ROAD SAFETY & SIMULATION INTERNATIONAL CONFERENCE 2017

RSS2017

Safety Assessment of Control Design Parameters through Vehicle Dynamics Model

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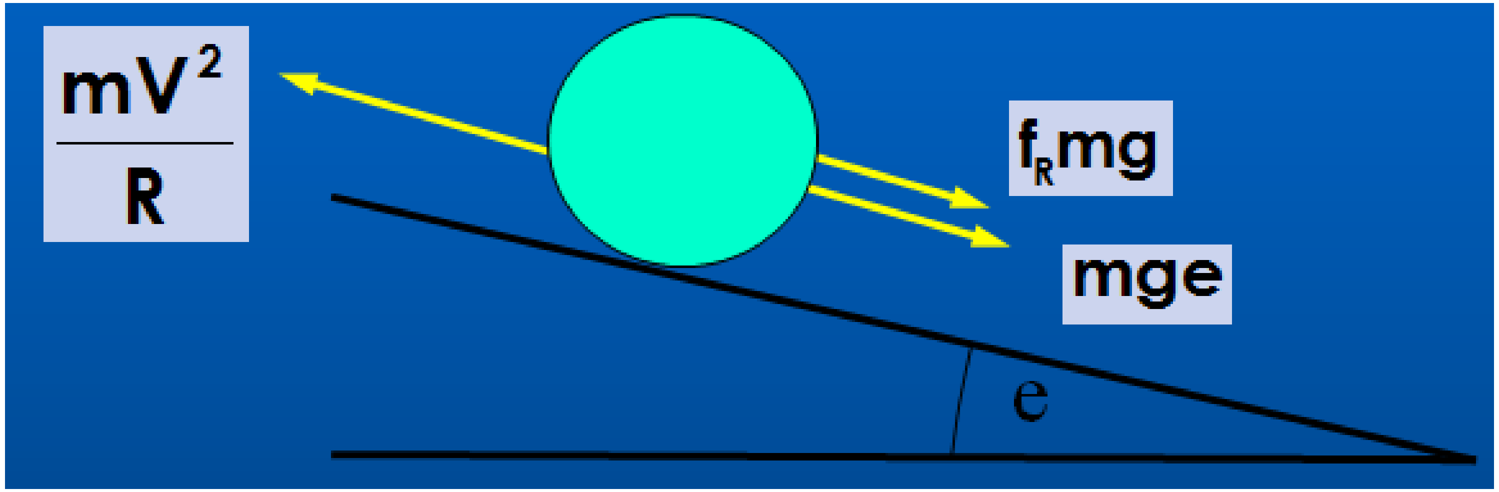
Background

- Design speed
  - key parameter for defining critical geometric elements

- Road design practice
  - simplified approach
  - failure to assess interactions between parameters

$$R_{min} = \frac{V^2}{127(f_{R,perm} + e_{max})}$$

where
R_{min} : minimum curve's radius (m)
V : vehicle speed – usually design speed (km/h)
e_{max} : maximum superelevation rate (%/100)
m : vehicle's mass
$f_{R,perm}$: permissible side friction factor as a portion of peak friction



Point Mass Deficiencies

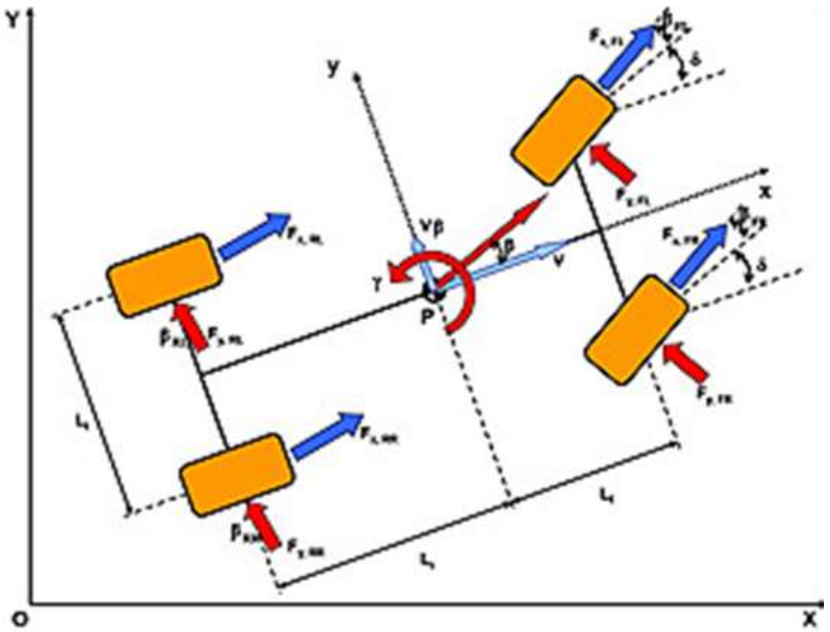
- Steady state cornering is assumed
  - acceleration effect is ignored
- Key vehicle parameters ignored
  - type, mass and position of gravity (mass) center, loading - driving configuration, horse-power supply, etc.
- Vehicle motion is examined independently in tangential - lateral direction of travel
  - respective friction components interact
- Utilized lateral friction based on empirical vehicle accident considerations
  - assumed as fixed portion of the relevant peak (40%-50%)
- Longitudinal profile disregarded

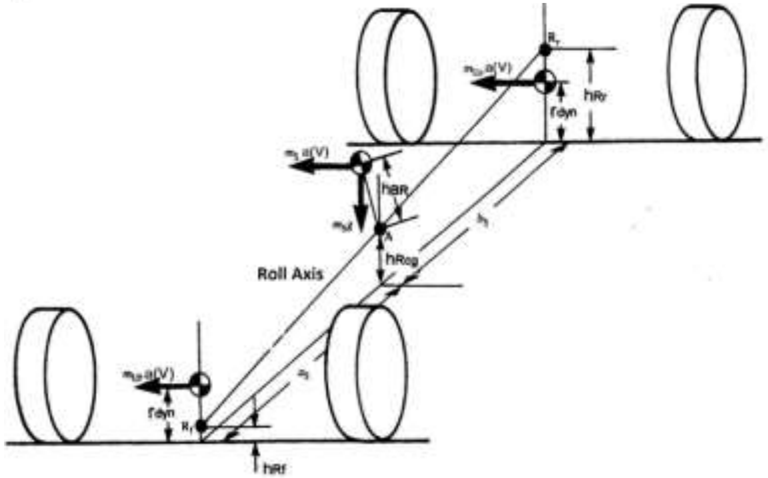
Necessity for More Sophisticated Models

- Current control grade values
  - based mostly on experience
  - limitations from the operational point of view

  and not an outcome of a safety assessment

- Simulate vehicle's cornering process
  - especially in cases of steep grades (reduction of safety margin)
  - upgrade road sections more critical in terms of horizontal radii requirements



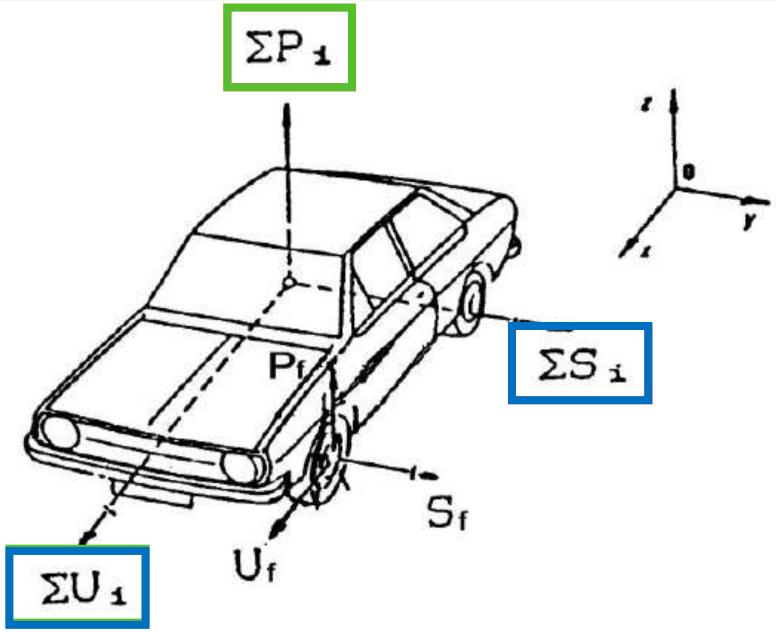


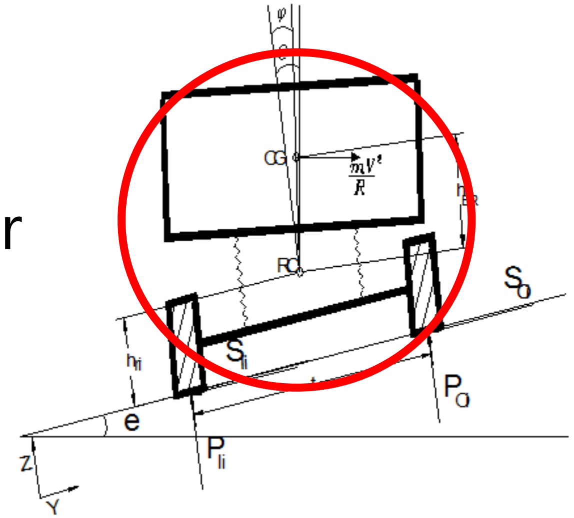
Objective

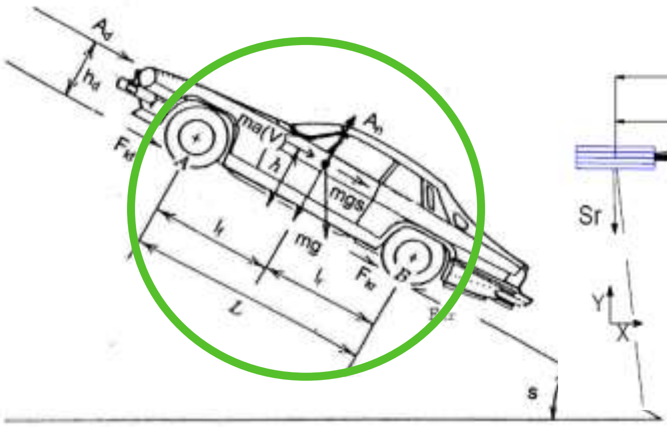
- Lift restrictions imposed by point mass model
- Assess the ability of a typical passenger car to maintain design speed values for the corresponding control design parameters
    - critical upgrade values
    - various tire – road friction values
- Investigate the safety impact of vehicle's peak attainable constant speed against design parameters imposed by design speed

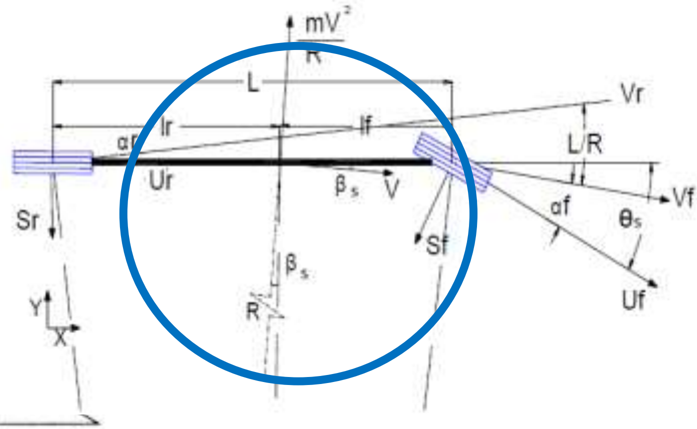
Vehicle Dynamics Model

- Moving 3D coordinate system
- Parameters correlated
  - vehicle technical characteristics
  - road geometry
  - tire friction
- 4-wheel model
  - lateral load transfer



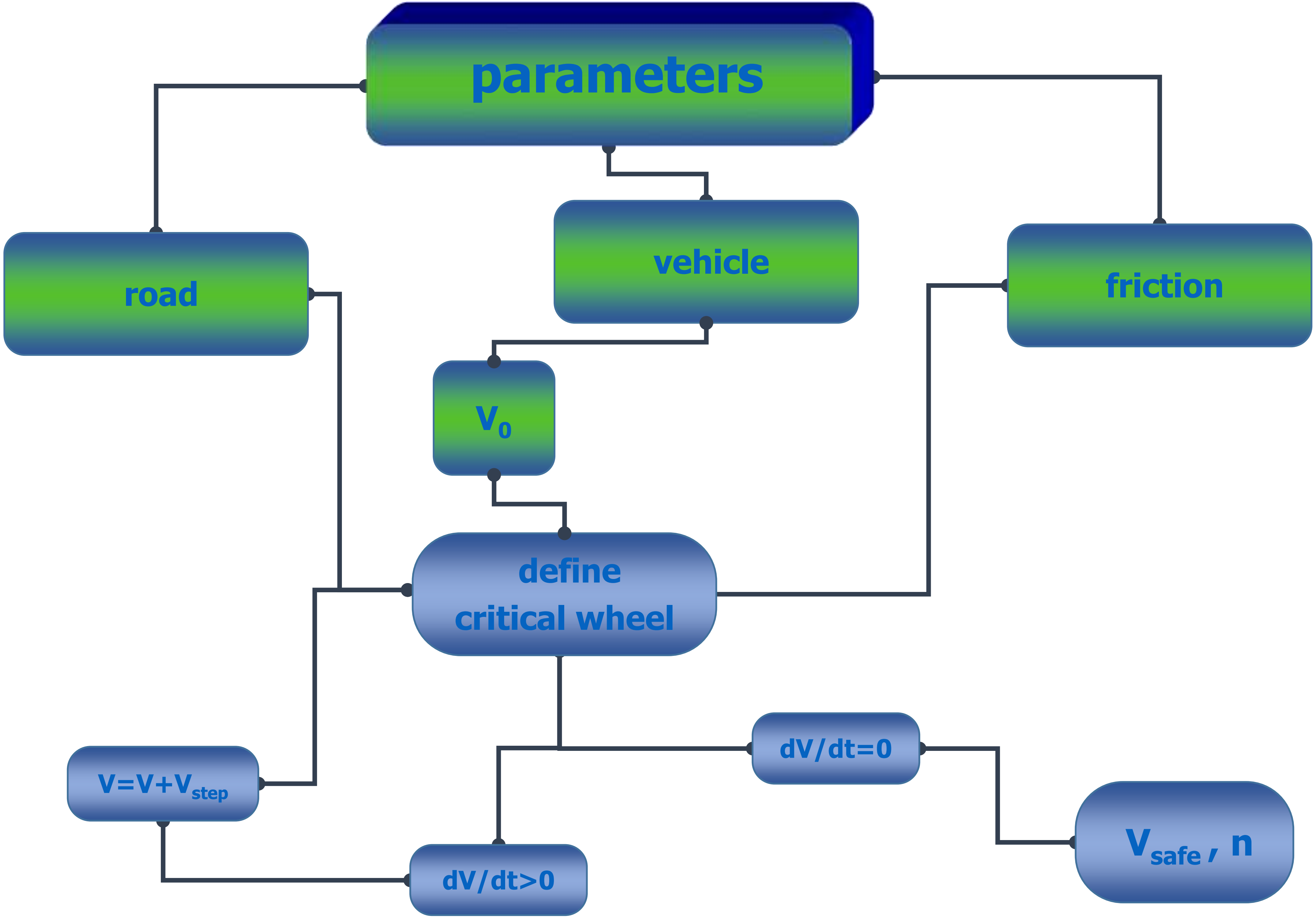






Methodology

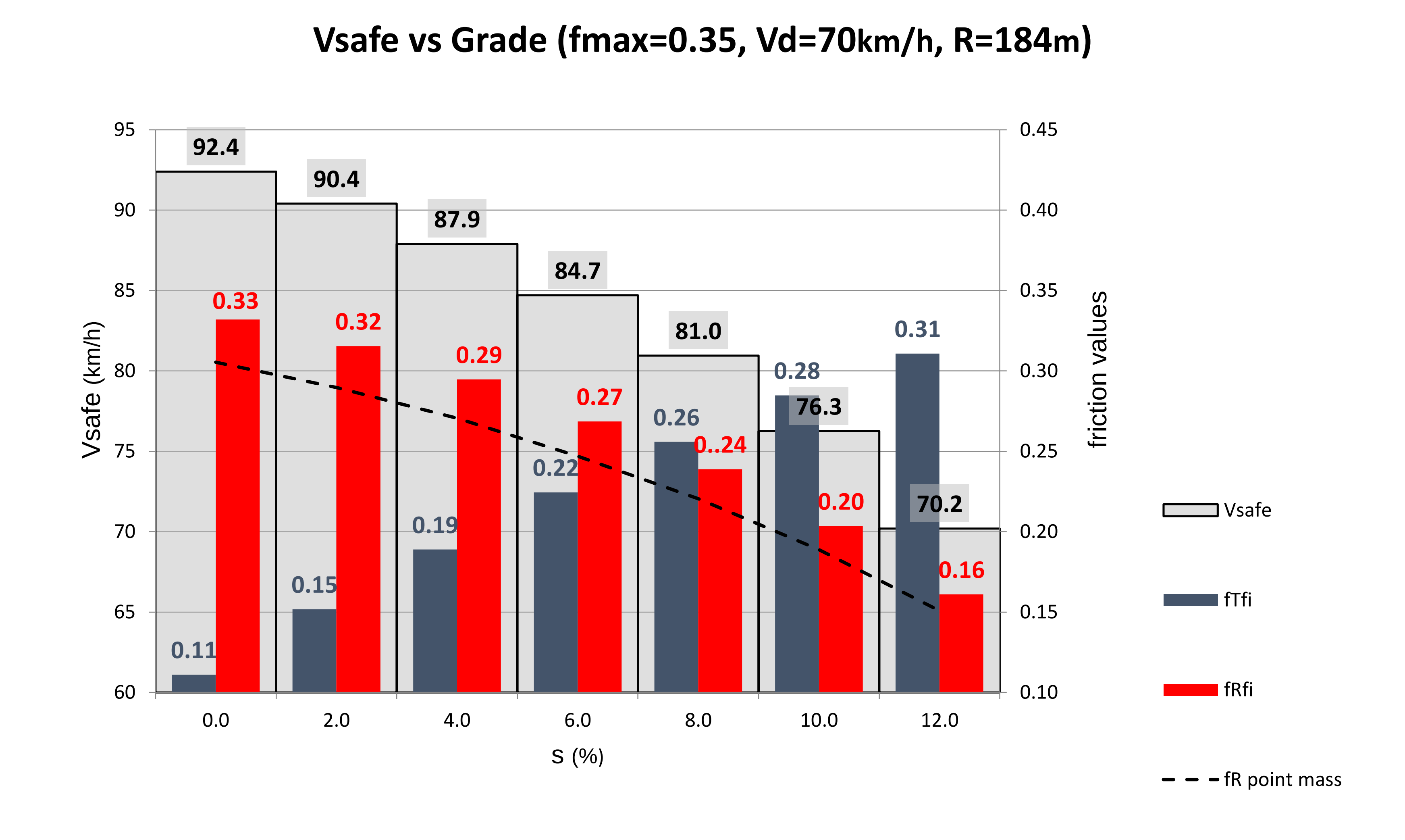
- Output: V_{safe}
  vehicle's peak attainable constant speed
  - C class passenger car utilized
    (KIA Proceed)
  - assessment for AASHTO-2011 design guidelines
    (V_d =50km/h – V_d =90km/h)
  - 3 pavement friction values (0.35, 0.50, 0.65)
  - definition of critical wheel
    (impending skid conditions)



parameters
road
vehicle
friction
V0
define
critical wheel
V=V+Vstep
dV/dt=0
dV/dt>0
Vsafe , n

Grade Impact during V_{safe} Determination

- **Impending skid**

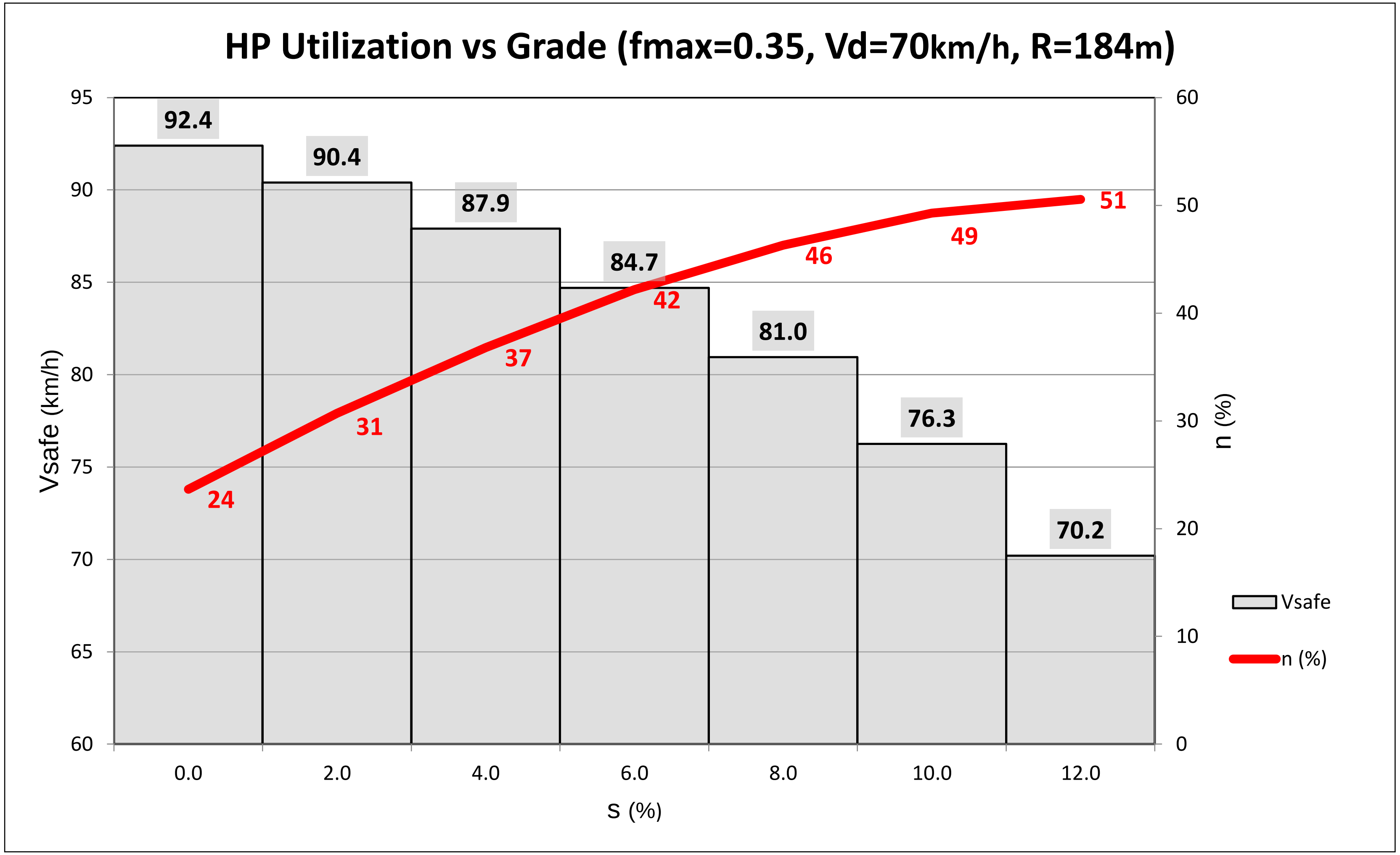


$f_{R\ demand}$:
critical on mild grades

$f_{T\ demand}$:
critical on steep grades

HP Utilization Rates during V_{safe} Determination

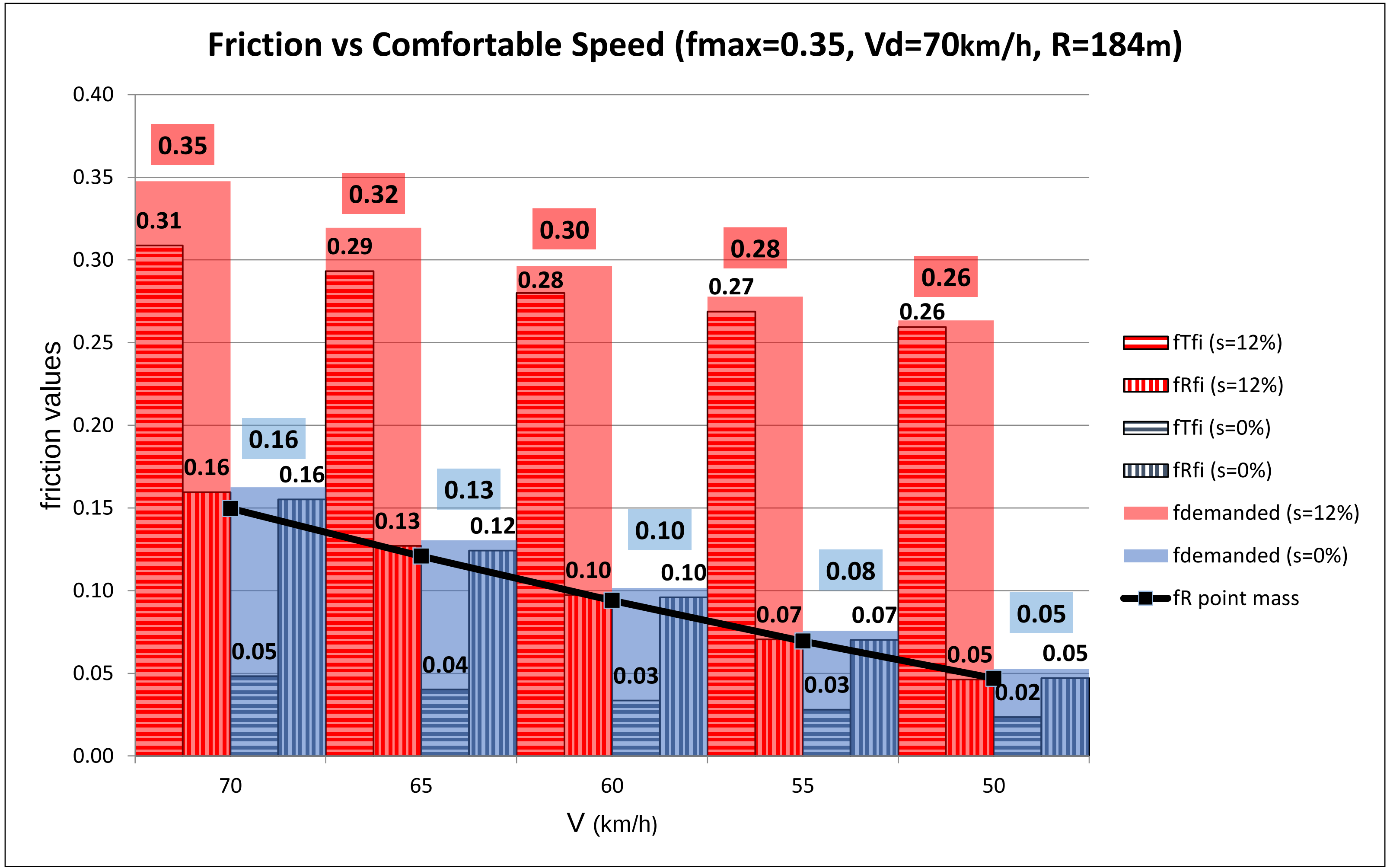
- **Impending skid**



vehicle skids when driven above suggested HP utilization values

Friction Safety Margins for V < V_{safe}

- **Comfortable driving**

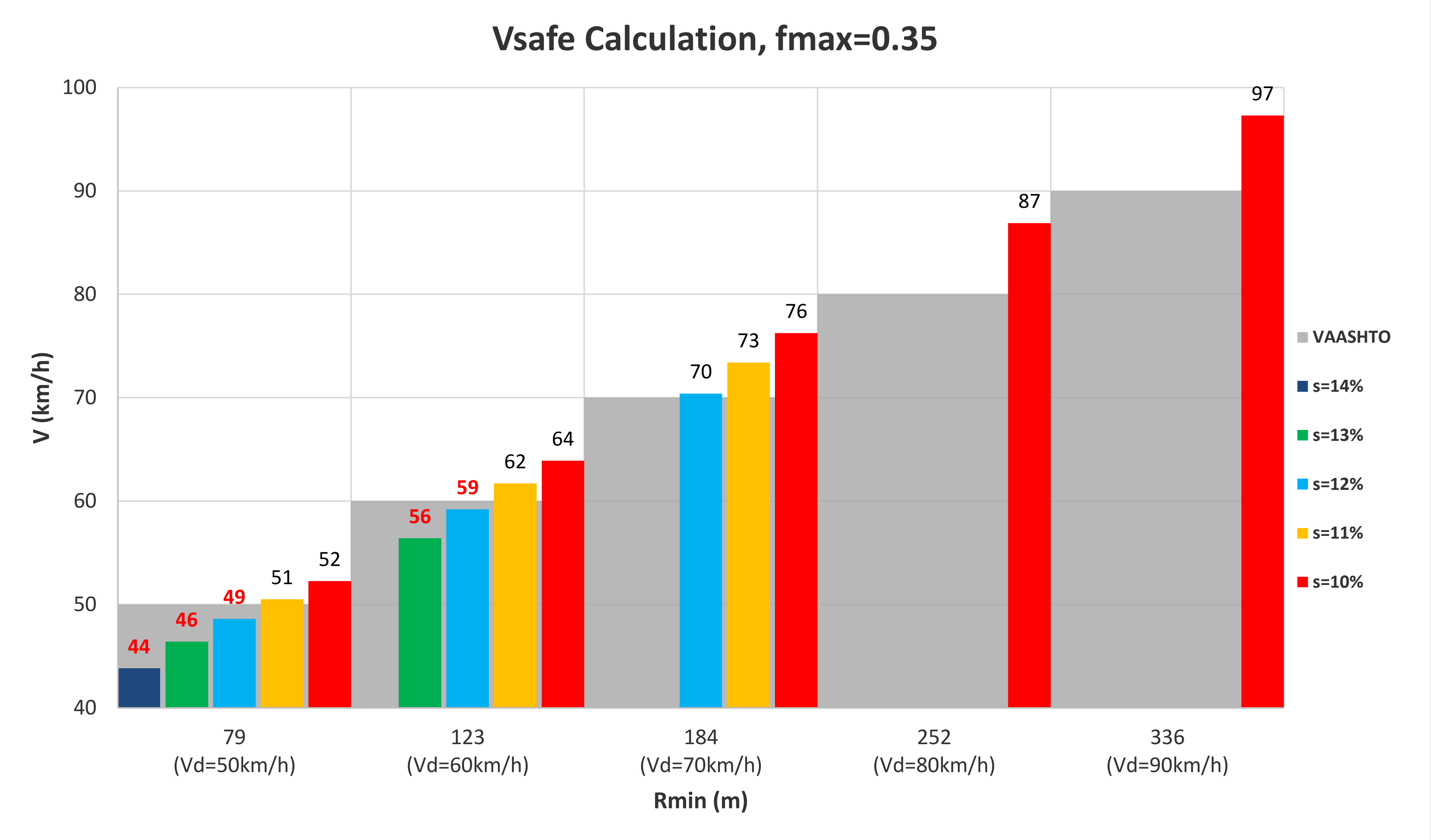


f_T : grade dependent

$f_R \approx f_R$ point mass model

V_{safe} Variation for Control Design Values (f_{max} = 0.35)

- **Impending skid**

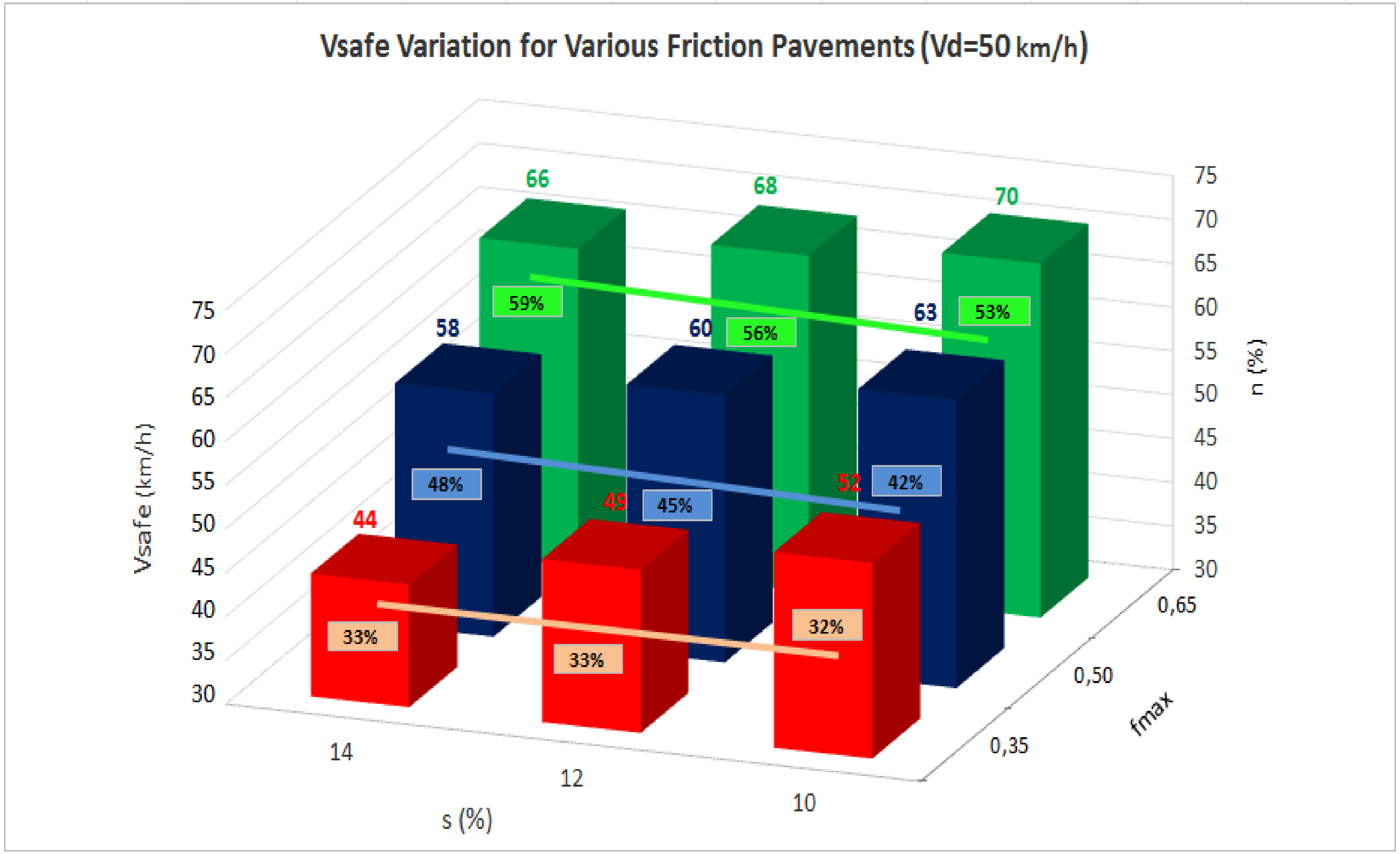


critical cases (f_{max} = 0.35):

- V_d = 50km/h, s>11%
- V_d = 60km/h, s>11%

V_{safe} Variation for Control Design Values (V_d = 50km/h)

- **Impending skid**



critical cases (V_d = 50km/h):

- $f_{max} < 0.40$
- s > 11%

Conclusions

- Investigation of the ability a C-class passenger car on steep grades to maintain Vd
  - AASHTO 2011 design guidelines (V_d =50km/h – V_d =90km/h)
  - 3 pavement friction values (0.35, 0.50, 0.65)
- 2 cases examined for assessing safety margins
  - comfortable curve negotiation ($V<V_{safe}$)
  - V_{safe} impending skid conditions

Conclusions

Comfortable curve negotiation ($V<V_{safe}$)

- $f_{R\ demand}$ independent to grade
- $f_{T\ demand}$ increases with grade

Conclusions

V_{safe} impending skid conditions

- $f_{R\ demand}$ critical on mild grades
- $f_{T\ demand}$ critical on steep grades

- Steady state cornering not always feasible
  - V_d = 50km/h, s>11%, f_{max} = 0.35
  - V_d = 60km/h, s>11%, f_{max} = 0.35

- Point mass model model somehow underrates lateral friction requirements

- Vehicles equipped with excessive HP rates must be driven very conservatively in road with poor friction pavement

Recommendations - Further Research

- Identified critical cases
  to be treated cautiously through actions
  - adoption of acceptable parameter arrangements (new alignments)
  - posted speed management (existing alignments)
  - scheduling friction improvement programmes more accurately (both cases)

- Assessment on entire vehicle fleet

- Further analysis of interaction between driver – vehicle

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