User perceptions of highway roughness

Kevan Shafizadeh and Fred Mannering

Background

- **States invest millions of dollars annually measuring the physical condition of their highways**

- **Such measurements are used to allocate resources for repair and reconstruction**
  - *Are the correct factors being measured?*
  - *How do physical measurements correspond to public perceptions?*

Factors usually measured:

- *Rutting*
- *Faulting*
- *Cracking*
- *Patching*
- *Spalling*

Rutting
(surface deflection in wheel path):

Alligator (fatigue) Cracking:

Slippage Cracking:

Traverse Thermal Cracking:

Patching:

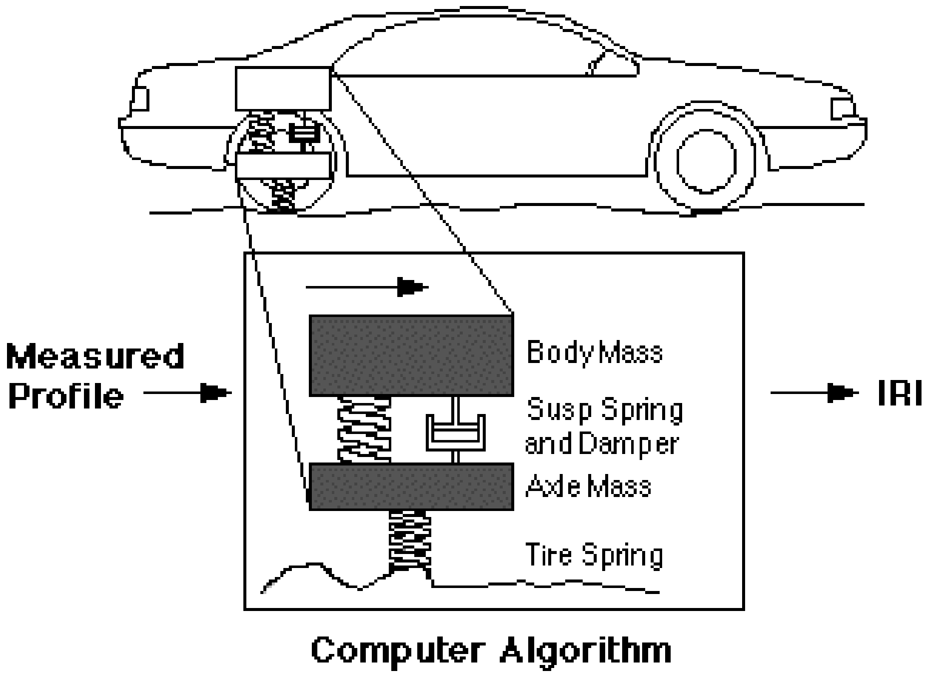
Spalling:

Faulting:

International Roughness Index (IRI)

- *Widely accepted measure of pavement condition*
- *IRI procedures were developed by the World Bank in Brazil*
- *Measures suspension movement over some longitudinal distance (in/mi)*
- *IRI correlates with vertical passenger acceleration and tire load*

International Roughness Index (IRI)



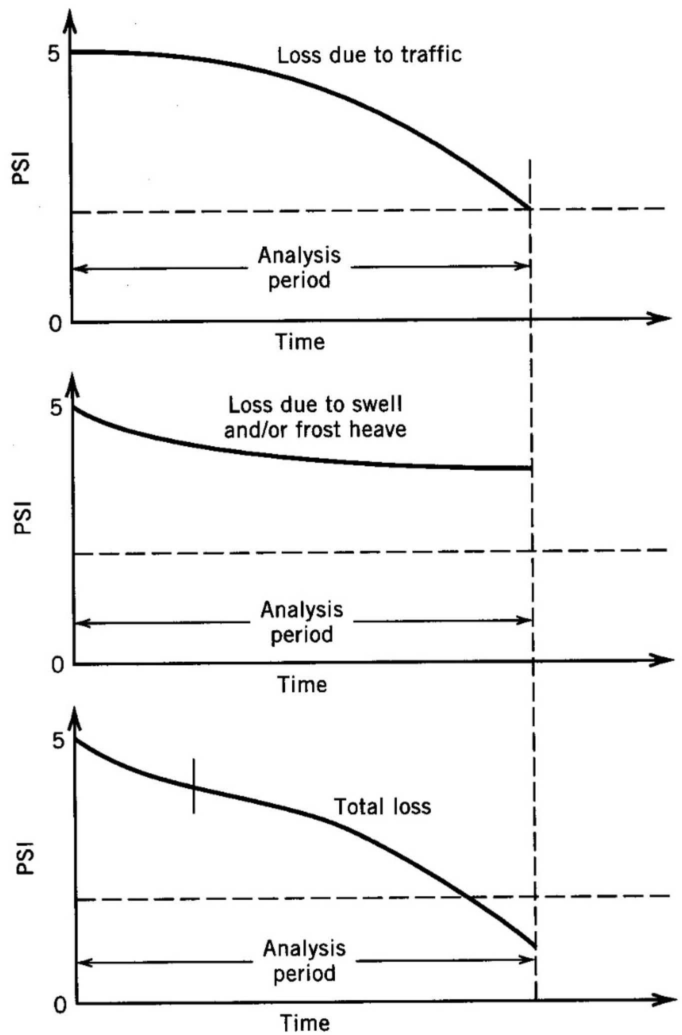
IRI and pavement quality

- **Very good** (<60 in/mi),
- **Good** (61-94 in/mi),
- **Fair** (95-119 in/mi for Interstates, 95-170 in/mi for other roads),
- **Mediocre** (120-170 in/mi for Interstates, 171-220 in/mi for other roads) and
- **Poor** (>170 in/mi for Interstates, >220 in/mi for other roads)

Present Serviceability Index (PSI) and IRI

- **Excellent** (4.1– 5.0) ~ (IRI<60 in/mi),
- **Good** (3.1– 4.0) **~** (61-94 in/mi),
- **Fair** (2.1– 3.0) **~** (95-170 in/mi for Interstates, 95-220 in/mi for other roads),
- **Poor** (1.1– 2.0) **~** (>170 in/mi for Interstates, >220 in/mi for other roads)
- **Very Poor** (0 – 1.0)

PSI in pavement design



PSI in pavement design

- Initial and terminal PSI used in pavement design equations
- Terminal PSI is critical in determining Load Equivalency Factors to get W_{18}

PSI in pavement design

- **Flexible pavements:**

$$\log_{10} W_{18} = Z_R S_o + 9.36\left[\log_{10}(\mathrm{SN}+1)\right] - 0.20 + \frac{\log_{10}\left[\Delta \mathrm{PSI}/2.7\right]}{0.40 + \left[1094/(\mathrm{SN}+1)^{5.19}\right]}$$

$$+ 2.32 \log_{10} M_R - 8.07$$

- **Rigid pavements**

$$\log_{10} W_{18} = Z_{\mathrm{R}} S_o + 7.35\left[\log_{10}(D+1)\right] - 0.06 + \frac{\log_{10}\left[\Delta \mathrm{PSI}/3.0\right]}{1 + \left[1.624 \times 10^{7}/(D+1)^{8.46}\right]}$$

$$+ (4.22 - 0.32\mathrm{TSI}) \log_{10}\left(\frac{S_c' C_d\left[D^{0.75} - 1.132\right]}{215.63 J\left\{D^{0.75} - \left[18.42/(E_c/k)^{0.25}\right]\right\}}\right)$$

Study Motivation

- To determine how user perceptions of pavement roughness (the intent of PSI) relate to the IRI and other factors

What makes a road feel rough?

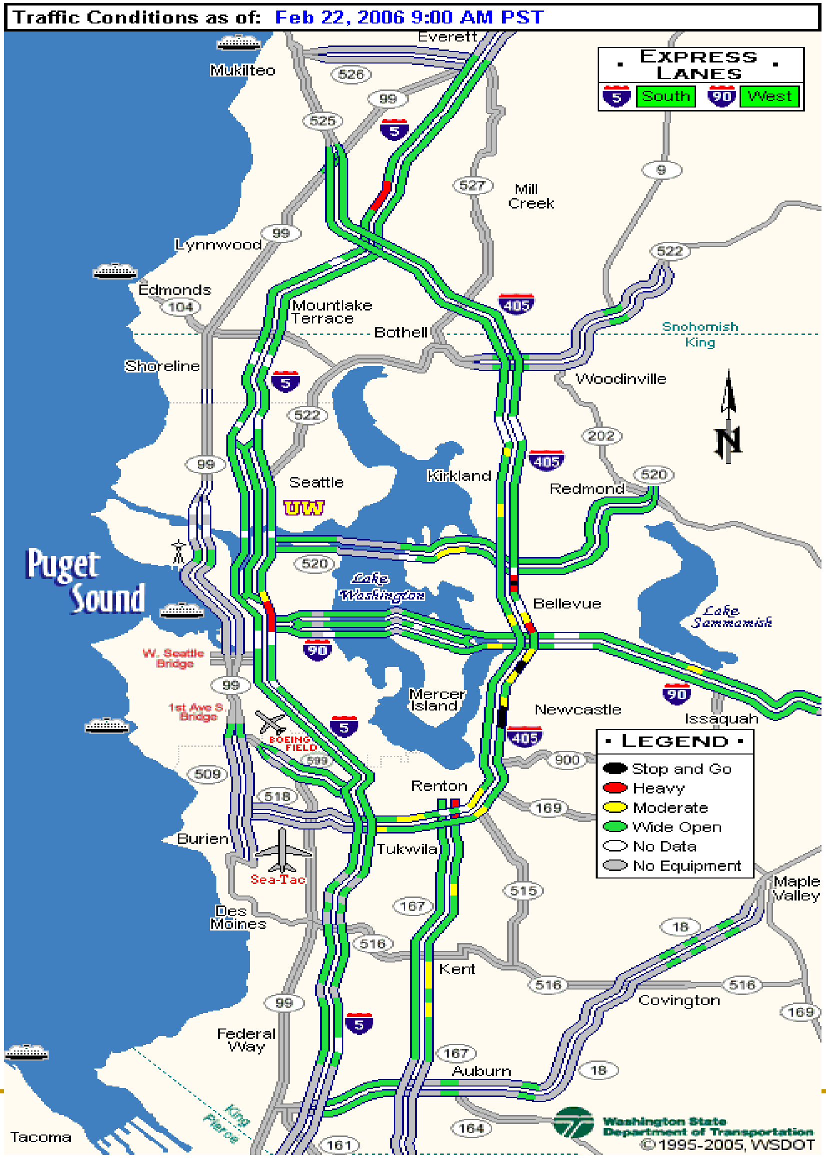
Factors likely to determine roughness opinion

- Socioeconomic (age, income, etc.)
- Type of vehicle driven
- Interior noise level
- Passenger expectations when driving from one pavement condition to the next
- Physical measures of pavement condition

Study approach:

- *Have **56 individuals** drive a variety of vehicles **(mid-sized sedan, sport-utility vehicle, pick-up truck, minivan)***
- *Individuals drive over a circuit of Seattle freeways that includes **40 segments** with detailed data from pavement databases **(IRI, Pavement structural condition, patching, pavement type, etc.)***

Seattle Freeway Map:



Study approach (continued):

- *In addition to physical pavement measurements, on the 40 sections data are collected on:*
  - *1(smooth) to 5 (rough) scale of roughness impression*
  - *Interior vehicle noise*
  - *Vehicle speed*
  - *Weather conditions*
  - *Pavement surface (wet or dry)*

Statistical Modeling Methodology

- *Ratings of roadway roughness on a scale from one to five – with one being the smoothest and five being the roughest.*

- *Use an ordered probit model. Define an unobserved variable z for each observation n*

$$z_n = \beta \mathbf{X}_n + \varepsilon_n$$

where:

X *is a vector of variables determining the discrete ordering for observation n,*

β *is a vector of estimable coefficients, and*

ε *is a random disturbance*

Observed ordinal data are defined:

$$
\begin{aligned}
y_n &= 1 && \text{if } z_n \le \mu_0 \\
&= 2 && \text{if } \mu_0 < z_n \le \mu_1 \\
&= 3 && \text{if } \mu_1 < z_n \le \mu_2 \\
&= 4 && \text{if } \mu_2 < z_n \le \mu_3 \\
&= 5 && \text{if } z_n > \mu_3
\end{aligned}
$$

where:

μ's are estimable thresholds that define y_n

Figure 14.1: Illustration of an ordered probability model with $\mu_0 = 0$.

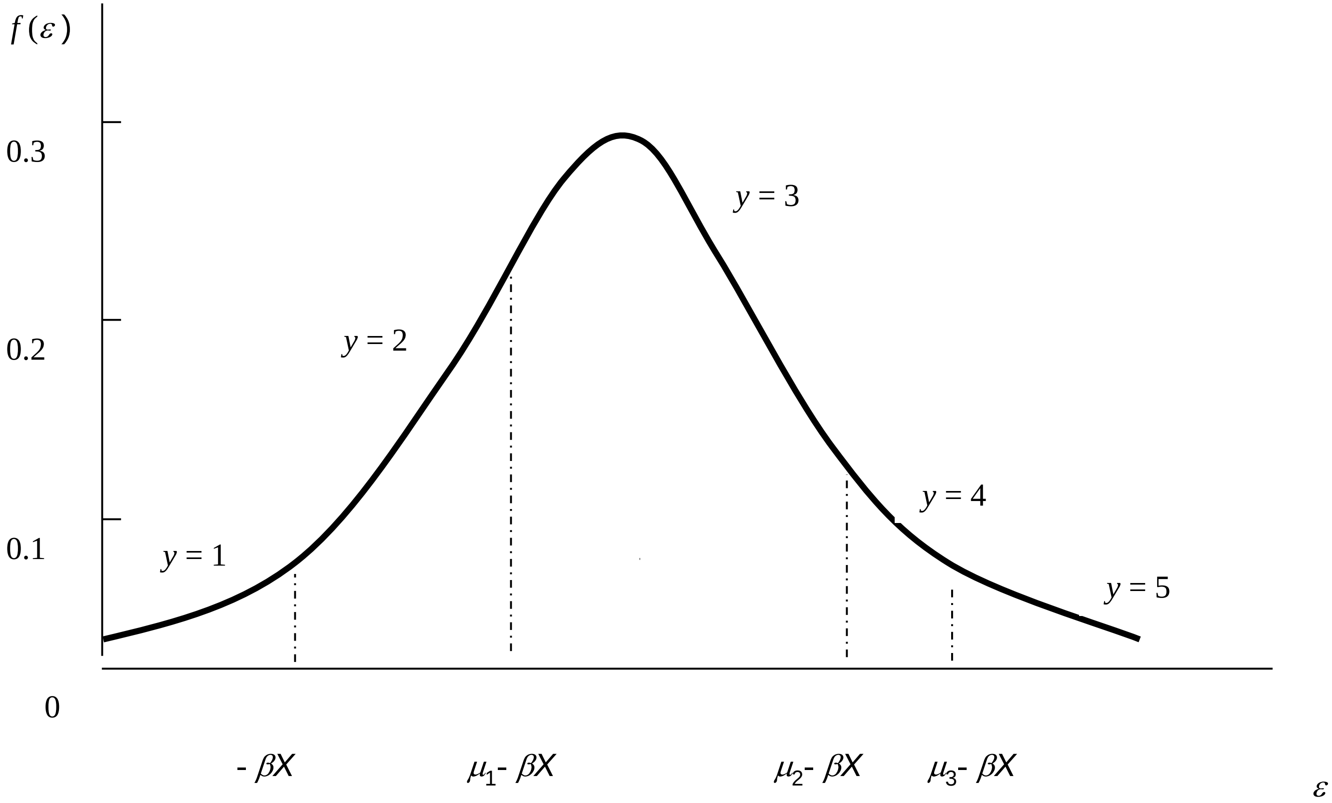
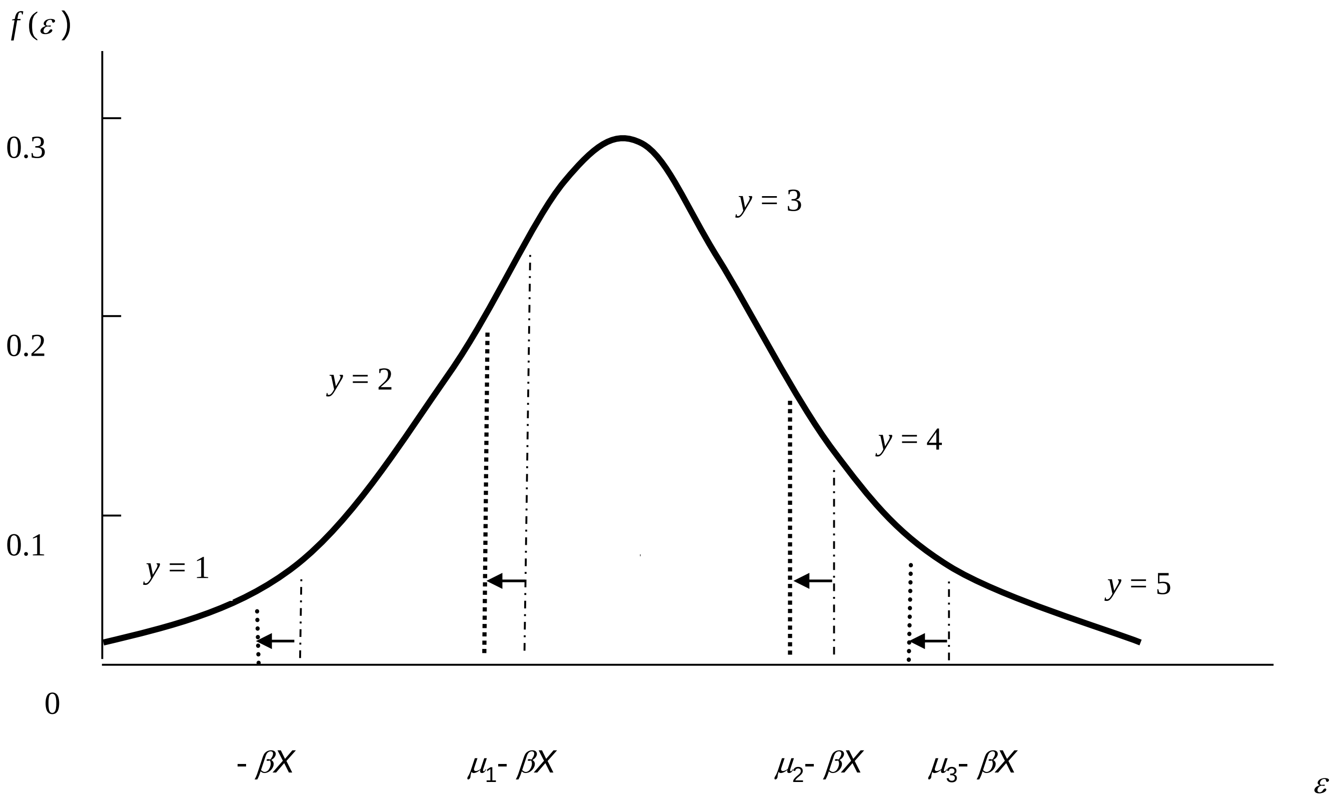


Figure 14.2: Illustration of an ordered probability models with an increase in βX (with $\mu_0 = 0$).



Random effects:

- *To account for repeat observations (56 subjects) (40 opinions for each person) a random effects model is used:*

$$z_{ic} = \beta \mathbf{X}_{ic} + \varepsilon_{ic} + \boldsymbol{\varphi}_i$$

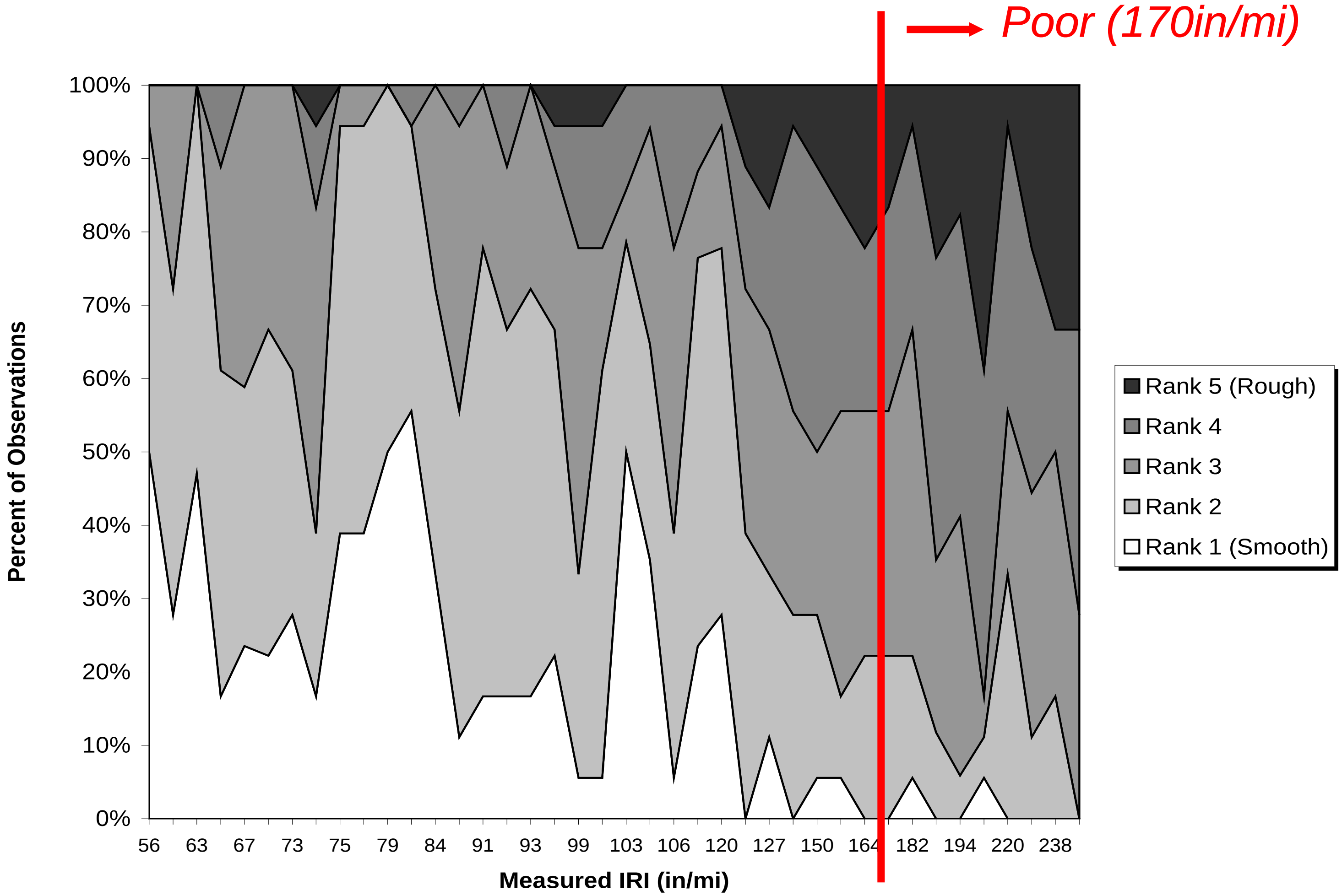
- *Where:*

  I denotes an individual (1 to 56);

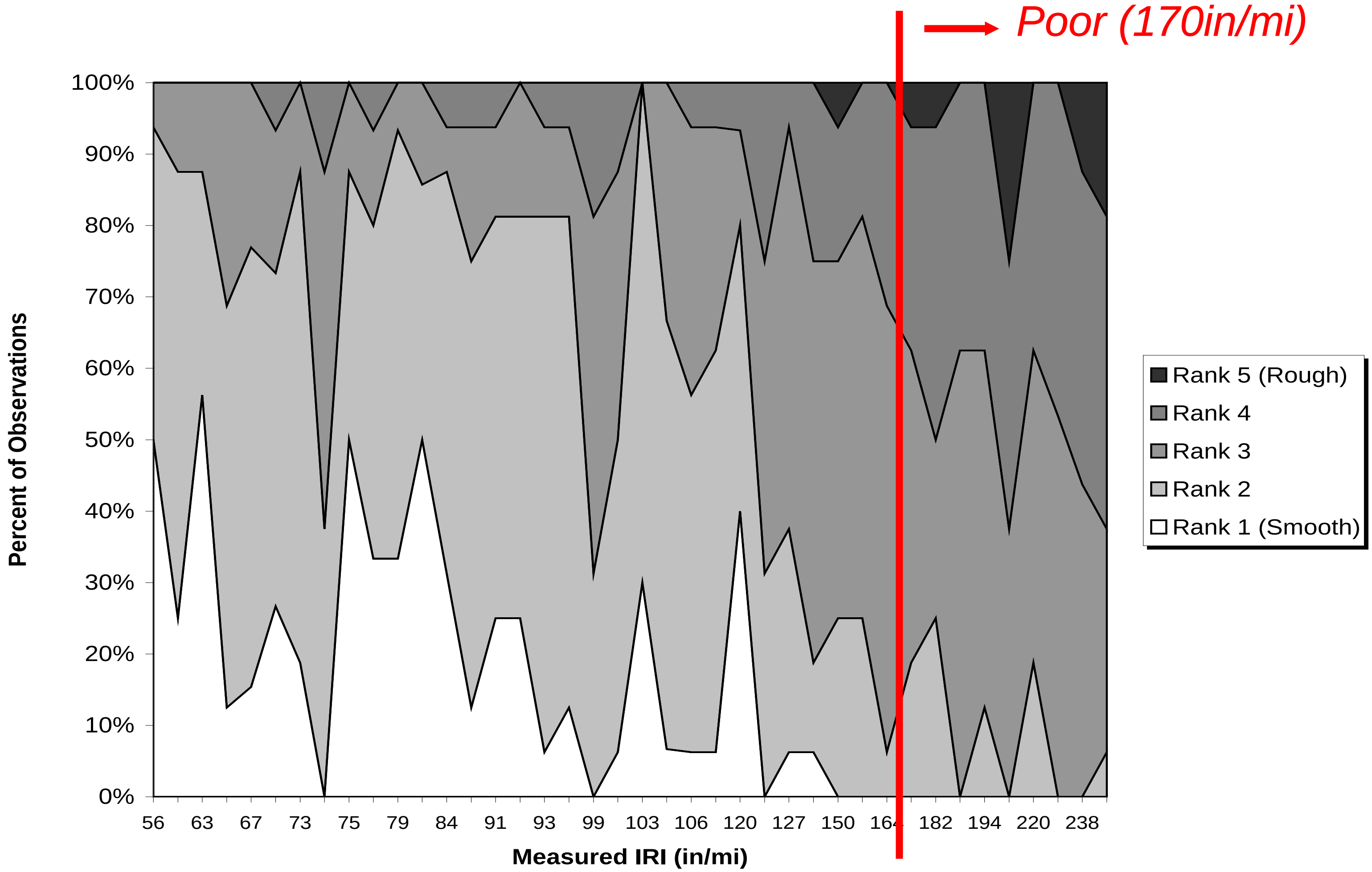
  c denotes roadway segments (1 to 40) and,

  φ_i *is an individual specific error term that is normally distributed*

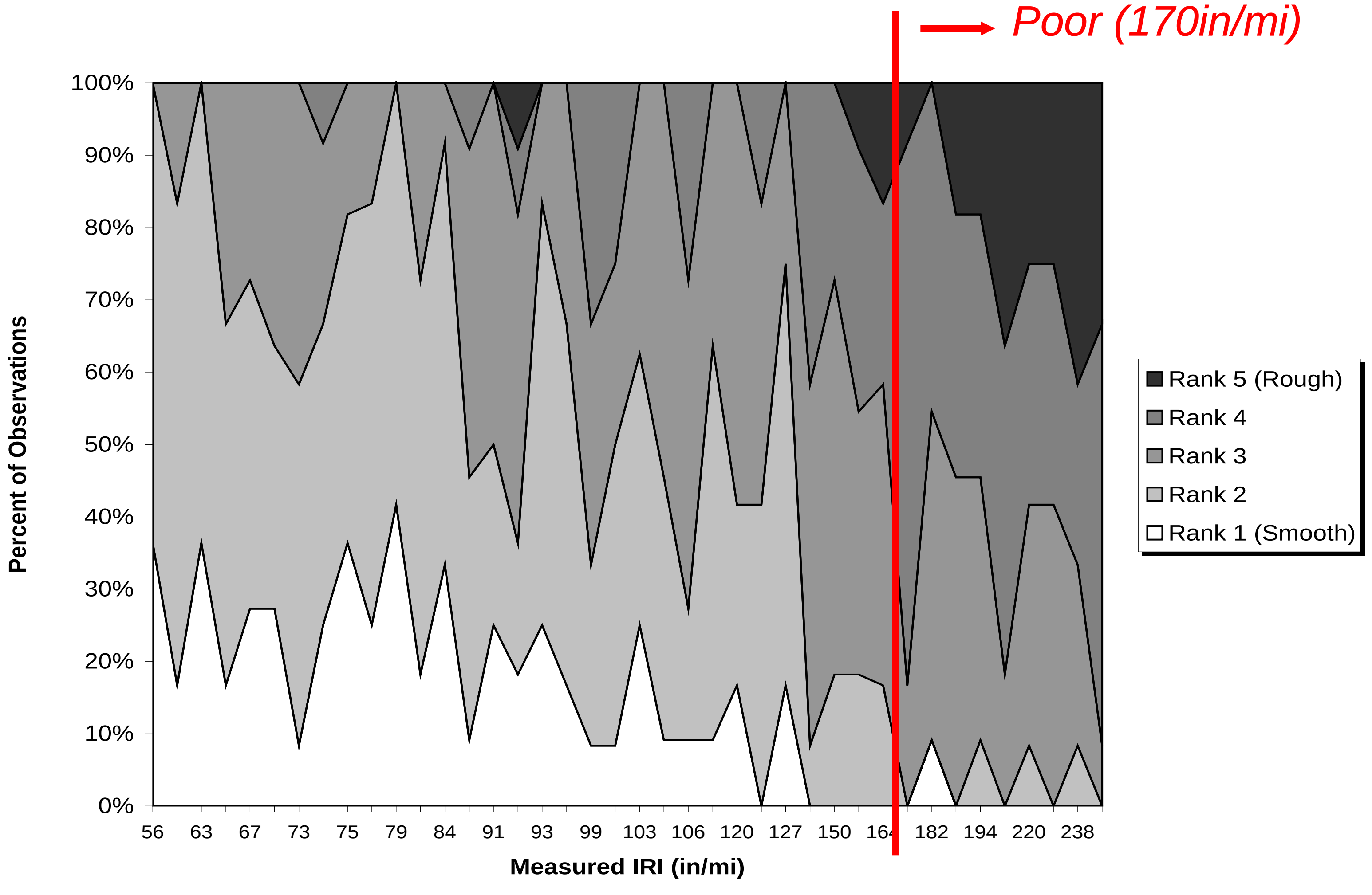
General results (midsized vehicle)



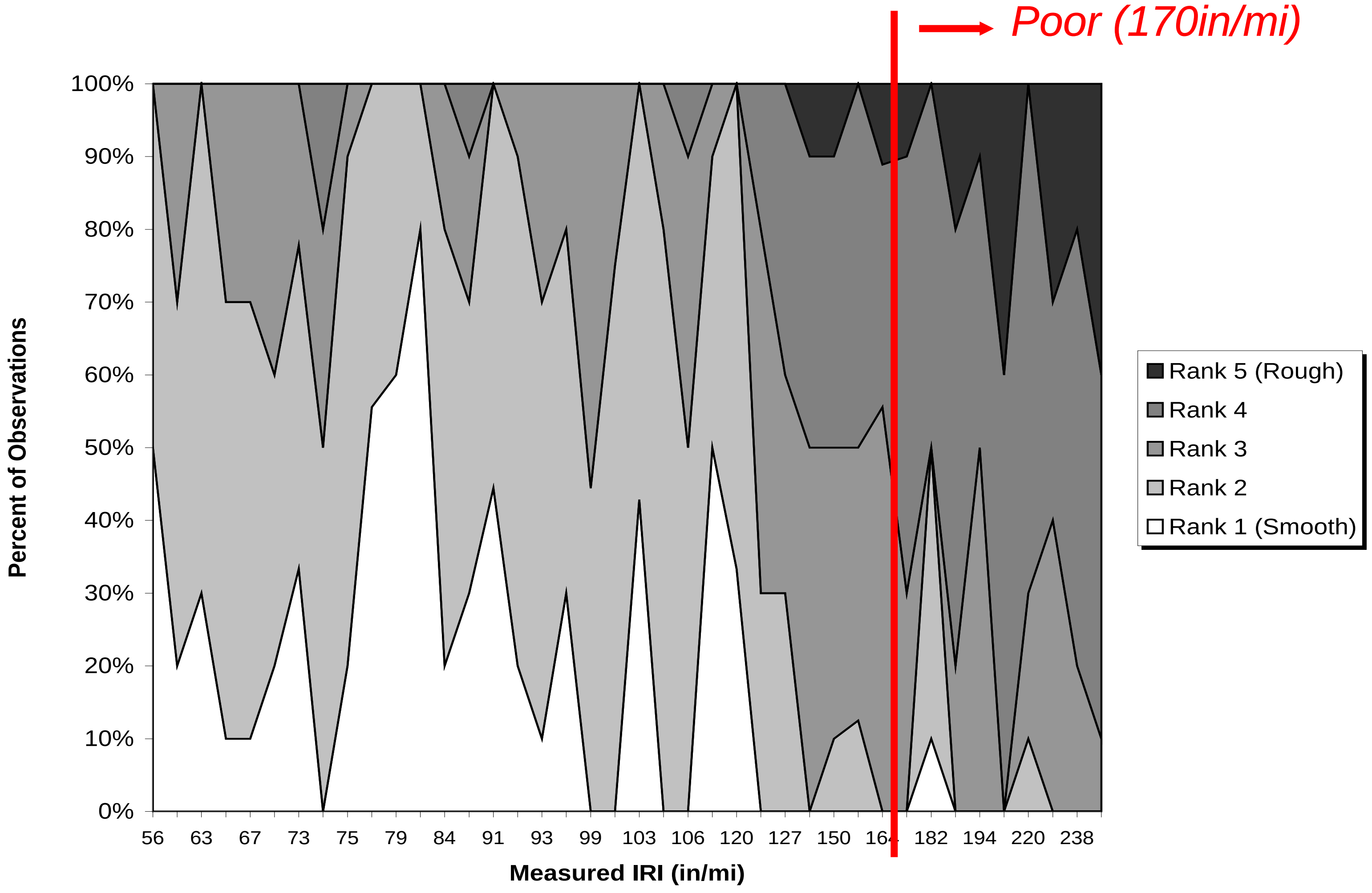
General results (SUV)



General results (pickup truck)



General results (minivan)



Summary data:

Percent of male/female respondents	64.5/35.5
Avg. household size	2.7
Average household annual income category (US dollars)	55,000 – 64,999
Avg. respondent age category (years)	41 – 45

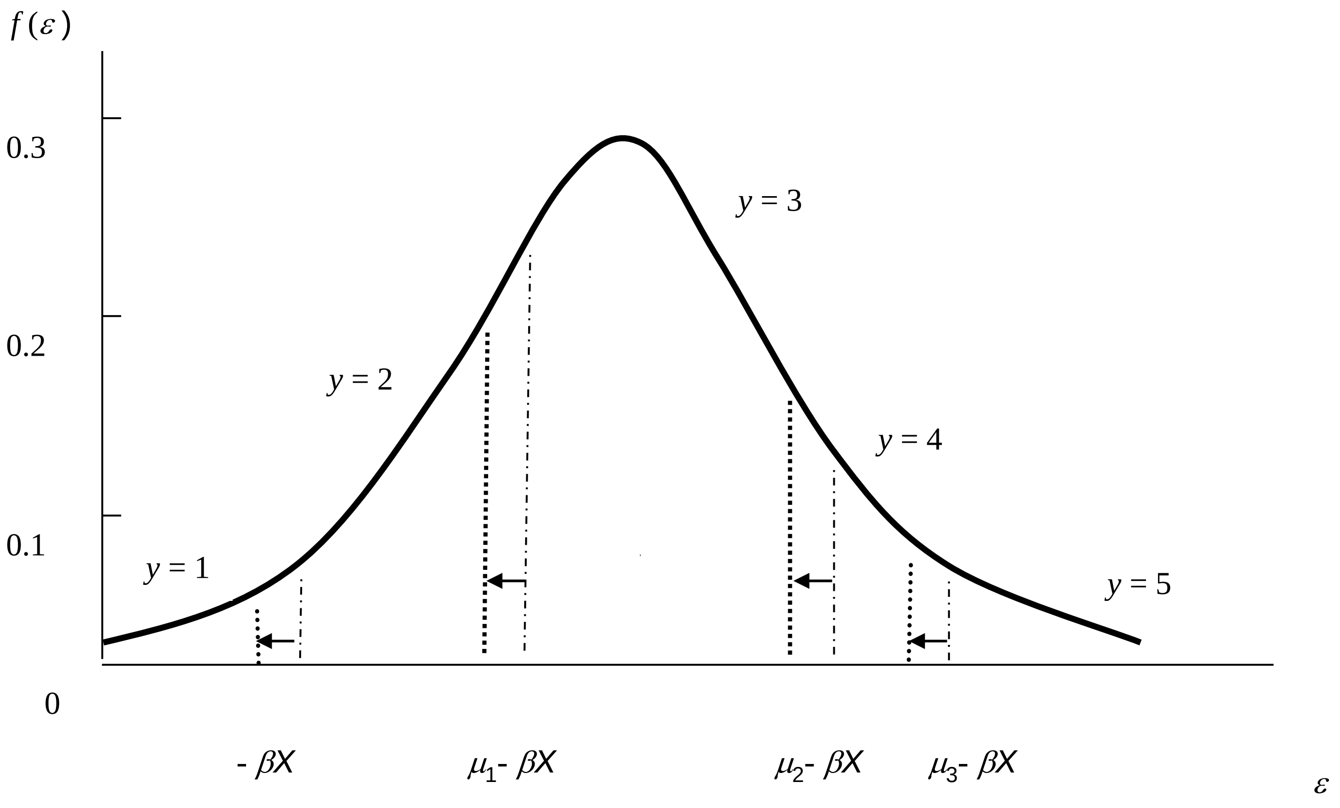
Summary data (continued):

Avg. test segment IRI measurement (in/mi)	122.75 (fair/mediocre)
Avg. roadway segment surface age (years)	17.43
Pavement structural condition (PSC) index of roadway	90.78
Percent of segments by surface type: rigid/flexible	35.1/64.9

Interpretation of results: Marginal effects

- Marginal effects give the change in category probabilities (1=smooth, 2, 3, 4, 5=rough) resulting from a one unit change in the variable.
- Obtained by integrating the probability density function

Figure 14.2: Illustration of an ordered probability models with an increase in βX (with $\mu_0 = 0$).



Results: Socioeconomics (1=smooth, 5=rough)

Variable	Marginal Effects				
	[*y* = 1]	[*y* = 2]	[*y* = 3]	[*y* = 4]	[*y* = 5]
Gender indicator (1 if participant was female, 0 if male)	0.0451	0.0994	-0.0669	-0.0598	-0.0178
Older age indicator (1 if participant was over age 55, 0 otherwise)	0.0620	0.1190	-0.0916	-0.0693	-0.0200

Results: Pavement condition (1=smooth, 5=rough)

Variable	Marginal Effects				
	[*y* = 1]	[*y* = 2]	[*y* = 3]	[*y* =4]	[*y* = 5]
IRI measurement (in/mi) of roadway segment	-0.0008	-0.0019	0.0011	0.0012	0.0004
Age of roadway segment surface (years)	-0.0017	-0.0043	0.0026	0.0026	0.0008
Patch indicator (1 if the segment appeared to have patch work, 0 otherwise)	-0.0363	-0.1035	0.0462	0.0704	0.0232
Pavement structural condition (PSC)	0.0017	0.0043	-0.0026	-0.0026	-0.0008

Results: Vehicle (1=smooth, 5=rough)

Variable	Marginal Effects				
	[*y* = 1]	**[*y* = 2]**	**[*y* = 3]**	**[*y* = 4]**	**[*y* = 5]**
Noise (dB) inside test vehicle during evaluation	-0.0085	-0.0209	0.0126	0.0128	0.0039
Noise increase indicator (1 if the noise inside test vehicle during evaluation increases by 3 dB or more between two adjacent test segments, 0 otherwise)	-0.0410	-0.1326	0.0386	0.0993	0.0358
Speed (km/h) of test vehicle during evaluation	0.0011	0.0028	-0.0017	-0.0017	-0.0005

Results: Vehicle (continued) (1=smooth, 5=rough)

Variable	Marginal Effects				
	[*y* = 1]	**[*y* = 2]**	**[*y* = 3]**	**[*y* = 4]**	**[*y* = 5]**
Sport-utility test vehicle indicator (1 if sport utility was test vehicle type, 0 otherwise)	0.0892	0.1629	-0.1270	-0.0968	-0.0283
Minivan test vehicle indicator (1 if minivan was test vehicle type, 0 otherwise)	0.0530	0.0995	-0.0791	-0.0571	-0.0163

Summary

- *Physical measurements of the pavement are correlated to public perceptions, but many other factors are significant*
- *Must consider more than IRI in determining pavement condition*