Relationships between road design, driver behavior and safety in four-lane highways

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Presentation Agenda

1. Background & objectives
2. Data collection
3. Risk perception factors
4. Speed and crash factors
5. Simultaneous equations model
6. Conclusions

How we Measure Road Safety

- **Nominal safety** – compliance with road design guidelines and standards
- **Objective safety**
  - Measured with crashes
  - Likelihood of crash on the road for a particular driver
- **Subjective / perceived safety**
  - Safety as perceived and interpreted by drivers
  - Driver behavior → free-flow speed selection
- **Need to predict safety on new or modernized roads**

Objectives

- Perform an exploratory analysis of the relationship between road characteristics, human behavior, and crashes
- Develop an advanced model that links
  - human behavior as influenced by perceived risk
  - objective risk, and
  - road characteristics of four-lane highways in rural and suburban areas

DATA COLLECTION

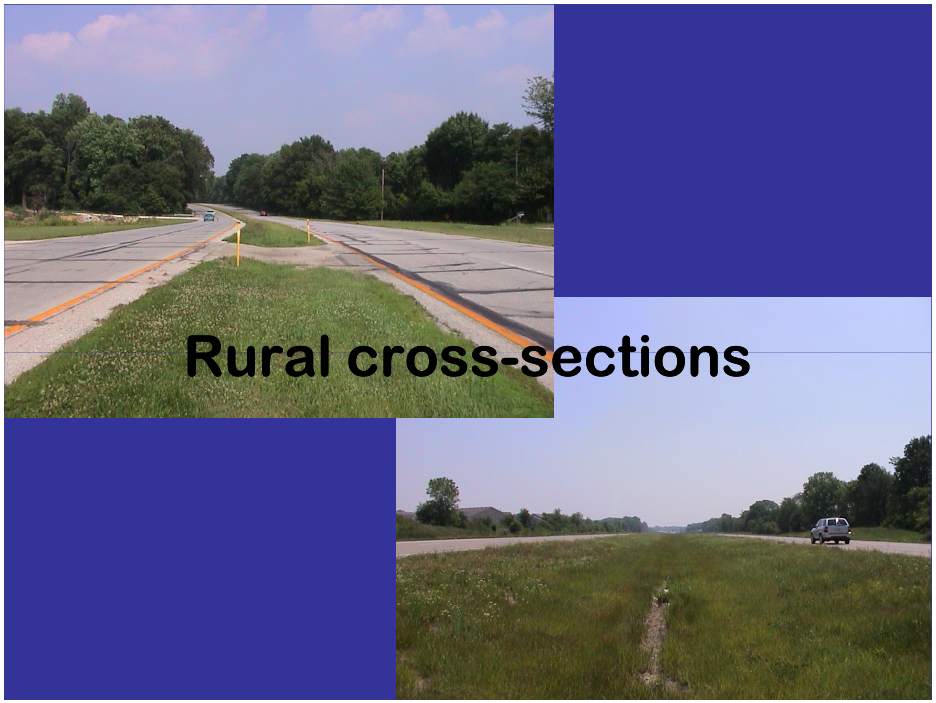
Road characteristics

Free-flow speeds

Crash rates

Selection Criteria

Section characteristic	Criteria
Location	Suburban to rural
Highway type	U.S. and state highways
Highway functional class	Arterial to collector
Annual average daily traffic	Higher than 1000 vpd
Posted speed limit	55 mph preferred, at least 40 mph
Terrain	All types
Pavement surface type	Rigid (PCC) to flexible (AC)
Pavement condition	Surface and markings in good condition
Development type	Commercial, residential to no-development
Access control	Full, partial to no control
Median type	All types to undivided
Curbs	All types to no curb
Sidewalks	Yes to no
Traffic control	No stop sign or traffic signal within 0.5 mile
Section length	Approximately 1 mile



Rural cross-sections

Suburban cross-sections

RISK PERCEPTION STUDY

Safety ratings vs. speed and crash rate

Risk perception factors

Some Details About the Survey

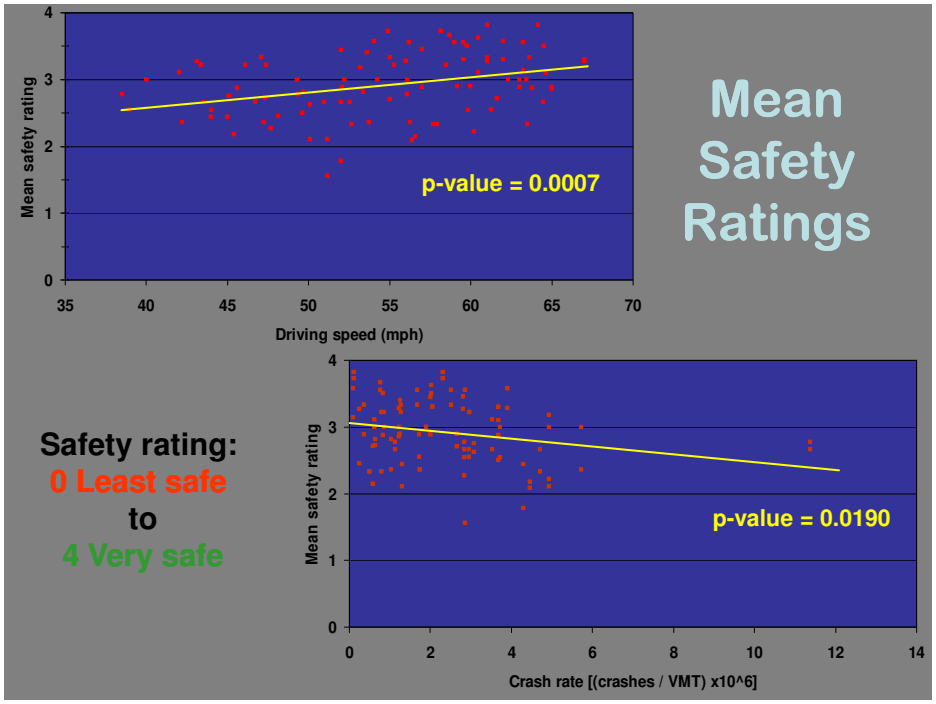
- 112 licensed drivers participated voluntarily
- 48 observation sites in four-lane highways
- Sections were categorized into four groups of 12, according to their crash rates
  - One section was selected from each group
  - Each section was shown at two different speeds
- Eight video clips were shown to each subject
- Risk perception questionnaire
  - Safety rating: **0 least safe to 4 very safe**
  - Identify hazardous road characteristics

Videotaped Sequence of Highway Section

Impact of Road Characteristics on Safety Rating

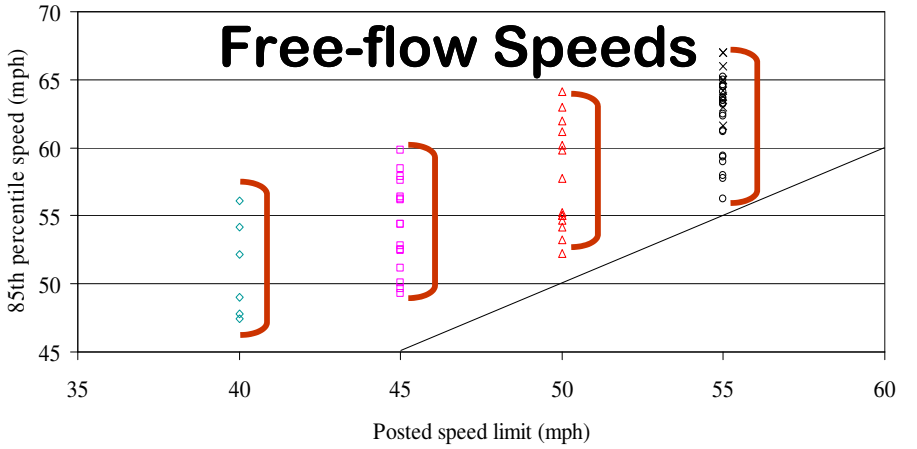
Road Variable	Less Safe ← Very Safe
Cross-section width (in feet)	→
Rural area	→
Presence of two-way left turn median lane	→
Intersection density (# per mile)	←
Median opening density (# per mile)	←
Driveway density (# per mile per direction)	←
Commercially-developed area (section has 10 or more commercial driveways per mile per direction)	←

Not statistically significant



SEPARATE SPEED AND CRASH MODELS

- Observed free-flow speeds
- Speed prediction models
- Crash performance functions



Speed	Mean value	Standard deviation	Minimum value	Maximum value
Mean speed, mph	53.72	5.30	42.05	62.29
85th percentile speed, mph	58.69	5.29	47.46	67.00

Speed Models

- **Typical OLS speed model**

$$V_i = \sum_k b_k X_{ik} + \varepsilon$$

- **Free-flow speed model** ***(Figueroa and Tarko, 2005, TRR 1912)***

$$V_{ip} = m_i + Z_p \cdot \sigma_i + \varepsilon = \sum_j a_j \cdot X_{ij} + \sum_k b_k \cdot (Z_p \cdot X_{ik}) + \varepsilon$$

1. Separates impacts on **mean speed** from impacts on individual **speed dispersion**
2. More efficient in identifying relationships between diverse road characteristics and speeds
3. Estimate the entire range of speed variability

OLS-PD Speed Model

$$
\begin{aligned}
V_p = {} & 56.95 - 4.84 \times PSL_{50} - 5.35 \times PSL_{45} - 7.84 \times PSL_{40} \\
& + 2.58 \times RA + 1.26 \times 10^{-3} \times SD - 0.39 \times ID \\
& - 0.51 \times MOD + 0.04 \times ICLR - 2.21 \times ECLR_{\leq 25} \\
& + 5.56 \times Z_p - 0.49 \times (Z_p \times PSL_{45}) - 0.49 \times (Z_p \times PSL_{40}) \\
& - 0.53 \times (Z_p \times RA) - 3.60 \times 10^{-4} \times (Z_p \times SD) + 0.02 \times (Z_p \times ID) \\
& + 0.04 \times (Z_p \times MOD) - 3.17 \times 10^{-3} \times (Z_p \times ICLR) \\
& + 0.17 \times (Z_p \times ECLR_{\leq 25}) - 0.32 \times (Z_p \times TWLT)
\end{aligned}
$$

PSL = posted speed limit, RA = rural area, SD = sight distance, ID = intersection density, MOD = median opening density, ICLR = internal clear zone, ECLR = external clear zone, $ECLR_{<25}$ = binary for narrow external clear zone, TWLT = binary for two-way left turn median lane

factors

May be considered as crash frequency factors

May be considered as crash severity factors

Factor (increase in / presence of…)	Mean speed	Speed dispersion
	Increases	Increases
	Decreases	Increases
Sight distance	Increases	Decreases
Intersection density	Decreases	Increases
Median opening density	Decreases	Increases
Roadside clear zone	Increases	Decreases
Median width	Increases	Decreases
TWLT median lane	-	Decreases

All the parameters in the model are significant at a 93 percent confidence level
Adjusted R-squared is 0.884

Crash Models

$$\lambda_i = \mathbf{L} \cdot \mathbf{AADT} \cdot \mathbf{e}^{(-6.962 + 0.082 \cdot ID + 0.481 \cdot COM + 0.623 \cdot ECLR_{<20})}$$

$$
\begin{aligned}
CR = {} & 0.661 + 0.883 \times PSL_{45} + 2.337 \times PSL_{40} \\
& + 0.261 \times ID + 0.248 \times MOD \\
& - 0.810 \times TWLT + 2.099 \times SW + 1.496 \times PB
\end{aligned}
$$

Where:
L = section length, AADT = annual average daily traffic, PSL = posted speed limit, ID = intersection density, MOD = median opening density, $ECLR_{<20}$ = binary for narrow external clear zone, TWLT = binary for two-way left turn median lane, COM = binary for high commercial development, SW = binary for sidewalk, PB = binary for polelines and embankments

Crash factors

Factor (increase in / presence of…)	Crash Frequency	Crash rate
Section length	Increases	VMT
Traffic volume	Incre s	
Posted speed limit		Decreases
Intersection den		eases
Median opening dens		eases
Commercial driveway de		Increases
Roadside clear zone	Decr ses	-
TWLT median lane	-	Decreases
Roadside obstructions	-	Increases
Model fit	$\rho^2 = 0.694$	$R^2 = 0.473$

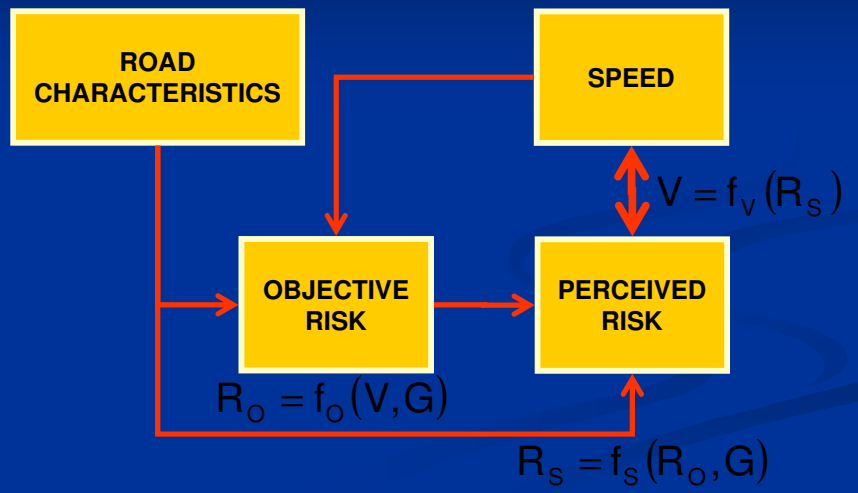
As mean speed decreases…
Safety deteriorates

All the parameters in the models are significant at a 90 percent confidence level

SYSTEM OF SIMULTANEOUS EQUATIONS MODEL

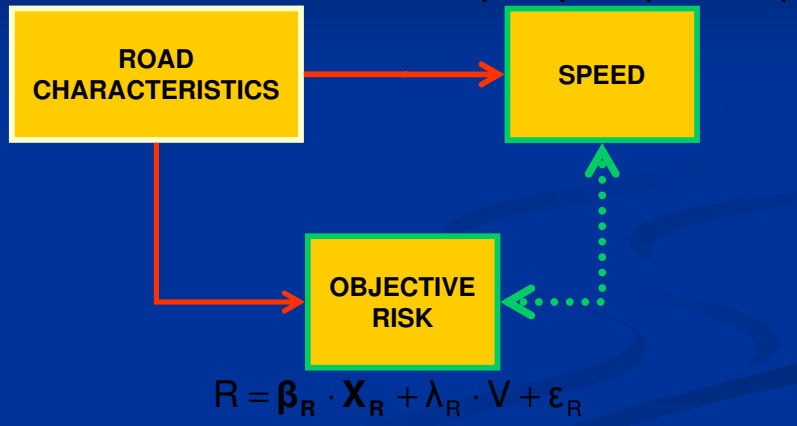
- System of relationships
- Development of simultaneous equations
- Speed and objective risk factors

System of Relationships



Simplified System of Relationships

$$V = \beta_V \cdot X_V + \lambda_V \cdot R + \varepsilon_V$$



$$R = \beta_R \cdot X_R + \lambda_R \cdot V + \varepsilon_R$$

LEGEND: EXOGENEOUS RELATIONSHIP — ENDOGENEOUS RELATIONSHIP

System of Simultaneous Equations

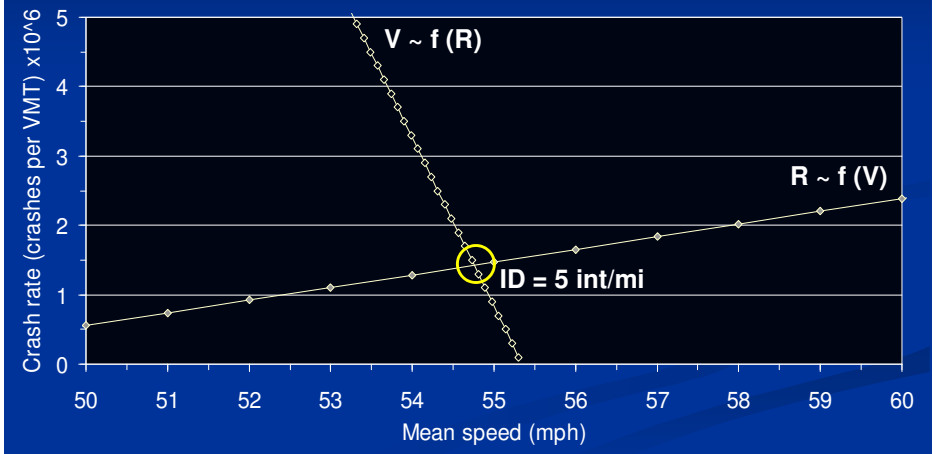
$$V = 52.122 - 0.413 \times R \quad \leftarrow \text{ENDOGENOUS VARIABLE}$$
$$- 3.755 \times PSL_{50} - 5.460 \times PSL_{45} - 7.640 \times PSL_{40}$$
$$+ 3.417 \times RA + 0.043 \times CW + 2.405 \times ECLR_{20} - 1.771 \times HC$$

$$R = -10.443 + 0.183 \times V \quad \leftarrow \text{ENDOGENOUS VARIABLE}$$
$$+ 1.485 \times PSL_{50} + 2.462 \times PSL_{45} + 4.394 \times PSL_{40}$$
$$+ 0.335 \times ID + 0.344 \times MOD - 0.926 \times TWLT$$
$$+ 2.491 \times SW + 1.512 \times PB$$

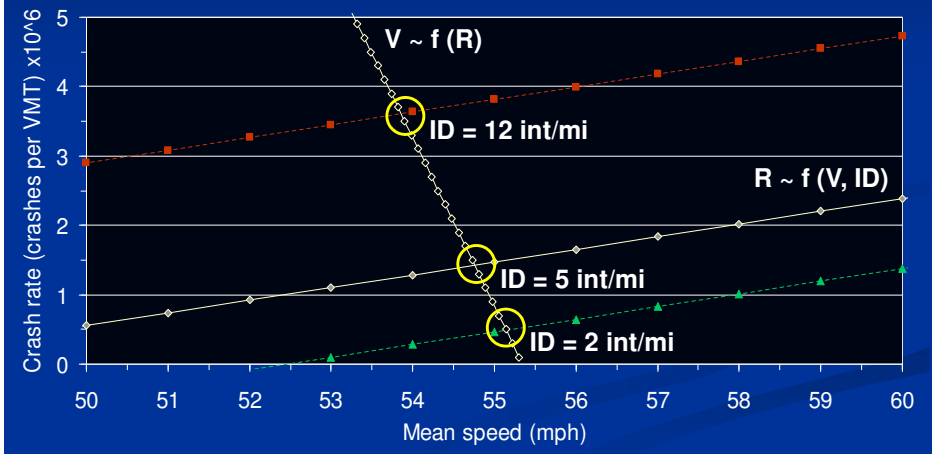
All the parameters in the models are significant at a 90 percent confidence level

Legend:
PSL = posted speed limit, RA = rural area, CW = cross-section width, ECLR = narrow clear zone, HC = horizontal curve, ID = intersection density, MOD = median opening density, TWLT = median lane, SW = sidewalk, PB = roadside obstruction

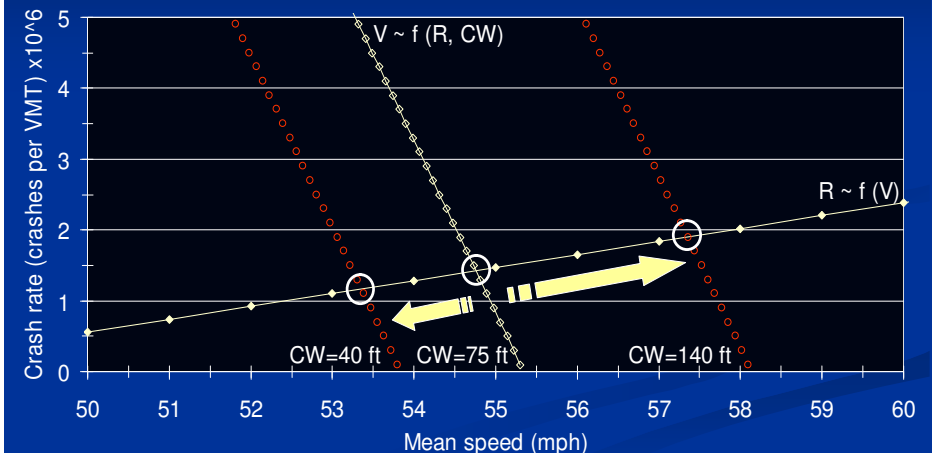
Behavior of the System of Simultaneous Equations



Behavior of the System of Simultaneous Equations



Behavior of the System of Simultaneous Equations



Conclusions

- Typical speed and safety prediction models that appraised separately the effect of road characteristics failed to identify the endogenous relationship between the driver behavior (speed) and objective risk (crash rate)
- Advantages of model of simultaneous equations
  - improved the identification of road characteristics as speed or crash rate factors
  - considered the endogenous relationship between objective risk and driver behavior
  - provide deeper understanding of the effect of the road characteristics and driver behavior and their impact on safety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Road Safety
EDUCATION
ENFORCEMENT
Thanks!