Road Design

TTP Orientation Seminar
November 2008
Productive Capital Stocks
Interstate, Non-interstate State & Local Systems
Billions of 2000$'s
1921-2005

Productive Highway Capital Stocks
and the
Contribution of Highways to Growth in GDP
Volume I
Barbara M. Fraumeni
Capital Outlays for Highways in US

[Graph showing millions of constant 2000 dollars over years from 1956 to 1998]
Highway Capital Outlay and GDP in 2000$\text{s}
Rates of Growth 1950-2005

Productive Highway Capital Stocks
and the
Contribution of Highways to Growth in GDP
Volume I
Barbara M. Fraumeni
Total Kilometers of All Roads and Urban Roads in the US

![Graph showing the total kilometers of all roads and urban roads in the US over time. The graph includes a note indicating a change in data collection method in 1977.](image-url)
<table>
<thead>
<tr>
<th>State</th>
<th>State gas excise tax</th>
<th>Other state taxes*</th>
<th>State tax total</th>
<th>State + federal tax total</th>
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</thead>
<tbody>
<tr>
<td>California</td>
<td>18.0</td>
<td>26.4 (7.25% + 1.2)</td>
<td>44.4</td>
<td>62.8</td>
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<tr>
<td>Connecticut</td>
<td>25.0</td>
<td>8.9 (7%)</td>
<td>43.9</td>
<td>62.3</td>
</tr>
<tr>
<td>New York</td>
<td>8.0</td>
<td>32.9</td>
<td>40.9</td>
<td>59.3</td>
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<tr>
<td>Washington</td>
<td>37.5</td>
<td>0</td>
<td>37.5</td>
<td>55.9</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>27.0</td>
<td>4.0</td>
<td>31.0</td>
<td>49.4</td>
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<tr>
<td>Maine</td>
<td>27.6</td>
<td>1.5</td>
<td>29.1</td>
<td>47.5</td>
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<tr>
<td><strong>U.S. Average</strong></td>
<td><strong>18.2</strong></td>
<td><strong>10.4</strong></td>
<td><strong>28.6</strong></td>
<td><strong>47</strong></td>
</tr>
<tr>
<td>Massachusetts</td>
<td>21.0</td>
<td>2.5</td>
<td>23.5</td>
<td>41.9</td>
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<tr>
<td>Vermont</td>
<td>19.0</td>
<td>1.0</td>
<td>20.0</td>
<td>38.4</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>18.0</td>
<td>1.6</td>
<td>19.6</td>
<td>38.0</td>
</tr>
<tr>
<td>New Jersey</td>
<td>10.5</td>
<td>4.0</td>
<td>14.5</td>
<td>32.9</td>
</tr>
<tr>
<td>Alaska</td>
<td>8.0</td>
<td>0</td>
<td>8.0</td>
<td>26.4</td>
</tr>
<tr>
<td><strong>US Average diesel</strong></td>
<td></td>
<td></td>
<td><strong>24.4</strong></td>
<td><strong>53.6</strong></td>
</tr>
</tbody>
</table>

* (general sales tax, average county/local sales tax, environmental fees, wholesale taxes) Fed tax = 18.4 cents/gal
Topics

• Network design
• Facility design
• Pavement and materials
Network Design

• What are the two main purposes of streets/roads/highways?
• What’s the main difference between streets vs. roads vs. highways?
Fig. 21—Plan of the residential districts, dated November 1929.
preliminary studies for a
GENERAL PLAN for the city of
City of Sunnyvale, 1957
ITE Street Layout Principles, 1984

FIGURE 1. Illustration of Layout Principles
City of Austin, Comprehensive Plan, 1994
Benefits of grid…?

• More direct routes
  – Less distance
    • Less driving (?)
      – Less pollution, energy consumption, noise, etc.
    • More walking/biking
      – More exercise, less weight, better health, etc.
  – Better efficiency
    • Emergency response time
    • City services
Figure 4.1. Eugene’s Block Requirements

Block length is defined as the distance along a street between the centerline of two intersecting through streets, including “T” intersections, but excluding cul-de-sacs.

Source: Eugene Local Street Plan, 1996.

Source: Handy, Paterson, and Butler 2003
Figure 4.2. Calculation of Connectivity Index in Cary, NC

The measure of connectivity is the number of street links divided by the number of nodes. Nodes exist at street intersections as well as cul-de-sac heads. Links are the stretches of road that connect nodes. Stub outs shall also be considered as links.

In this example, there are 11 links (circles) and 9 nodes (stars); therefore, the connectivity index is 1.22.


Source: Handy, Paterson, and Butler 2003
Table 4.1. Summary of Requirements for Intersection Spacing and Cul-de-Sacs

<table>
<thead>
<tr>
<th>Block Length Cities</th>
<th>Max Intersection Spacing for Local Streets (feet)</th>
<th>Max Intersection Spacing for Arterials</th>
<th>Are Street Stubs Required?</th>
<th>Are Cul-de-Sacs Allowed?</th>
<th>Max Cul-de-Sac Length? (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metro, OR</td>
<td>530</td>
<td>530</td>
<td>No</td>
<td>No w/exceptions</td>
<td>200</td>
</tr>
<tr>
<td>Portland, OR</td>
<td>530</td>
<td>530</td>
<td>Yes</td>
<td>No w/exceptions</td>
<td>300</td>
</tr>
<tr>
<td>Beaverton, OR</td>
<td>660</td>
<td>1,000</td>
<td>Yes</td>
<td>No w/exceptions</td>
<td>200</td>
</tr>
<tr>
<td>Eugene, OR</td>
<td>600</td>
<td>None</td>
<td>Yes</td>
<td>No w/exceptions</td>
<td>400</td>
</tr>
<tr>
<td>Fort Collins, CO</td>
<td>(1)</td>
<td>660 - 1,320 (2)</td>
<td>Yes</td>
<td>Limited</td>
<td>660</td>
</tr>
<tr>
<td>Boulder, CO</td>
<td>(3)</td>
<td>None</td>
<td>Yes</td>
<td>Yes, discouraged</td>
<td>600</td>
</tr>
<tr>
<td>Huntersville, NC</td>
<td>250 - 500</td>
<td>No data</td>
<td>Yes</td>
<td>No w/exceptions</td>
<td>None</td>
</tr>
<tr>
<td>Cornelius, NC</td>
<td>200 - 1,320</td>
<td>(4)</td>
<td>Yes</td>
<td>No w/exceptions</td>
<td>250</td>
</tr>
<tr>
<td>Raleigh, NC</td>
<td>1,500 (5)</td>
<td>No data</td>
<td>Yes</td>
<td>Yes</td>
<td>400 - 800 (6)</td>
</tr>
<tr>
<td>Conover, NC</td>
<td>400 - 1,600</td>
<td>No data</td>
<td>Yes</td>
<td>Yes</td>
<td>500</td>
</tr>
</tbody>
</table>

Connectivity Index

<table>
<thead>
<tr>
<th>Cities</th>
<th>Index</th>
<th>Max Intersection Spacing (feet)</th>
<th>Are Street Stubs Required?</th>
<th>Are Cul-de-Sacs Allowed?</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middletown, DE</td>
<td>1.4</td>
<td>None</td>
<td>Yes</td>
<td>Yes, discouraged</td>
<td>1,000</td>
</tr>
<tr>
<td>Cary, NC</td>
<td>1.2</td>
<td>1,250 - 1,500</td>
<td>Yes</td>
<td>Yes</td>
<td>900</td>
</tr>
<tr>
<td>Orlando, FL (7)</td>
<td>1.4</td>
<td>None</td>
<td>Yes</td>
<td>Yes</td>
<td>700 (30 units)</td>
</tr>
</tbody>
</table>

Notes:
1. Maximum block size is 7 to 12 acres, depending on zoning district.
2. Limited movement intersections required every 660 feet; full movement intersections required every 1,320 feet.
3. Not specified by code, but staff tries to achieve 300 to 350 foot spacing.
4. Intersection spacings on arterials is regulated by the state Department of Transportation.
5. Requirements in place for Southeast Sector and under consideration for rest of city.
6. Within a Mixed-Use Center, no street block face shall exceed 660 feet in length.
7. 400 ft in residential areas, 800 ft in commercial areas; Transportation Director may approve up to 10% longer.

Source: Handy, Paterson, and Butler 2003
<table>
<thead>
<tr>
<th>Block Length Cities</th>
<th>Max Spacing Between Bike/Ped Connections (feet)</th>
<th>Local Street Widths (Paved, in feet)</th>
<th>Are Private Streets Allowed?</th>
<th>Are Gated Streets Allowed?</th>
<th>Strategies to Address Cut-Through Traffic (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metro, OR</td>
<td>330</td>
<td>&lt; 28 encouraged</td>
<td>(2)</td>
<td>(2)</td>
<td>None</td>
</tr>
<tr>
<td>Portland, OR</td>
<td>330</td>
<td>20 - 32</td>
<td>Limited</td>
<td>No</td>
<td>Not related</td>
</tr>
<tr>
<td>Beaverton, OR</td>
<td>330</td>
<td>25.5 minimum</td>
<td>No, waivers</td>
<td>No</td>
<td>May require traffic calming.</td>
</tr>
<tr>
<td>Eugene, OR</td>
<td>(3)</td>
<td>20 - 34</td>
<td>Limited</td>
<td>Limited</td>
<td>Narrow streets, calming if nec.</td>
</tr>
<tr>
<td>Fort Collins, CO</td>
<td>700</td>
<td>24 - 36</td>
<td>Limited</td>
<td>No</td>
<td>Not related</td>
</tr>
<tr>
<td>Boulder, CO</td>
<td>(4)</td>
<td>24 - 36</td>
<td>No</td>
<td>No</td>
<td>Narrow streets and site design</td>
</tr>
<tr>
<td>Huntersville, NC</td>
<td>None</td>
<td>18 - 26</td>
<td>No</td>
<td>No</td>
<td>Avoid long, straight streets</td>
</tr>
<tr>
<td>Comelius, NC</td>
<td>None</td>
<td>18 - 26</td>
<td>Yes</td>
<td>No</td>
<td>On-street parking, narrow streets</td>
</tr>
<tr>
<td>Raleigh, NC</td>
<td>None</td>
<td>26</td>
<td>Limited</td>
<td>Discouraged</td>
<td>Narrow streets</td>
</tr>
<tr>
<td>Conover, NC</td>
<td>None</td>
<td>22</td>
<td>No</td>
<td>No</td>
<td>Avoid long, straight streets</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Connectivity Index Cities</th>
<th>Max Spacing Between Bike/Ped Connections (feet)</th>
<th>Local Street Widths (Paved, in feet)</th>
<th>Are Private Streets Allowed?</th>
<th>Are Gated Streets Allowed?</th>
<th>Strategies to Address Cut-Through Traffic (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middletown, DE</td>
<td>No data</td>
<td>24 - 32</td>
<td>No</td>
<td>No</td>
<td>Narrow streets and trees</td>
</tr>
<tr>
<td>Cary, NC</td>
<td>If index waive: 27</td>
<td>Yes</td>
<td>No</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Orlando, FL (8)</td>
<td>None</td>
<td>24 minimum</td>
<td>Yes</td>
<td>No</td>
<td>Design features, traffic calming</td>
</tr>
</tbody>
</table>

Notes:
(1) Traffic calming incorporated into connectivity requirements; city may have separate traffic calming program.
(2) Not regulated.
(3) No maximum distance, but each development must have a plan showing pedestrian connectivity, including connections to cul-de-sacs.
(4) No requirements, but staff suggests spacing similar to local streets (300 to 350 feet).
(5) Requirements in place for Southeast Sector and under consideration for rest of city.

Source: Handy, Paterson, and Butler 2003
Facility Design

• Responsibility for building:
  – City/County: local streets, collectors, arterials
  – State: highways, freeways

• Influence on professional practice:
  – Institute of Transportation Engineers (ITE)
  – American Association of State Highway and Transportation Officials (AASHTO)
Guidelines for Residential Subdivision Street Design

A Recommended Practice
of the Institute of Transportation Engineers

http://www.ite.org/bookstore/RP-011C.pdf
FIGURE 1. Typical Cross Section
1 ft = 0.3 m

http://www.ite.org/bookstore/RP-011C.pdf
## Table 2
Collector Street Design Guidelines

<table>
<thead>
<tr>
<th>Reference Number</th>
<th>Terrain Classification</th>
<th>Development Density</th>
<th>Right-of-Way Width (feet)</th>
<th>Pavement Width (feet)</th>
<th>Type of Curb</th>
<th>Sidewalk Width (feet)</th>
<th>Sidewalk Distance from Curb Face (feet)</th>
<th>Minimum Sight Distance (feet)</th>
<th>Maximum Grade</th>
<th>Minimum Spacing Along Major Traffic Route (feet)</th>
<th>Design Speed (mph)</th>
<th>Minimum Centerline Radius (feet)</th>
<th>Minimum Tangent Between Reverse Curves (feet)</th>
<th>Street Lighting</th>
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</thead>
<tbody>
<tr>
<td>2.04.01.</td>
<td></td>
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<td></td>
<td></td>
<td>35</td>
<td>480</td>
<td>100</td>
<td>See Discussion</td>
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<td>2.04.02.</td>
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<td>Development Density</td>
<td>Right-of-Way Width (feet)</td>
<td>Pavement Width (feet)</td>
<td>Vertical Face</td>
<td>4-6</td>
<td>250</td>
<td>4%</td>
<td>1,300</td>
<td>25</td>
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<td>4-6</td>
<td>24-36</td>
<td>4%</td>
<td>1,300</td>
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<td>24-36</td>
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<td>24-36</td>
<td>4%</td>
<td>1,300</td>
<td>25</td>
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<td>24-36</td>
<td>4%</td>
<td>1,300</td>
<td>25</td>
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<td>Pavement Width (feet)</td>
<td>Vertical Face</td>
<td>4-6</td>
<td>24-36</td>
<td>4%</td>
<td>1,300</td>
<td>25</td>
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<td>Vertical Face</td>
<td>4-6</td>
<td>24-36</td>
<td>4%</td>
<td>1,300</td>
<td>25</td>
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<td>Development Density</td>
<td>Right-of-Way Width (feet)</td>
<td>Pavement Width (feet)</td>
<td>Vertical Face</td>
<td>4-6</td>
<td>24-36</td>
<td>4%</td>
<td>1,300</td>
<td>25</td>
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<td>Development Density</td>
<td>Right-of-Way Width (feet)</td>
<td>Pavement Width (feet)</td>
<td>Vertical Face</td>
<td>4-6</td>
<td>24-36</td>
<td>4%</td>
<td>1,300</td>
<td>25</td>
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<td>Vertical Face</td>
<td>4-6</td>
<td>24-36</td>
<td>4%</td>
<td>1,300</td>
<td>25</td>
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<td>4-6</td>
<td>24-36</td>
<td>4%</td>
<td>1,300</td>
<td>25</td>
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<td>Vertical Face</td>
<td>4-6</td>
<td>24-36</td>
<td>4%</td>
<td>1,300</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td>See Discussion</td>
</tr>
</tbody>
</table>

*a Assumes no superelevation - see discussion.*

http://www.ite.org/bookstore/RP-011C.pdf
Residential Neighborhood Street
Parallel Parking One Side

Residential Neighborhood Street
Parallel Parking Both Sides

Source: http://www.ashland.or.us/Files/street%20standards_001.pdf
Innovations/Trends

• Traffic Calming
• Skinny Streets
• “Complete the Streets”
• Others…
"Traffic calming is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior and improve conditions for non-motorized street users."

- ITE Subcommittee on Traffic Calming
### Speed Control Measures

<table>
<thead>
<tr>
<th>Vertical Deflection</th>
<th>Horizontal Deflection</th>
<th>Horizontal Narrowing</th>
<th>Other Measures</th>
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<tbody>
<tr>
<td>Speed Humps</td>
<td>Traffic Circles</td>
<td>Neckdowns</td>
<td>Examples</td>
</tr>
<tr>
<td>Speed Tables</td>
<td>Roundabouts</td>
<td>Center Island Narrowings</td>
<td></td>
</tr>
<tr>
<td>Raised Crosswalks</td>
<td>Chicanes</td>
<td>Chockers</td>
<td></td>
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<tr>
<td>Raised Intersections</td>
<td>Realigned Intersections</td>
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<tr>
<td>Textured Pavements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed Lumps *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed Cushion *</td>
<td></td>
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<tr>
<td>Split Speed Hump *</td>
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### Volume Control Measures

<table>
<thead>
<tr>
<th>Divertive, Restrictive</th>
<th>Other Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Closures</td>
<td>Examples</td>
</tr>
<tr>
<td>Half Closures</td>
<td></td>
</tr>
<tr>
<td>Diagonal Diversers</td>
<td></td>
</tr>
<tr>
<td>Lateral Shift *</td>
<td></td>
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<tr>
<td>Median Barriers</td>
<td></td>
</tr>
</tbody>
</table>

http://www.trafficcalming.org/measures2.html
Traffic Circles

Roundabouts

http://www.trafficcalming.org/measures2.html
Chicanes

Neckdowns

http://www.trafficcalming.org/measures2.html
Narrow Street Scenarios

28 Ft Street
Parking on both sides

24 Ft Street
Parking on one side

20 Ft Street
No on-street parking allowed

Narrow Streets (any downside?)

Canyon Rim Village, Medford

Let’s Complete America’s Streets!

http://www.completestreets.com/early.html
a policy on

Geometric Design of Highways and Streets

2004

American Association of State Highway and Transportation Officials
Pavements
Pavement Life Cycle

• Infrastructure Life Cycle
  – Deployment
  – Maintenance
  – Rehabilitation
  – Reconstruction (Abandonment? Reuse?)

• Goal at all stages is greater efficiency
  – how is efficiency defined?
<table>
<thead>
<tr>
<th>Years</th>
<th>Infrastructure</th>
<th>Pavement Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970-2050</td>
<td>Management</td>
<td>M &amp; R Scheduling, Condition Assessment</td>
</tr>
<tr>
<td>Years</td>
<td>Infrastructure</td>
<td>Pavement Research</td>
</tr>
<tr>
<td>------------</td>
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</tr>
<tr>
<td>1995-2025</td>
<td>Reconstruction</td>
<td>Reconstruction, Materials Optimization, Traffic Considerations, ReDesign</td>
</tr>
<tr>
<td>2010-2050</td>
<td>Sustainability</td>
<td>Materials ReUse, Vehicle/Pavement Interaction, New Materials, Information Technology Integration</td>
</tr>
</tbody>
</table>
Is There a Pattern?
Continued expansion of the system boundaries in which pavement problems are defined

Materials
Pavement
Pavement Network
Transportation Facility Network
Sustainable Transportation Infrastructure System
Pavement Types

• Asphalt Concrete Surface
  – Granular bases
  – Subgrade
• Concrete Surface
  – Various bases
  – Subgrade
• Surface Treatment
  – Thin sprayed asphalt on granular bases
• Permeable Pavement
  – Open graded asphalt or concrete layers, open granular layers, on uncompacted subgrade
What Causes Pavement Distress?

- Traffic
- Environment
- Interaction of traffic/environment, construction quality, materials, design
California: 1912

Australia: 1914
Traffic Variables

Highways - it’s the trucks

• Loads
• Tire pressures
• Speeds
• Dynamics (interaction with roughness)
• Which are most important?
• One fully loaded truck pass causes same damage as about 5,000 passes of an SUV
Traffic

• Measurement of traffic
  – counts
  – load measurements

• Prediction of future traffic
  – growth factors for vehicle repetitions
  – will load limits change on highways?
  – are your loads controlled?
Big Truck - 1960
Big Truck - 2001
Super Single Tires
Australian for “truck”

“Road Train”
Local Government Pavement Design

• Some agencies
  – Standard cross sections and materials
  – Little or no construction inspection (particularly compaction)
  – No money for testing and analysis

• Other agencies
  – Design for particular traffic, environment, soils
  – Good construction inspection
  – Testing and analysis (is there a net cost savings?)

• Standard specifications and design methods
  – Greenbook (mostly in S. California)
  – Use of state specifications (much of N. California, joint powers financing, federally funded projects)
  – Use of consultants
What are Pavements Made Of? and will this change?

• Most pavements are made of engineered soils and processed rock
• Asphalt concrete is 85% aggregate by volume; 10% asphalt; some plastic, rubber modifiers
• Portland cement concrete is 70% aggregate by volume; 11% portland cement; up to 25% of cement replaced by fly ash; some steel

• Nearly all of these materials can be perpetually recyclable into the same infrastructure
Fifty-Year Aggregate Demand Compared to Permitted Aggregate Resources

The pie diagrams show the projected 50-year demand for aggregate as of January 2006 compared to currently permitted aggregate resources (in short tons). The 50-year demand for a particular study area is graphically represented by one of four pie diagram sizes. Study area boundaries are shown on the index map of aggregate studies (lower left).

*Permitted aggregate resources (also called aggregate reserves) are those portions of resources for which state and local agencies have granted mining permits. Examination of aggregate resource information gives in each aggregate study report. See accompanying text for references to these reports.
Pavements: will the demand for them increase or decrease?

Pavements sorted by transportation mode
- Streets, roads, highways, freeways, parking
- Railroads, switching yards, intermodal yards
- Runways, taxiways, aprons
- Land-side port facilities, container yards
- Bike paths, sidewalks, other hardscape
What is the impact on pavements of efforts to improve sustainability?

- Vehicle fuel economy and fuel type will change
- Fuel type change impact on available materials?
- Fuel economy change impact on functional and structural requirements?
  - Smoothness requirements
    - Impacts on product life cycle and waste
  - Pneumatic tire loads and inflation pressures
  - Operating speeds and suspension systems
  - Repetitions
How can the environmental impact of pavements be reduced?

- Understand the pavement life cycle
- Identify environmental costs
- Consider environmental costs in decision-making
- Identify how to reduce environmental costs considering interactions with other systems
- Determine how to make new methods standard practice
Some basic good practices

• Minimize the annual use of new materials
  – Perpetual reuse
  – Make materials/pavements last longer
  – Thinner pavements

• Reduce the environmental costs of new materials and recycling
  – Local materials
  – Reduce energy needs
  – Low-impact materials

• Reduce the delay associated with construction
Caltrans Funded UCPRC Research

Sustainability Issues:
- Nonrenewable fuel depletion
- Greenhouse gas emissions
- Global climate change
- Local air quality

Projects:
- Modified Binders
- Deep In Situ Recycling
  - Foamed asphalt
  - Pulverization
- Warm Mix Asphalt
Deep In-Situ Recycling

Cracked AC repeated overlays
Granular layers
Subgrade

gind

New AC Overlay
Recycled Layer
Remaining Granular
Subgrade

Currently developing project selection, mix design and construction guidelines
New pulverization and in-place stabilization equipment
Warm mix asphalt

• Additives to asphalt concrete
  – reduce temperature for effective compaction of asphalt concrete

• Advantages:
  – Better compaction in cold weather
  – Reduced energy costs
  – May reduce emissions

• Possible disadvantages:
  – May increase risk of rutting, moisture damage
Asphalt paving with conventional mix
Same project with Warm Mix Asphalt
Caltrans Funded UCPRC Research

Sustainability Issues:
- Congestion
- Low mobility
- Fatalities and injuries

Projects: CA4PRS
- Faster construction from innovative scheduling;
  • Shorter closures
  • Less traffic delay
  • Fewer accidents
Los Angeles Basin Freeway Network

Santa Monica
San Fernando Valley
Los Angeles

Santa Monica
San Fernando Valley
Los Angeles

San Bernardino
Riverside

Ports of LA, Long Beach
Orange County

concrete pavements to be rebuilt 2000-2015
project lengths 2 to 50 km
I-710 Traffic Detour Plan - Simulation Boundary
Simulation Before Construction
I-710 Reduction of Pavement Thickness Using Mechanistic Design

**Conventional design**
- 535 mm thick asphalt concrete
- 8 % air-voids, same mix design throughout

**Mechanistic design**
- 75 mm PBA-6a
- 125 mm, 5 % air-voids, AR-8000
- 75 mm, Rich Bottom
CA4PRS: Case Study on I-15 Devore Reconstruction Project
<table>
<thead>
<tr>
<th>Construction Scenario</th>
<th><strong>Schedule Comparison</strong></th>
<th><strong>Cost Comparison ($M)</strong></th>
<th>Max. Peak Delay (Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Closures</td>
<td>Closure Hours</td>
<td>User Delay</td>
</tr>
<tr>
<td>One Roadbed Continuous (24/7)</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>
Caltrans Funded UCPRC Research

Sustainability Issues:
- Life Cycle Analysis

Projects:
- Long-life pavement design
- Comparison of life cycle environmental costs for 20, 40 and 100 year pavement design lives using PaLATE
CO₂ Payback Period
Using Life Cycle Analysis

• Savings are not immediately realized
  – Payback ~30-45 years in the future
• Future is highly uncertain
  – Technological advancements
  – Uncertain demand
• What’s the right analysis period?