Flexible Pavement Design in the 2002 Design Guide

2002 Southeastern
Pavement Management &
Design Conference
June 25, 2002

2002
Design Guide
NCHRP 1-37A

1-37A Project Team

Principal Investigator
John P. Hallin

Co-PI (Implementation)
Kenneth McGhee

Flexible Pavement
Matthew W. Witczak

Rigid Pavement
Michael I. Darter

Resource Pool:
ERES-ARA; ASU; UMd;
Fugro-BRE; Consultants

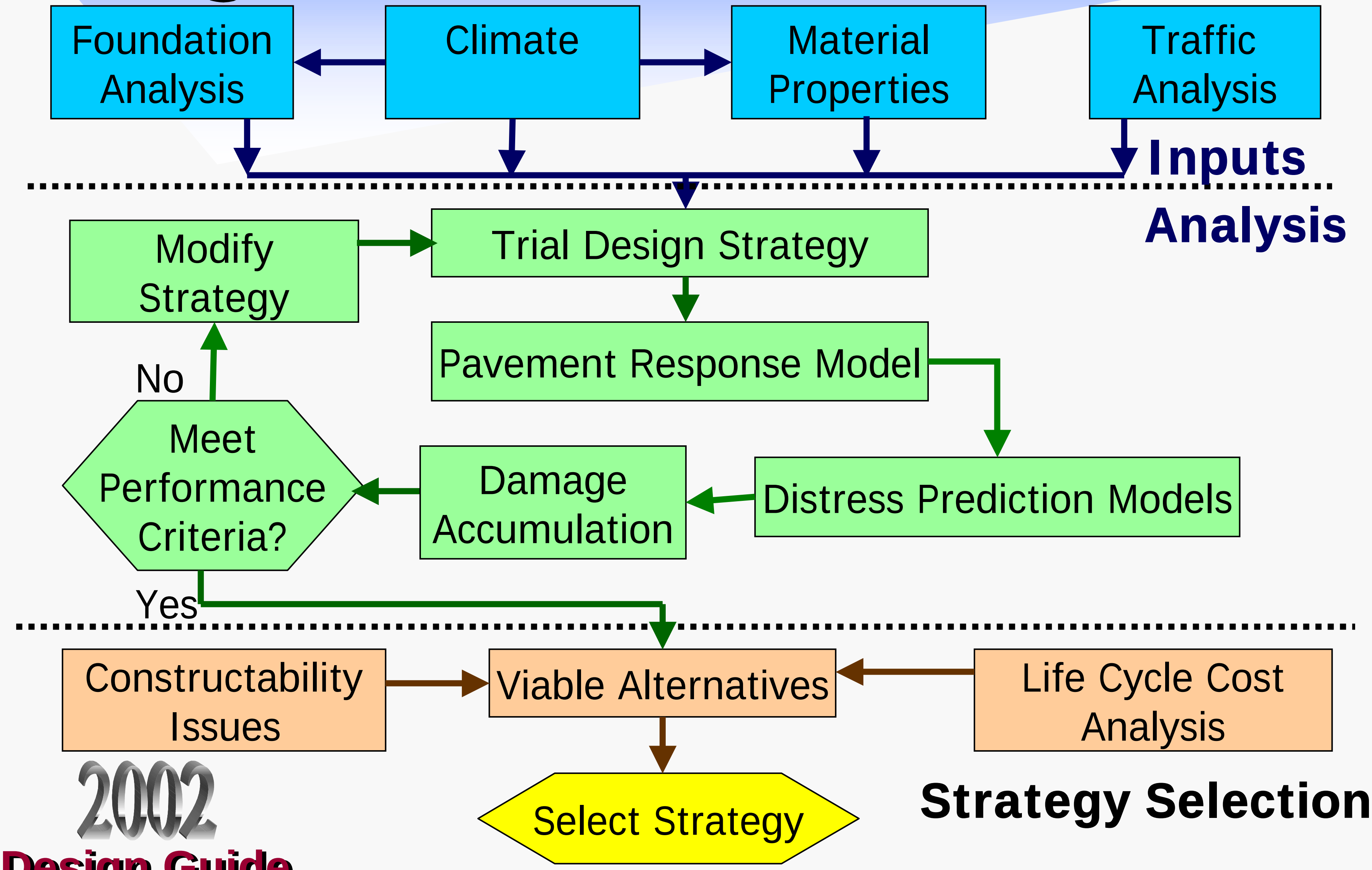
Outline

- Overview of Design Process
- Key Details
  - Material Properties
  - Pavements
  - Pavement Response Models
  - Distress Models
  - Calibration
- Summarize

Design Process Overview

- Mechanistic-Empirical Models
  - Predict Development of Distresses
- Best Approach Available
- Link Between Structural Design and Asphalt Concrete Mixture Design
  - Simple Performance Test (NCHRP 9-19)
  - Completion of Superpave Mix Analysis System (Future NCHRP Project)

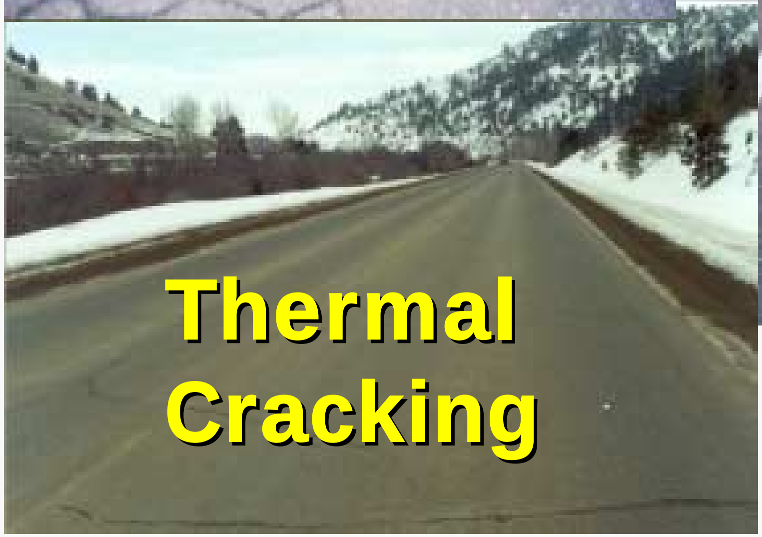
Design Process Overview



2002 Design Guide

NCHRP 1-37A

Predicted Distresses:



Cumulative Incremental Damage Approach

- ***Changes over time (season) are addressed***
  - ***Material strength and stiffness***
    - ***Aging***
    - ***Moisture and temperature***
  - ***Traffic (seasonally and over time)***

Damage Calculation Methodology:

Fracture:

$$\Delta DI = \sum_{k=1}^{m} \sum_{i=1}^{j} \left[\frac{n_i}{N_{(\varepsilon_t)i}} \right]_k$$

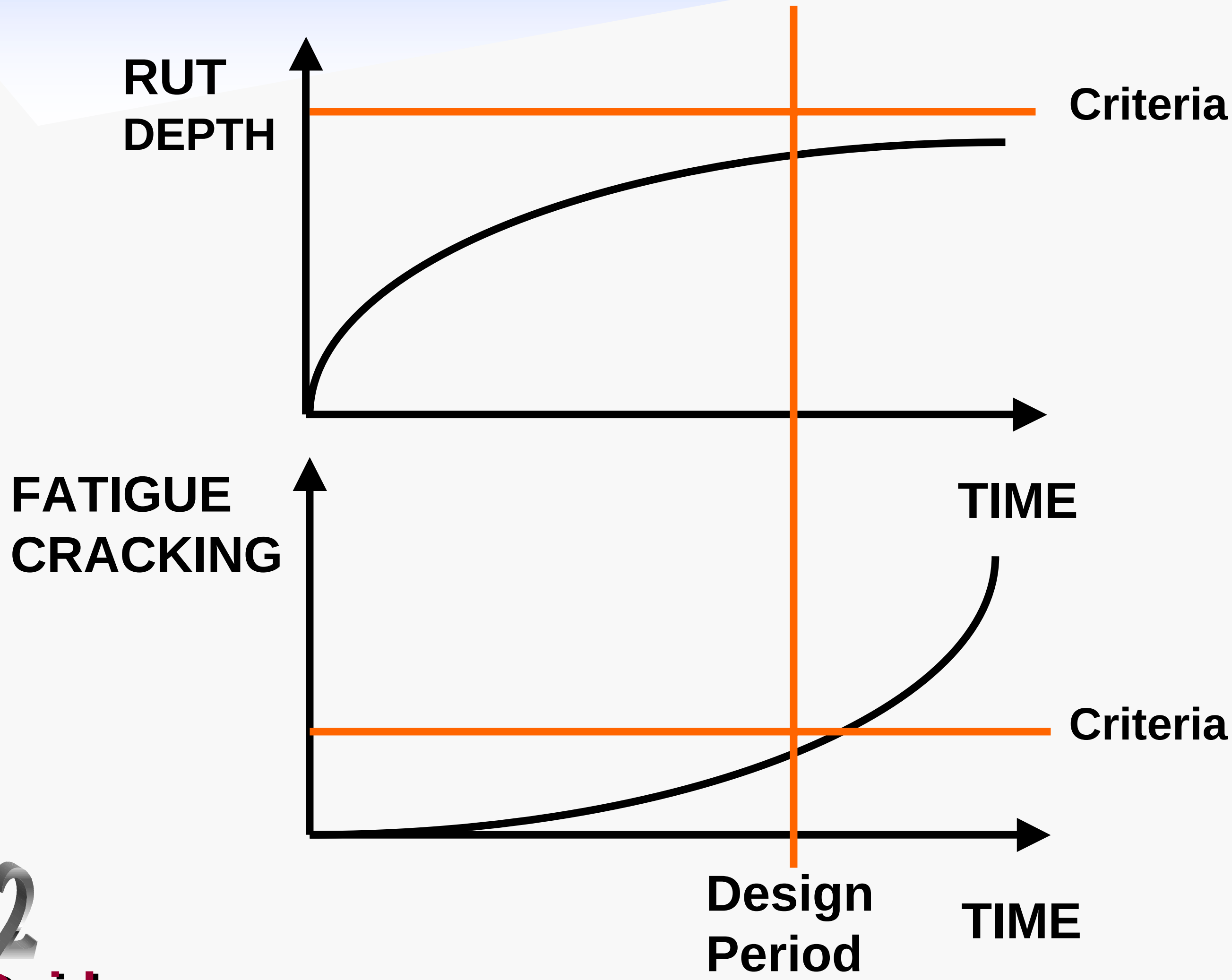
Distortion:

$$\Delta RD = \sum_{k=1}^{m} \sum_{i=1}^{j} \sum_{d=1}^{l} \left[\varepsilon_{P(d)} (h_d) \right]_{k,i}$$

k = Load increment
i = Time/season increment
d = Thickness increment

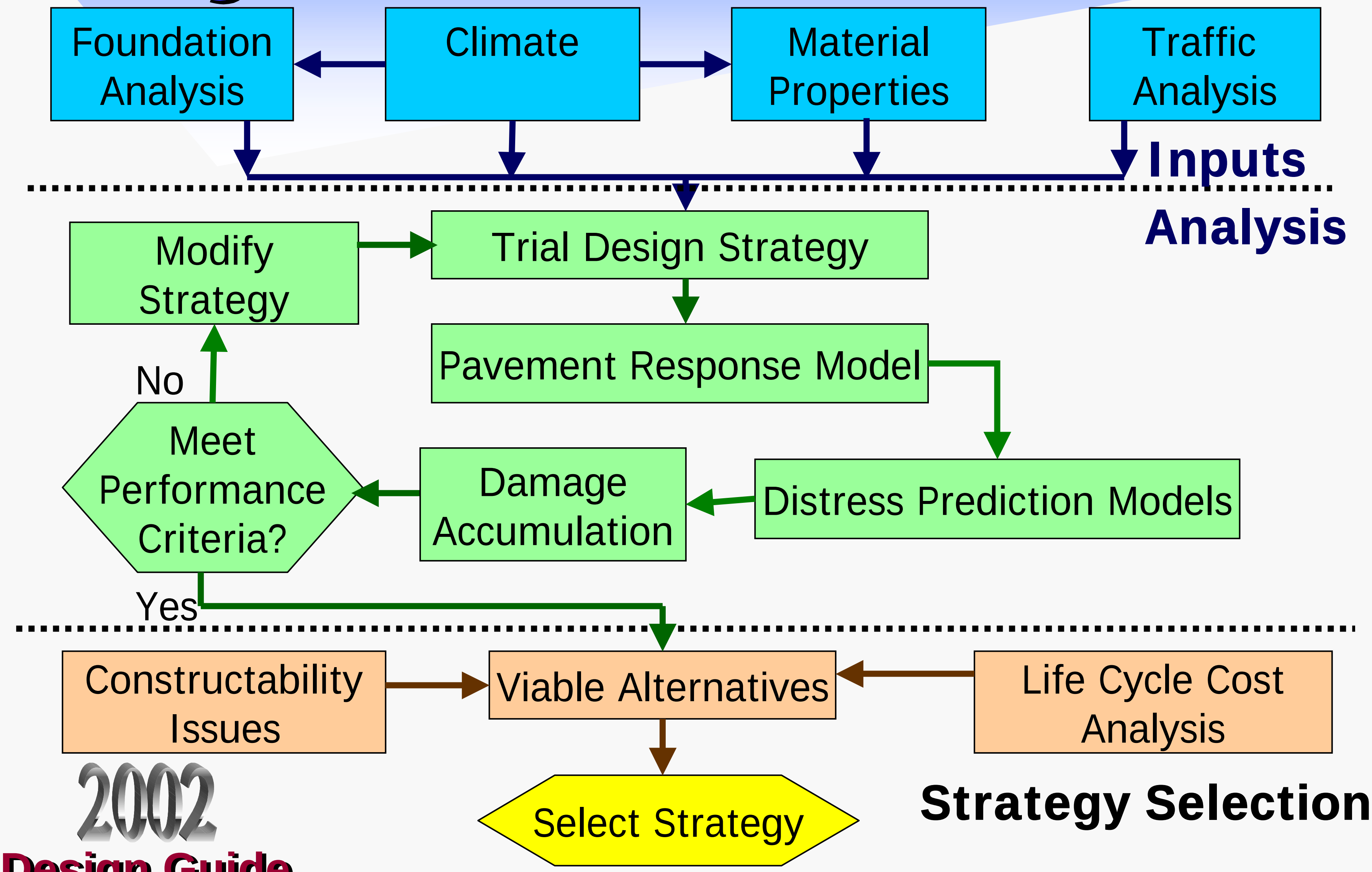
2002
Design Guide
NCHRP 1-37A

Damage:



2002
Design Guide
NCHRP 1-37A

Design Process Overview



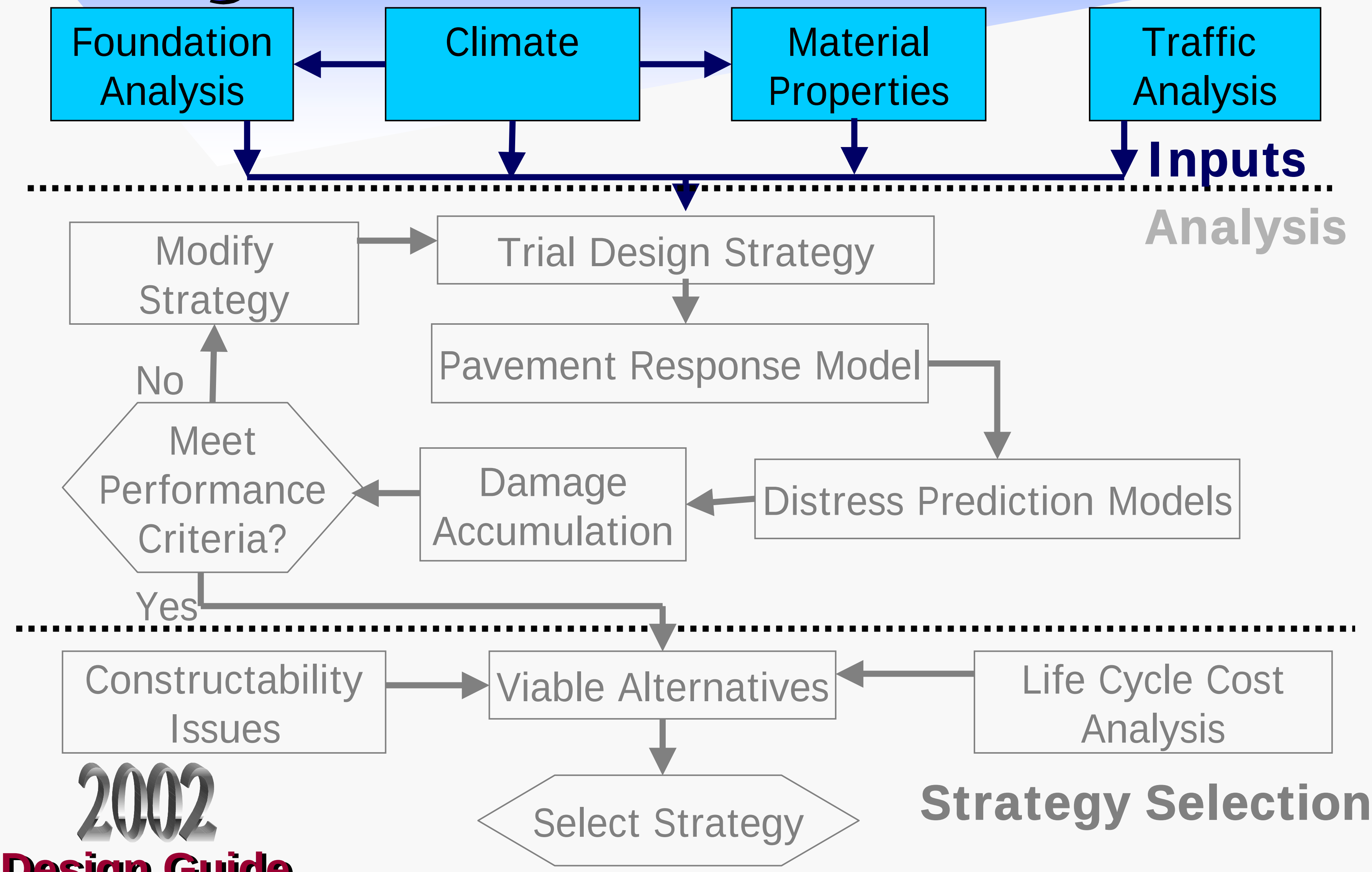
2002 Design Guide

NCHRP 1-37A

Key Elements of Flexible Pavement Design

2002
Design Guide
NCHRP 1-37A

Design Process



2002 Design Guide

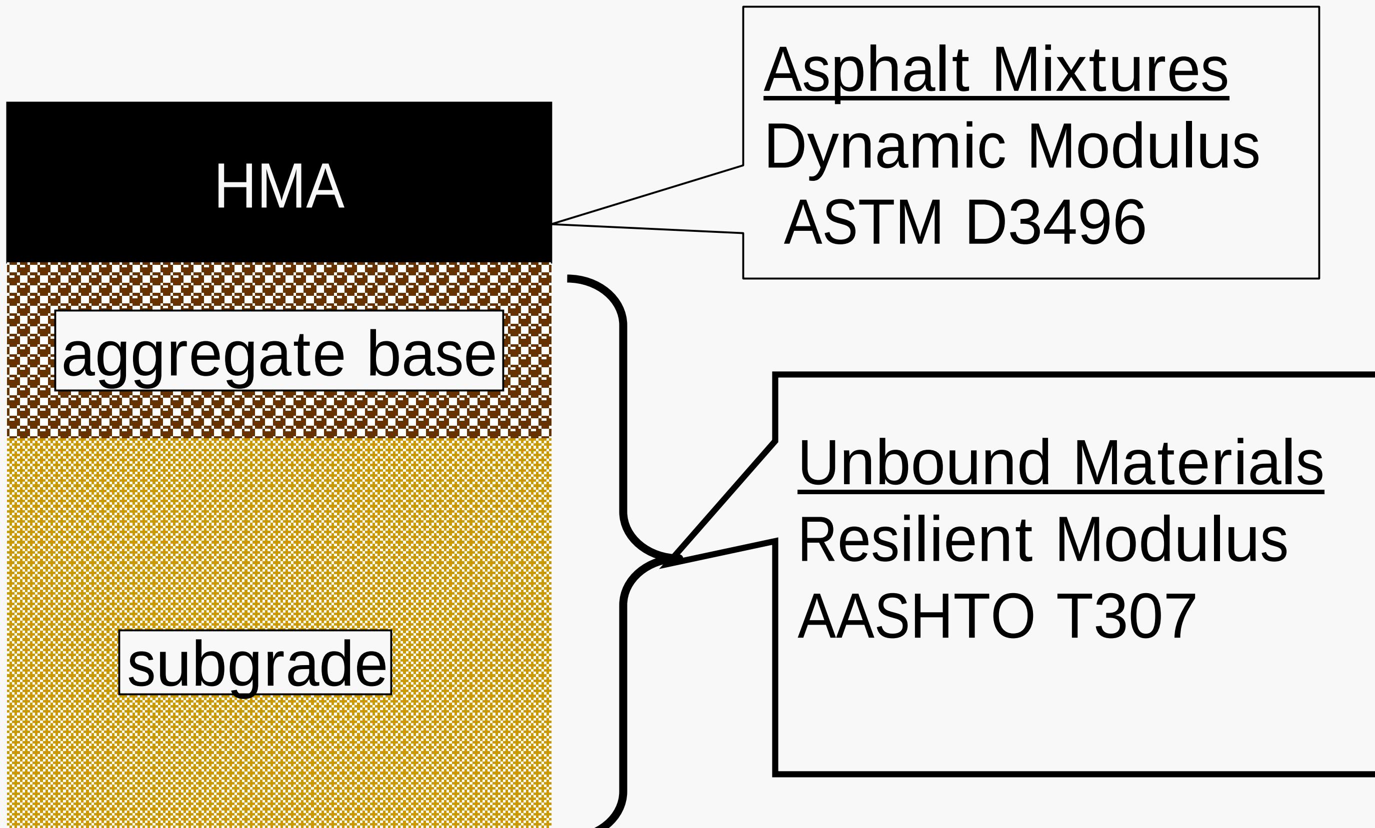
NCHRP 1-37A

Design Inputs:

Input Level	Determination of Input Values	Knowledge of Input Parameter
1	Project/Segment Specific Measurements	Good
2	Correlations/Regression equations, Regional values	Fair
3	Defaults, Judgement	Poor

Materials Characterization

Modulus of Elasticity



2002
Design Guide
NCHRP 1-37A

Design Inputs:

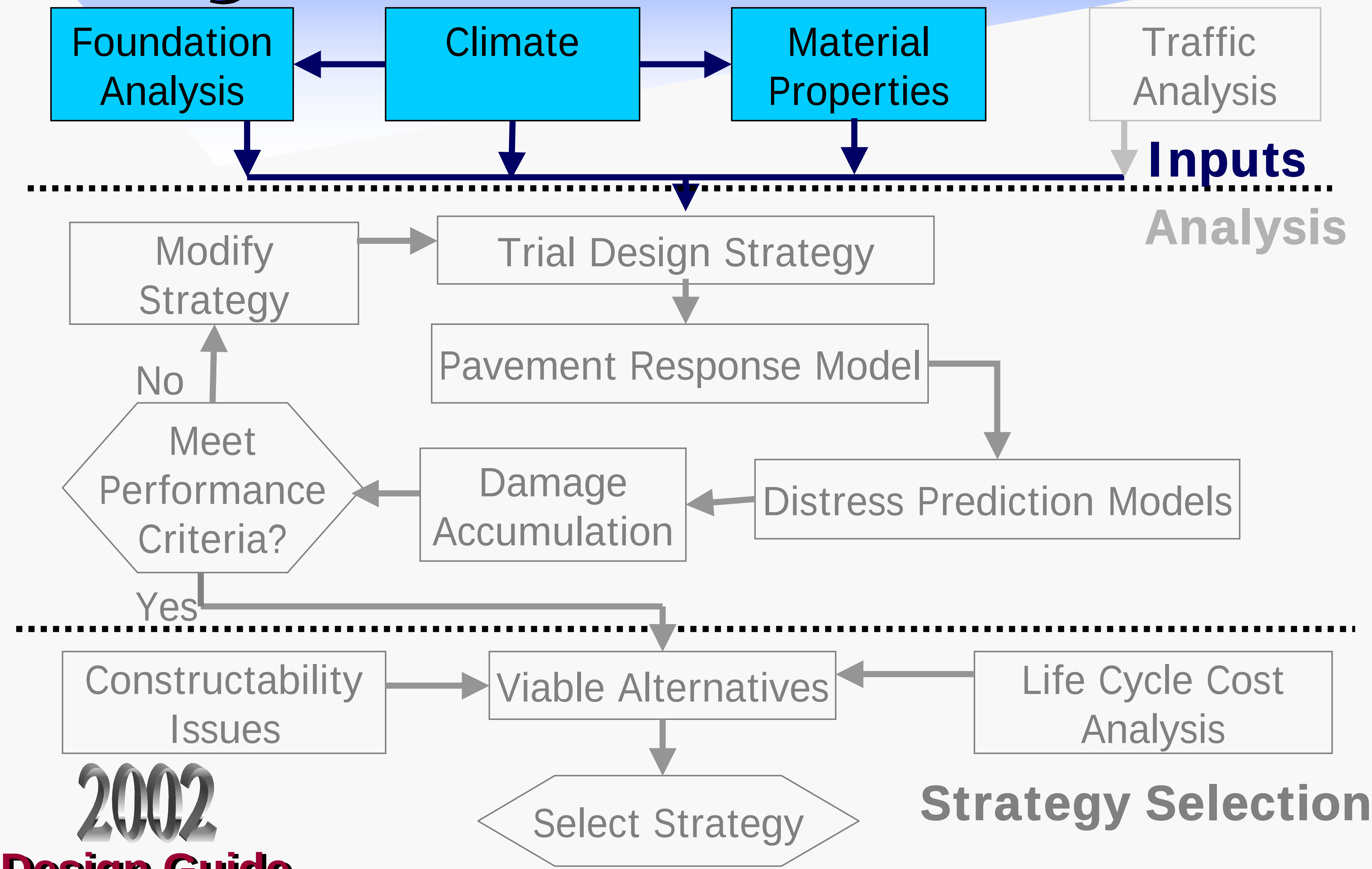
Input Level	Unbound Material Modulus	Knowledge of Input Parameter
1	Laboratory Modulus Tests NDT	Good
2	Correlation With CBR, R, DCP	Fair
3	Default Values Based on Soil Classification	Poor

Design Inputs:

Input Level	Asphalt Concrete Modulus	Knowledge of Input Parameter
1	Laboratory Modulus Tests NDT	Good
2	Mix Volumetrics and Measured Binder Properties	Fair
3	Mix Volumetrics and Specified Grade	Poor

2002
Design Guide
NCHRP 1-37A

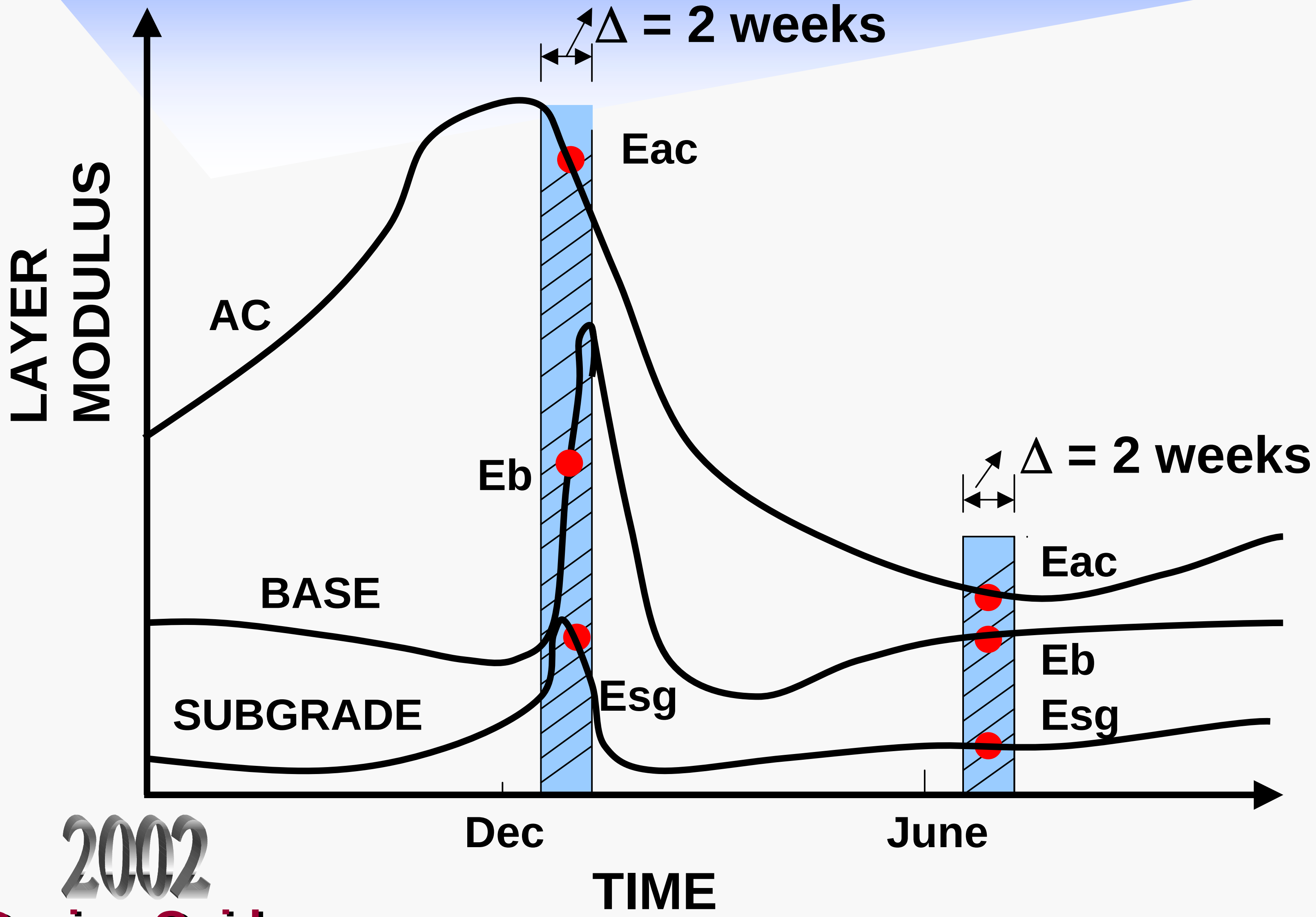
Design Process



2002 Design Guide

NCHRP 1-37A

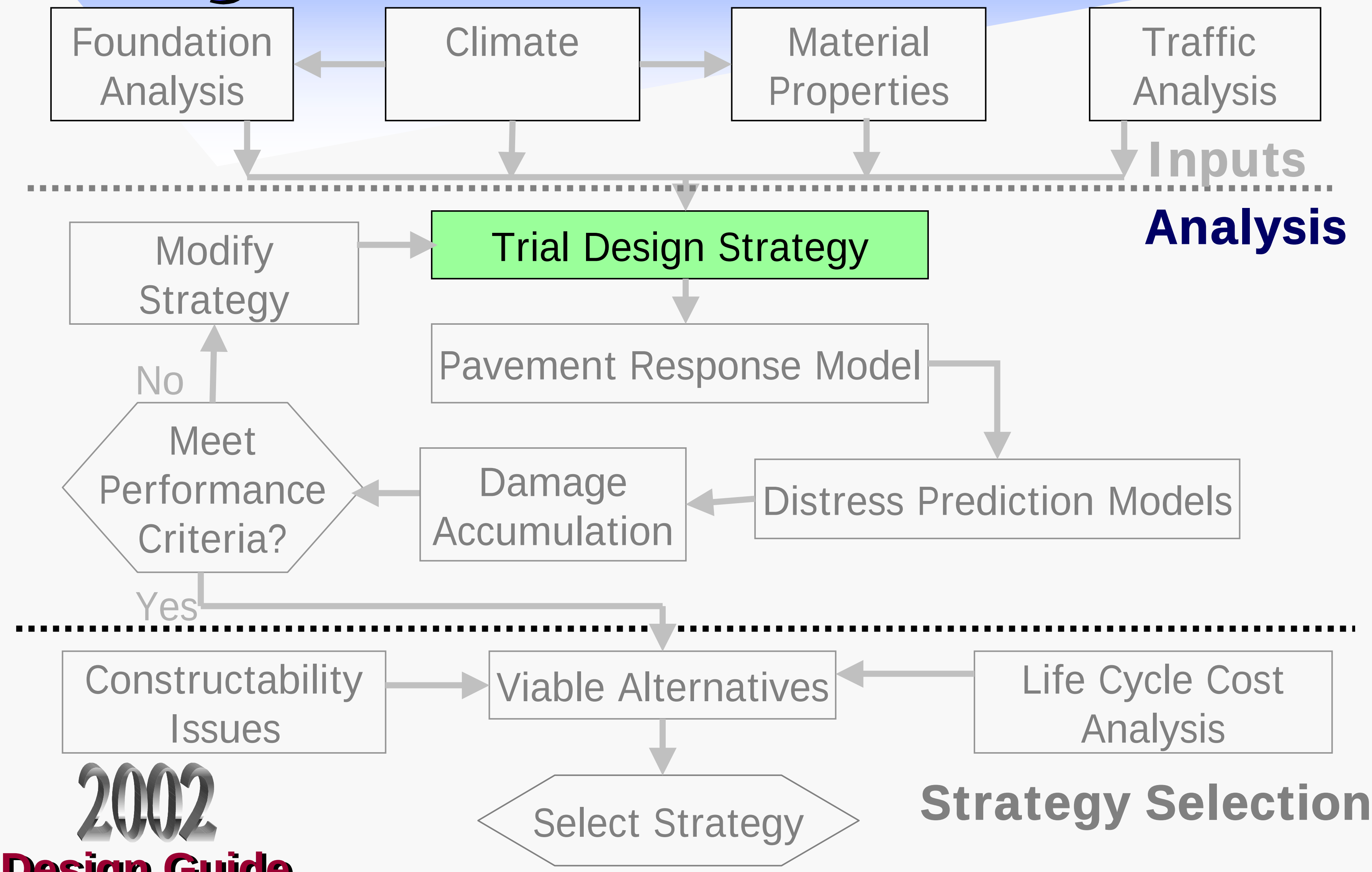
ANNUAL MODULUS VARIABILITY



2002 Design Guide

NCHRP 1-37A

Design Process

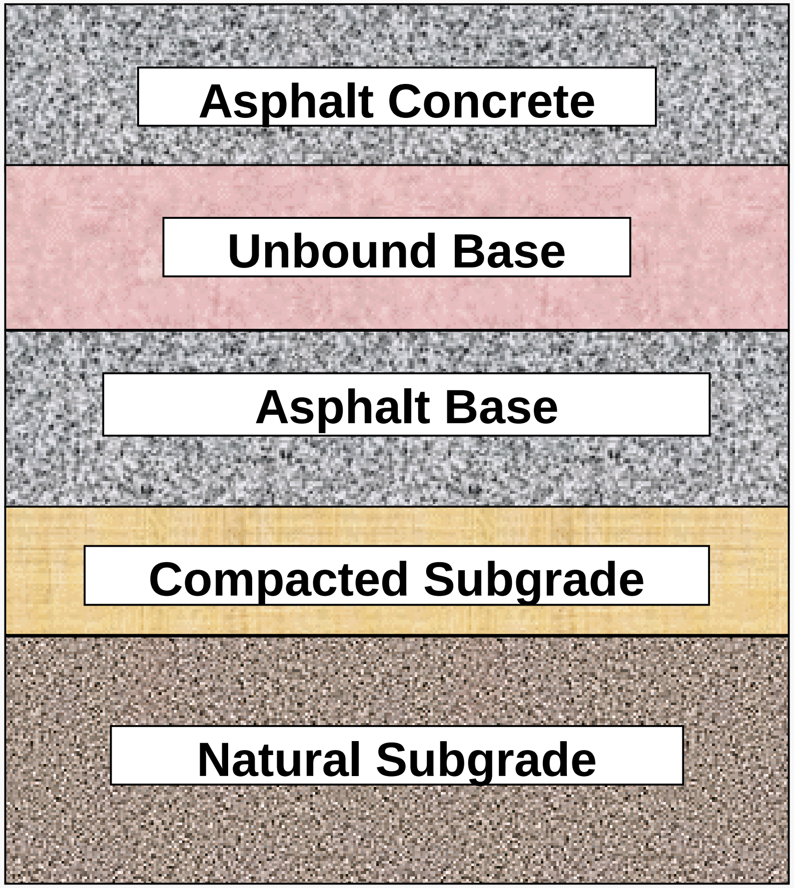


2002 Design Guide

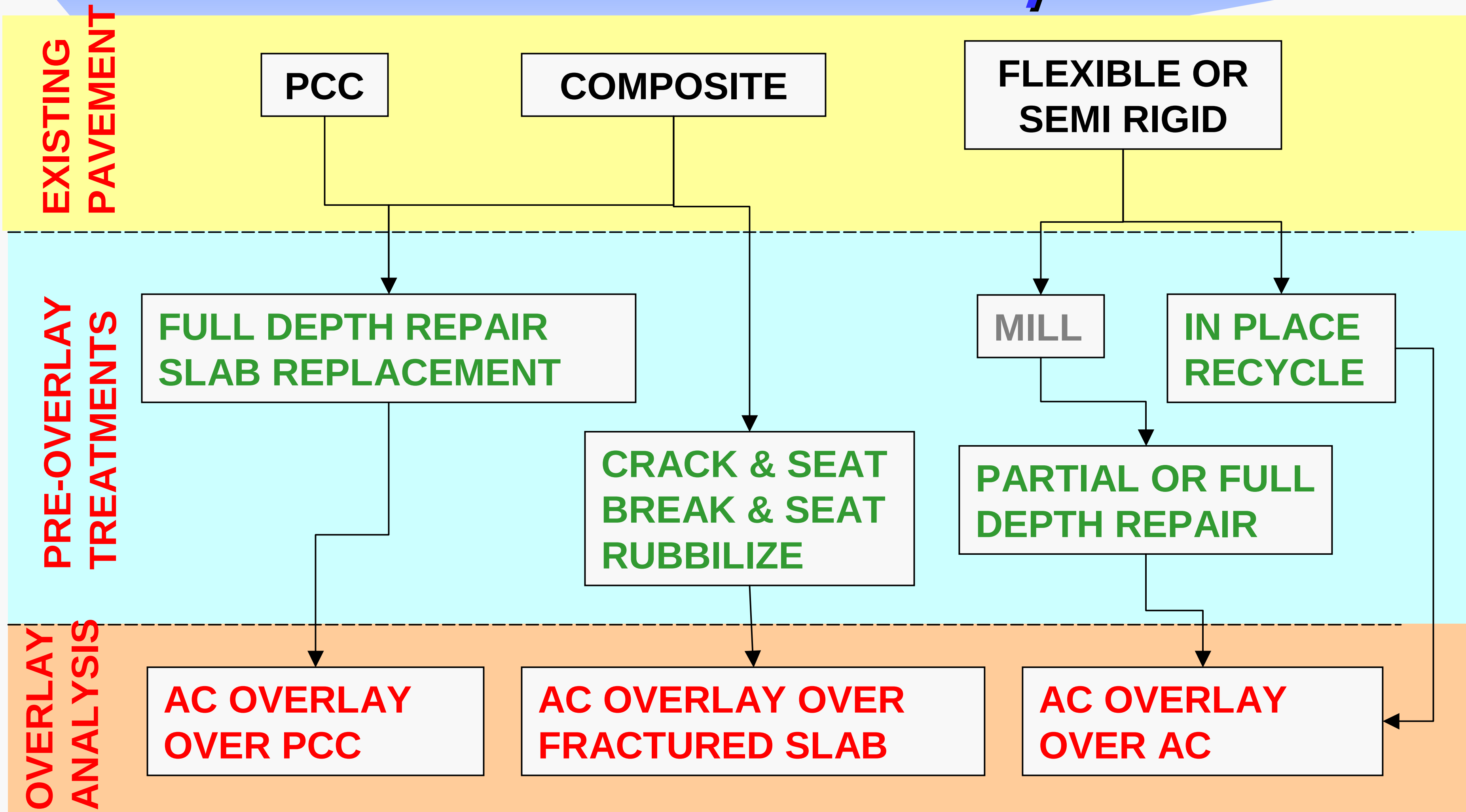
NCHRP 1-37A

New Pavement Structures

- Conventional Flexible
- Deep Strength
- Full Depth Asphalt
- Cement Treated Base
- Sandwich Pavement



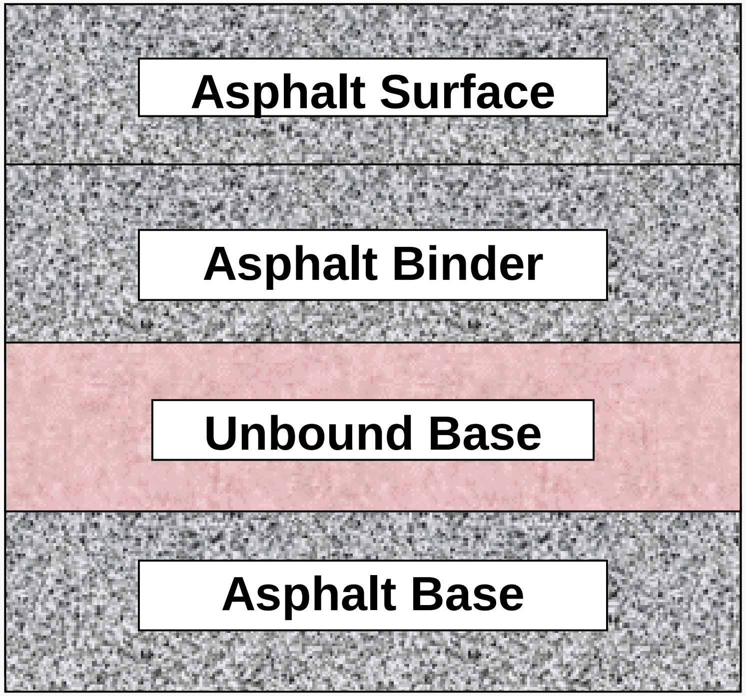
Rehabilitation With Asphalt



2002
Design Guide
NCHRP 1-37A

Overlay Structures

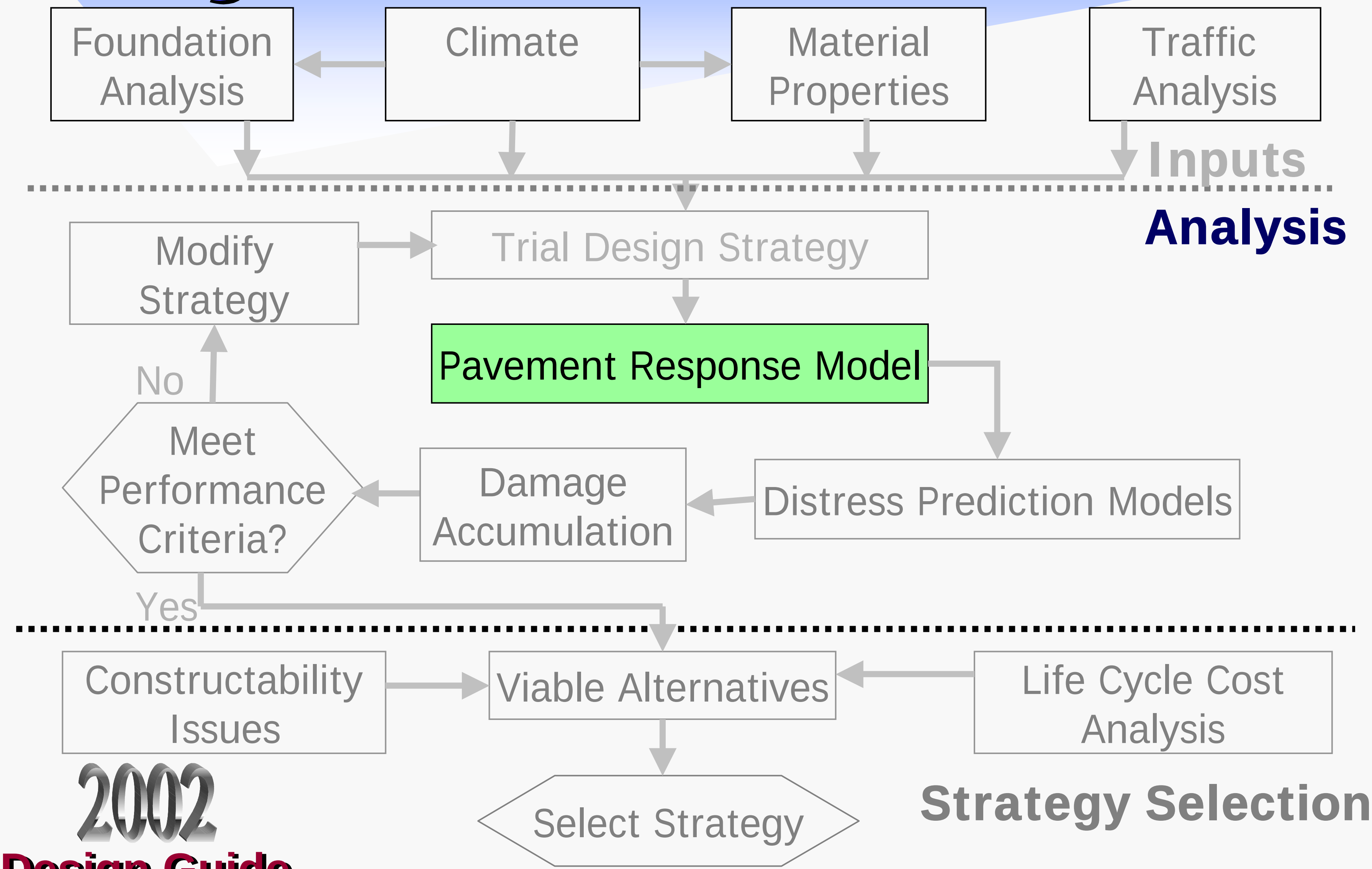
- Asphalt Concrete
- Cement Treated
- Unbound



Pavement Structures

- Very Flexible
- Limitations
  - Maximum of 14 Layers
  - Maximum of 3 New Asphalt Layers and One Existing Asphalt Layer
  - Maximum of 4 Overlay Layers
  - Users Ability to Characterize Layers

Design Process

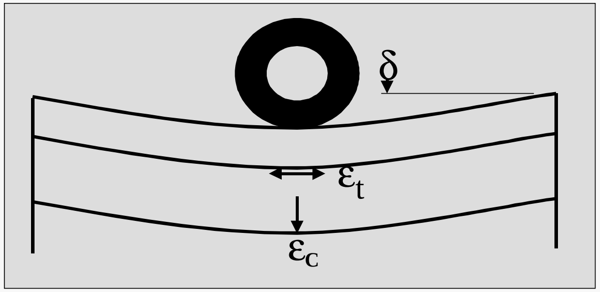


2002 Design Guide

NCHRP 1-37A

Pavement Response Models

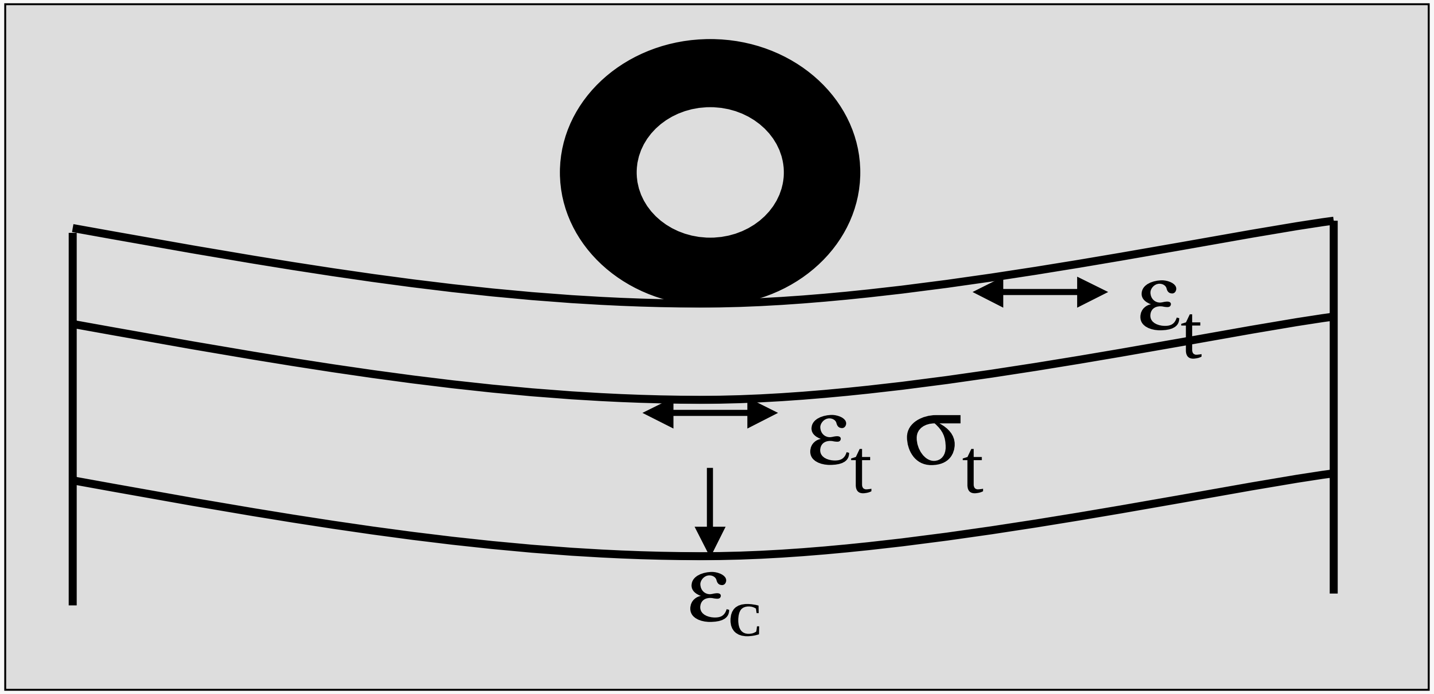
- Multilayer Elastic Solution
  - JULEA
  - Majority of Solutions
- Axisymmetric Finite Element Analysis
  - Modified Version DSC
  - Non-Linear Unbound Material



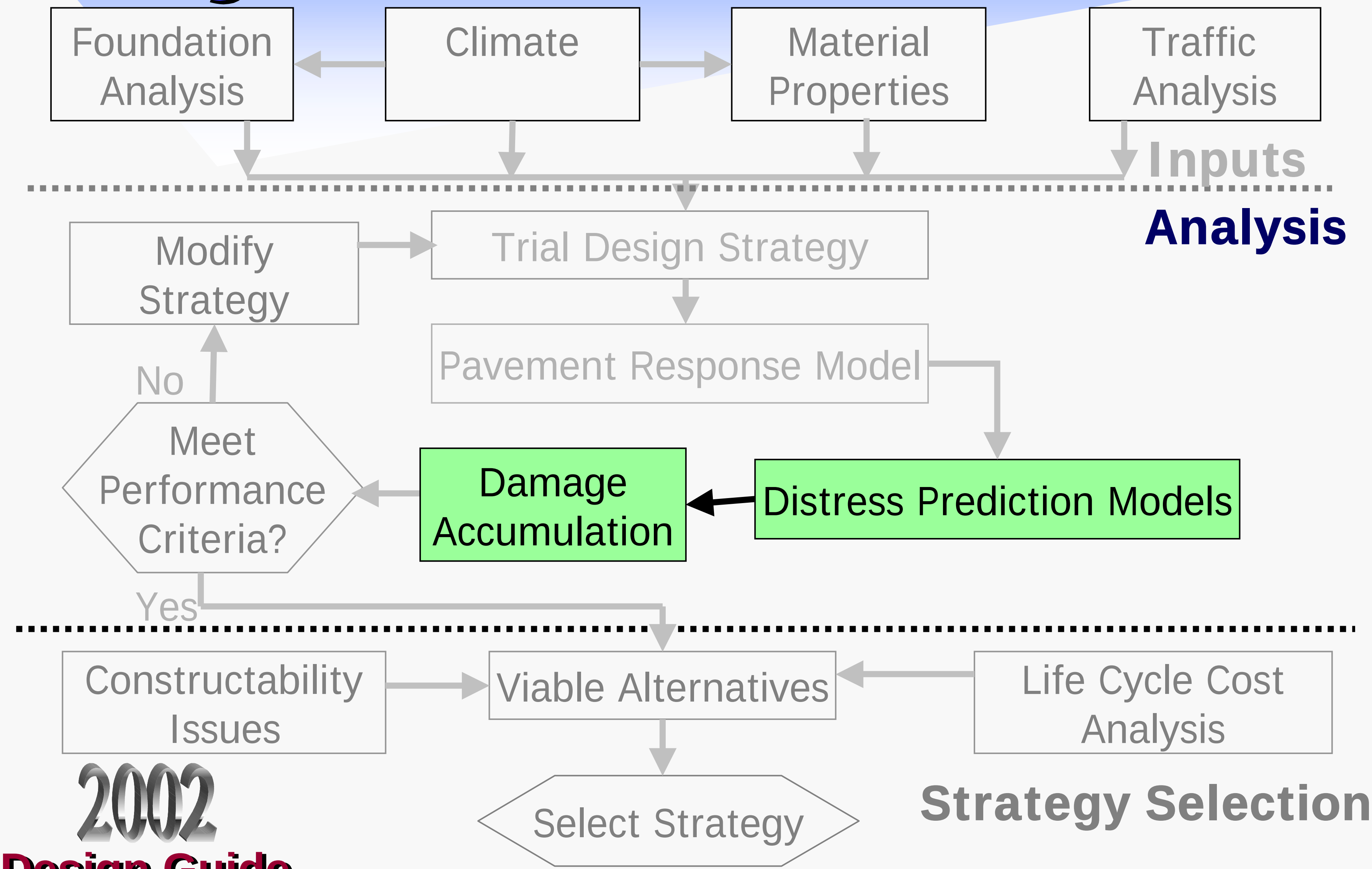
2002
Design Guide
NCHRP 1-37A

Pavement Response Models

- Critical Load Induced Strains or Stresses

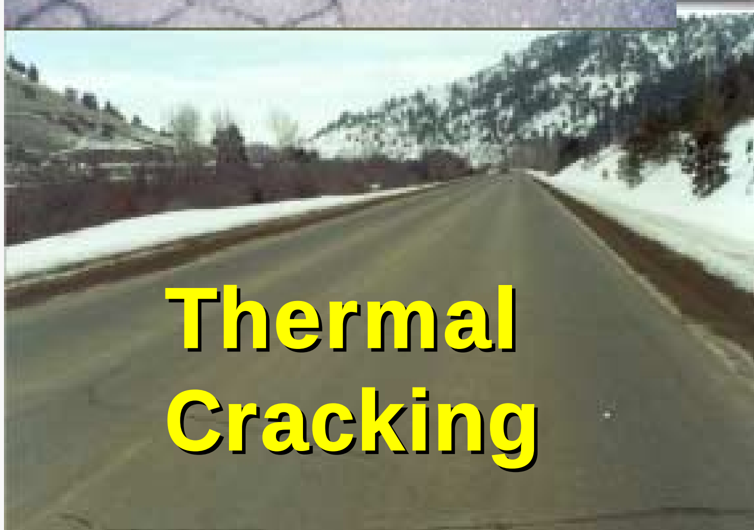


Design Process



2002 Design Guide
NCHRP 1-37A

Predicted Distresses:



Rutting

HMA-Rutting

$$\log\left(\frac{\varepsilon_p}{\varepsilon_r}\right) = -3.15552 + \log\beta_{r_1} + 1.734\beta_{r_2}\log T$$

$$+ 0.39937\beta_{r_3}\log N$$

ε_p = plastic strain

ε_r = resilient strain

T = layer temperature (deg F)

N = no of load repetition

βr_1, βr_2, βr_3 = calibration factors

2002 Design Guide

NCHRP 1-37A

Unbound Material-Rutting

$$\delta_a(N) = \beta_{s_1} \varepsilon_v \, h \left(\frac{\varepsilon_o}{\varepsilon_r}\right) \left[e^{-\left(\frac{\rho}{N}\right)^{\beta}} \right]$$

δ_a = permanent deformation for the layer

N = number of repetitions

ε_v = average vertical strain (in/in)

h = thickness of the layer (in)

ε_o, β, ρ = material properties

ε_r = resilient strain (in/in)

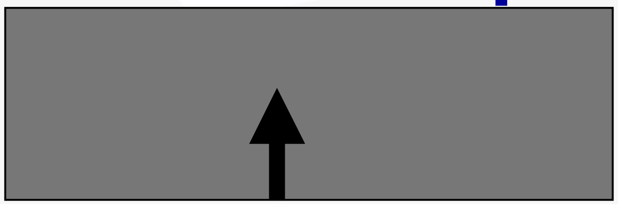
β_{s1} = Calibration factor

Fatigue Cracking

2002
Design Guide
NCHRP 1-37A

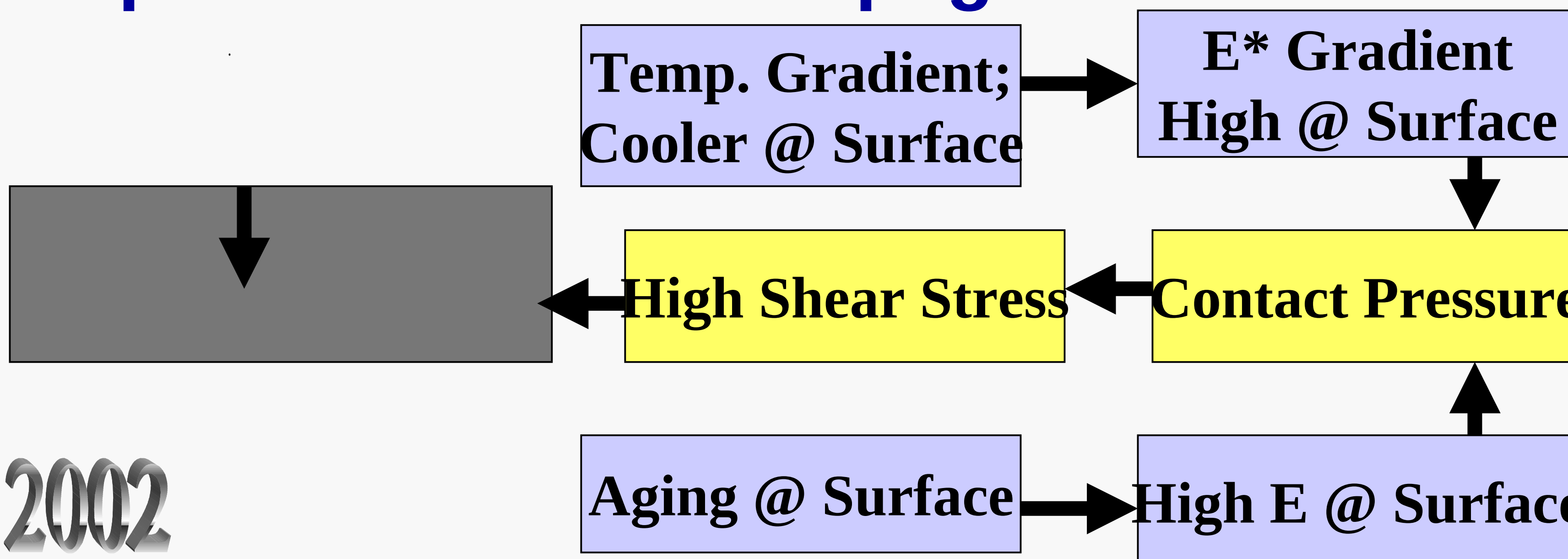
Simplified Fatigue Model

- **Bottom – Up Crack Propagation:**



Classical Fatigue Mechanism.

- **Top – Down Crack Propagation**



HMA Fatigue Cracking General Model Form

$$N_f = \beta_{f_1} k_1 \left(\frac{1}{\varepsilon_t}\right)^{k_2 \beta_{f_2}} \left(\frac{1}{E}\right)^{k_3 \beta_{f_3}}$$

$\beta_{f_1}; \ \beta_{f_2}; \ \beta_{f_3}$ → Calibration Factors

CTB-Fatigue

$$N_f = 10^{\left(\frac{0.972\,\beta_{C_1} - \sigma_s / M_r}{0.0825\,\beta_{C_2}} \right)}$$

σ_s = tensile stress

M_r = modulus of rupture

βc_1, βc_2 = calibration factors

Thermal Cracking

2002
Design Guide
NCHRP 1-37A

HMA-Thermal Fracture

- Uses SHRP Thermal Fracture Model
  - Roque, Hiltunen, and Buttlar
  - Improvements Since SHRP
  - Recalibrated Using Approximately 30 Sections in NCHRP Project 9-19

HMA-Thermal Fracture

- Thermal Fatigue
  - Propagation of Cracks Through the Asphalt Layer
- Thermal Stresses
  - Temperature
  - Mixture Properties
  - Friction
- Mixture Fracture Properties

Pavement Smoothness or IRI

2002
Design Guide
NCHRP 1-37A

Generalized Smoothness Model

$$IRI = IRI_O + \Delta IRI_D + \Delta\ IRI_{SF}$$

IRI_O = **Initial IRI**

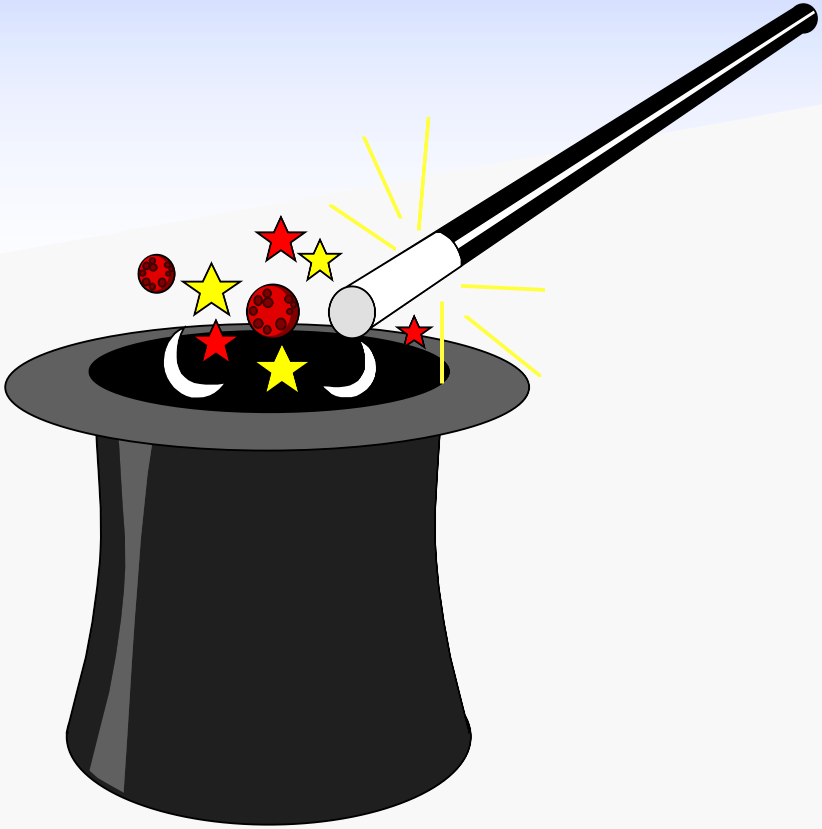
ΔIRI_D = **Change in IRI due to distress**

ΔIRI_{SF} = **Change in IRI due to site factors**

IRI-Distress Model Summary

Variable	Unbound Base	ATB	CTB	HMA OVERLAY	
				HMA	PCC
Site Factor	X	X			
Age	X	X		X	X
Alligator Ckg	X	X	X	X	
Rut Depth	X		X		X
Transverse Ckg.	X	X	X	X	X
Block Ckg.	X		X		
Longitudinal Ckg.	X		X	X	
Pot Holes				X	
Patching		X		X	

Calibration



Calibration

- Rutting and Fatigue Cracking Models
  - 94 LTPP Sections for New Design
  - 79 LTPP Sections for Rehabilitation
- Thermal Fracture Model
  - Previously Calibrated Using 30 Sections
- Smoothness
  - From LTPP Database

Summary

Summary

- Major Improvement for Flexible Pavement Design
- Best Approach for Structural Design
- Provides Link Between
  - Structural Design
  - Asphalt Mixture Design

Summary

- Wide Range of Pavement Structures
  - New
  - Rehabilitated
- Direct Consideration of Major Factors
  - Traffic
  - Climate
  - Materials
  - Support

Summary

- Uses Best Available Mechanistic-Empirical Models
  - Rutting
  - Fatigue Cracking
  - Thermal Cracking
- Models Calibrated Using LTPP Data
- Include Method for Local Calibration

Summary

- Models to Predict Change in Smoothness
  - Predicted Distresses
  - Site Factors
- Multiple Acceptance Criteria
  - Distresses
  - Smoothness

Flexible Pavement Design in the 2002 Design Guide

2002 Southeastern
Pavement Management &
Design Conference
June 25, 2002

2002
Design Guide
NCHRP 1-37A