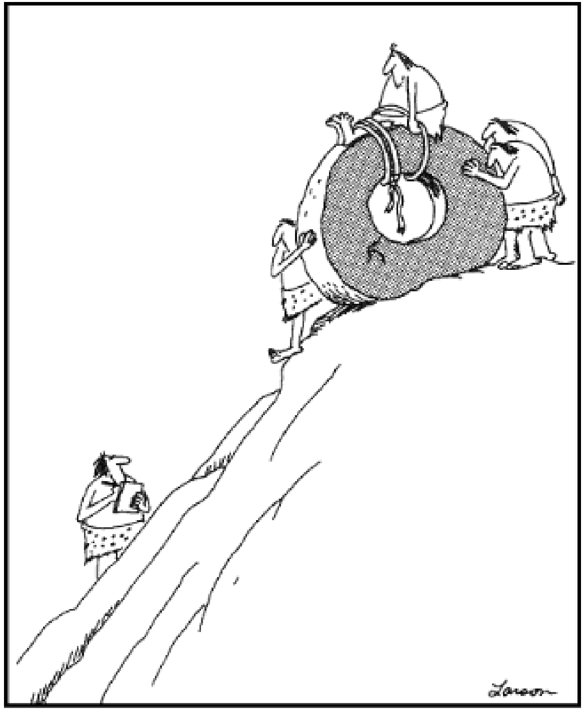
Performance-based Superelevation Transition Design

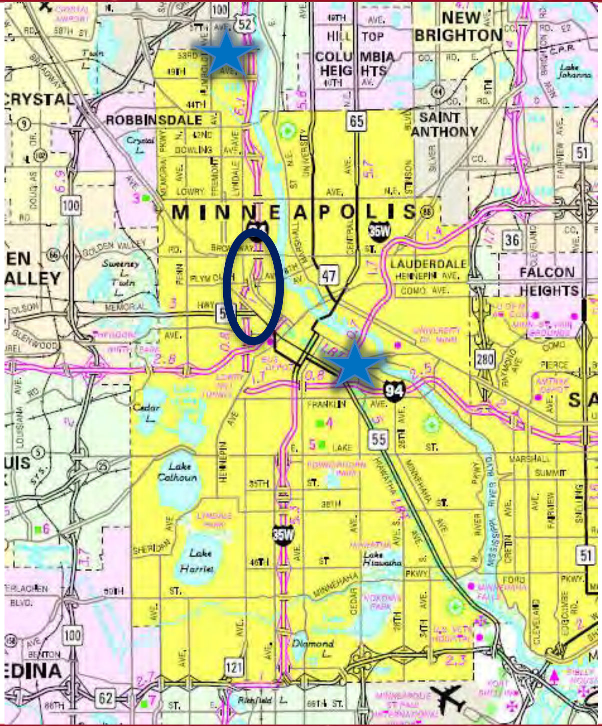
CTS Transportation Research Conference
November 3, 2016

Hopefully not…



Early experiments in transportation

Observation



Observation

I-94 in North Minneapolis

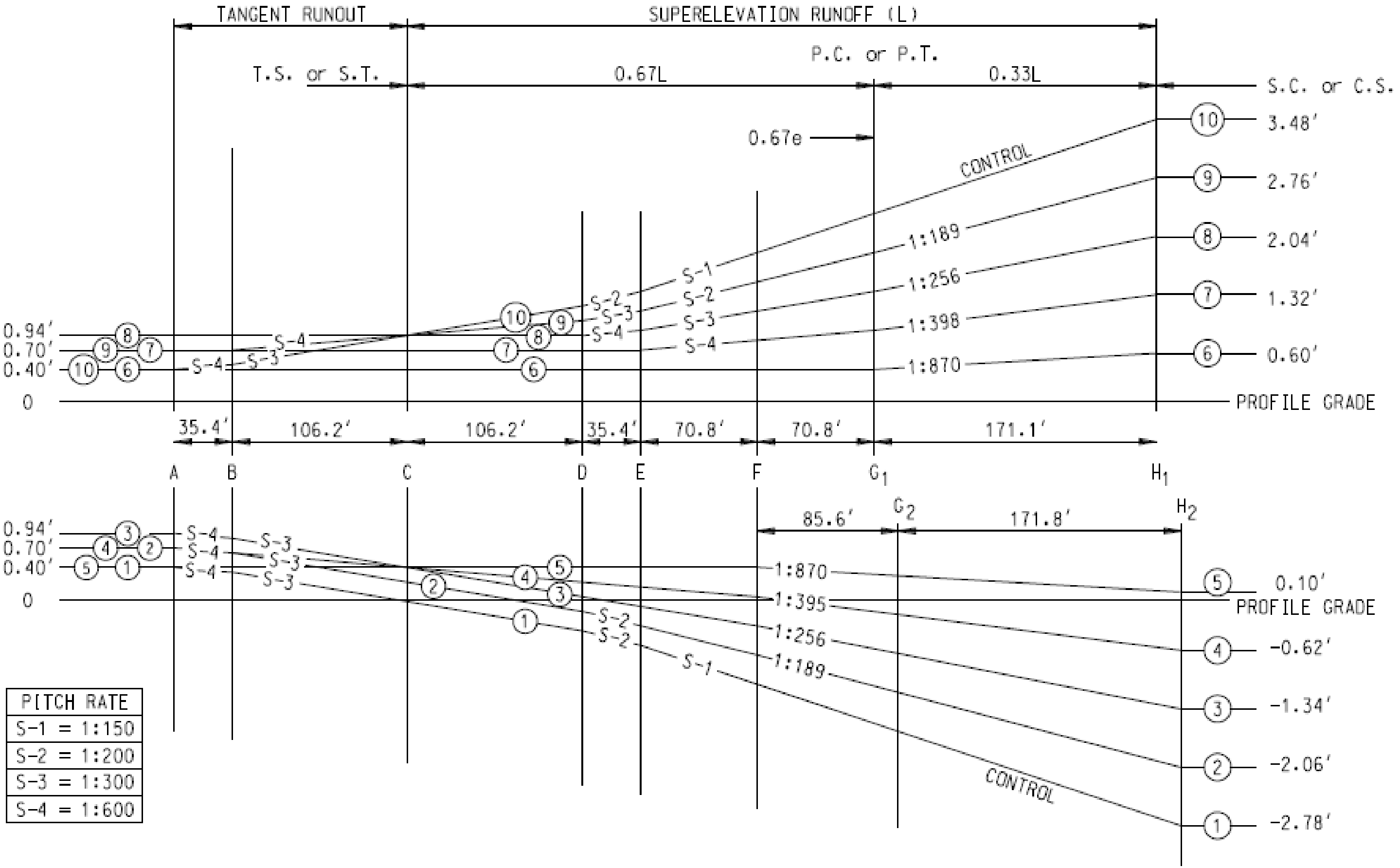
Applicable Criteria

Minnesota DOT (MnDOT) Road Design Manual:

- Two-thirds of the runoff length on tangent; one-third on curve
- 1:400 transition rate; wider pavements require longer transitions

AASHTO "Green Book":

- "…with a large majority of agencies using 0.67 (i.e. 67 percent) [of the runoff length on the tangent]."
- "…values for the proportion of runoff length on tangent in the range of 0.7 to 0.9 (i.e. 70 to 90 percent) offer the best operating conditions." (NCHRP Report 439)



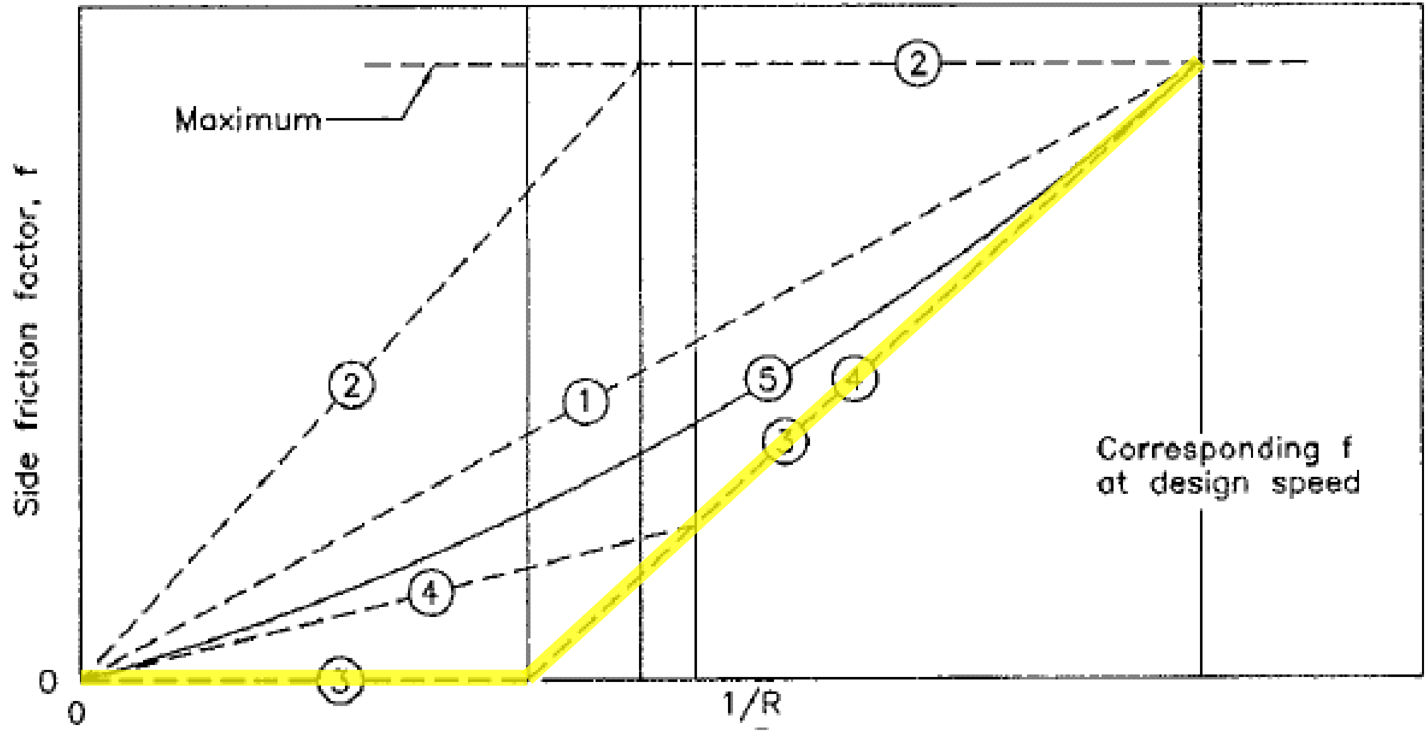
PITCH RATE
S-1 = 1:150
S-2 = 1:200
S-3 = 1:300
S-4 = 1:600

Observation

Observation

S = 1:200

Proportion of runoff on tangent: 50%



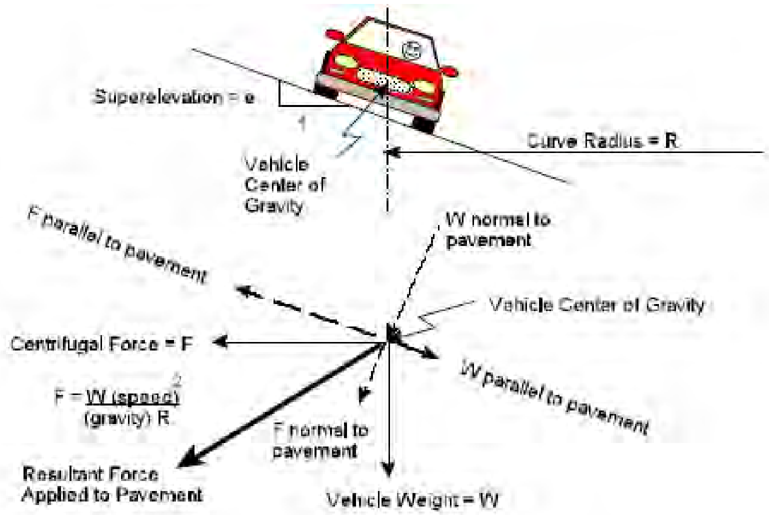
Green Book Figure 3-7: Methods of Distributing Superelevation and Side Friction

Hypothesis

The current national criteria for superelevation transition design – which errs on the side of oversupply of superelevation through the transition – does not optimize driver comfort and may result in erratic operating characteristics.

Physical Concepts

Force Balance in a Curve



Physical Concepts

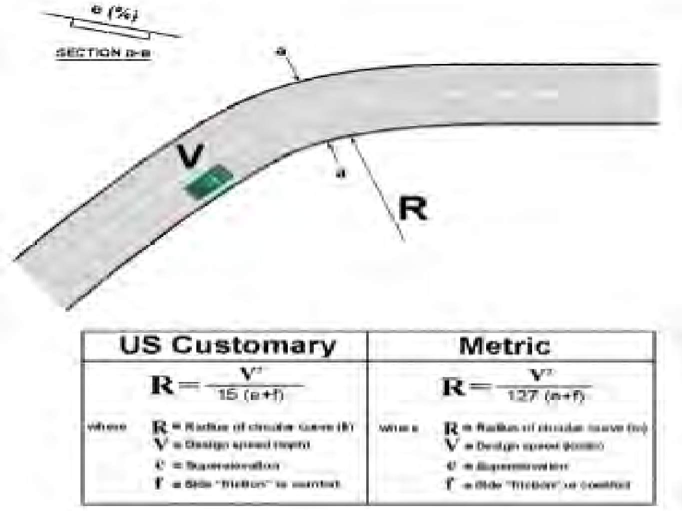
$$e + f = V^2 / 15R$$

e = superelevation rate

f = side friction factor

V = design speed (mph)

R = radius of curve (ft)



Investigative Approach

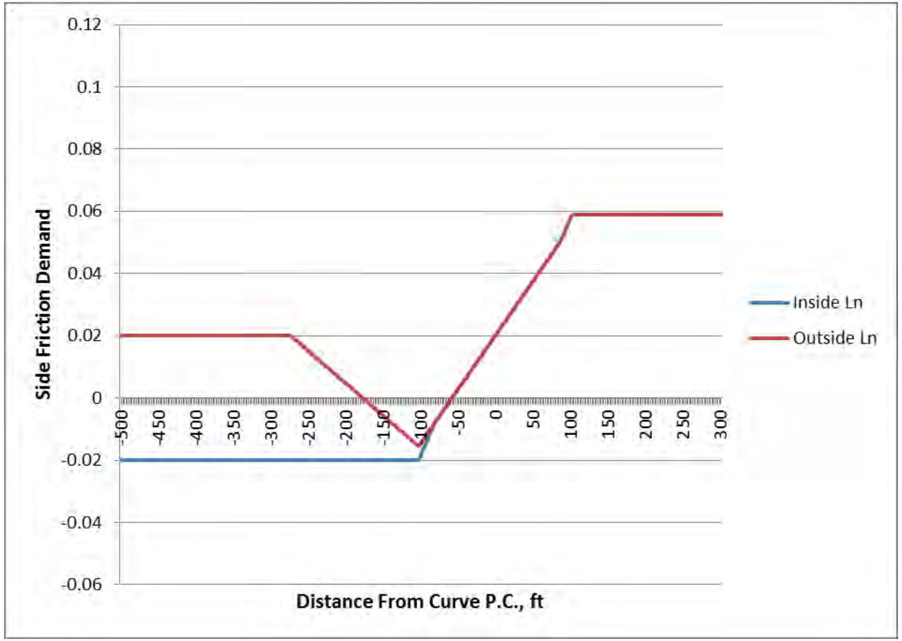
$$f = V^2 / 15R - e$$

- Side friction (f) computed every two feet through a tangent runout / superelevation transition
- Driving path incorporates a spiral transition of an assumed length based on a 2-second travel time
  - Green Book Table 3-21 (NCHRP Report 439)
- Typical section: 2% normal cross slope
- Spreadsheet allows interactive testing of various combinations of parameters

Investigative Approach

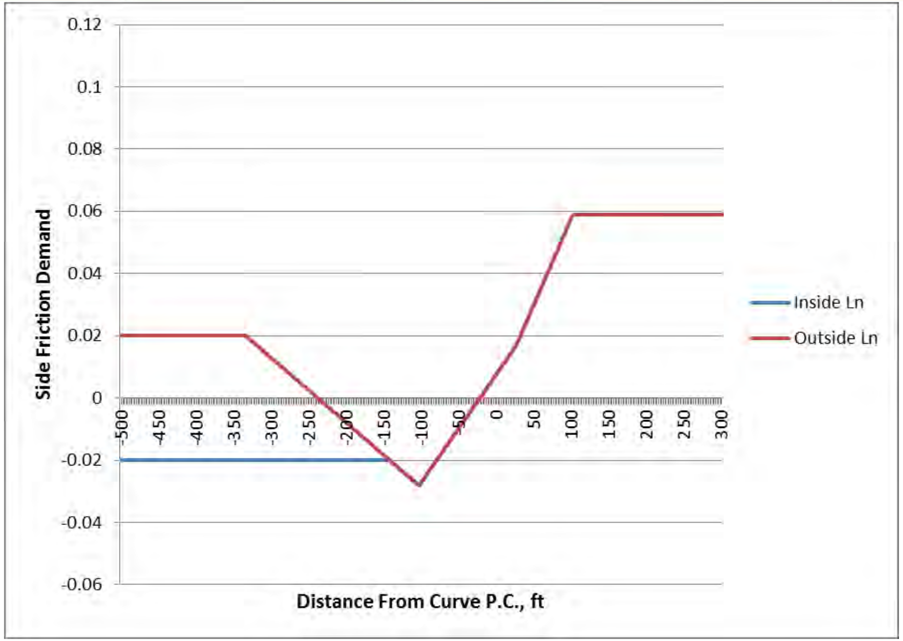
			e		Driven		f	
			Inside Ln	Outside Ln	D	R	Inside Ln	Outside Ln
Speed:	70	-500	0.02	-0.02	0	#DIV/0!	-0.02	0.02
Dc =	2	-498	0.02	-0.02	0	#DIV/0!	-0.02	0.02
R =	2864.789	-496	0.02	-0.02	0	#DIV/0!	-0.02	0.02
full e =	0.055	-494	0.02	-0.02	0	#DIV/0!	-0.02	0.02
% e on tangent:	0.6667	-492	0.02	-0.02	0	#DIV/0!	-0.02	0.02
transition rate:	400	-490	0.02	-0.02	0	#DIV/0!	-0.02	0.02
assumed Ls	205	-488	0.02	-0.02	0	#DIV/0!	-0.02	0.02
		-486	0.02	-0.02	0	#DIV/0!	-0.02	0.02
		-484	0.02	-0.02	0	#DIV/0!	-0.02	0.02
		-482	0.02	-0.02	0	#DIV/0!	-0.02	0.02
		-480	0.02	-0.02	0	#DIV/0!	-0.02	0.02
		-478	0.02	-0.02	0	#DIV/0!	-0.02	0.02
		-476	0.02	-0.02	0	#DIV/0!	-0.02	0.02
		-474	0.02	-0.02	0	#DIV/0!	-0.02	0.02
		-472	0.02	-0.02	0	#DIV/0!	-0.02	0.02
		-470	0.02	-0.02	0	#DIV/0!	-0.02	0.02
		-468	0.02	-0.02	0	#DIV/0!	-0.02	0.02
		-466	0.02	-0.02	0	#DIV/0!	-0.02	0.02

Findings



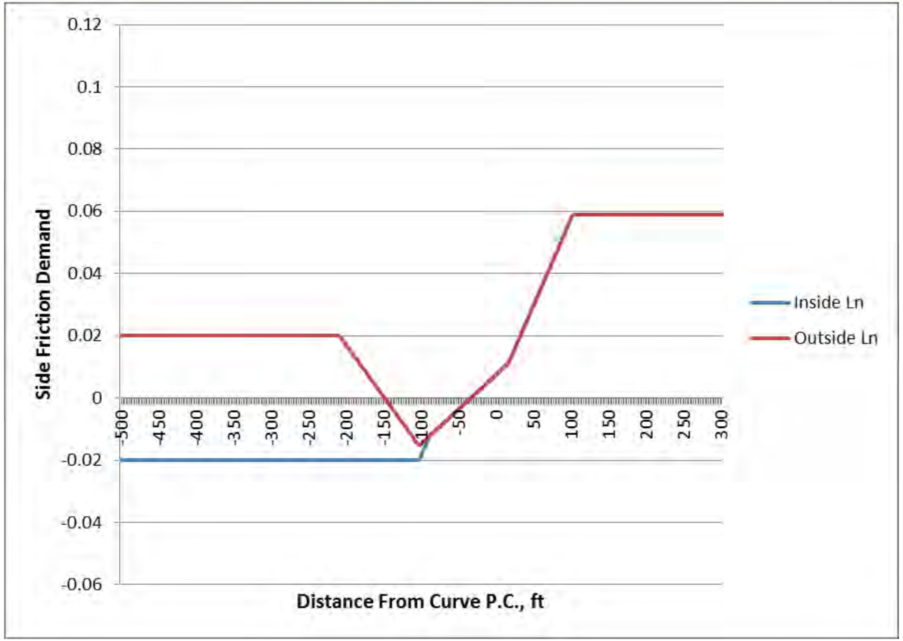
DS = 70 mph; D_c = 2°00'; e = 0.055; S = 1:400; 67% on tangent

Findings



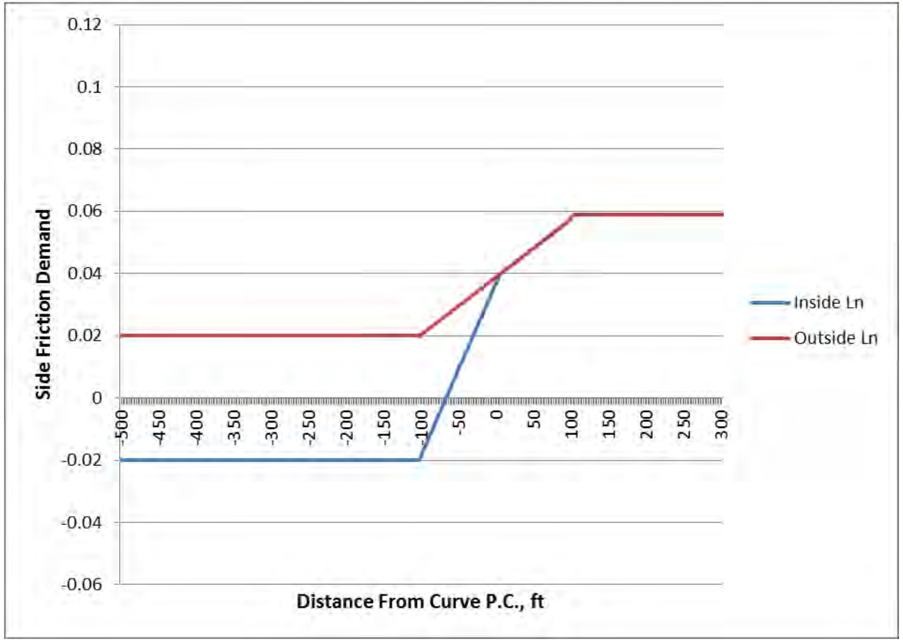
DS = 70 mph; D_c = 2°00'; e = 0.055; S = 1:400; 90% on tangent

Findings



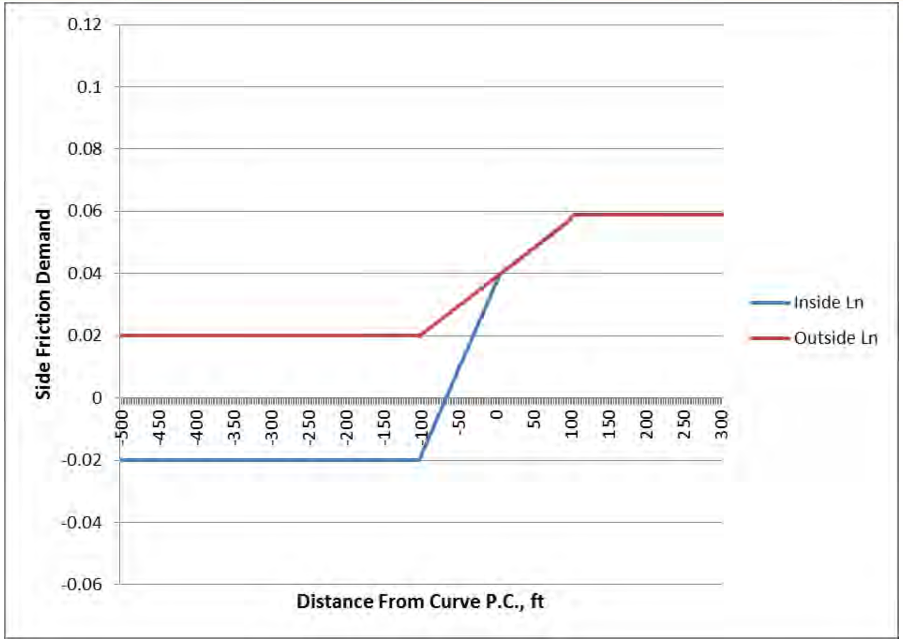
DS = 70 mph; D_c = 2°00'; e = 0.055; S = 1:250; 90% on tangent

Findings



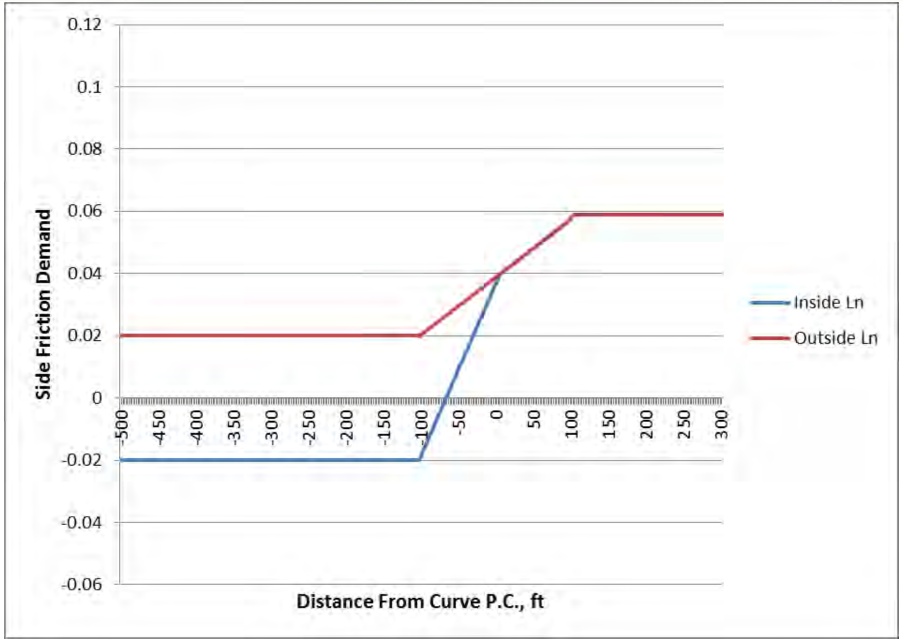
DS = 70 mph; D_c = 2°00'; e = 0.055; S = 1:225; 33% on tangent

Findings



DS = 70 mph; D_c = 2°00'; e = 0.055; S = 1:225; 33% on tangent

Findings



DS = 70 mph; D_c = 2°00'; e = 0.055; S = 1:225; 33% on tangent

Findings

DS = 60 mph

$D_c = 3^{\circ}15'$

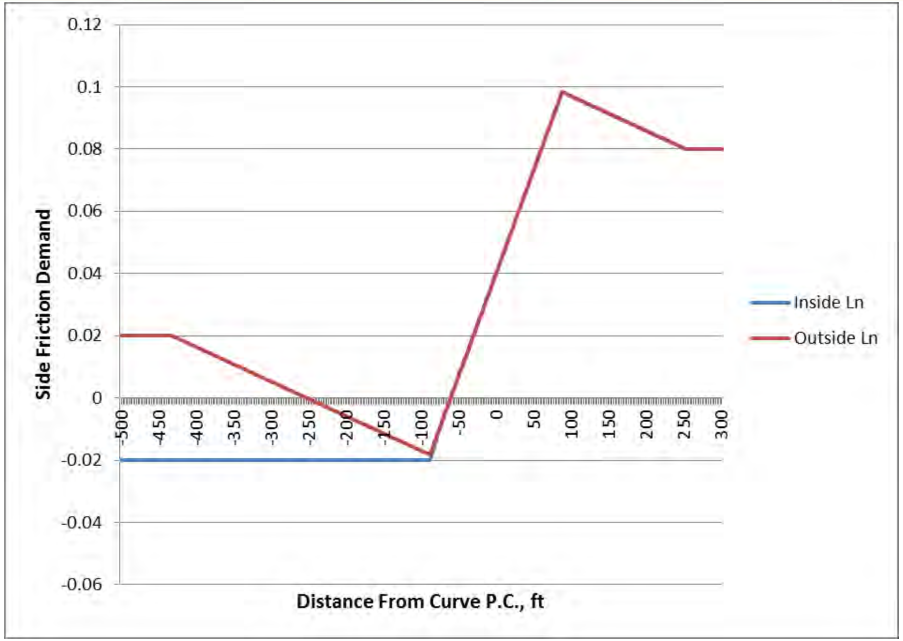
e = 0.056

Back to I-94…

Proportion of runoff on tangent: 50%

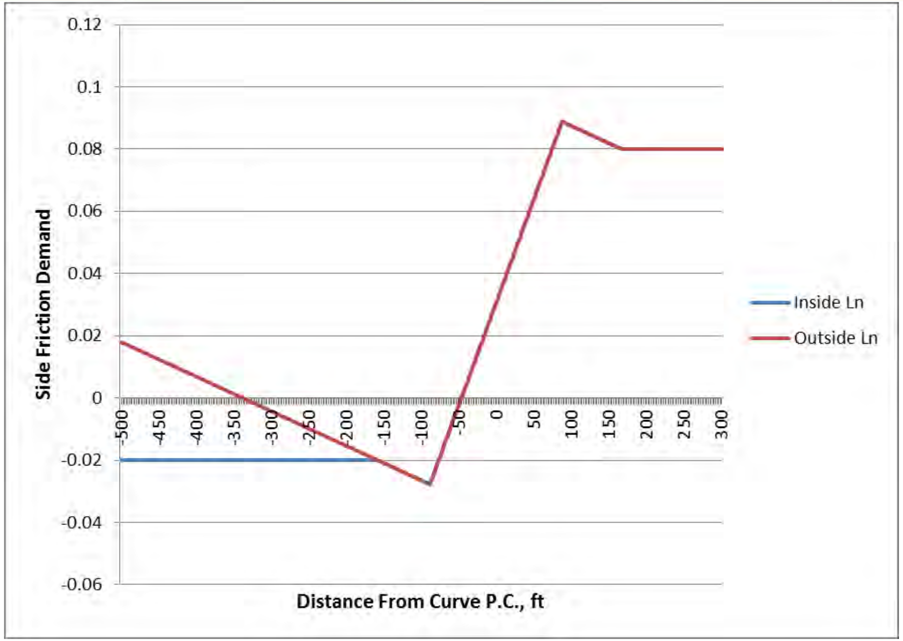
S = 1:750

Findings



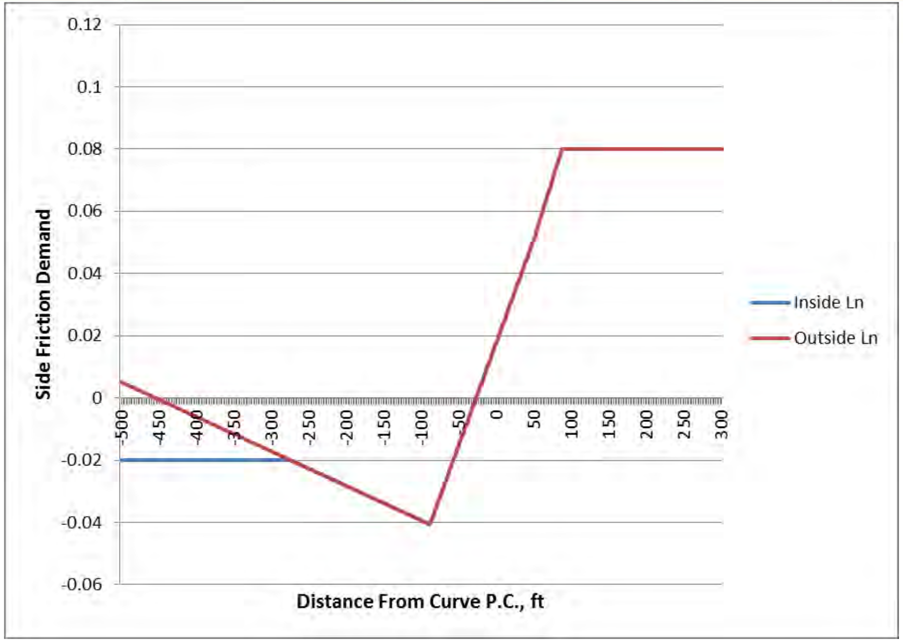
DS = 60 mph; D_c = 3°15'; e = 0.056; S = 1:750; 50% on tangent

Findings



DS = 60 mph; D_c = 3°15'; e = 0.056; S = 1:750; 67% on tangent

Findings



DS = 60 mph; D_c = 3°15'; e = 0.056; S = 1:750; 90% on tangent

Conclusions

- Observations of negative side friction and markedly varying friction with "standard" designs are confirmed by the methodology
- Optimal driver comfort appears to be provided by tailoring transition rate and runoff placement to particular circumstances
  - Generally much less runoff on tangent than recommended by AASHTO
  - Transition rates sometimes faster than recommended by AASHTO
- Optimal driver comfort into spiraled curves is provided by fitting the full transition – runout and runoff – to the length of the spiral

Conclusions

- Very long transitions lead to apparent discomfort BOTH early in the transition and well into the curve proper
- Overarching conclusion: driver comfort does not appear to be served by adherence to AASHTO criteria
  - …particularly the recommendation to provide up to 90% of runoff on the tangent
  - Standards are based on comfort considerations, but they may unwittingly create discomfort…and maybe erratic driving

Recommendations

- This methodology should be explored and refined
- Additional research!
  - Correlate predictions with actual measured effects
- AASHTO Green Book
  - Additional flexibility for both transition rate and placement
  - Reconsider the recommendation to provide up to 90% of runoff on tangent
  - Discuss the phenomenon of negative side friction in transitions – dovetails with NCHRP Report 774 recommendations

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