VILNIUS TECH
Vilnius Gediminas Technical University

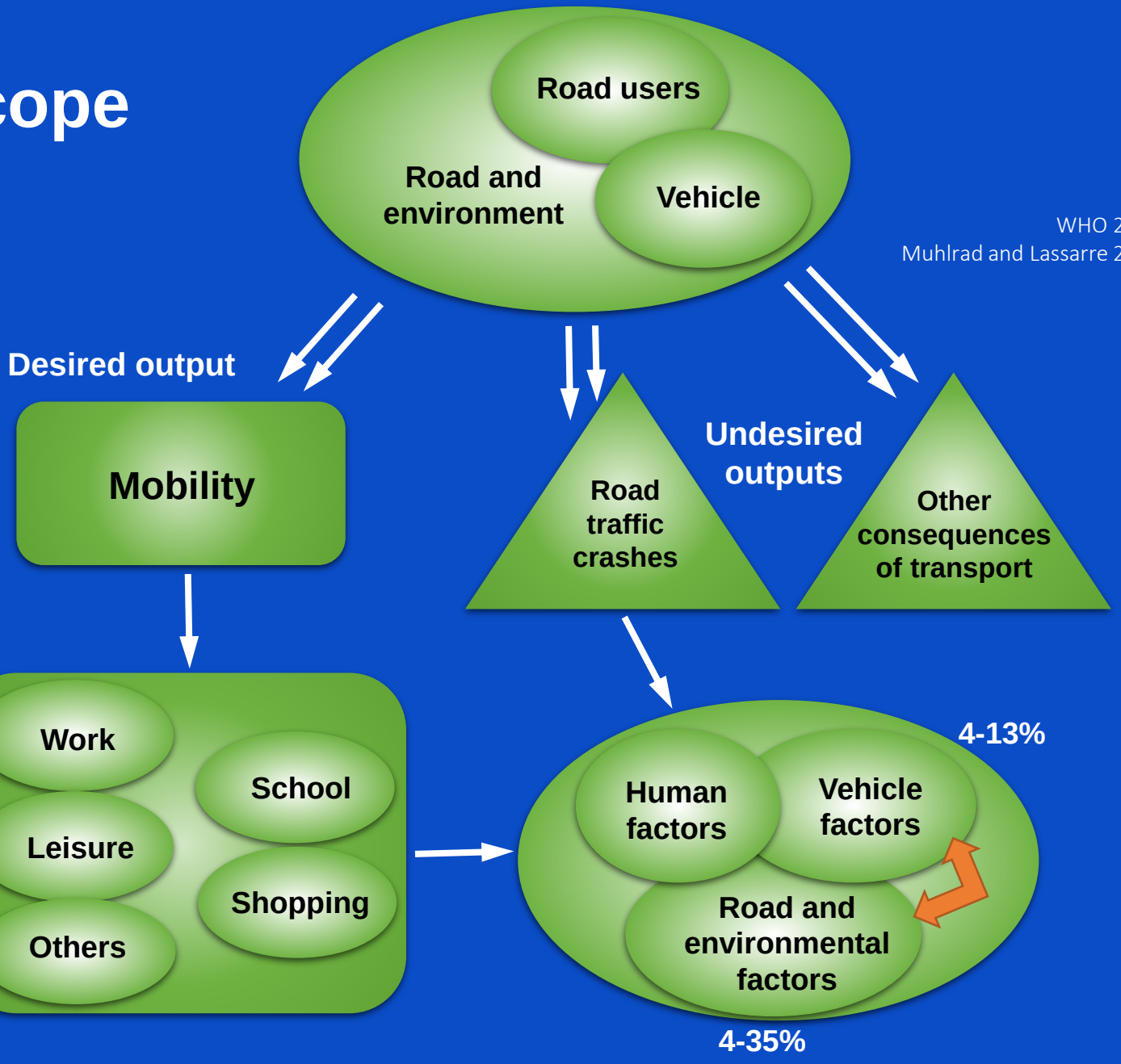
Vidas Žuraulis, Vytenis Surblys,
Department of Automobile Engineering

ASSESSMENT OF RISKY CORNERING ON HORIZONTAL ROAD CURVE BY IMPROVING VEHICLE SUSPENSION PERFORMANCE

The scope

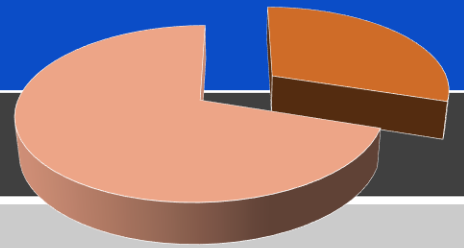
- 1.35 mln. road traffic deaths
- 1.48 mln. COVID-19 deaths

- The potential…
- The attention and efforts worldwide…
- The reaction from institutions and society...



Driving Risk on Horizontal Road Curves

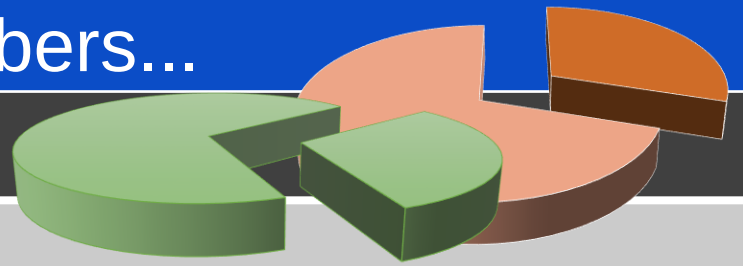
some numbers...



Horizontal curves related numbers	Location	Scope	Source, years
25% - 30%	-	Part of all road fatalities	Lamm et al. 1999
30%	Australia	Part of crashes occur on road curves	Shields et al. 2001
87%	U.S.	Run-off-road and head-on crashes (part of all fatal crashes at horizontal curves)	Torbic et al. 2004
76%		Single vehicle crashes in which the vehicle left the road and hit a fixed object or overturned (part of all fatal crashes at horizontal curves)	
1.5 - 4	-	times greater accident rate than on straight sections	Aram 2010
21%	North Carolina	Part of reported collisions on curves on two-lane roads (2003 – 2005)	Hummer et al. 2010
14%		Part of reported collisions on curves on all roads (2003 – 2005)	
63.44%	Queensland, Australia	Part of fatalities	Queensland Transport, 2006
25.17%		Part of required hospitalisation	
40%	West Europe	Part of run-off-road crashes when single vehicles are involved	SafetyNet 2010
10%	Europe	Part of single-vehicle or run-off-road accidents	ERA-NET ROAD 2012
45%		Part of single-vehicle or run-off-road considering only fatal accidents	
25%	U.S.	Part of all fatal crashes occur on horizontal road curves	Federal Highway Administration 2014

Driving Risk on Horizontal Road Curves

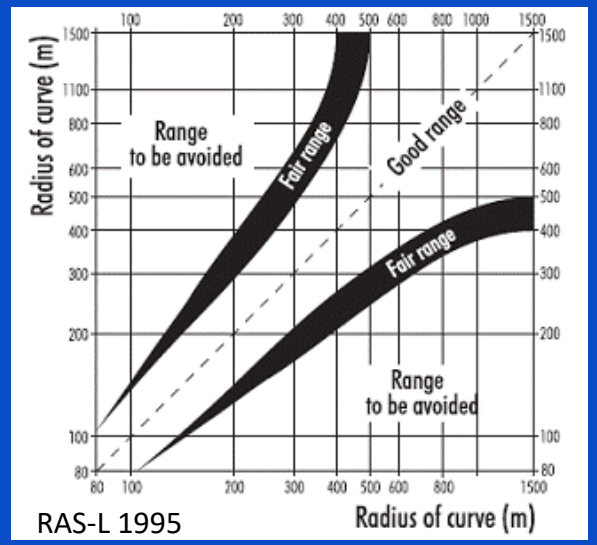
some numbers...



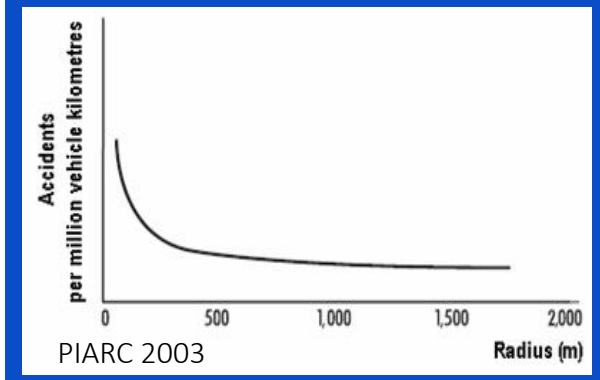
Horizontal curves related numbers	Location	Notes	Source, years
13%	Spain	Part of all road fatalities	Dirección General de Tráfico 2015
35%	Croatia	Part of total accidents with fatalities occurred along horizontal curves	Maljković and Cvitanić 2016
22.6%	Czech Republic	Part of all horizontal road curves with at least one road accident	Bíl et al. 2019
13%	Lithuania	Part of all fatal road accidents (2015-2019)	Lithuanian Road Police 2020
39%	Australia	Part of fatality crashes (between 1 July 2008 and 30 June 2009)	Rakotonirainy et al. 2015
22%	-	Road departure crashes without loss of control	Mastinu and Ploechl 2014
42%	U.S.	Lane departure crashes occurred at horizontal curves	The American Association of State Highway and Transportation Officials, 2008
71%	Norway	Speeding and driving under the influence of alcohol (The proportion of crashes that occurred in curves single-vehicle crashes)	Høye 2020
46%		Speeding and driving under the influence of alcohol (The proportion of crashes that occurred in curves among other crashes)	
60% - 70%	-	Single vehicle run-off-the-road accidents of all fatal crashes	Calvi 2015
23.1%	-	Extremely severe crashes occurred on the downgrade horizontal curve segments	Xu et al. 2020

Driving Risk on Horizontal Road Curves

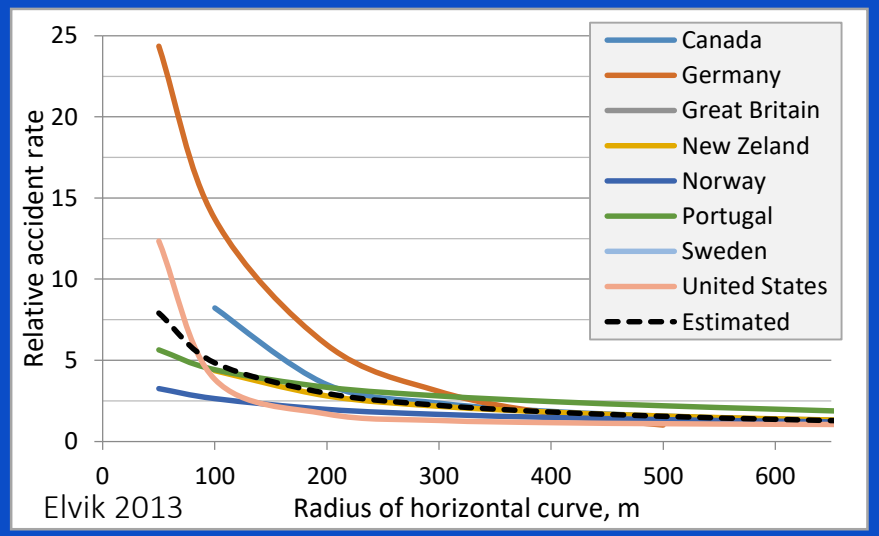
some figures...



RAS-L 1995



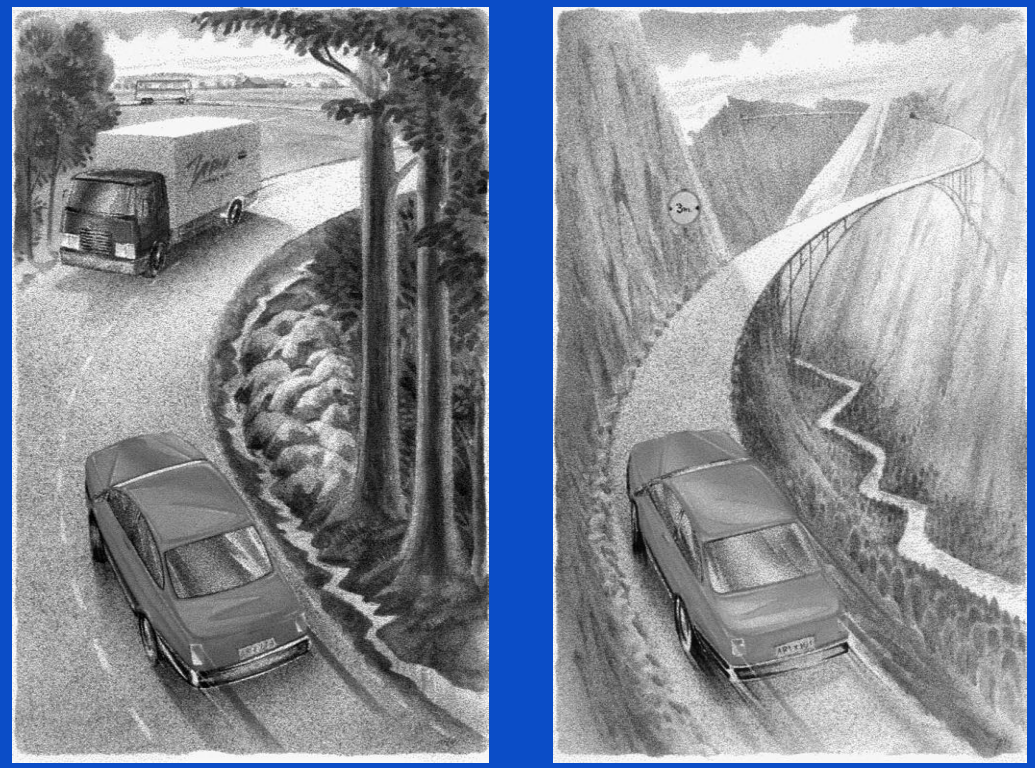
PIARC 2003



Elvik 2013

"Our inability to sense danger in kinetic energy."

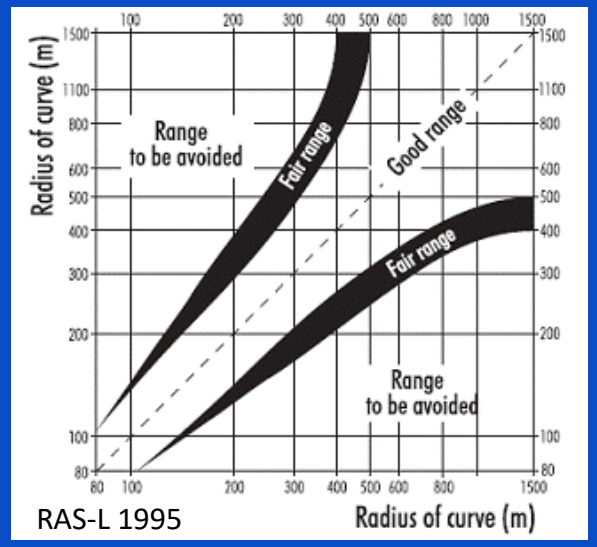
"Our fear of falling makes the danger in kinetic energy obvious."



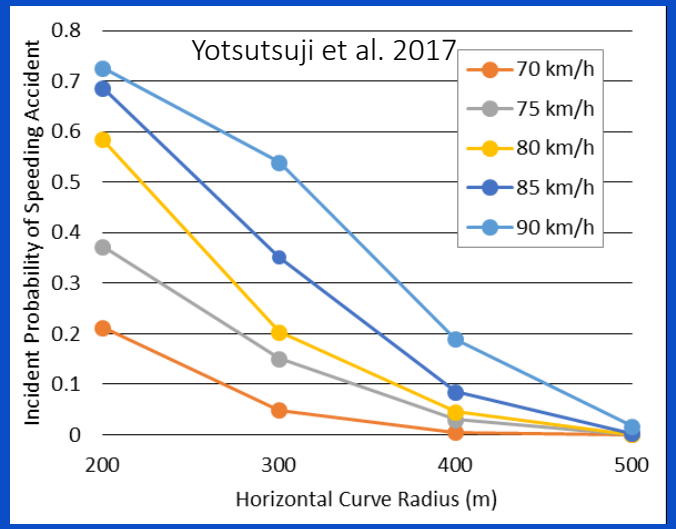
Prof. Claes Tingvall, Swedish National Road Administration

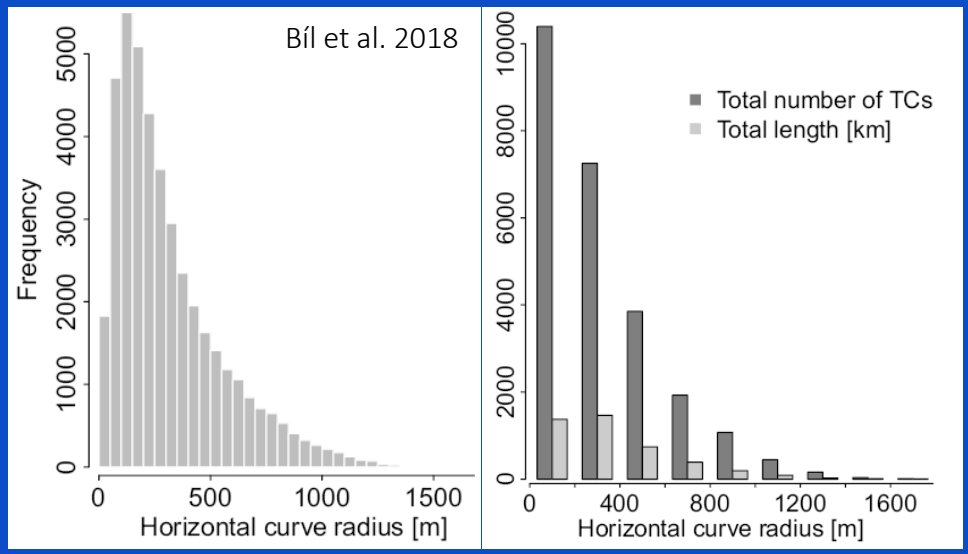
Driving Risk on Horizontal Road Curves

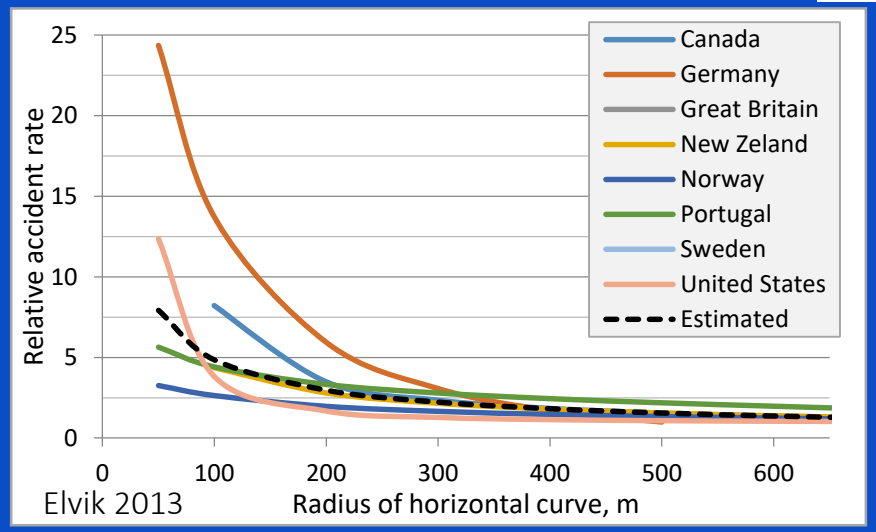
some figures...



RAS-L 1995



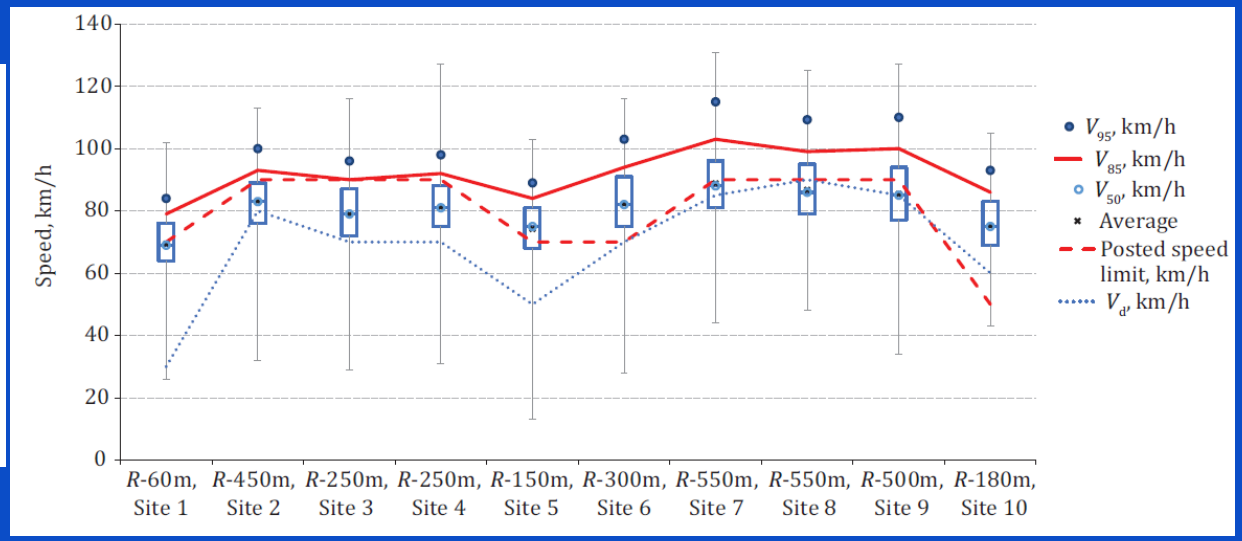




Elvik 2013

Mindaugas Šeporaitis, Viktoras Vorobjovas, Audrius Vaitkus

Evaluation of Horizontal Curve Radius Effect on Driving Speed in Two Lane Rural Road. Pilot Study



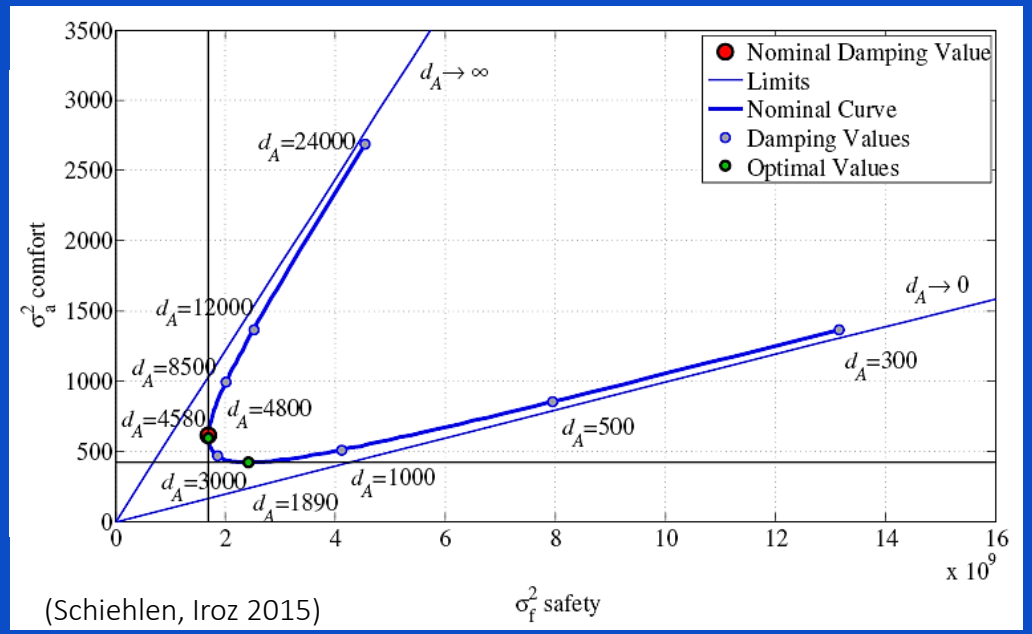
Driving Risk on Horizontal Road Curves

ROAD INFRASTRUCTURE SAFETY MANAGEMENT (2008/96/EC)

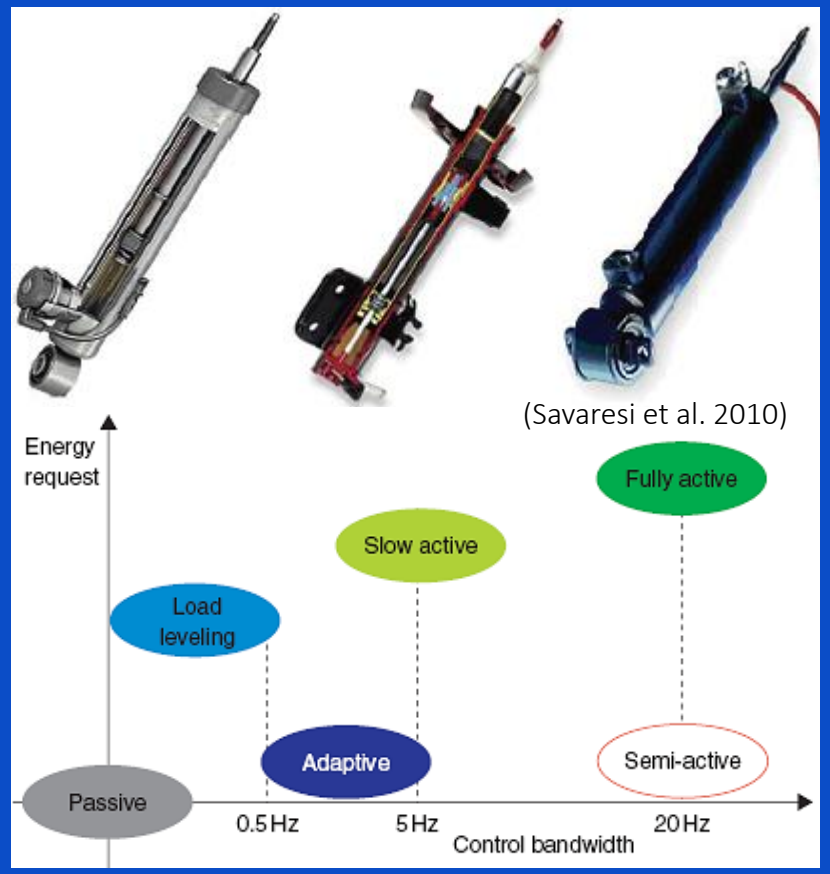
Mandatory principles for *safe road* design and building ⟷ The importance of *maintenance* and renewal

Risk Reduction Perspectives

The importance of ***maintenance*** and renewal



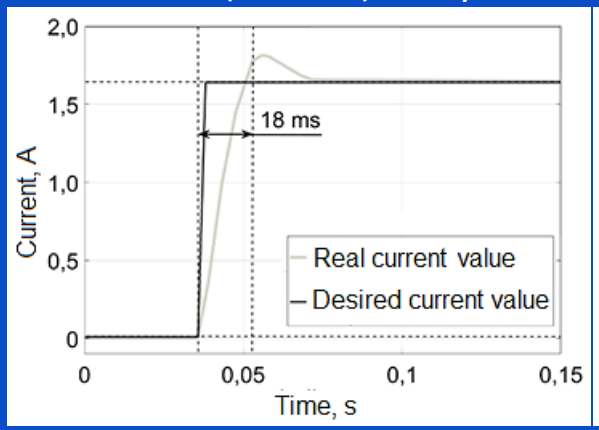
(Schiehlen, Iroz 2015)



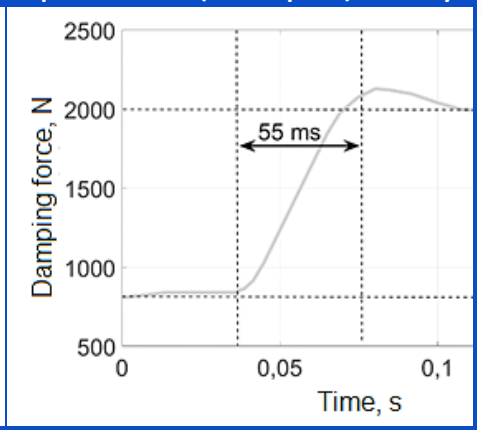
Risk Reduction Perspectives

The importance of *maintenance* and renewal

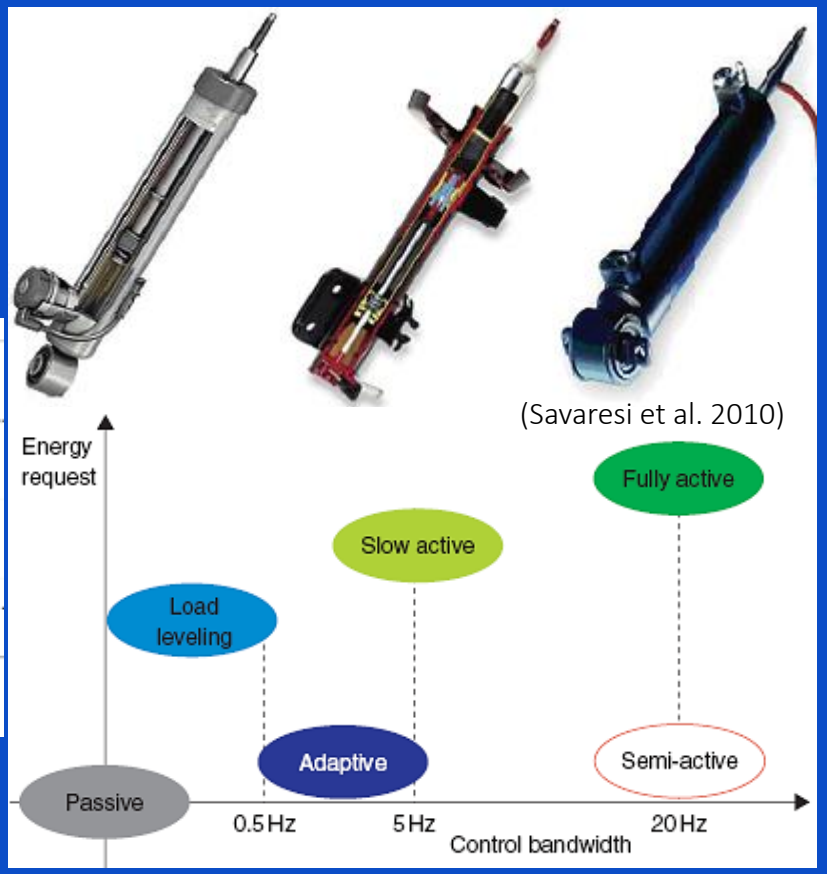
Control (current) delay



Operation (damper) delay

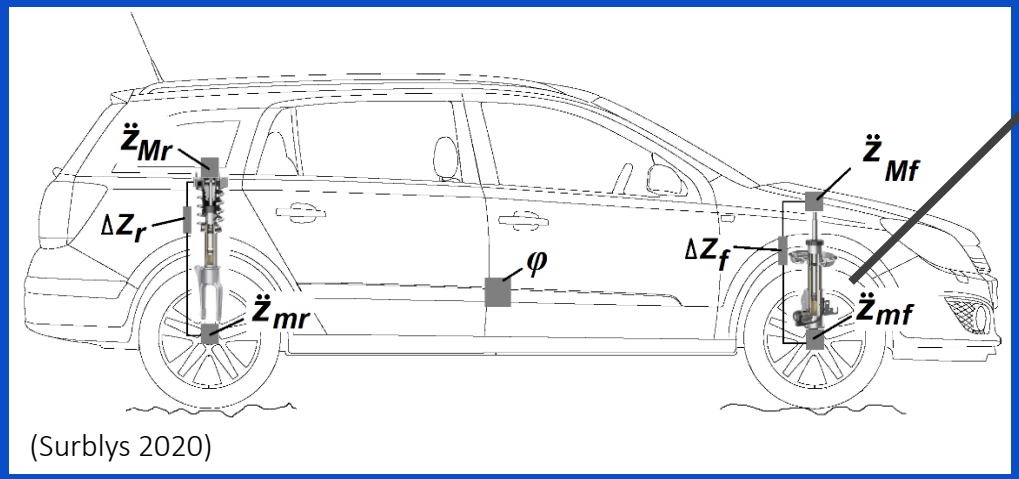


Damping forces of the shock absorber are altered within the maximum time – 0.073 s

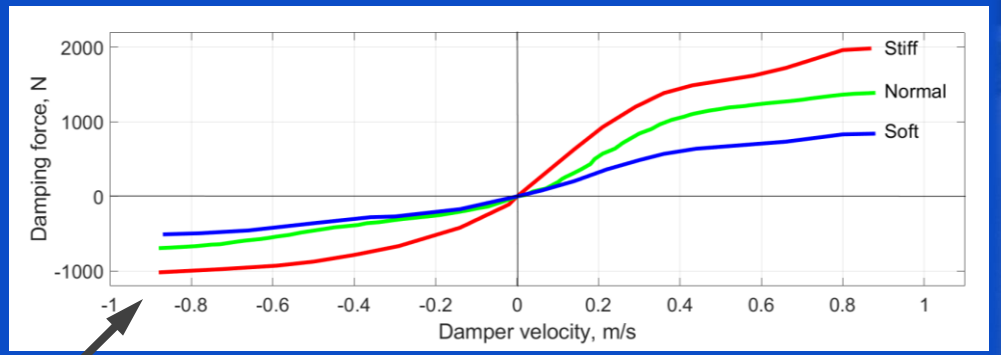


Risk Reduction – Vehicle Perspective

- Risk reduction
  - Driver
  - Road
  - Vehicle



(Surblys 2020)

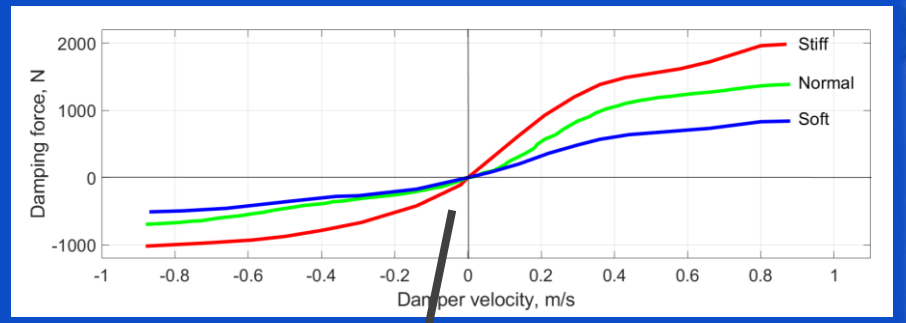


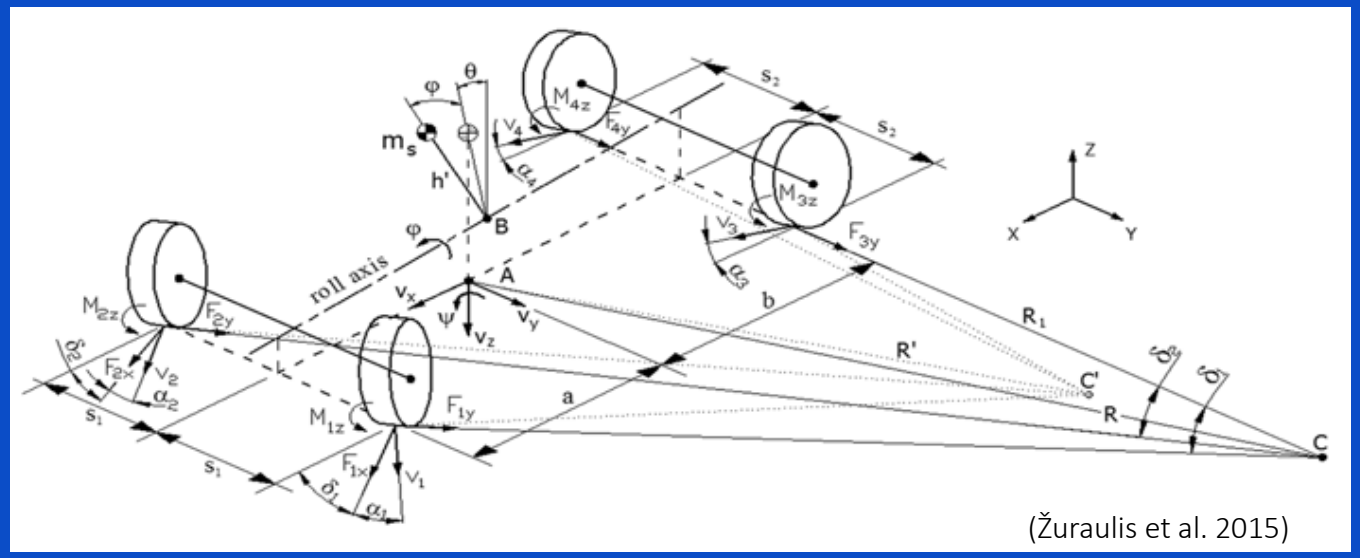
$$F_{cM}(\Delta\dot{z}) = a_0 + a_1 \cdot \cos(d \cdot \Delta\dot{z}) + b_1 \cdot \sin(d \cdot \Delta\dot{z}) + a_2 \cdot \cos(2 \cdot d \cdot \Delta\dot{z}) + b_2 \cdot \sin(2 \cdot d \cdot \Delta\dot{z}) + a_3 \cdot \cos(3 \cdot d \cdot \Delta\dot{z}) + b_3 \cdot \sin(3 \cdot d \cdot \Delta\dot{z}) + a_4 \cdot \cos(4 \cdot d \cdot \Delta\dot{z}) + b_4 \cdot \sin(4 \cdot d \cdot \Delta\dot{z}),$$

Risk Reduction – Vehicle Perspective

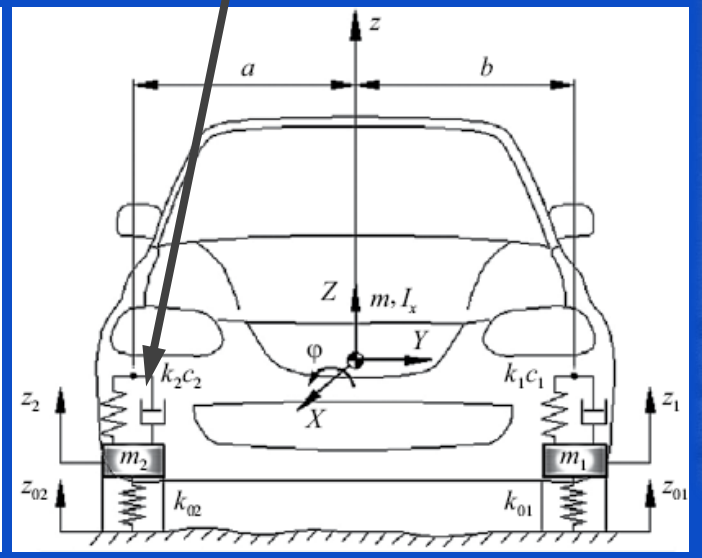
• Simulation

- **14 DOF vehicle model (MATLAB/Simulink)**
- **Sharp cornering maneuver:**
  - wheels steered δ =1.28 deg.
  - trajectory $R_{kin.}$=117 m, $R_{dyn.}$=70÷110 m
  - superelevation e = 4%, max. friction μ_{max} =0.85
  - driving speed during cornering v = 75÷95 km/h
  - lateral acceleration a_y =6÷8 m/s^2
  - body side-slip angle δ =5÷14 deg.





(Žuraulis et al. 2015)



(Žuraulis et al. 2013)

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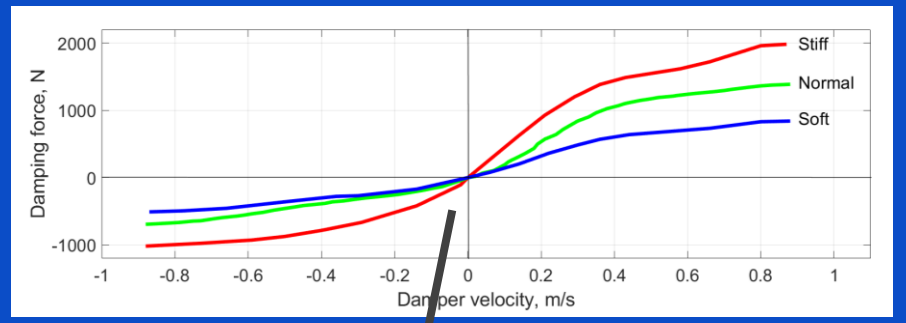
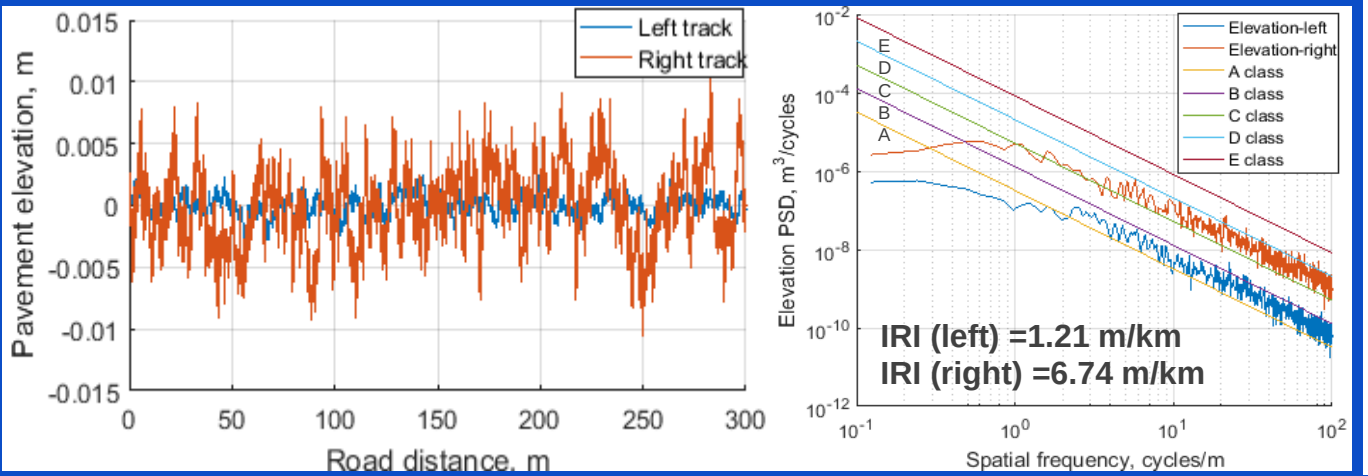
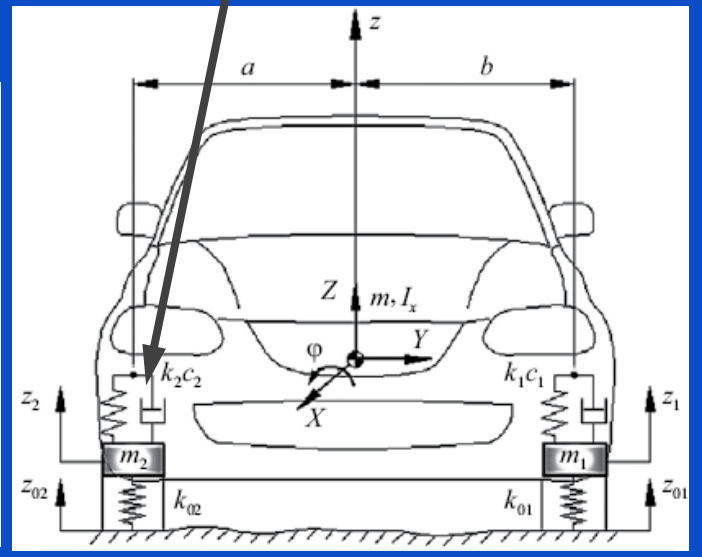
  - body side-slip angle δ =5÷14 deg.
  - *B class* roughness for left side wheels (inside)
  - *D class* roughness for left side wheels (outside corner)







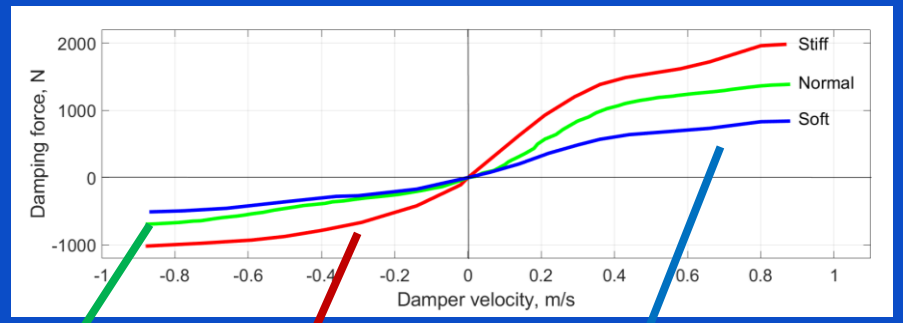
(Žuraulis et al. 2013)

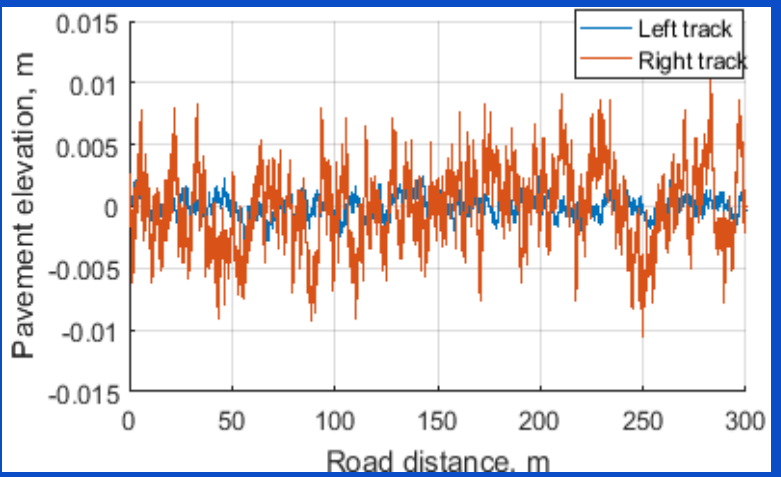
Risk Reduction – Vehicle Perspective

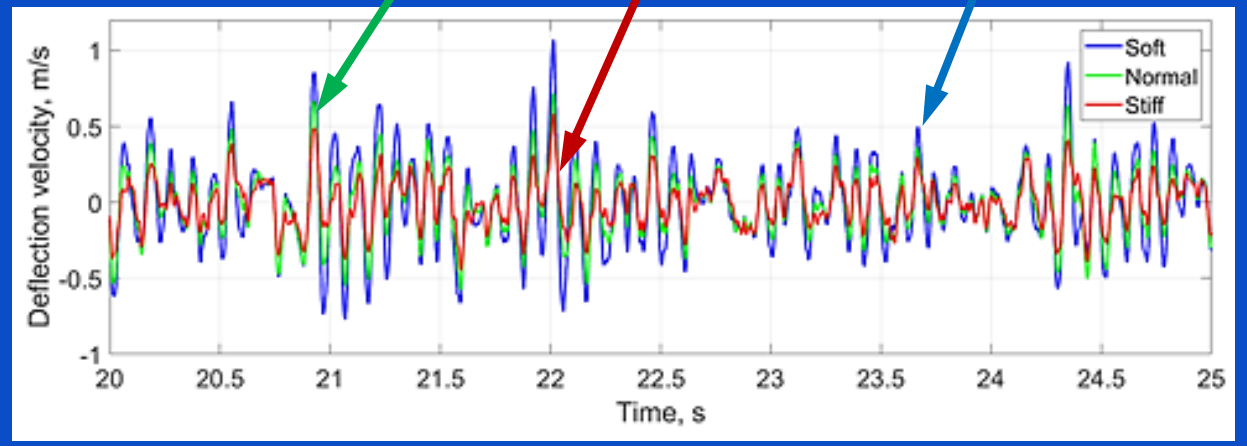
- Simulation
- **Results**

- **14 DOF vehicle model (MATLAB/Simulink)**
- **Sharp cornering maneuver**

Suspension damping mode	RMS of suspension deflection velocity, m/s			
	Left side		Right side	
	Front	Rear	Front	Rear
Soft	0.0566	0.0566	0.2852	0.2846
Normal	0.0479	0.0476	0.2179	0.2178
Stiff	0.0412	0.0411	0.1622	0.1602





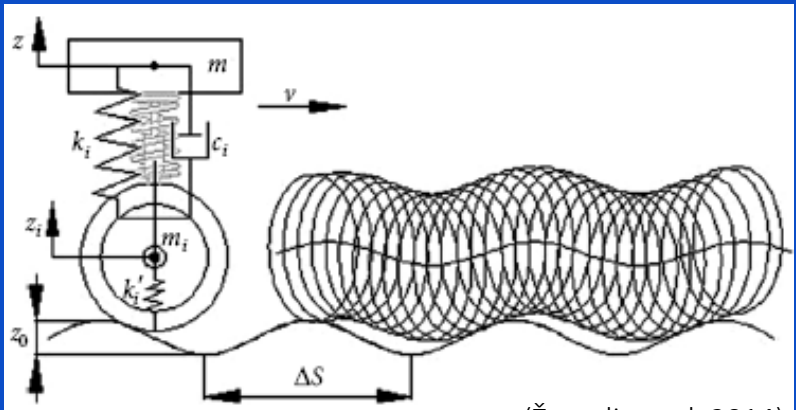


Risk Reduction – Vehicle Perspective

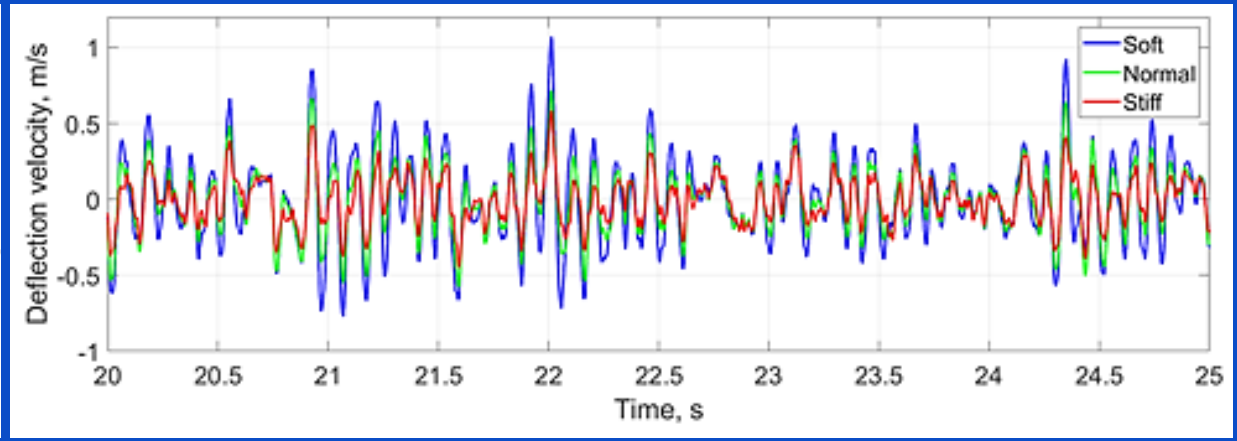
- Simulation
- **Results**

- **14 DOF vehicle model (MATLAB/Simulink)**
- **Sharp cornering maneuver**

Suspension damping mode	RMS of suspension deflection velocity, m/s				Dynamic Load Coefficient (DLC)			
	Left side		Right side		Left side		Right side	
	Front	Rear	Front	Rear	Front	Rear	Front	Rear
Soft	0.0566	0.0566	0.2852	0.2846	0.042	0.062	0.203	0.252
Normal	0.0479	0.0476	0.2179	0.2178	0.041	0.061	0.180	0.225
Stiff	0.0412	0.0411	0.1622	0.1602	0.042	0.067	0.173	0.216



(Žuraulis et al. 2014)



Risk Reduction – Vehicle Perspective

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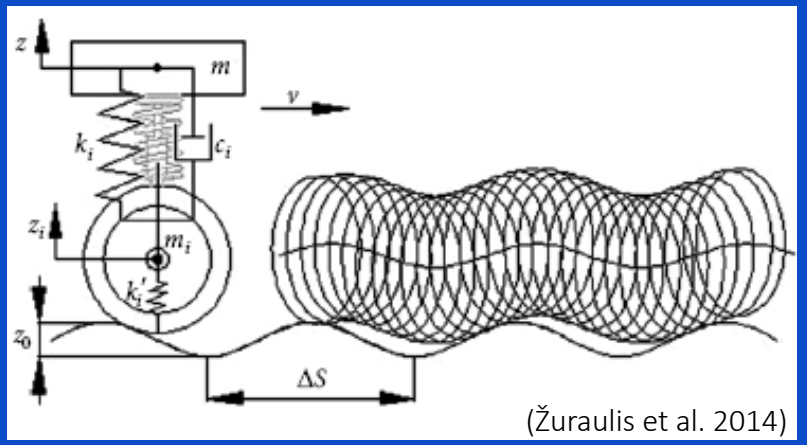

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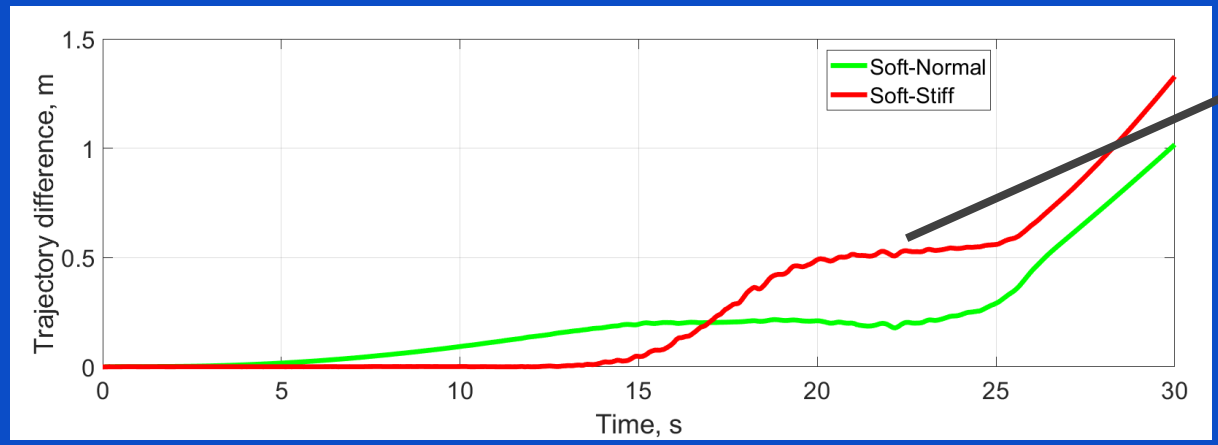
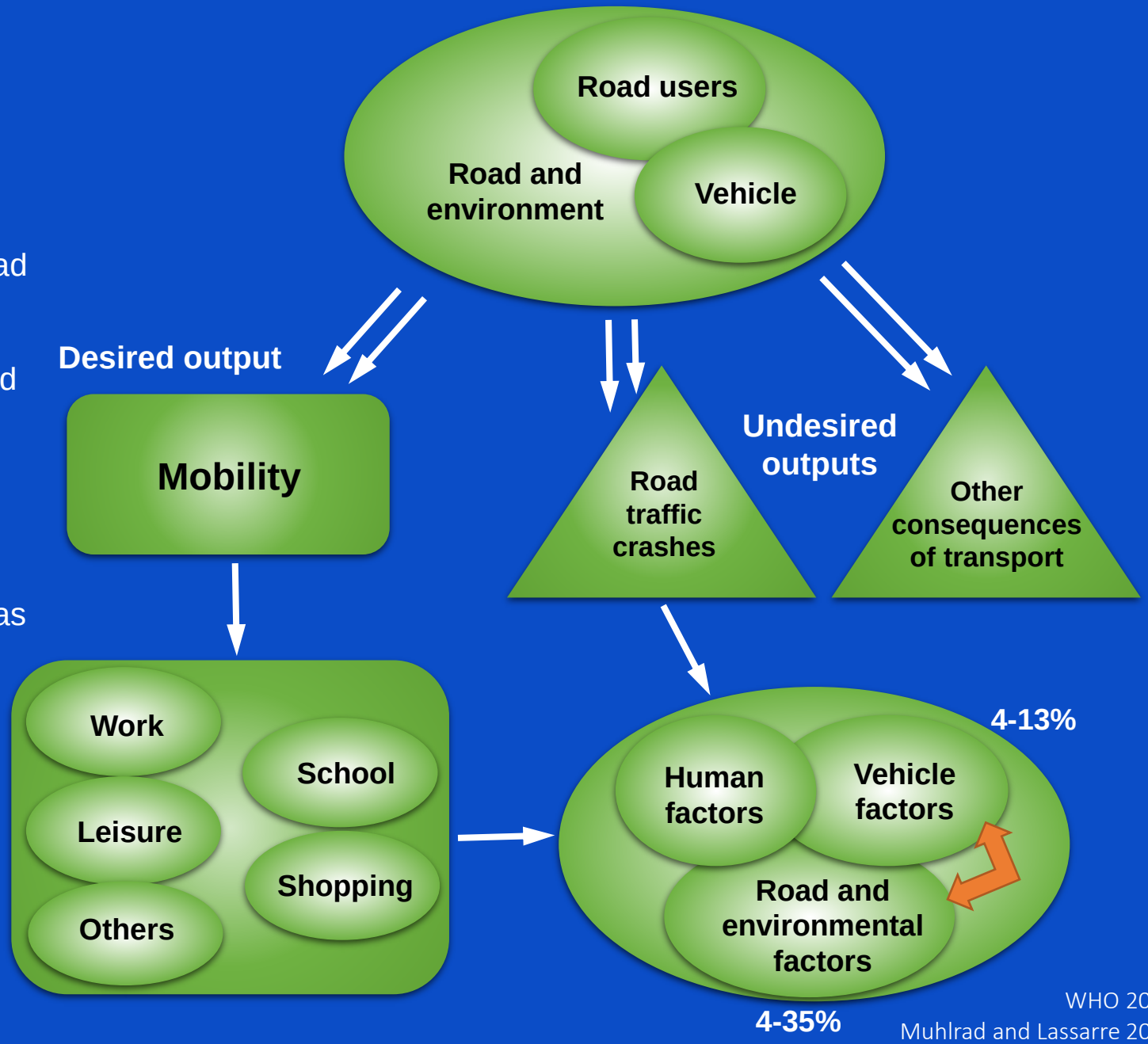


Conclusions

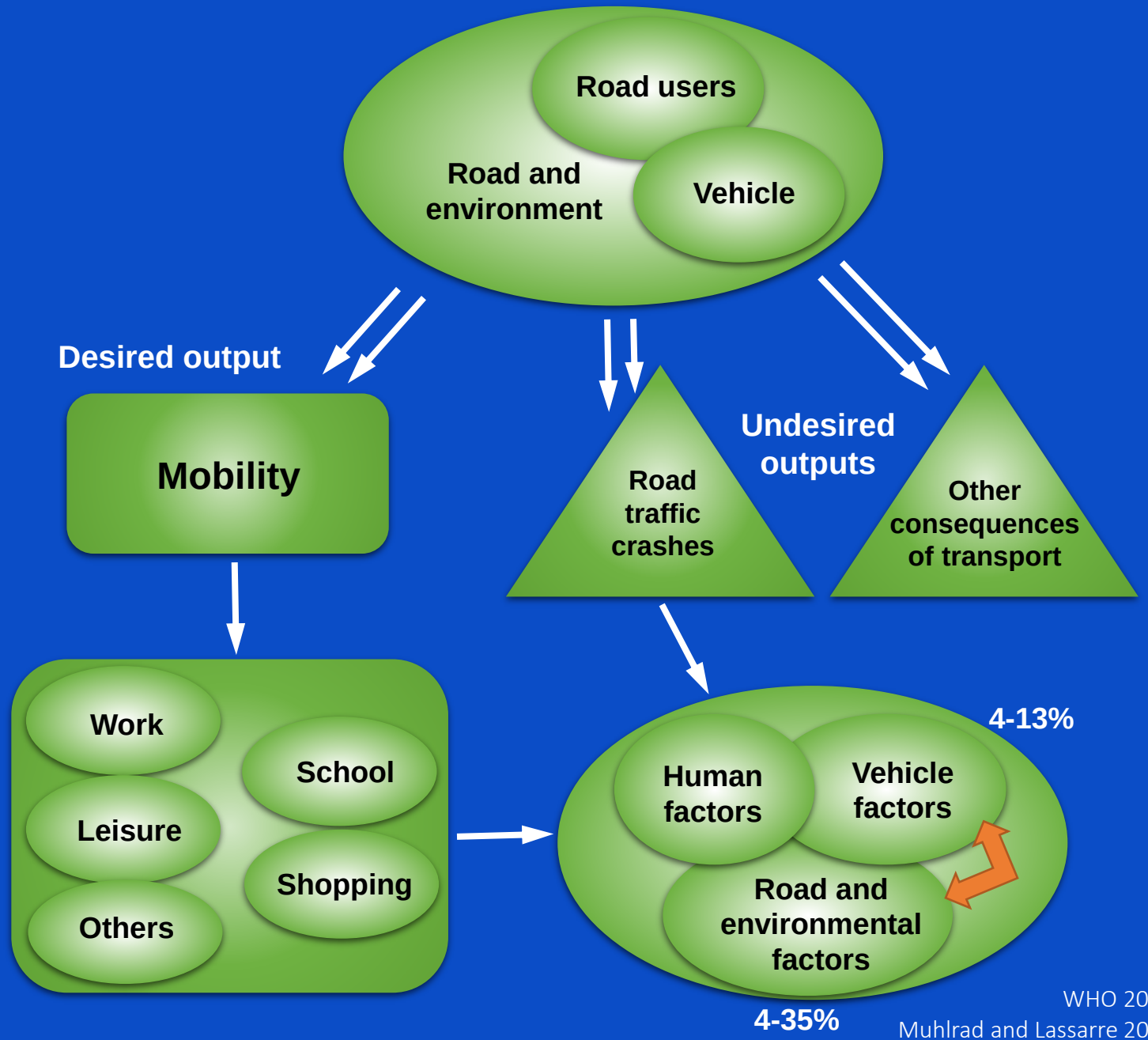
- Deterioration of the road surface at the edge of the road is a common case of pavement damage. Driving on such a pavement, different wheels have a variation in its contact with the road surface, which can be reduced by lower driving speed or active chassis systems.
- Suspension with higher damping force characteristic (*Stiff damping*) showed better vehicle stability results, despite the fact that the performance of vehicle dynamics is strongly non-linear and depends on combination of suspension stiffness-damping as well as tire-road interaction.
- Better tire-road interaction working on Stiff damping mode was estimated with lower Dynamic Load Coefficient values. The deviation from the driving trajectories utilising different suspension damping modes was from 0.2 to 0.5 m.
- Road-adjusted suspension decreases wheels contact loss, vehicle's outward displacement, and risk of possible accident.



WHO 2006
Muhlrad and Lassarre 2005

Thank you

Stay safe and healthy



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