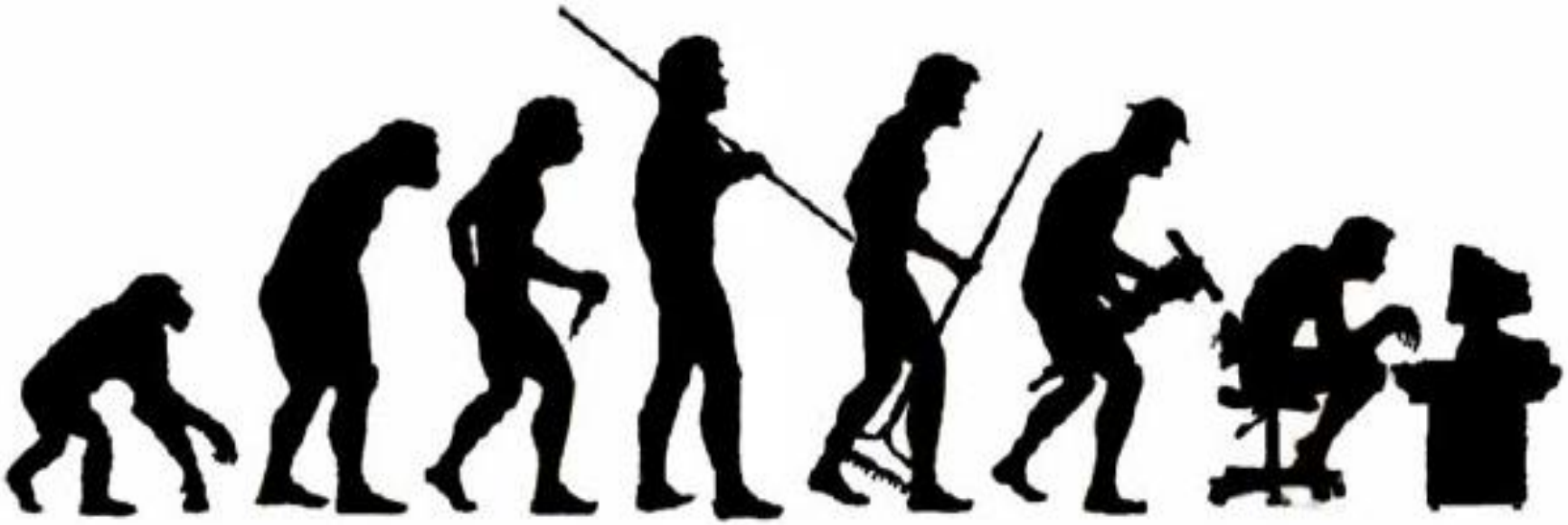
FLEXIBLE PAVEMENT DESIGN

WITH WATER-RESISTANT LAYERS

Evolution of Structural Design Approaches



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

Perpetual Pavements

AASHO Road Test

- 1958 - 1960 near Ottawa, Illinois
- Soil uniform and representative of large portion of US
- 4 large and 2 smaller loops
- Variables included
  - pavement thickness
  - load magnitude
  - environmental effects
- Introduced concept of serviceability (PSI)
- Forms basis of AASHTO Method

1993 AASHTO Design Equation

(Strictly Empirical - Based on AASHO Road Test)

$$\log W_{18} = Z_R S_0 + 9.36 \log(SN+1) - 0.20 + \frac{\log\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \log M_R - 8.07$$

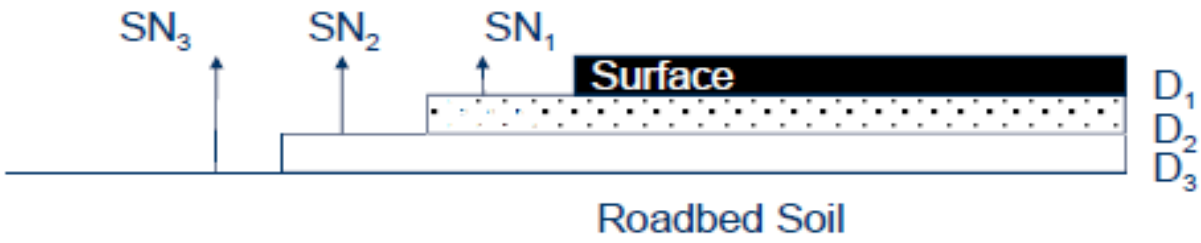
- Main Inputs
  - Traffic
  - Reliability
  - Variability
  - Performance

Resilient Modulus of the subgrade soil

Solve the Equation for Target Structural Number SN

1993 AASHTO Structural Design Method

Determine Depths of individual pavement layers…



- Materials
  - Modulus & Structural Coef.
  - Drainage Coefficient
- Outputs
  - Structural Number
  - Computed Depths

$$SN = a_1D_1 + a_2m_2D_2 + \ldots + a_nm_nD_n$$

…such that sum of all structural numbers SN ≥ Target *SN*

What has changed since AASHO Road Test ? & Where is the opportunity to optimize ?

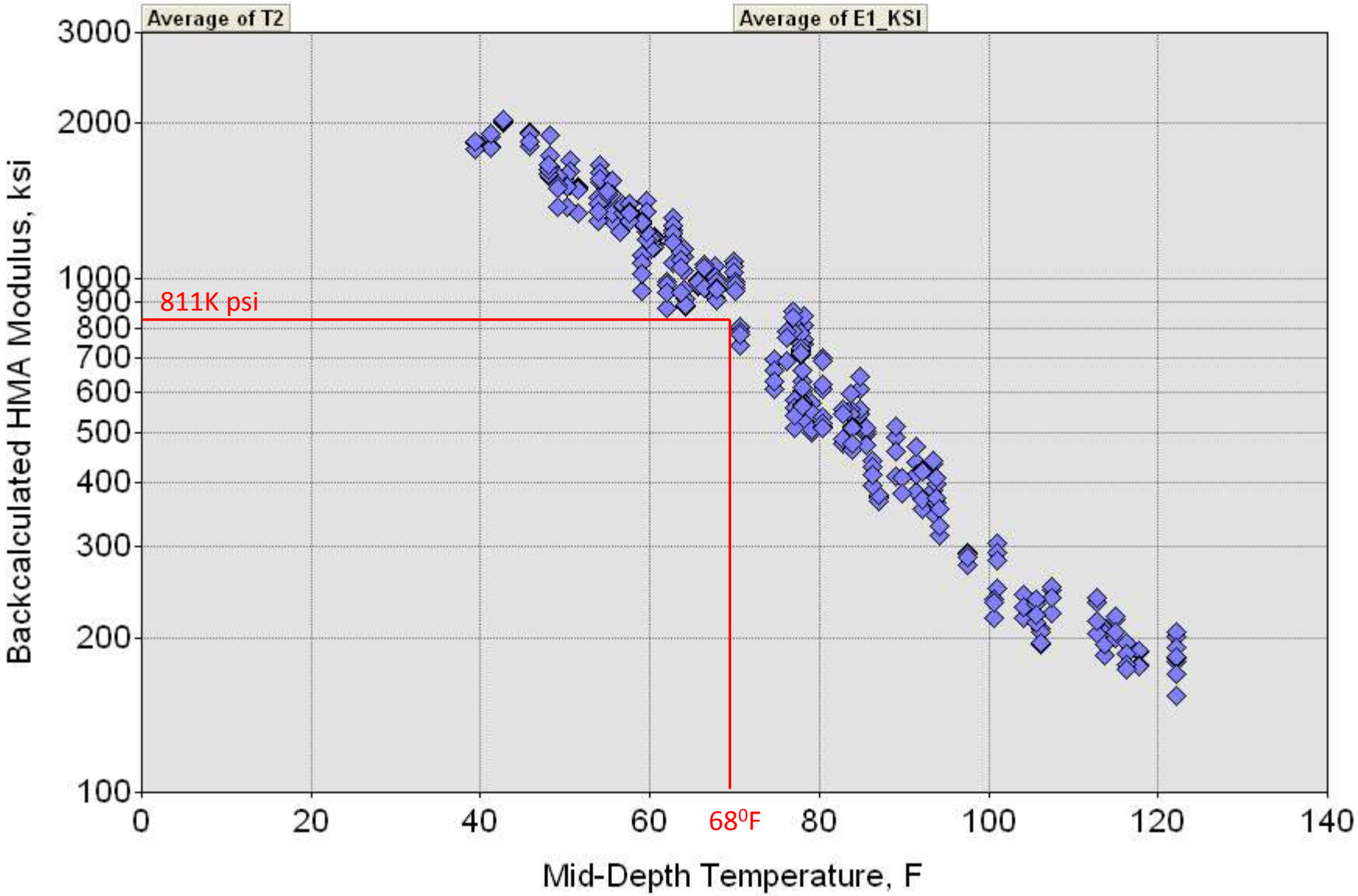
With the technological advancement, there are three major improvements since the AASHO Road test :

Better materials / HMA mixing methodology => Higher Moduli
– Effect : Higher Layer Coefficients (a_1, a_2, a_3…)

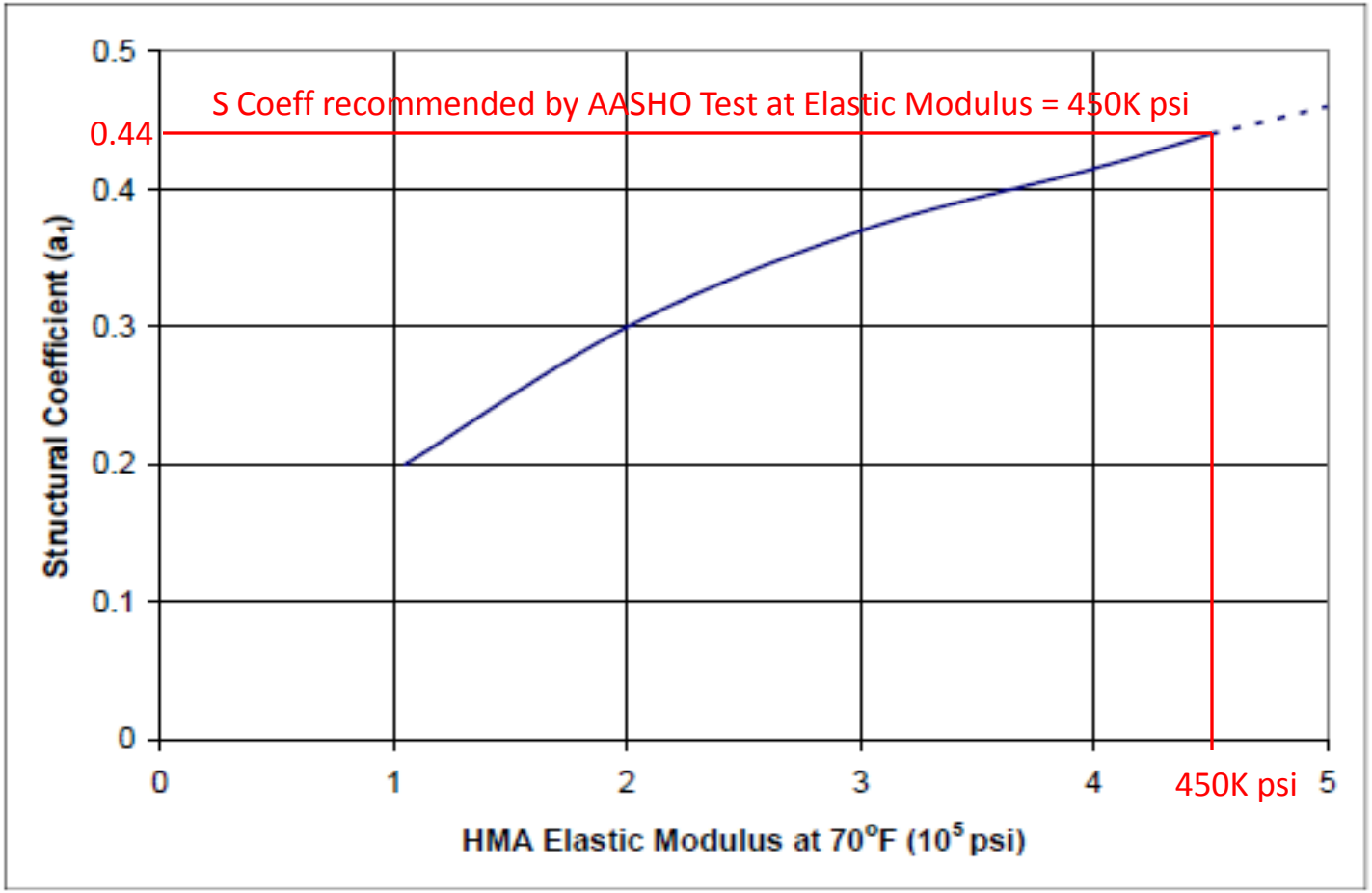
New technologies for Water-Resistant structural layers
– Effect : Higher Drainage Coefficients (m_2, m_3…)

Technologies for water-resistant subgrade with higher moduli
– Effect : Higher Resilient Modulus of subgrade (M_R)

NCAT Test : AC Modulus @ 68^0F is 811K psi



S Coeff @ 811K psi = 0.54 (Extrapolated)



AASHTO, 1993

Stronger Materials, ↑ Moduli ↑ Layer Coefficient

1960's AASHO Road Test recommended structural coefficient of **0.44 for asphalt pavement** layers

Better quality materials and mix design methodologies, coupled with new nanotechnology can now improve the resilient moduli of layers.

- Alabama DoT takes LC for asphaltic layers as 0.54
- Washington State DoT assumes 0.50 as LC

Assuming higher values for LC simply means lower depth of layer to hit target SN.

With LC of 0.54, Alabama state saves about 18% on road construction cost.

Drainage Coefficients

- Percent time the layer approaches saturation:

$$P = (S + R) / 365 \times 100$$

P = % time saturated

S = days of spring thaw

R = remaining days with rain if pavement will drain to 85% in 24 hours, otherwise use days of rain times drainage time in days

With new technology waterproofing, this is not relevant any more

New Tech : Drainage Coefficients = 1.35 to 1.40

Quality	95% Water Removed	% Time Saturated			
		<1%	1 - 5%	5 – 25%	>25%
Excellent	2 hours	1.40 – 1.35	1.35 – 1.30	1.30 – 1.20	1.20
Good	1 day	1.35 – 1.25	1.25 – 1.15	1.15 – 1.00	1.00
Fair	1 week	1.25 – 1.15	1.15 – 1.05	1.05 – 0.80	0.80
Poor	1 month	1.15 – 1.05	1.05 – 0.80	0.80 – 0.60	0.60
Very Poor	Never Drain	1.05 – 0.95	0.95 – 0.75	0.75 – 0.40	0.40

New nanotechnology ensures waterproofing
Time Saturation < 1%, 95% water removed within 2 Hours
Drainage Coefficient = 1.35 to 1.40

Effective Modulus of Subgrade

- Definition: an equivalent modulus that would result in the same damage if seasonal modulus values were actually used
- Uses AASHTO relative damage equation

$$\mu_f = 1.18 \times 10^8 M_R^{-2.32}$$

- Finding Mr_{eff}
  - Find u_f for each season
  - Determine weighted average u_f
  - Find Mr_{eff} corresponding to u_f

New technology ensures dry subgrade M_R through all seasons.
If subgrade M_R = 10K psi (based on weighted average μ_f)
It is safe to take it as 20K psi with new technology

New Tech Highway Design :
With LC = 0.54, DC = 1.2-1.4 and Subgrade M_R = 20K psi

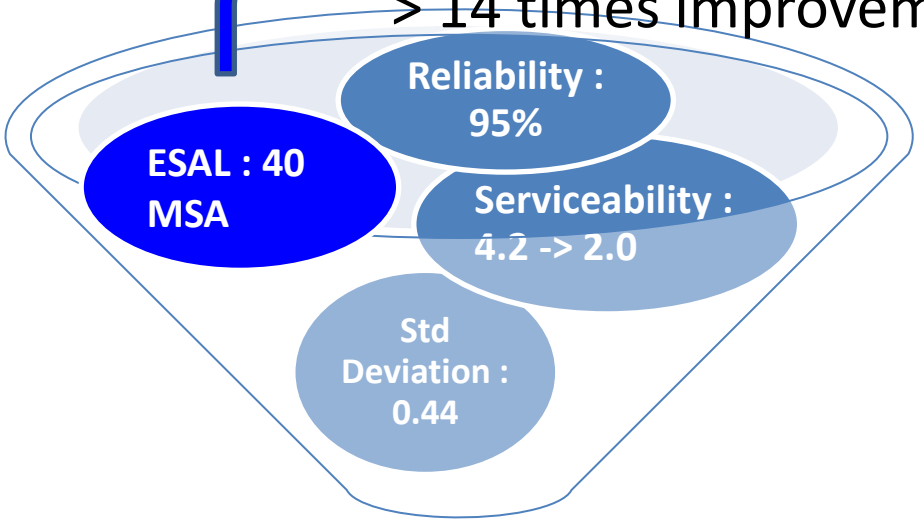
Description	Conventional Design DBM 100 mm WC 60 mm	New Tech Design-1 DBM 60 mm WC 50 mm (Zero Extra Cost)			New Tech Design-2 DBM 80 mm WC 50 mm (5.50% extra cost)		
Drainage Coefficient	1	1.2	1.3	1.4	1.2	1.3	1.4
Structural Number	5.19	5.27	5.62	5.92	5.78	6.17	6.56
Subgrade Modulus (psi)	10K	20K	20K	20K	20K	20K	20K
Equivalent MSA	40	230	380	574	475	790	1296
Times Improvement		6	10	14	12	20	32

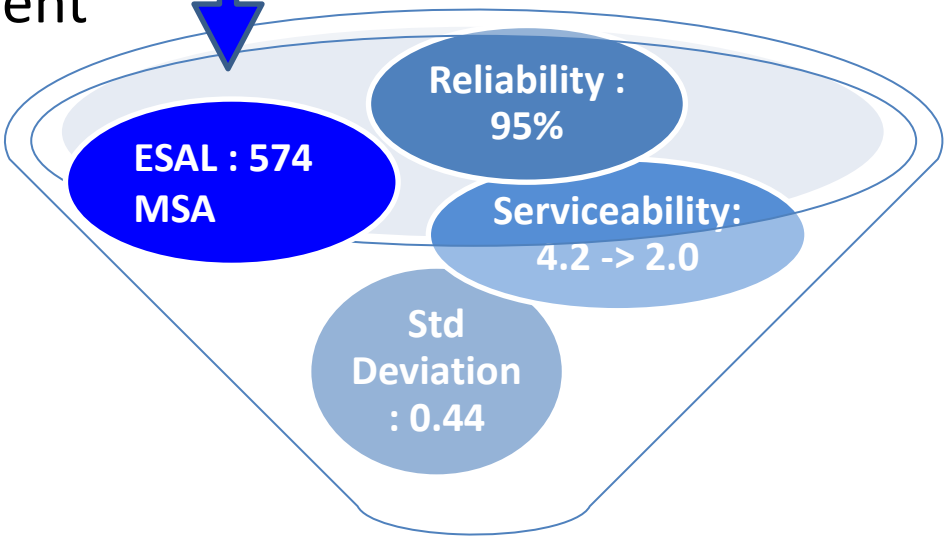
New Tech Highway Design : Zero Extra Cost

Standard Assumptions for
Conventional design
Drainage Coefficient – 1
Subgrade Modulus = 10K psi

New nanotechnology allows
Drainage Coefficient (DC) of 1.4
& Layer Coeff of 0.54
S_N = 5.92, giving ESAL of 574 MSA
(@ Subgrade modulus = 20K psi)

> 14 times improvement





Reqd Structural Number
S_N = 5.19

Design Process
with New Tech
@ zero extra cost

S_N : 5.92

Thank You