Sensitivity Analysis for the NONROAD Model

Draft NONROAD2002 Workshop

Ann Arbor, Michigan

November 5, 2002

Sensitivity Analysis: Purpose

- Verify that model performs as expected
  - do we see expected relationships between inputs and outputs?
  - Direction? Magnitude? Trend?
- Assess relative importance of various inputs
  - informs priorities for model improvement

Sensitivity Analysis: Method

- Vary an input through its range, while holding all others constant
  - test behavior at extremes
- Compare results in absolute and relative terms
- Calculate Relative Sensitivity ***R*** (Elasticity)

$$R = \frac{\Delta \text{Output}(\%)}{\Delta \text{input}(\%)} = \frac{\left(\dfrac{o_i - o_{\text{def}}}{o_{\text{def}}}\right)}{\left(\dfrac{i_i - i_{\text{def}}}{i_{\text{def}}}\right)}$$

NONROAD’s Input Types

- Emissions Calculation
  - “back bone” of exhaust emissions calculation
    - EF, Activity, Load, Rated Power, Population
    - can’t modify from GUI
- Projection Variables
  - model uses when forecasting (or back-casting)
    - population growth rate, median life, deterioration rate
    - can’t modify from GUI
- Scenario Options
  - apply to scenarios, rather than equipment
    - RVP, gasoline O_2 content, in-use S level, average temperature
    - easily modified in GUI

Scope of Presentation

- Exhaust emissions
  - Emission calculation inputs
  - Projection variables
  - Scenario Options (summary)
- Analyses performed using currently available public draft (June-2000 NONROAD)

Emissions Calculation

- Basic Exhaust Emissions Equation

$$I_{\text{exh}} = E_{\text{exh}} \cdot A \cdot L \cdot P \cdot N$$

I_{exh}	=	Emissions Inventory, ton/year
E_{exh}	=	Exhaust Emission Factor, g/hp-hr
A	=	Activity (hours/year)
L	=	Load Factor
N	=	Equipment Population

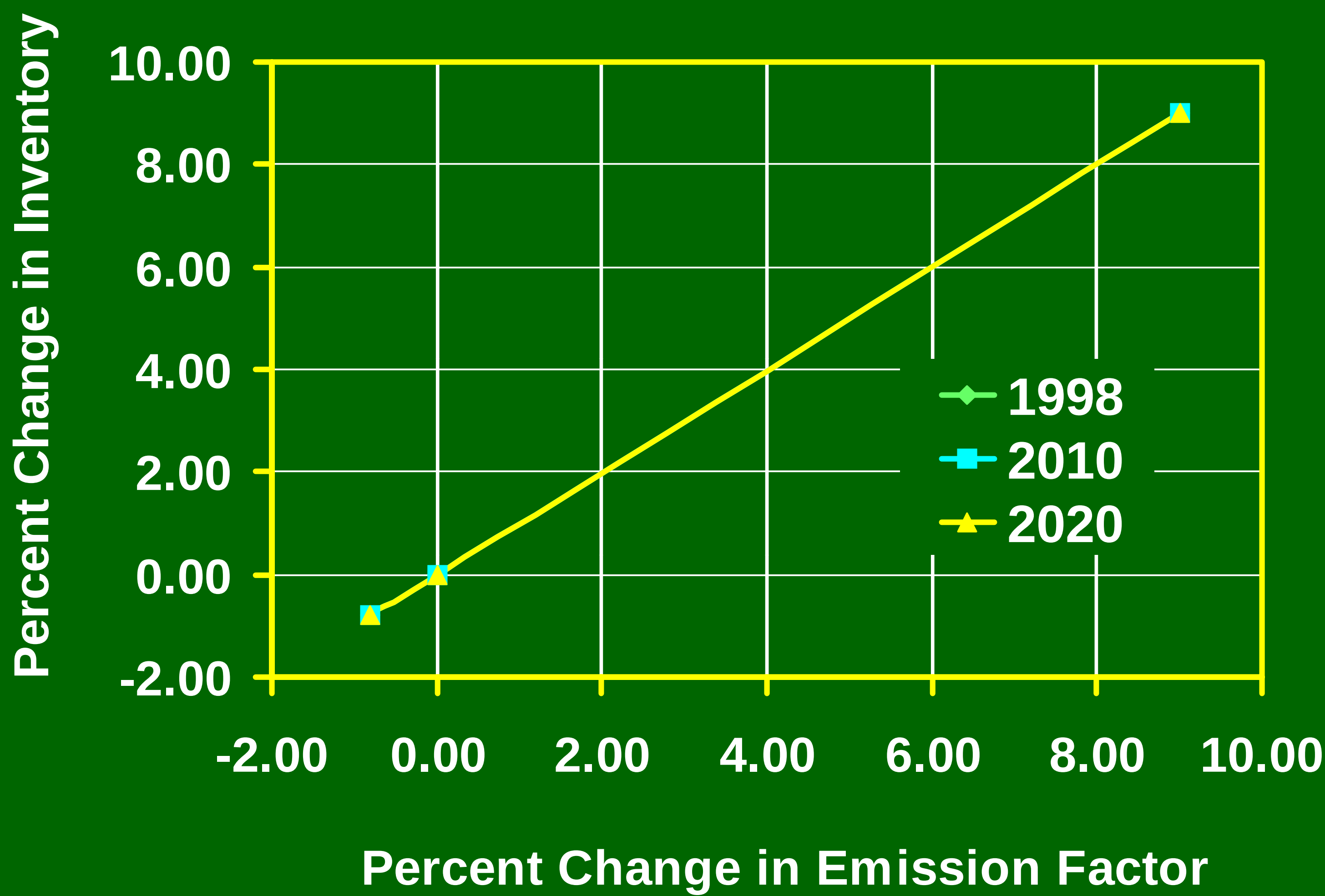
  – Can’t change in GUI; must modify input file
  – Expect linear behavior

Emissions Calculation: *Example*

Application: Rubber-tired Loader
Power Class: 100-175 hp
Input: NOx Emission Factor (E_{NOx})
Output: NOx Inventory (I_{NOx}, ton/year)

Setting	Multiple	E_{NOx}	I_{NOx}	ΔE (%)	ΔI(%)	R
Low	0.2	0.5	5,600	-80.0	-80.0	*1.0*
Nominal	1.0	2.5	28,100	0.0	0.0	
High	10.0	25.0	281,000	900.0	900.0	*1.0*

Emissions Calculation:
Relative Change in Inputs and Outputs



Equipment Population Projection

- NONROAD projects future (or past) emissions through change in equipment populations
- key input: annual growth rate (g, %/year)
- Population grows linearly on annual basis

$$N_y = N_{base}(1 + ng) \qquad n = y - base$$

- g varies by sector

Construction:	g = 3.2 %/year
Agricultural:	g = 2.6 %/year
Commercial:	g = 4.6 %/year

Equipment Population Projection

- User doesn't modify *g* directly
  - <u>is not listed in input file as such</u>
- Growth input file contains "reference populations" in selected years that reflect *g*
- When projecting, NONROAD recalculates *g* and applies to current year
- When between two reference years, the model extrapolates *g*

Equipment Population:
Reference Populations

<u>Example</u>: “Construction Diesel”
default g = 3.2 %/year

Reference Year (y)	***Formula:* 1,000(1+ng)**	**Reference Population**
1996	1,000(1 + 0g)	1,000
2000	1,000(1 + 4g)	1,128
2005	1,000(1 + 9g)	1,288
2010	1,000(1 + 14g)	1,448
2015	1,000(1 + 19g)	1,608
2025	1,000(1 + 29g)	1,928
2045	1,000(1 + 49g)	2,568

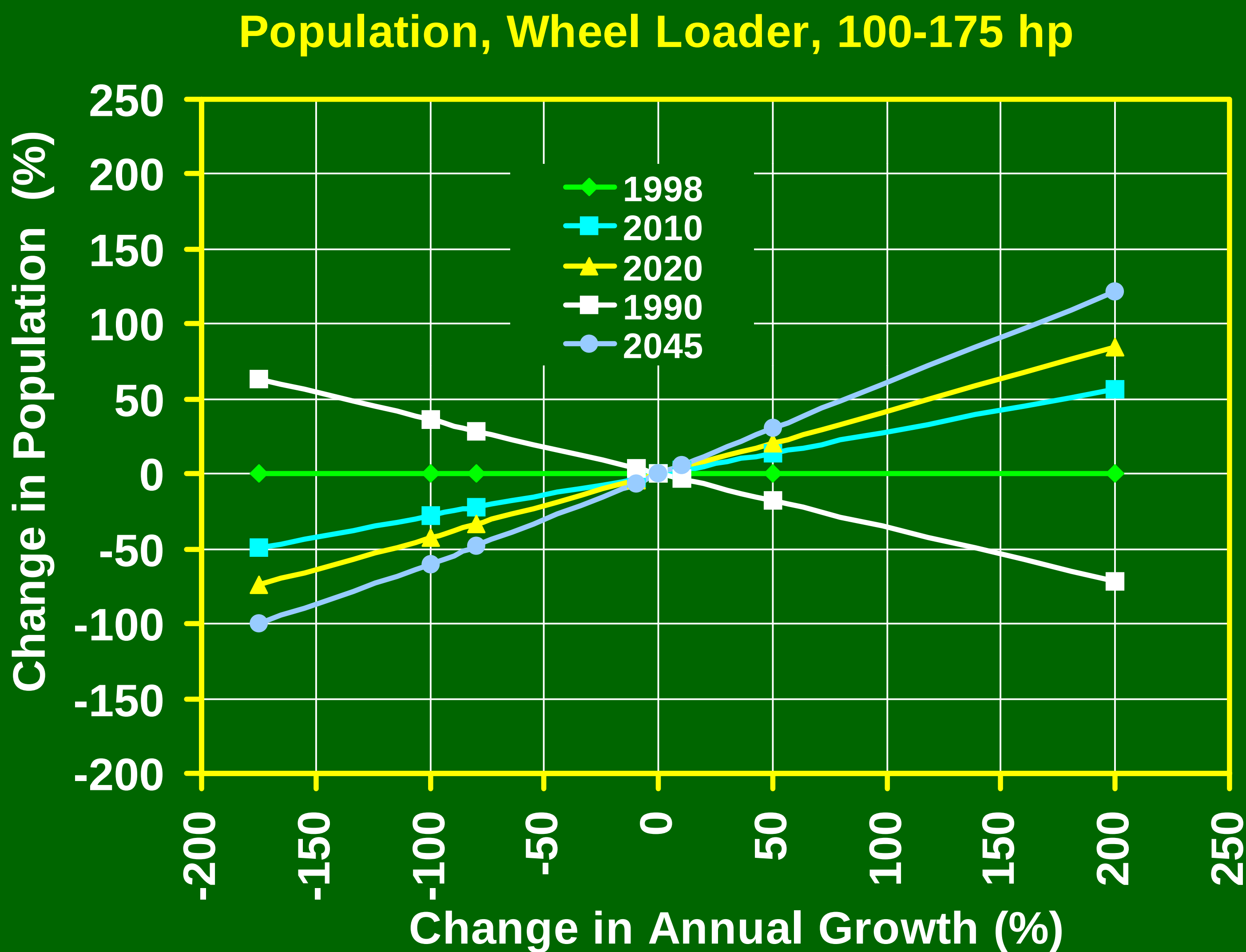
Equipment Population: *Example*

Application: Rubber-tired Loader
Power Class: 100-175 hp
Input: Annual growth rate (*g*, %/year)
Output: Equipment Population (*N*, thousands)
Year: projection in 2010

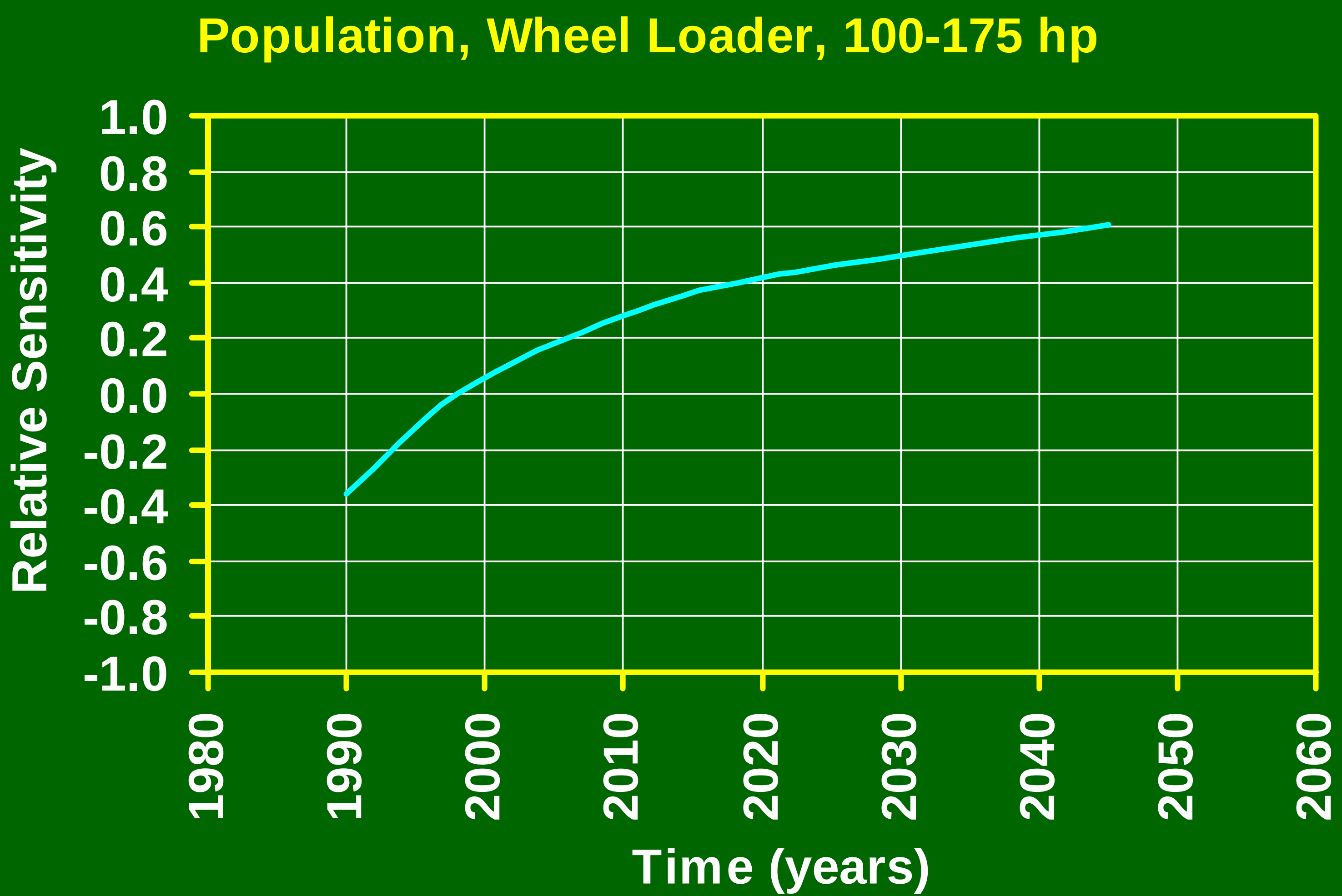
Multiple	***g***	***N***	**Δ*g*(%)**	**Δ*N*(%)**	***R***
-0.75	-2.5	49	-175	-50	*0.28*
0.00	0.0	70	-100	-28	*0.28*
0.20	0.7	75	-80	-23	*0.28*
0.90	3.0	95	-10	-3.0	*0.28*
1.00	3.3	97	0	0	---
1.10	3.6	100	10	3.0	*0.28*
1.50	5.0	111	50	14	*0.28*
3.00	9.9	152	200	56	*0.28*

Equipment Population:

Relative Change in Inputs and Outputs



Equipment Population:
Relative Sensitivity over Time



Equipment Median Life

- During projection, applies to engines "sold" into population in given year (*model-year cohort*)
  - Scrappage follows "*backwards S curve*" (reverse cumulative normal distribution)
- key input: median life (l_h, hrs @ full load)
  - period over which 50% of engines scrapped
- NONROAD uses "annualized median life" (l_y, years)

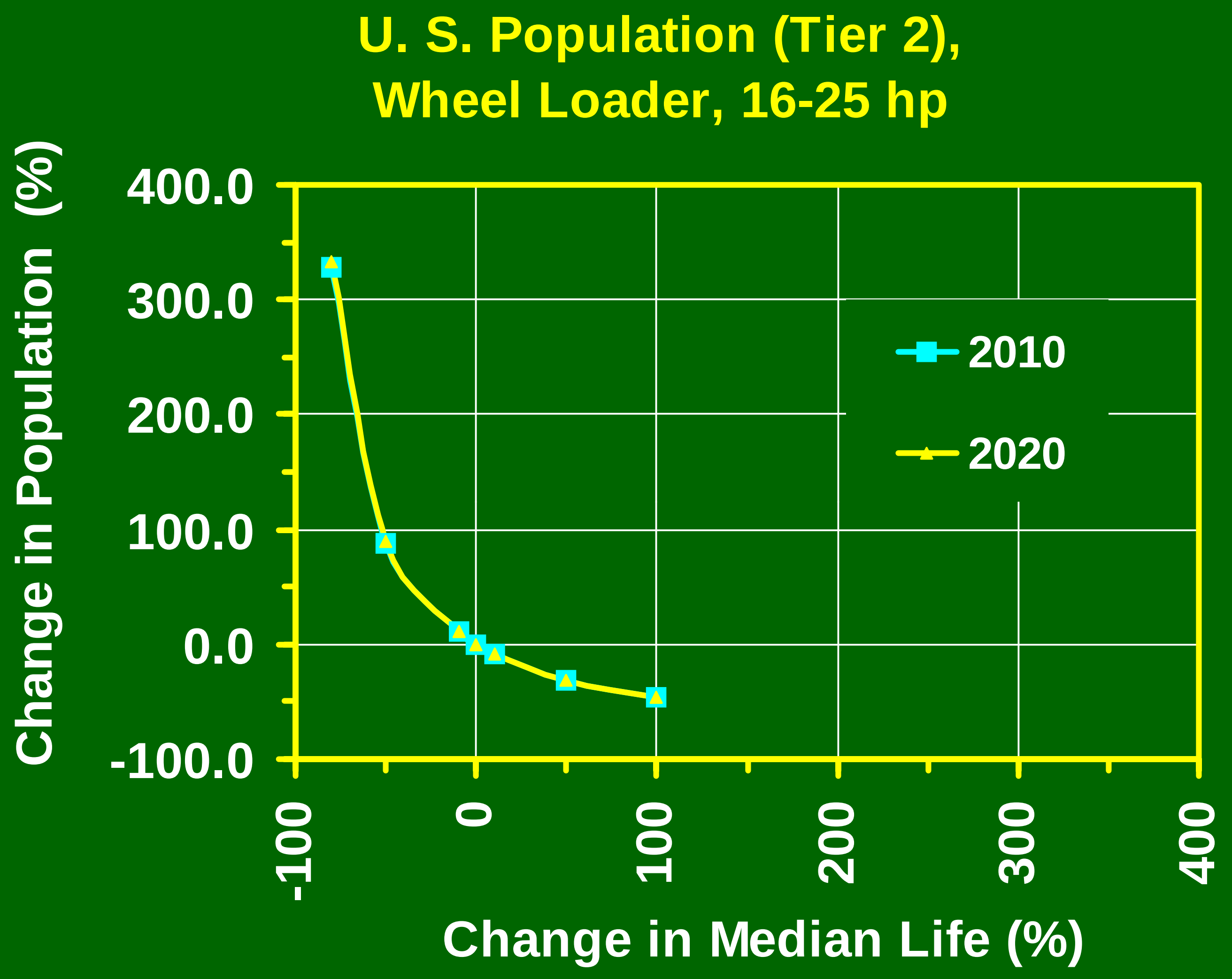
$$l_y = \frac{l_h}{A \cdot L}$$

Median Life: *Example*

Application: Rubber-tired Loader
Power Class: 16-25 hp
Input: median life (l_h, hours @ full load)
Output: Tier 2 Equipment Population (N, loaders)
Year: projection in 2010

Multiple	l_h	N	Δl_h(%)	ΔN(%)	R
0.2	500	817	-80	-330	*-4.1*
0.5	1,250	360	-50	-89	*-1.8*
0.9	2,250	210	-10	-10	*-1.0*
1.0	2,500	191	0	0	---
1.1	2,750	174	10	9	*-0.9*
1.5	3,750	131	50	32	*-0.6*
2.0	5,000	104	100	46	*-0.5*

Median Life:
Relative Change in Inputs and Outputs



Relative Deterioration Rate

- During projection, NONROAD applies deterioration to exhaust emission factors
  - reaches maximum at 1.0 median life
- key input: d (%ΔE_{exh} per % life expended)
  - applies to model year cohorts
  - varies by tech groups

$$D_y = B\left(1 + d\left(\frac{\text{age}}{l_y}\right)^b\right)$$

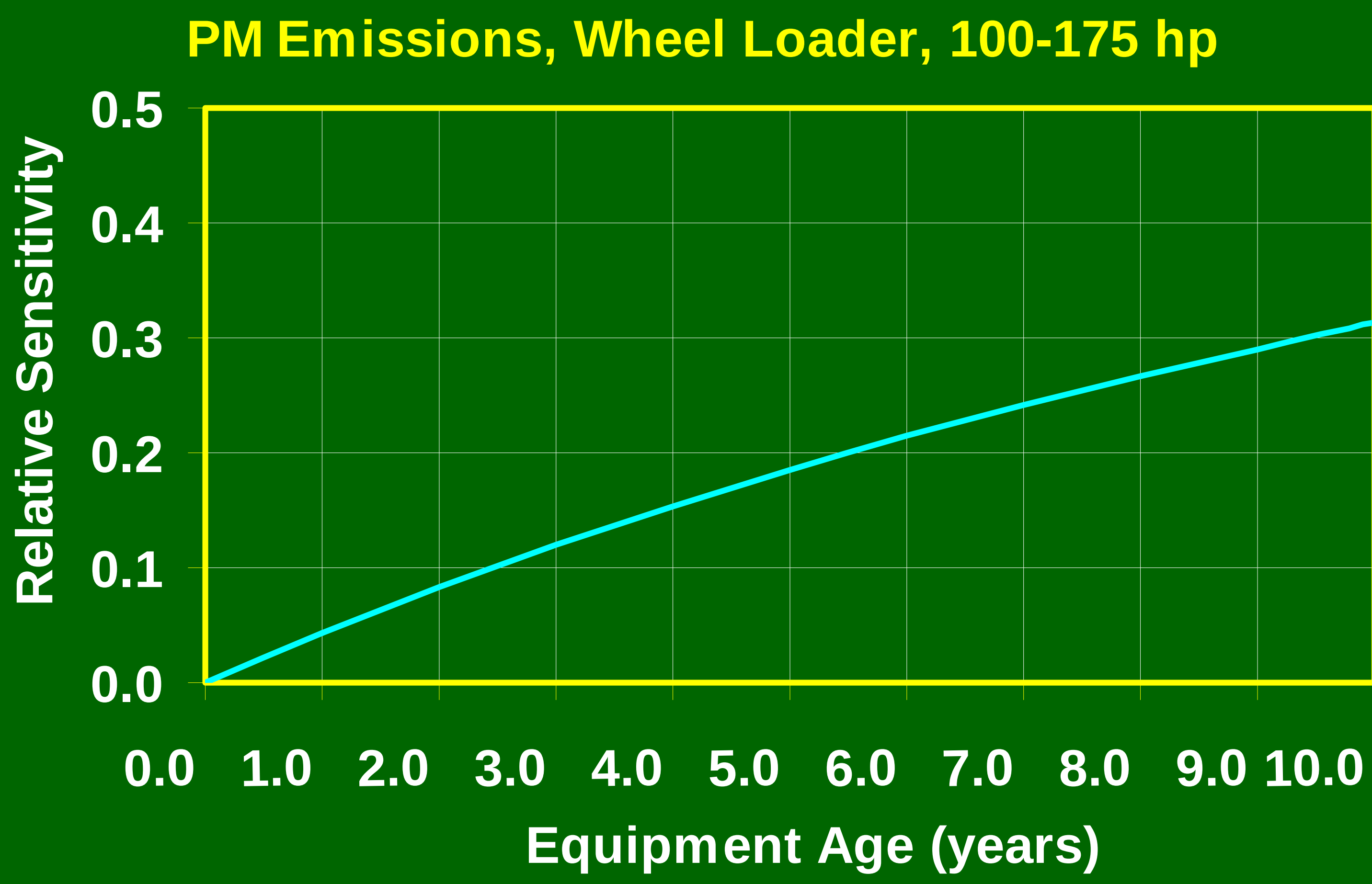
D_y = Emission factor in current year
B = Emission factor in model year
age = current year - model year
l_y = annualized median life, years
b = coefficient (b $\in$ 0.5, 1.0)

Deterioration: *Example*

<u>Application</u>: Rubber-tired Loader
<u>Power Class:</u> 100-175 hp
<u>Input</u>: *d* (% increase/% median life)
<u>Output</u>: PM Emission factor at age 10
<u>Reference</u>: Tier 2 emission factor (0.295 g/hp-hr)

Multiple	***d***	$D_{y,10}$	$\Delta d_{10}(\%)$	$\Delta D_{y,10}(\%)$	***R***
0.01	0.005	0.297	-99	-30	0.3
0.90	0.426	0.416	-10	-3	0.3
1.0	0.473	0.430	0	0	---
1.1	0.520	0.443	10	3	0.3
10.0	4.730	1.639	900	280	0.3

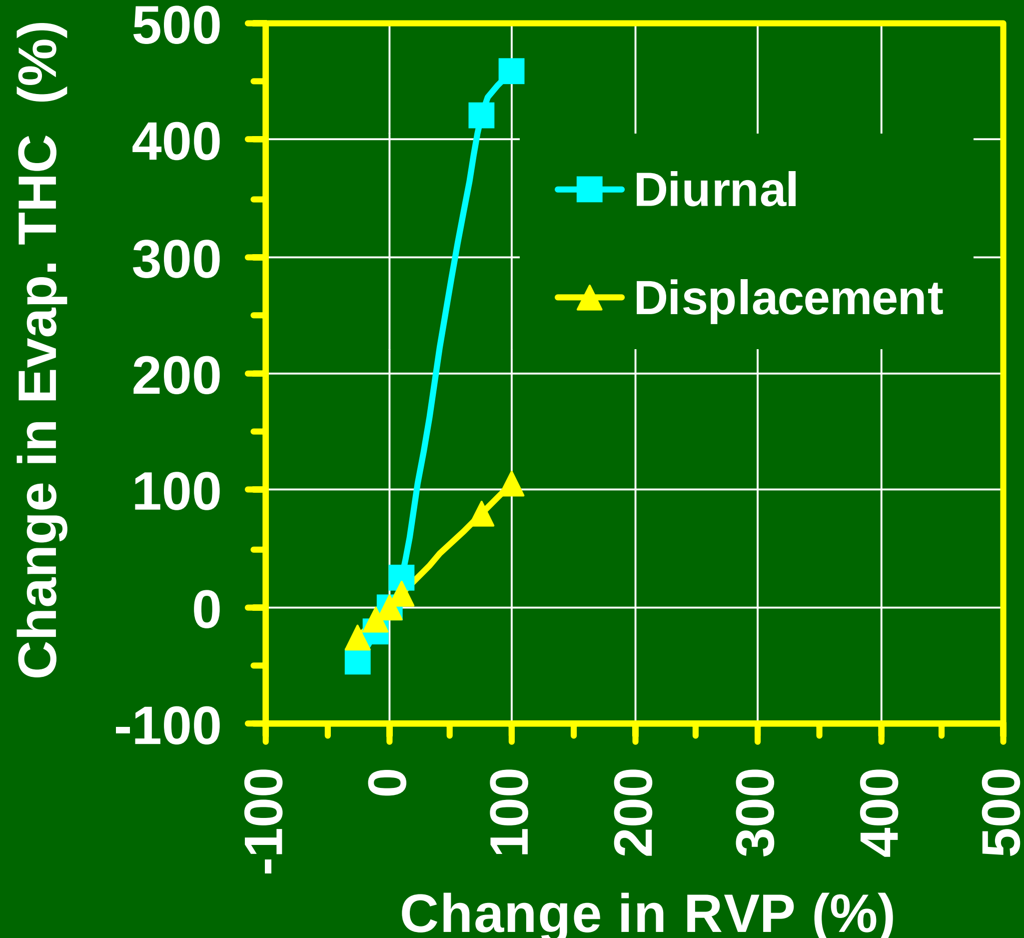
Relative Deterioration Rate:
Relative Sensitivity



Reid Vapor Pressure

Relative Change in Inputs and Outputs

Example:
Forklift
50-100 hp
Input: RVP
Output: Evap. HC,
diurnal,
displacement



Summary:
Sensitivities for Exhaust Emissions

Comparing Relative Sensitivities over time, in neighborhood of defaults (±10%)

Input	Output	Equipment	|*R*| 1998	|*R*| 2010	|*R*| 2020
E_{exh}	$I_{NOx,dsl}$	RT loader,100-175 hp	1.0	1.0	1.0
g_{const}	N_{equip}	RT loader, 100-175 hp	0.0	0.28	0.42
l_h	$I_{NOx,dsl}$	RT loader, all	0.20	0.40	0.05
$d_{PM,dsl}$	$I_{PM,dsl}$	RT loader, all	0.21	0.18	0.17
T_{ave}	$I_{CO,gas}$	4S Generator	0.20	0.20	0.20
T_{ave}	$I_{NOx,gas}$	4S Generator	0.65	0.65	0.65
O_2^{gas}	$I_{NOx,gas}$	2S Generator, 3-6 hp	0.32	0.32	0.32
O_2^{gas}	$I_{NOx,gas}$	4S Generator, 6-11 hp	0.20	0.20	0.20

Summary:
Sensitivities for Evaporative Emissions

Comparing Relative Sensitivities over time, in neighborhood of defaults (±10%)

Input	Output	Equipment	|*R*| 1998	|*R*| 2010	|*R*| 2020
T_{ave}	$I_{THC,disp}$	4S Inboard, 3-6 hp	1.4	1.4	1.4
T_{ave}	$I_{THC,disp}$	4S Inboard, 100-175 hp	0.31	0.31	0.31
RVP	$I_{THC,disp}$	4S Forklift, 50-100 hp	1.1	1.1	1.1
RVP	$I_{THC,diurnal}$	4S Forklift, 50-100 hp	2.3	2.3	2.3