U.S. Roadway Infrastructure

- 2,674,821 miles paved
- 1,417,901 miles unpaved

Forty-two percent of America’s major urban highways remain congested, costing the economy an estimated $101 billion in wasted time and fuel annually. While the conditions have improved in the near term, and Federal, state, and local capital investments increased to $91 billion annually, that level of investment is insufficient and still projected to result in a decline in conditions and performance in the long term. Currently, the Federal Highway Administration estimates that $170 billion in capital investment would be needed on an annual basis to significantly improve conditions and performance.
Economics of Roadbuilding

- Estimates according to ARTBA
  - Construct new 2-lane undivided road
    - $2-$3 million per mile in rural areas
    - $3-$5 million in urban areas
  - Construct a new 4-lane highway
    - $4-$6 million per mile in rural and suburban areas
    - $8-$10 million per mile in urban areas
  - Construct a new 6-lane Interstate highway
    - $7 million per mile in rural areas
    - $11 million or more per mile in urban areas
  - Expand an Interstate Highway from 4 lanes to 6 lanes – about $4 million per mile
  - Mill and resurface a 4-lane road – about $1.25 million per mile

http://www.artba.org/about/transportation-faqs/
Evolution of Pavement Thickness Design

Pre 1950’s Experience

1960’s Development of Empirical Methods

1980’s Initial Mechanistic-Empirical Methods

1990’s NCRHP 1-37A M-E Design

2000’s Implementation of M-E Methods
Empirical Flexible Pavement method

\[ \log \left( \frac{\Delta \text{PSI}}{4.2 - 1.5} \right) \] 
\[ = \frac{1094}{0.4 + \frac{1094}{(S + Z)^{5.19}}} \] 
\[ + 2.32 \log M_R - 8.07 \]

Figure 23. Test vehicles, showing typical axle arrangements and loadings.

Figure 26. During periods of adverse weather traffic operations were governed by safety considerations. Snow and ice conditions usually resulted in operating at reduced speeds.

Figure 92. Automatic batch-type plant used to produce binder course mixture; dryers in tandem.
Flexible Pavement Design Curves

Figure 23. Main factorial experiment, relationship between design and axle load applications at $p = 1.5$ (from Road Test equations).

HRB, 1962

Extrapolation
Mechanistic-Empirical Pavement Design
AASHTO M-E Design Software

Database/Enterprise Login
- Open ME Design with database connection.
- Login: mcr0010
- Password:
- Instance:

About Pavement ME Design
- AASHTOWare® Mechanistic-Empirical Pavement Design
- Copyright: AASHTOWare® 2013
- License status: Standard (Expires at July 1, 2015)
- Version 2.0, Build 2.0.19, Date: 01/23/2014
- Reset ME Design to default screen position

OK Cancel
Major Limitation of M-E Design

- Pavement performance prediction
  - Evaluation
  - Calibration
  - Verification
Perpetual Pavements
What is a Perpetual Pavement?

- 35+ years of service
- Minimal structural improvements
- No deep structural distresses
  - Problems at surface easily and quickly remedied
Perpetual Pavement Design

\[ \begin{align*}
H_1 & \quad E_1 \\
H_2 & \quad E_2 \\
H_3 & \quad E_3 \\
H_4 & \quad E_4 \\
H_5 & \quad E_5
\end{align*} \]
Perpetual Pavement Design Software

PerRoad 3.5

Press F1 to access full help file. Press Shift+F1 to access context-sensitive pop-up help.

Functional Classification: Urban Collector

Two-Way AADT: 1000 (500 to 5000)

%Trucks: 1 (1 to 20)

%Growth: 1 (0 to 3)

Design Trucks: 63482 (Total Trucks in 30 Years)

Design ESALs: 18917 (Total ESALs in 30 Years)

AASHTO Soil Classification: A-1-a

Soil Modulus: 29500 (10,000 to 30,000 psi)

Aggregate Base Thickness: 4 (0 to 10 in.)

HMA Modulus: 800000 (400,000 to 1,000,000 psi)

Calculated HMA in. Calculated thickness rounded up to nearest 0.25".

Design HMA in.
NCAT Test Track – Perpetual Experiments

1.7 mile
46 – 200 ft sections
Test Sections – Experiment 1

N3 (PG 67-22)

1.2 Surface Mix
1.8 Upper Intermediate Mix
2.7 Lower Intermediate Mix
2.1 Upper Base Mix
1.3 Lower Base Mix
6 Aggregate Base

N4 (PG 76-22)

1 Mix
1.7 Upper Intermediate Mix
2.3 Lower Intermediate Mix
1.8 Upper Base Mix
2 Lower Base Mix
6 Aggregate Base

- Designed with 1993 AASHTO Guide to Fail after 10 Million ESALs
- Survived 30 million ESALs with excellent performance
AC Modulus at 20C

Section-Research Cycle

Average Backcalculated Modulus, ksi

N3-2003
N4-2003
N3-2009
N4-2009

0 100 200 300 400 500 600 700 800 900 1000 1100 1200

12%
20%

12%
Rutting Performance

Million Equivalent Single Axle Loads

Failure

Rut Depth, mm

Date

10/20/03 01/18/04 04/17/04 10/14/04 07/16/04 10/09/05 04/12/05 07/06/06 07/04/06 04/02/07 07/01/07 09/29/07 12/28/07 03/27/08 06/25/08 09/23/08 12/22/08 03/22/09 06/20/09 09/18/09 12/17/09 03/12/10 06/10/10 09/12/10 12/12/10 03/12/11 06/10/11 09/12/11

N3
N4
International Roughness Index

Failure

Million Equivalent Single Axle Loads

Date

International Roughness Index, in/mile

N3  N4
Forensic Trenching
N8 - Rehabilitation

Original Construction
- Original SMA
- Original Dense AC
- Rich AC

Conventional Rehabilitation (Before HPM)
- Rehab SMA
- Rehab Dense
- Rich AC

HPM Rehabilitation (After HPM)
- HPM
- Rich HPM
- Original Dense

Depth from Surface of Pavement, in.
- 0
- 2
- 4
- 6
- 8
- 10
- 12
- 14
- 16
- 18
- 20

Depth of Mill & Inlay

Paving Fabric
N8 After 1st Rehabilitation @ 3.5 MESAL
Cash Flow Diagram

Discount Rate = 2%

Initial Construction

32% Increase

Cost, $/Lane/Mile

Year

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36

N9

N8

Conventional mill
& inlay

Resurfacing

N8

HPM mill
& inlay
Net Present Value

26% Savings

Net Present Value ($/lane/mile)

Section
N8 (non-perpetual)
N9 (perpetual)
Future Challenges

SMA

RAS

RAP

GTR

CIR

WMA
http://www.hgmeigs.com/images/evotherm_temp.jpg

DARWin
http://www.calrecycle.ca.gov/Tires/BizAssist/images/CrumbRubber.jpg

AASHTO Guide for Design of Pavement Structures

PerRoad
Summary

• Pavement thickness design in transition
  – From empirical to mechanistic-empirical
• M-E design much more robust
  – Better traffic/climate/materials/performance characterization
  – Capable of adapting to new conditions
• Perpetual pavements are key to sustainable future
  – Incorporation of sustainable materials is critical
Thank you!