovery time and thixotropy

SANJ PG64-16 (1.4 percent strain)

Rest periods of 2, 5 and 10 times loading period
Information technology and pavement

• Freight and personal users will soon have better information about pavement and use it to make route decisions using cell phone apps:
  – Smoothest route
  – Least fuel use route
  – Least freight damage route

• Pavement roughness condition will soon be crowd-sourced to public and road owner with $500 systems
  – Can get IRI using calibrations like Class 1 profilers
Information Technology and Pavement

- Pavement tools need updated data and models, make them web-based, and connected to each other with same data
  - PMS
  - ME design systems
  - LCCA
  - LCA
- Update information routinely

Data

Need strong foundation to perform desired operations
Cost, Financing and Confidence in Government to Deliver Pavement Efficiently

- Tax increase
  - April 4 passed by legislature (2/3 majority)
  - April 28 signed
  - First increase since 1993
- $2.5 billion per year for state highways
- $2 billion for local roads

California gas tax increase is now law. What it costs you and what it fixes
Cost, Financing and Confidence in Government to Deliver Pavement Efficiently

Gas tax vote prompts recall campaign against Southern California Democrat

Initiative filed to repeal California gas tax increase

Main arguments:
• Government is wasteful in road spending
• Road taxes not spent on roads
• “Why can’t roads be made to last longer?”
• “Why are roads so expensive?”

• Negative reaction April 11 to June 15
Cost, Financing and Confidence in Government to Deliver Pavement Efficiently

• Poll taken June 8

If you don’t like California’s gas tax increase, you’re not alone
The Forgotten Half of Our Pavements

National $ Spent on Transportation in 2008 (US Census Bureau)

<table>
<thead>
<tr>
<th></th>
<th>STATE GOVERNMENT</th>
<th>LOCAL GOVERNMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>97,508,989</td>
<td>61,053,150</td>
</tr>
</tbody>
</table>

VEHICLE MILES TRAVELED (IN MILLIONS)

115,190, 35%
180,259, 55%
31,414, 10%

CENTERLINE MILES (IN MILLIONS)

75,208, 44%
15,160, 9%
13,537, 8%
65,166, 39%

LANE MILES (IN MILLIONS)

170,555, 45%
132,804, 35%
50,462, 13%
27,074, 7%
Urban pavements fail because of utilities

• Most urban pavements are scaled down highway pavements

• Invent new materials and structures to handle utilities?
Pavements are an important part of the urban environment

Sacramento

- Pavements: 39%
- Vegetation: 29%
- Roofs: 19%
- Other: 14%

Akbari et al. 2003 <doi:10.1016/S01692046(02)00165-2>
Other issues with current approach to urban pavement

- **Active transportation**
  - Street geometric and surface designs generally don’t consider it
  - Bike path and trails are scaled down highway pavement designs

- **Urban forests**
  - Impermeability
  - Pavement and root growth

- **Noise**
  - Tire pavement noise at higher speeds
  - Non-absorptive for noise
Pavements = urban hardscape not just roads and streets

- Stormwater management, groundwater infiltration
- Tire pavement noise
- Human thermal comfort
- Pedestrian and bicycle functionality
- Better interaction with urban forestry
Heat Budget on Human Body

Respiration heat $C_{res}$ and $E_{res}$

Sweat evaporative heat $E_{sw}$

Convention heat $C$

Net radiation $R$

$T_a, RH, SR, WS, SVF$

Direct solar radiation $I$

Diffuse reflected radiation $D$

Emitted radiation $E$

$M$ is the metabolic rate (W/m²). $W$ is the rate of mechanical work (W/m²). $S$ (W/m²) is the total storage heat flow in the body.
Thermal Impacts of Albedo and Reflection

More reflective asphalt? Thin reflective coatings for asphalt? Thin concrete with high SCM?

Wall, 52 °C
Asphalt (B1), 60 °C

13:00 8/15/2012

Wall, 55 °C
Concrete (C1), 45 °C
Status of local government pavement knowledge in California

• Agencies
  – Some agencies have some staff with university training in pavement; other agencies have no staff with university or other formal pavement training
  – Heavy reliance on consultants

• Consultants
  – Some have excellent staff
  – Many have no staff with university or other formal training

• Issues:
  – Old, poorly understood specifications, design methods
  – Construction quality control for most important issues: compaction, concrete mix designs
Jobs and Workforce

• Supply:
  – Are we producing enough pavement students?
  – Are students interested in pavement?
  – What today’s students want:
    • Solve important problems
    • Be able to use their creativity and skills
    • Have positive impact
    • This is same as other generations

• Demand:
  – Are government and industry prioritizing hiring students with pavement training, or generalists?
  – Are we making use of and rewarding pavement training?
  – Are we providing the environment to attract people?
Takeaways: do we have stationarity?

• Stationarity is not always true
  – Demands on pavements can change, potentially rapidly
  – People want more from pavement, and more people are involved in decision-making

• Changes in California
  – Number of trucks increasing rapidly
    • Especially last mile due to internet purchase deliveries
  – Electric vehicles and natural gas may increase loads some
  – Autonomous vehicles may cause important loading patterns in space and time
  – Increasing attention to local roads, multi-functionality
  – Users will soon have much better information about pavement and make decisions with it
  – Low willingness to pay for state-wide tax for pavement
Takeaways: what do our customers want?

• Pavements we deliver must do more:
  – More sustainable
  • Cost
  • Smooth
  • Construction delay
  • Small CO2e impacts, more important local effects

• Handle multiple modes and purposes in urban areas
  – Think of pavement as hardscape, not just for vehicles
    • Active transportation (bikes, walking)
    • Local thermal environment, tree-compatible pavement
    • Stormwater
    • Utilities
Takeaways: what do we need to do differently?

• Make pavement last longer for same cost, faster repairs
• Make all tools and data web-based for continuous update
• Deliver innovation and training that is developed to match the capabilities of the workforce
  – Do $5 of development for each $1 of research
  – Find solutions for local government
• Increase the capabilities of the work force, and put value on pavement knowledge in employment
• Think beyond asphalt vs concrete, think pavement
• Find a way to communicate to public about pavement
  – Rightly or wrongly, government is not seen as cost-effective deliverer of these services
  – Communicate the science and technology innovations
  – They are interested!
Change Management in Government: Obstacles

• Leaders are chosen based on command of policy, technical expertise, or political connections, not ability to lead change

• Leaders usually have limited time in office

• Rules in place to limit corruption also tend to limit flexibility

• Penalties for failure are always larger than any rewards for success

• In a democracy there are many stakeholders with different goals to manage

https://hbr.org/2006/05/change-management-in-government
Change Management in Government: Steps to Success

• Identify improved performance against mission as the fundamental objective of the transformation effort

• Win over internal and external stakeholders

• Create a road map
  – Vision, priorities, program
  – Make the road map a part of the culture of the organization

• Take a comprehensive approach
  – Leadership, structure, processes, infrastructure (including technology), people, and performance management

• Need leaders
  – Reward their efforts

Adapted from Frank Ostroff, Harvard Business Review, 2006
Change Management in Government: Communicating with the Public

• What is our message about what is being done that is positive and better

• Livability and Quality of Life, relate to people’s lives
  – Access by different modes, shared prosperity, environmental impact, public participation, safe and healthy communities, wise use of resources

• Relate to people’s pocketbooks

• Set goals and measure and report progress

• Have the right messengers
  – Trusted messengers who are informed about pavement progress, not necessarily pavement engineers!
California Pavement Research Road Map Areas

• Design, materials and construction
  – Mechanistic-empirical design
  – Performance based specifications
  – Construction quality

• Environmental, maintenance
  – Recycling technologies
  – Life cycle assessment (LCA)

• Maintenance
  – Preservation technologies
  – Pavement management
    • Pavement management system (PMS)
    • Life cycle cost analysis (LCCA)
**Communication of pavement road map**

- Entire program communicated in plain language on two A3 pages

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**Caltrans Division of Research, Innovation and Systems Information and UC Pavement Research Center**

#### Prioritized Topics

<table>
<thead>
<tr>
<th>Design, Materials &amp; Construction</th>
<th>Envisional</th>
<th>Maintenance</th>
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<tbody>
<tr>
<td><strong>Mechanical-Empirical Design</strong></td>
<td><strong>Environmental</strong></td>
<td><strong>Pavement Management</strong></td>
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<tr>
<td>Test and Include additional regional materials for Caltrans ME Standard Material Guidelines (SPE 4.05, TID 2711)</td>
<td>Continue tools and monitoring of a few selected projects (SRQ) pilot for which monitoring began in 2015/16</td>
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<tr>
<td>Include procedures for standardization of testing and communication of results to the public</td>
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<tr>
<td><strong>Performance-Based Specifications</strong></td>
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**Caltrans Program Areas**

- Communication of pavement road map
- Entire program communicated in plain language on two A3 pages

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</table>
Research arc in detailed road maps for each subject area

<table>
<thead>
<tr>
<th>Concept</th>
<th>Research</th>
<th>Development</th>
<th>Implementation</th>
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<tbody>
<tr>
<td>LA Districts, TRB, and UCPRC Conceptualization -1997-2000</td>
<td>Development of Construction Work Zone Traffic Analysis - Paramics, FREQ, HDM - Selection of approach -2001</td>
<td>Extension of new treatments in CA4PRS -V-2.5, 2010</td>
<td>Reestablish district competency and maintain; training new PAVIA version</td>
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<td></td>
<td>Development of emission model for construction work zones</td>
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<td>Training in Districts and industries in need</td>
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<td></td>
<td>Safety analysis</td>
<td>Integration of construction productivity construction stage LCA outputs</td>
<td>Develop guidance and manual for improving construction productivity and Construction Work Zone Traffic</td>
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<td></td>
<td>Conceptual schedule estimation</td>
<td>Validate emission models for Construction Work Zone traffic</td>
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<td></td>
<td>Updating risk analysis</td>
<td>Collect new construction productivity data</td>
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<td>Develop material staging algorithms and optimization</td>
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<td></td>
<td>Development of emission for materials and equipment usage</td>
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<tr>
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<td>Update and calibrate construction Work Zone traffic analysis</td>
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Local Government: the forgotten 50%

State and federally funded research and development for highways

Technical Advisory Group: League of Cities, Association of Counties

Partnered with teaching universities

Modeled on Minnesota, Iowa programs

Training, development of appropriate technology, specialized research for local governments
<table>
<thead>
<tr>
<th>Construction Scenario</th>
<th>Schedule Comparison</th>
<th>Cost Comparison ($M)</th>
<th>Max. Peak Delay (Min)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Total Closures</td>
<td>Closure Hours</td>
<td>User Delay</td>
</tr>
<tr>
<td>1 Roadbed Continuous</td>
<td>2</td>
<td>400</td>
<td>5.0</td>
</tr>
<tr>
<td>72-Hour Weekday Continuous</td>
<td>8</td>
<td>512</td>
<td>5.0</td>
</tr>
<tr>
<td>55-Hour Weekend Continuous</td>
<td>10</td>
<td>550</td>
<td>10.0</td>
</tr>
<tr>
<td>10-Hour Night-time Closures</td>
<td>220</td>
<td>2,200</td>
<td>7.0</td>
</tr>
</tbody>
</table>
I-15 Devore Web-Surveys
Public Perception Changes

**Before-construction**

- No, Cancel project: 14%
- Continuous closures: 7%
- Negative Other: 11%
- Adding lane: 4%
- No, Nighttime or weekend: 64%

**After-construction**

- Yes: 70%
- No: 30%

*Do you support 72-h (3-weekday) Weekday closures?* 

*Do you support future “Rapid-Rehab” projects?*
Expectations for Transportation Segment of the Economy

S. David Freeman
UCLA Seminar: Infrastructure Investment for Sustainable Growth (October, 2010)

– Transportation sector about to enter a period of profound change similar to energy sector in 1970s and 1980s
– Regulations will be implemented requiring increasing energy efficiency and environmental performance
– Transformation necessary to maintain economic competitiveness of US

– We are no longer rich enough to make many mistakes and still be able to achieve our goals
– I would add: we need to better focus our research, translate our results into practice, and communicate to the public to achieve our goals
Thanks to many colleagues

Questions?