EFFECTS OF CENTERLINE RUMBLE STRIPS ON SAFETY, EXTERIOR NOISE, AND OPERATIONAL USE OF THE TRAVEL LANE

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Outline

1. Background / Motivation
2. State-of-the-Art (Published in the Journal of Transportation Research Forum)
3. Safety Effectiveness Study (Accepted for publication in the Journal of Transportation Safety and Security)
4. Exterior Noise Study (Published in the Journal of Transportation Engineering)
5. Driver's Behavior Study
6. SPF Analysis to Provide Recommendations

1. Background

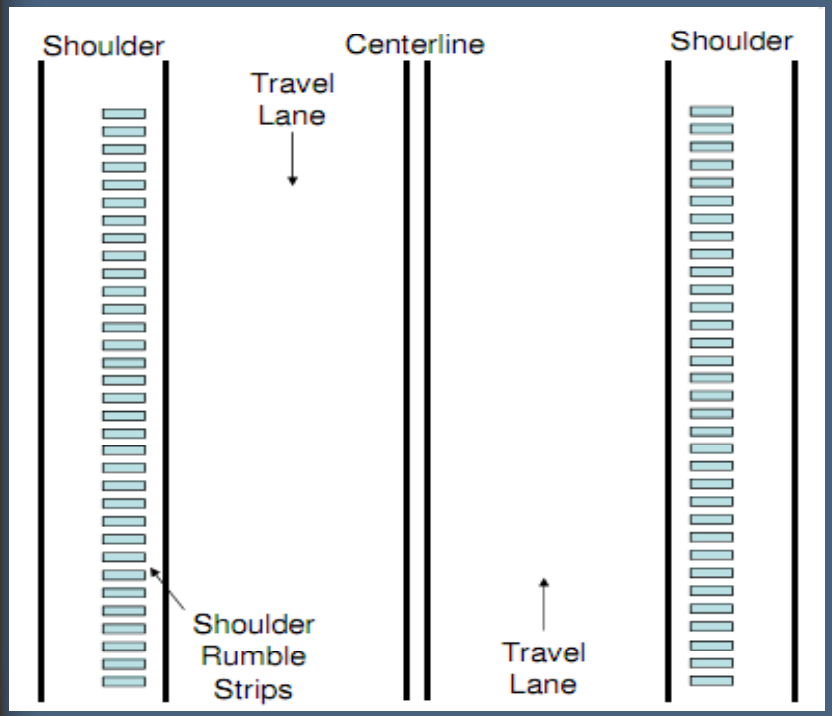
- ✓ The total cost of traffic crashes in the US ≈ **$166.7 billion** (Meyer 2008).
- ✓ In Kansas: total cost of crash fatalities ≈ **$433 million** (CDC 2005).
- ✓ Roadway departures ≈ 40% of all crashes.
- ✓ Roadway departures in the US on rural highways: **23,169 fatalities.**
- ✓ Cross-over fatal crashes = 2,579 (NHTSA 2009).

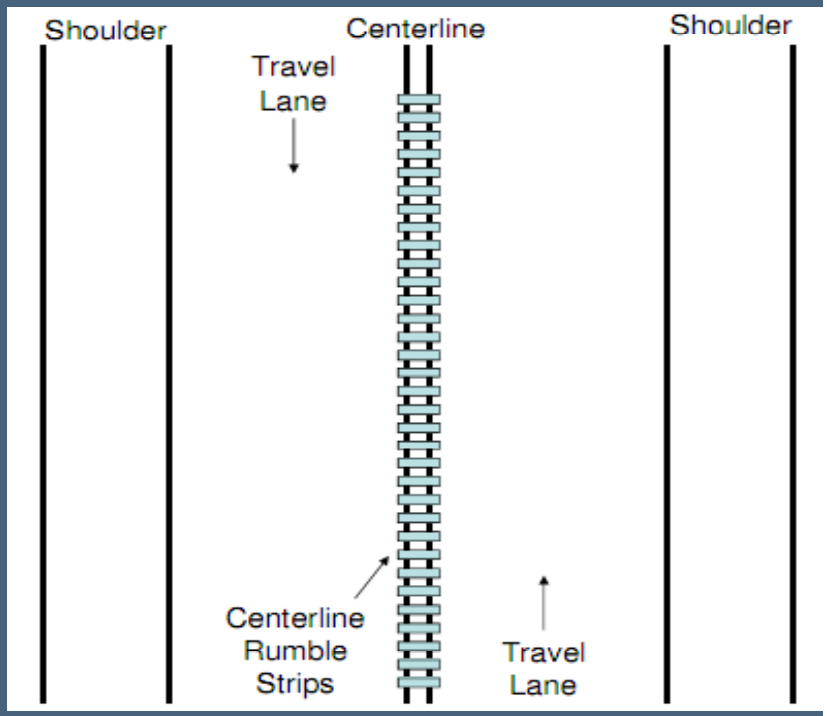
Background

- **Rumble Strips**: grooved or raised patterns. They produce noise and vibration to warn drivers they are leaving the lane
- Four different installation types: raised, milled, rolled, and formed



SRS vs. CLRS





Source: Torbic et al. (2009)

Examples of CLRS







Kansas CLRS Patterns



Rectangular Shaped



Football Shaped

Groove dimensions:

length12 in, width 7 in, depth 0.5–0.625 in, spacing 12 in.

Kansas CLRS Cost: $3,000 to 4,500 per mile (Buckley, 2008)

Circumstances that affect cost:

- Speed at which rumble strips can be milled
- Pavement type
- Length of project



Source: Buckley, 2008

The Problem

- ✓ Centerline Rumble Strips are effective to prevent cross-over crashes.
- ✓ There are some potential concerns.
- ✓ How to reduce potential concerns and keep effectiveness?
- ✓ Objectives: Provide guidelines, and to study when CLRS are beneficial

2. State-of-the-Art

- ✓ Objective: Obtain national updated information.
- ✓ A survey was emailed to the 50 states. It consisted of 17 questions regarding their policies for installation of CLRS.
- ✓ Total response rate of this survey was 60% or 30 state DOTs.
- ✓ States using CLRS: 36 (found from this study + literature).
- ✓ Reported total length of CLRS > 11,000 miles.

State-of-the-Art

- ✓ Predominant pattern: length = 16 in, width = 7 in, depth = 0.5 in , and spacing = 12 in, continuous.
- ✓ 17 states have written guidelines.
- ✓ Some good practices:
  - ✓ Adopt minimum AADT (1,500 – 3,000);
  - ✓ Adopt minimum PSL (45 – 55 mph);
  - ✓ Adopt minimum crash rate;
  - ✓ Discontinue in intersections and bridge decks;

State-of-the-Art

- ✓ Adopt a pattern able to generate 10 dBA above the ambient in-vehicle sound level;
- ✓ Adopt a minimum pavement depth (1.5 – 2.5 inches);
- ✓ Install CLRS if pavement is in good condition or only on new pavements;
- ✓ Adopt a minimum lane width (10 – 12 ft);
- ✓ Adopt a minimum shoulder width (2 – 4 ft).

3. Safety Effectiveness of CLRS

- ✓ Objectives: Calculate results for conditions in Kansas
- ✓ In Kansas there are two patterns of CLRS: football and rectangular. Which one is better?
- ✓ Data from 29 sections of highway that received CLRS was analyzed (approximately 590 km or 366 miles).
- ✓ Before-and-after comparison using two methods: Naïve method and Empirical Bayes (EB) method.

Methodology

- Crashes considered:
  - Total Correctable (excluding animals, ice, and intersections).
  - Fatal and injury crashes.
  - Correctable cross-over (head-on and sideswipes in opposite direction).
  - Run-off-the-road (ROR) crashes: among the total correctable, collisions with fixed objects and non-collisions caused by vehicles that overturned or rollover.

Section	Annual Crashes Treated Sections - Before Period	Expected Annual Crashes Similar Sections - Before Period	Annual Crashes - Projection for After Period - No Treatment	Annual Crashes - What Happened in the After Period	Naïve Before-and-After Comparison	EB Before-and-After Comparison (95% CI)
Total Correctable: Overall Kansas	131.75	115.87	113.95	81.22	-38.36%	**-29.21% (-10.00% , -48.42%)**
Total Correctable: Only Rectangular	117.75	102.74	96.75	75.22	-36.12%	**-22.85% (-0.91% , -44.80%)**
Total Correctable: Only Football	14.00	13.12	17.20	6.00	-57.14%	**-66.93% (-36.41% , -97.44%)**
Cross-over: Overall Kansas	19.00	16.22	17.28	5.92	-68.86%	**-67.19% (-37.56% , -96.82%)**
Cross-over: Only Rectangular	15.00	13.10	12.92	5.42	-63.89%	**-60.35% (-22.15% , -98.55%)**
Cross-over: Only Football	4.00	3.12	4.36	0.50	-87.50%	**-90.28% (-62.17% , -100%)**
ROR: Overall Kansas	76.75	65.87	61.31	50.07	-34.77%	**-19.19% (-46.91% , +8.52%)**
ROR: Only Rectangular	71.25	59.87	54.23	46.57	-34.64%	**-15.15% (-45.54% , +15.24%)**
ROR: Only Football	5.50	6.01	7.07	3.50	-36.36%	**-54.97% (-0.22% , -100%)**
FI: Overall Kansas	55.42	47.66	45.40	30.38	-45.17%	**-34.05% (-6.34%, -61.76%)**
FI: Only Rectangular	51.92	43.51	39.82	27.88	-46.29%	**-31.11% (-0.76%, -61.47%)**
FI: Only Football	3.50	4.14	5.59	2.50	-28.57%	**-60.22% (-3.73%, -100%)**

Conclusions

- ✓ Correctable crashes were reduced by 29.21%, with 95% CI of (-10.00%, -48.42%)
- ✓ Crashes involving fatalities and injuries were reduced by 34.05%, with 95% CI of (-6.34%, -61.76%)
- ✓ Cross-over crashes were reduced by 67.19%, with 95% CI of (-37.56%, -96.82%)
- ✓ ROR showed a not statistically significant reduction of 19.19%, with 95% CI of (-46.91%, +8.52%)
- ✓ The two methods applied presented statistically similar results
- ✓ There was no statistical significant difference between football shaped and rectangular shaped CLRS

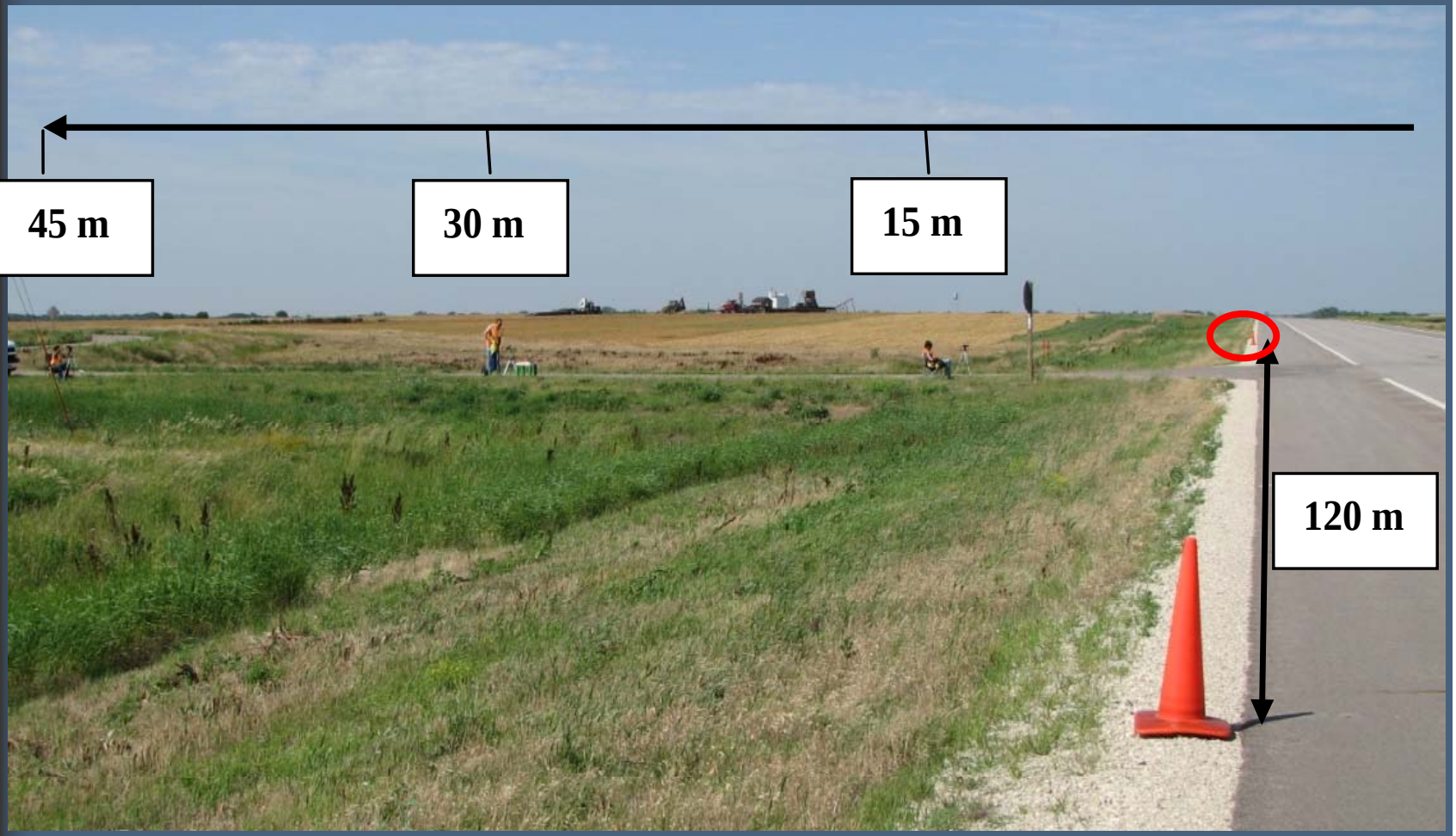
4. Exterior Noise

- Objectives:

✓ To quantify the levels of exterior noise produced by CLRS and smooth asphalt pavement and verify the effects of speed, vehicle type, CLRS shape, and distance on exterior noise levels.

✓ To determine a minimum distance from residences and businesses for installation of CLRS.

Data Collection



Data Collection

- ✓ 10 locations (5 with football and 5 with rectangular)
- ✓ Speed (64 km/h and 105 km/h or 40 mph and 65 mph)
- ✓ Pavement (over smooth and over CLRS)
- ✓ Distance (15, 30, 45 m or 50, 100, 150 feet)
- ✓ Vehicle (Ford Taurus, Chevy Express van)
- ✓ Data point = Average of 3 replicates per run
- ✓ Accounted for wind contribution: $A_{wind} = —[\ 0.88 \times log_{10}\ (\ L \div 15\ )\ ] \times U \times \cos\theta$





Contrasts



Smooth Football:
61.17 dBA

VS.



Smooth Rectangular:
61.80 dBA

Not Statistically Different: P-value = 0.0581

Contrasts



VS.

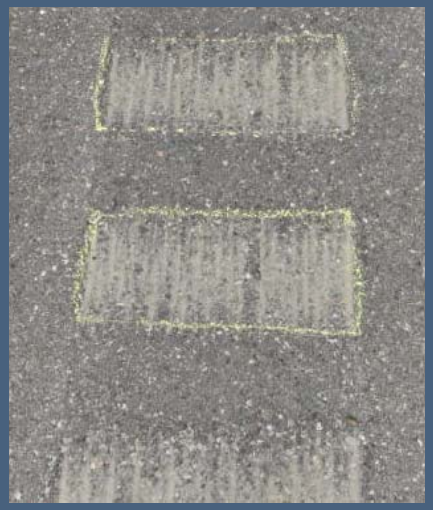


Overall Smooth: 61.17 dBA

Overall CLRS: 68.90 dBA

Statistically Different: P-value < 0.0001

Contrasts



Rectangular: 68.83 dBA

VS.



Football: 68.97 dBA

Not Statistically Different: P-value < 0.9318

Contrasts



Smooth F: 61.17 dBA

VS.



Football: 68.97 dBA

Statistically Different: P-value < 0.0001

Contrasts



VS.



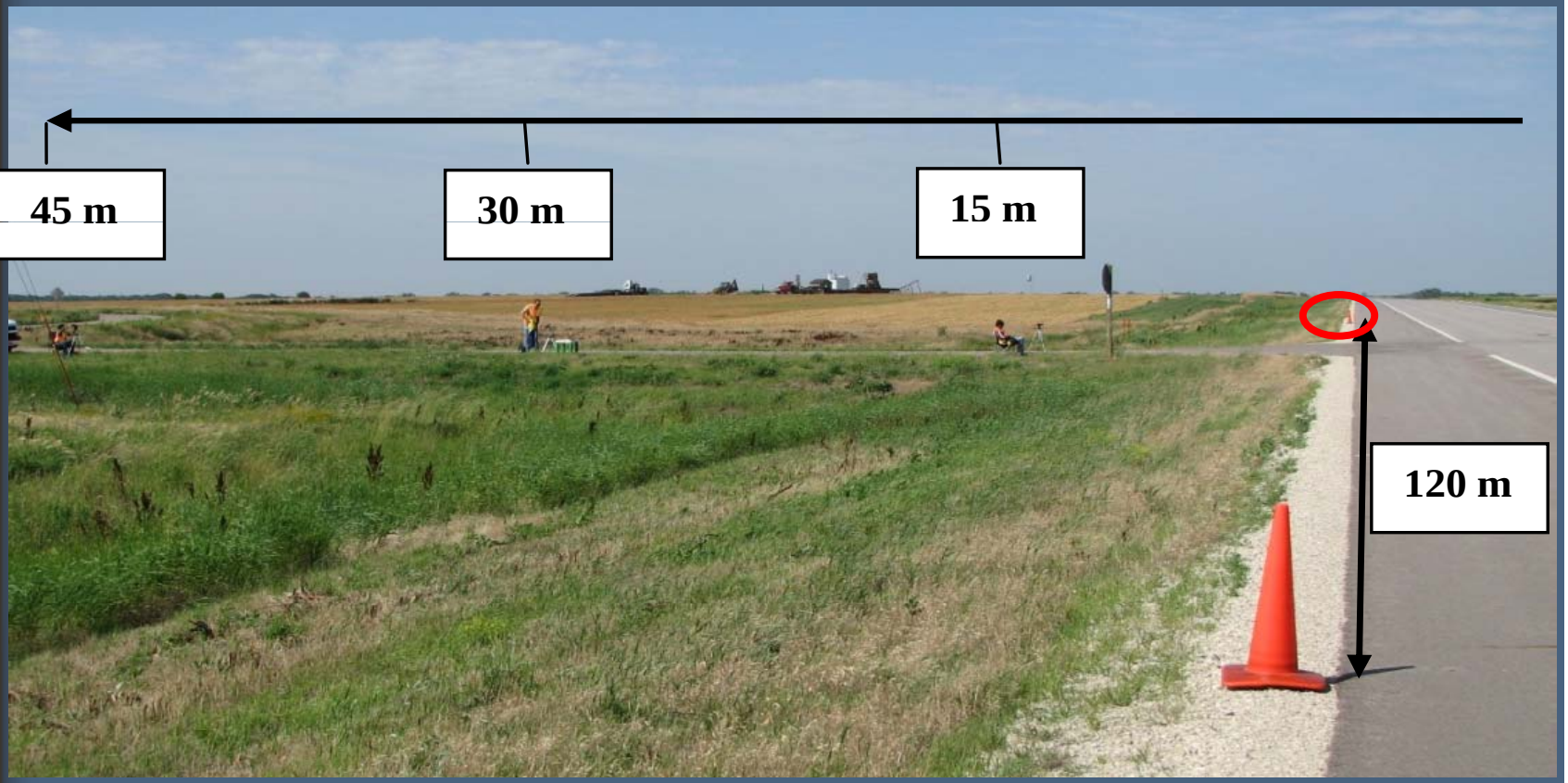
Rectangular: 68.83 dBA

Smooth R: 61.80 dBA

Statistically Different: P-value < 0.0001

Contrasts

59.34 dBA VS. 64.50 dBA VS. 71.27 dBA



Statistically Different: P-value < 0.0001

Contrasts

66.71 dBA VS. 63.37 dBA





Statistically Different: P-value < 0.0001

Contrasts



64 km/h (40 mph): 61.42 dBA 105 km/h (65 mph): 68.65 dBA

Statistically Different: P-value < 0.0001

Minimum Distance Criterion

Model 1 = Taurus CLRS: Noise = 84.1 – 0.387 * Distance (m). Adj R^2 = 75.04%				Model 2 = Taurus Smooth: Noise = 75.5 – 0.424 * Distance (m) Adj R^2 = 70.10%			
Distance (m)	**Prediction**	**Real Average**	**Residual**	**Distance (m)**	**Prediction**	**Real Average**	**Residual**
15	78.27	78.36	-0.09	15	69.17	69.61	-0.44
30	72.47	71.89	0.58	30	62.82	61.46	1.36
45	66.67	66.58	0.09	45	56.46	56.69	-0.23
60	60.87	*	*	60	50.10	*	*
Model 3 = Van CLRS: Noise = 88.1 – 0.432 * Distance (m). Adj R^2 = 70.50%				**Model 4 = Van Smooth: Noise = 76.6 – 0.396 * Distance (m). Adj R^2 = 62.80%**			
Distance (m)	**Prediction**	**Real Average**	**Residual**	**Distance (m)**	**Prediction**	**Real Average**	**Residual**
15	81.67	81.91	-0.24	15	70.66	70.68	-0.02
30	75.20	74.27	0.93	30	64.72	64.28	0.44
45	68.73	68.76	-0.03	45	58.77	58.60	0.17
60	62.25	*	*	60	52.83	*	*

- ✓ Recommended Minimum Distance = 60 m (200 ft)

Conclusions

- ✓ External noise depends on the speed, type of vehicle, and distance.
- ✓ Both football and rectangular CLRS substantially increased the levels of external noise. There was no statistically significant difference between them.
- ✓ An estimated distance of up to 60 m from the centerline should be considered as the potential influence area.

5. A Study of Driver's Behavior

- ✓ Driver's behavior is often measured in terms of lateral position and speed. Importance: Safety and mobility

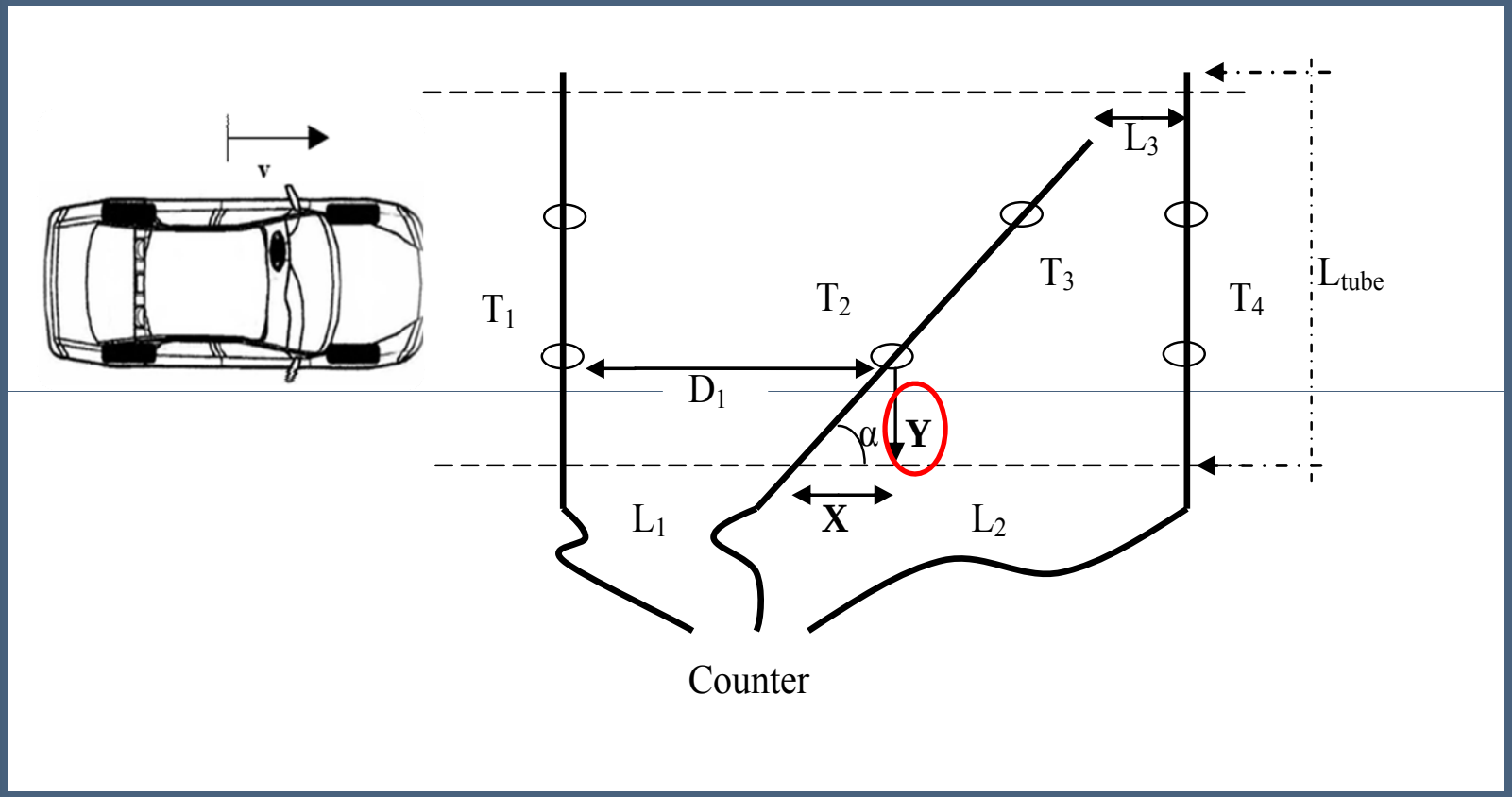
- ✓ Several studies were performed and showed effects of rumble strips on lateral position. They lack technical recommendations.

Data Collection





Data Collection



$$V = \frac{L_1 + L_2}{(T_4 - T_1)}$$

$$D_1 = V * (T_2 - T_1)$$

$$\alpha = \text{arc cosine}\left(\frac{L_2 - L_3}{L_{tube}}\right)$$

$$X = D_1 - L_1$$

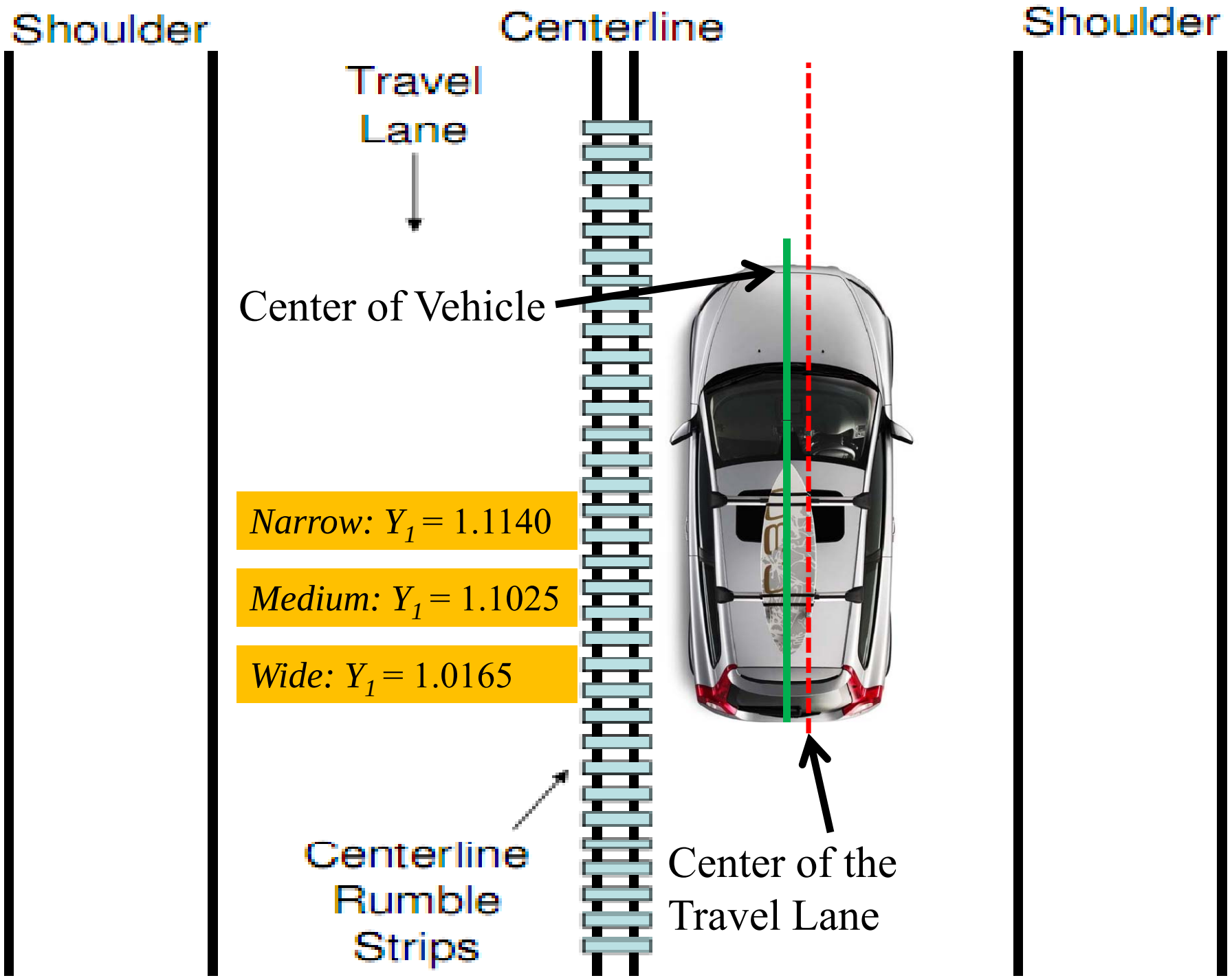
$$Y = X * \text{Tangent}(\alpha)$$

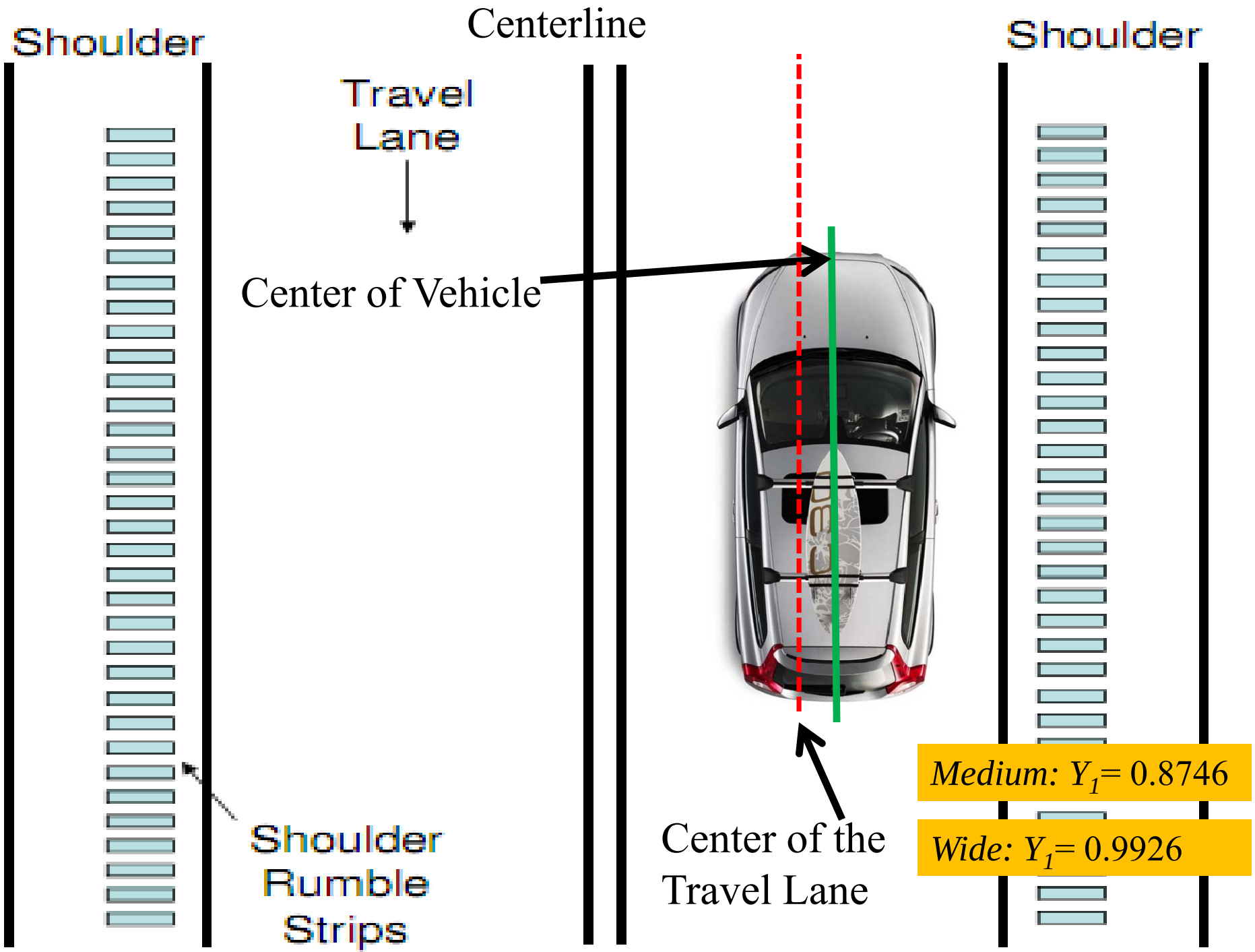
Data Collection / Analysis

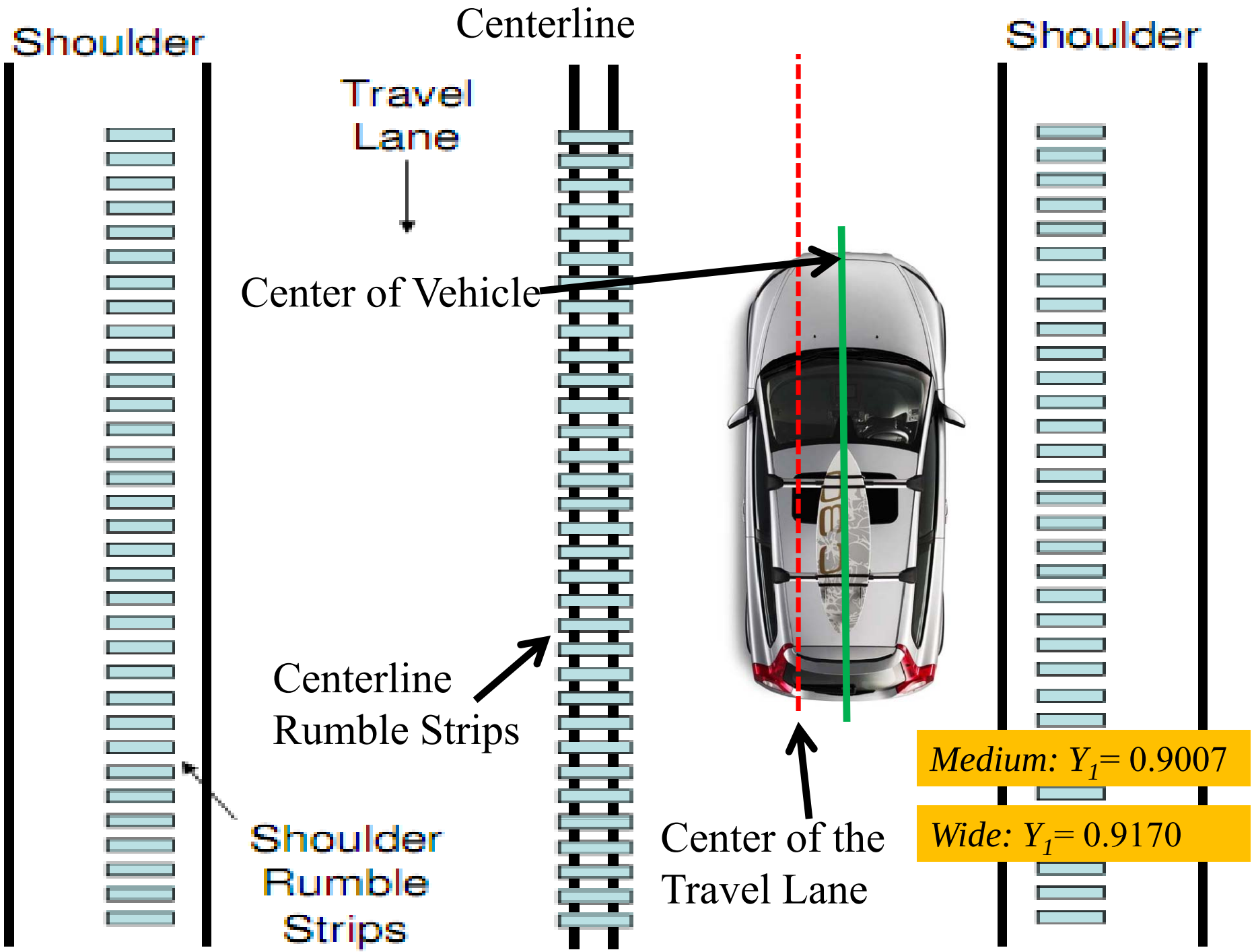
Shoulder Width Level	Shoulder Width (m ft)	Rumble Strips Configurations			
		CLRS only	SRS only	Both CLRS and SRS	Neither
Narrow	0.6 m or 2 ft	Trt A	-	-	Trt B
Medium	1.8 m or 6 ft	Trt C	Trt D	Trt E	Trt F
	2.4 m or 8 ft				
Wide	2.7 m or 9 ft	Trt G	Trt H	Trt I	Trt J
	3.0 m or 10 ft				

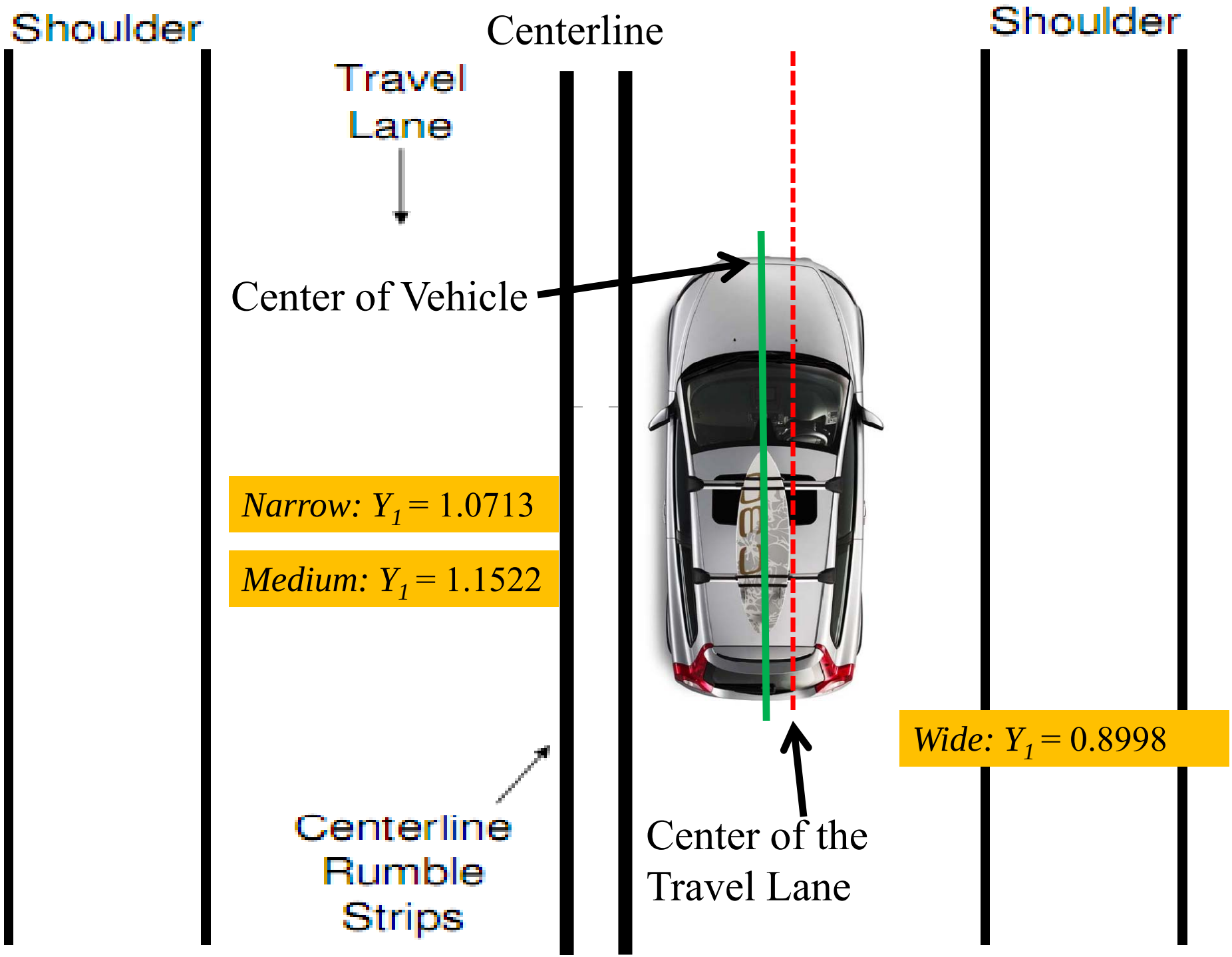
- ✓ Data was analyzed as a one-way ANOVA
- ✓ A second analysis was performed considering the shoulder width as a numerical variable (regression).

Treatment	Configuration SW / RS	Mean Y1	St. Error Y1	Mean Y2	St. Error Y2
A	Narrow / CLRS only	1.1140	0.02000	0.9816	0.007297
B	Narrow / Neither	1.0713	0.01837	0.9962	0.008044
C	Medium / CLRS only	1.1025	0.01816	1.0389	0.008634
D	Medium / SRS only	0.8746	0.01259	1.0061	0.005451
E	Medium / Both	0.9007	0.01746	1.0124	0.008707
F	Medium / Neither	1.1522	0.01685	1.0411	0.01307
G	Wide / CLRS only	1.0161	0.02274	1.0755	0.01017
H	Wide / SRS only	0.9926	0.02499	1.0082	0.006053
I	Wide / Both	0.9170	0.01292	1.0131	0.004894
J	Wide / Neither	0.8998	0.01392	0.9801	0.005683


Shoulder
Centerline
Shoulder
Travel Lane
Center of Vehicle
Narrow: Y_1 = 1.1140
Medium: Y_1 = 1.1025
Wide: Y_1 = 1.0165
Centerline Rumble Strips
Center of the Travel Lane

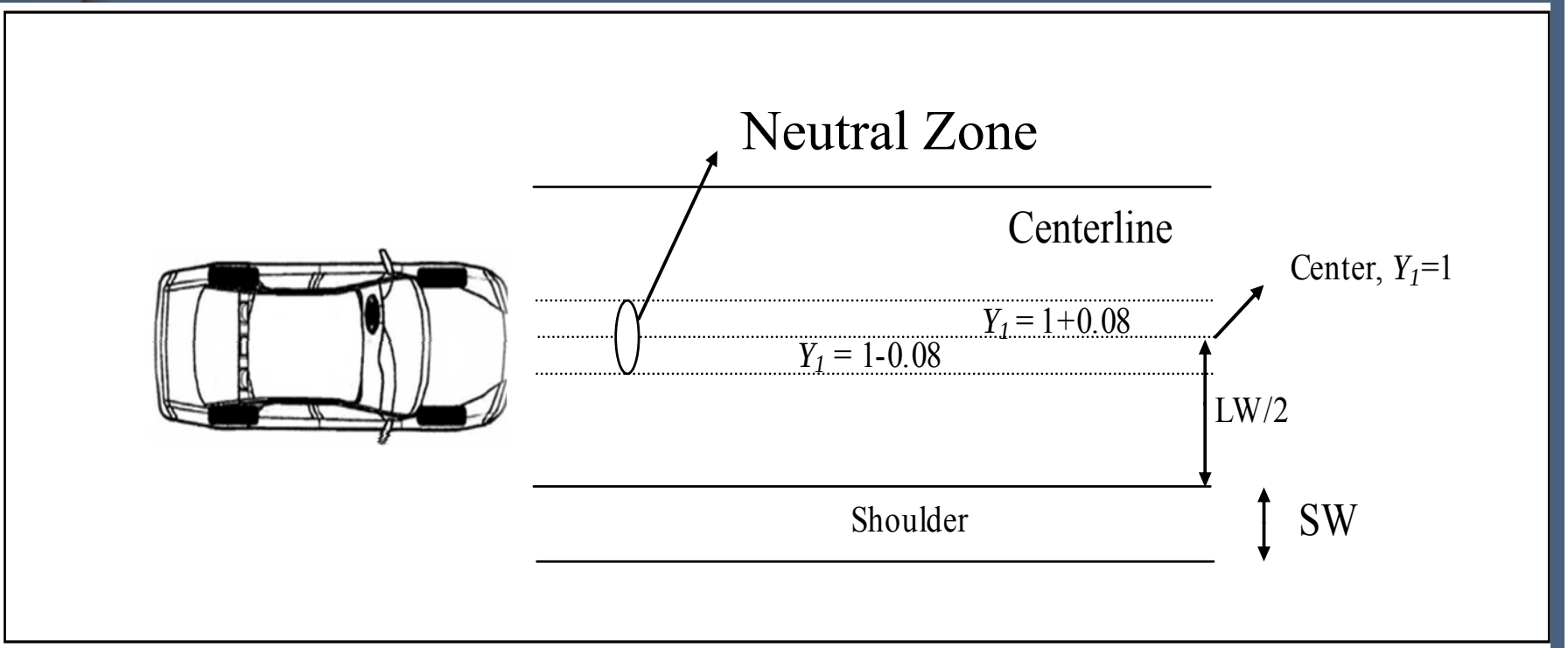

Shoulder
Centerline
Shoulder
Travel Lane
Center of Vehicle
Shoulder Rumble Strips
Center of the Travel Lane
Medium: Y_1= 0.8746
Wide: Y_1= 0.9926


Shoulder
Centerline
Shoulder
Travel Lane
Center of Vehicle
Centerline Rumble Strips
Shoulder Rumble Strips
Center of the Travel Lane
Medium: Y_1= 0.9007
Wide: Y_1= 0.9170


Shoulder
Centerline
Shoulder
Travel Lane
Center of Vehicle
Narrow: Y_1 = 1.0713
Medium: Y_1 = 1.1522
Wide: Y_1 = 0.8998
Centerline Rumble Strips
Center of the Travel Lane

Regression Analysis

CLRS only: $Y_1 = 1.1502 - 0.0389 * SW_m$
SRS only: $Y_1 = 0.6409 + 0.112 * SW_m$
Both : $Y_1 = 0.8054 + 0.03989 * SW_m$
Neither: $Y_1 = 1.1343 - 0.0605 * SW_m$



Results - Regression

- For CLRS only, the predicted minimum value of shoulder width for vehicles to operate in the assumed safest region would be 1.72 m or 5.64 ft .
- For SRS only = 2.47 m or 8.10 ft .
- For Both = 2.79 m or 9.15 ft .
- For neither = 0.85 m or 2.79 ft.

Conclusions

- ✓ Speed effect may be considered not practically significant.
- ✓ Narrow shoulders: for *CLRS only* and *neither*, drivers tended to travel closer to the centerline.
- ✓ Medium shoulders: drivers drove closer to the edgeline if SRS were present and closer to the centerline if SRS were not present .
- ✓ Wide shoulders: drivers drove closer to the centerline if *CLRS only* were present and closer to the edgeline otherwise.

Acknowledgements

- ✓ Dr. Rys and Dr. Russell;
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Questions?