6th International Symposium on HIGHWAY GEOMETRIC DESIGN

Passenger Cars Safety Assessment on Interchange Ramps

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Objective of the Study

The research aims to:

- Collect vehicle speed and acceleration data on interchange ramps and evaluate vehicle safety.
- Assess the safety margins for vehicles travelling on ramps within curved sections. For this scope field measurements with specific equipment were performed in a trumpet interchange.
- Examine the lateral acceleration of vehicles against vehicle skidding.
- Investigation between the speed differences in daytime and nighttime conditions in respect to the horizontal radius of each curve.
- Investigation between the speed differences in weather conditions i.e. heavy rain, normal rain, wet pavement and dry pavement conditions.

Data Collection

Reverse Trumpet Interchange Type was selected in a suburban area

Traffic composition: Mixed, with increased commercial trucks

- 10% motorcycles
- 72% Passenger Cars
- 18% Heavy Trucks

Automatic Traffic Counters was placed in 4 locations

Duration of the measurements was three consecutive days taking 24-hour data between 6th and 8th of July 2018)

Data Collection

Geometrical characteristics of the study interchange at measurement spots

Measurement spot	Curve radius	Road gradient	Superelevation
ATC-1	110 m	-1.57 %	2.00 %
ATC-2a	65 m	2.48 %	2.00 %
ATC-2b	30 m	-3.80 %	3.50 %
ATC-3 (Pir)	220 m	-4.00 %	-2.00 %
ATC-3 (Kor)	220 m	4.00 %	2.00 %

ATC: MetroCount MC5600

Data Collection

Traffic volume

- The Average Daily Traffic (ADT) counted in direction to Piraeus is 4.500 vehicles while the ADT counted in the direction to Korinthos was three times higher (13.000 vehicles).
- This finding further strengthens the assumption that this reverse type interchange is potentially dangerous, since the higher volume traffic is occurring on the loop of the interchange with the radius of 30m.

Data Collection

Lateral Acceleration Measurements

- Measurements were made using a Toyota Yaris (2013), the most widespread passenger vehicle in Greece, fitted with a Garmin GPS receiver and a Vericom VC4000DAQ accelerometer mounted on the frontal windshield.
- 10 measurement runs were performed at different speeds.
- In order to assess the vehicle safety on the ramps of the interchange, two theoretical models were utilized; the point-mass model and a vehicle dynamics model.
- For the validation of both theoretical models, the results of a test vehicle were output against the results from the models.

Data Analysis - Speed data processing

Free flow conditions

Only measurements with a headway greater than 6 seconds were utilized

Day-time

Data measured from 06:00 to 21:00 were considered day-time

Night-time

Data measured from 21:00 to 06:00 were considered night-time

Data Analysis - Speed data processing

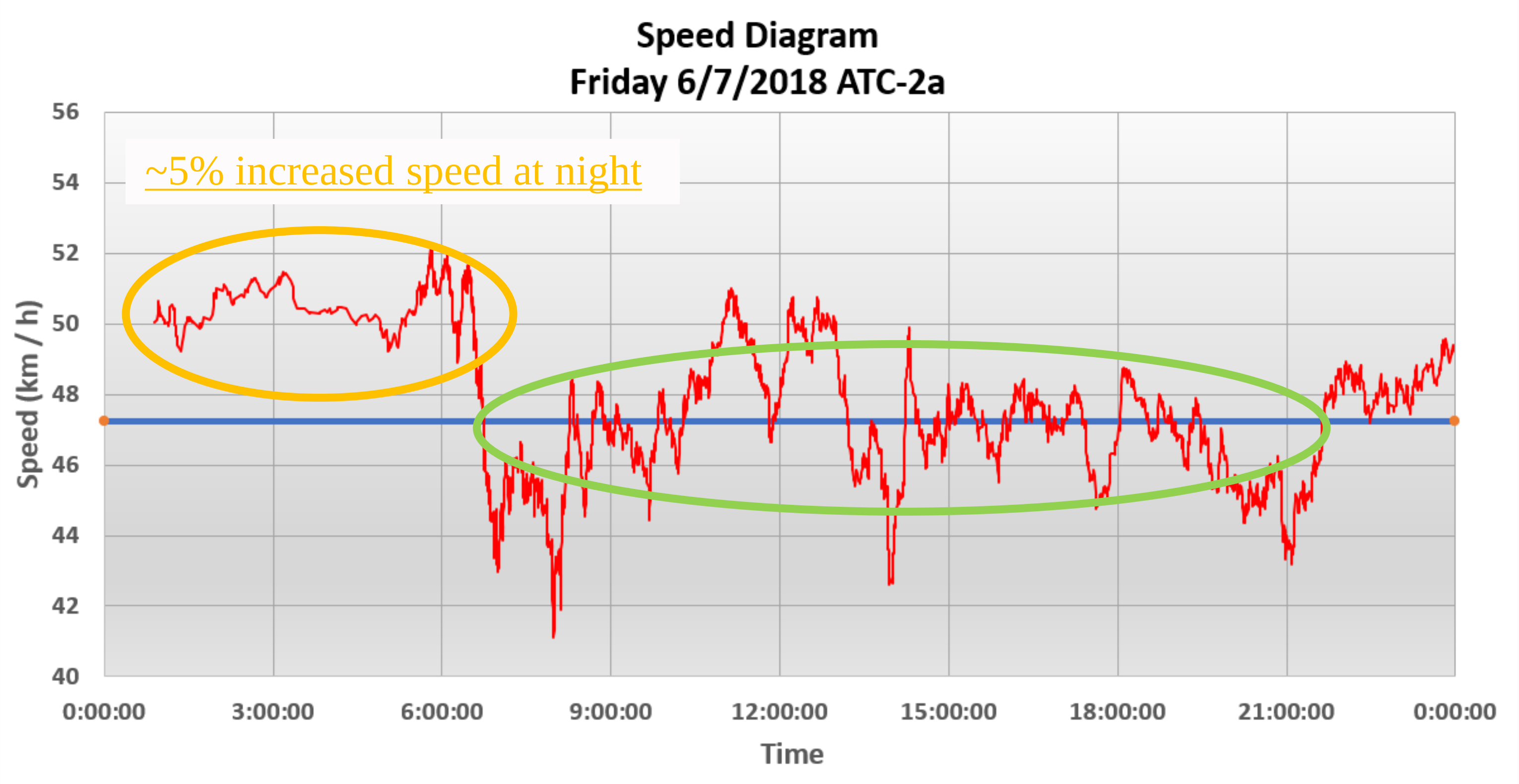
Workflow of analysis

- Raw data collected and determined the traffic volume at each ramp.
- Free-flow data were gathered to determine the following speeds: 85th, 50th, 15th percentile speeds as well as the maximum and minimum speed at each curve.
- The calculated operating speed was correlated to different weather conditions.
- Calculate the maximum attainable constant speed at impeding skid conditions for all examined curves, using the vehicle dynamics model.
- Compare the calculated operating speed and the maximum constant speed to assess the safety of vehicles using the ramps of the interchange.

Data Analysis - Speed data processing

<u>Speed change during all day (24-hour) was investigated</u>

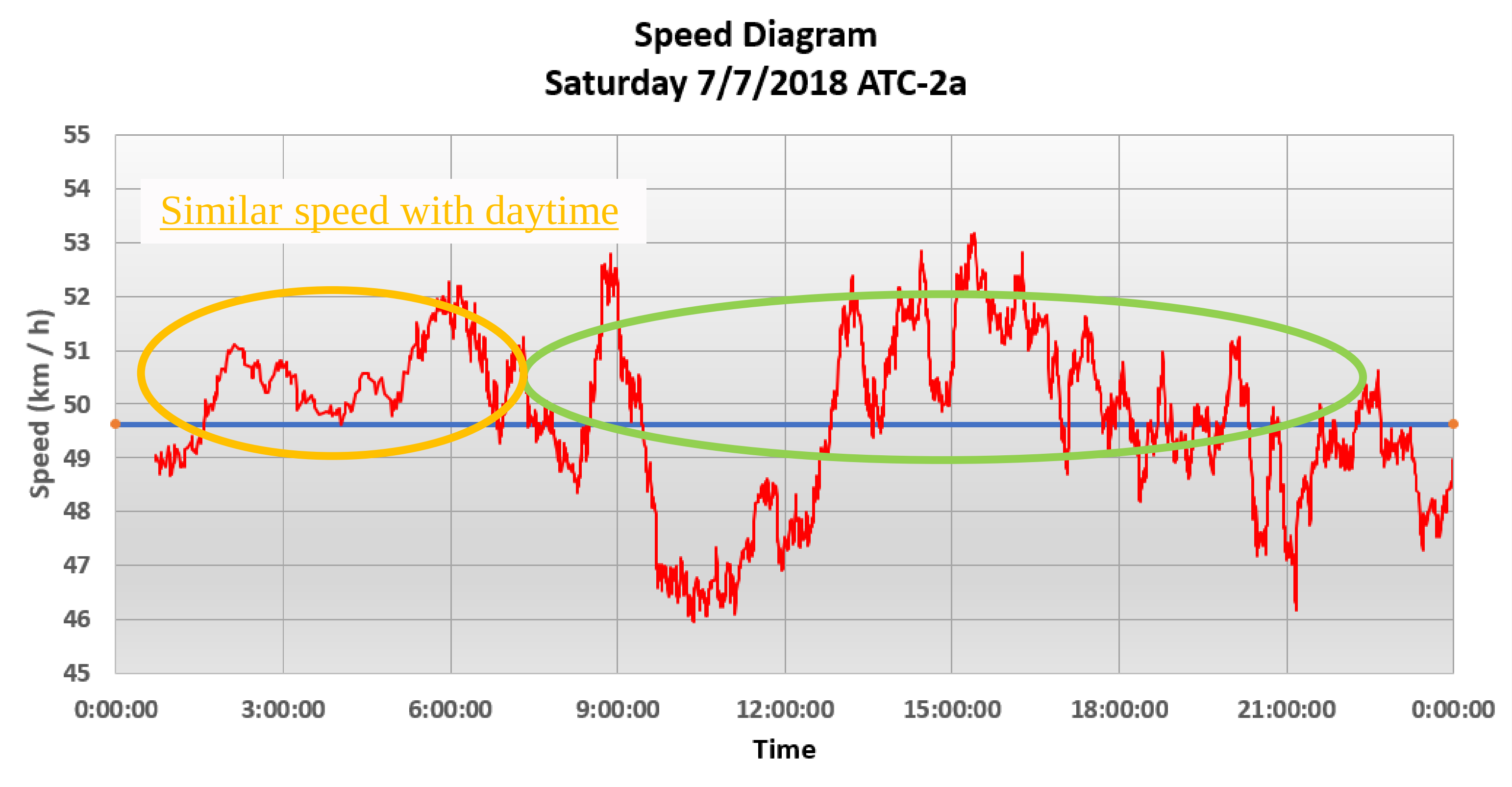
- Speed increase was observed during nighttime almost in all cases during Friday (working day).



Data Analysis - Speed data processing

Speed change during all day (24-hour) was investigated

- Speed increase was observed during nighttime almost in all cases during Friday (working day).
- On the other hand, during Saturday (half day) and Sunday (rest day) similar speed between daytime and nighttime was observed in many cases while in some cases a slight decrease on speed was found in nighttime in respect to daytime.

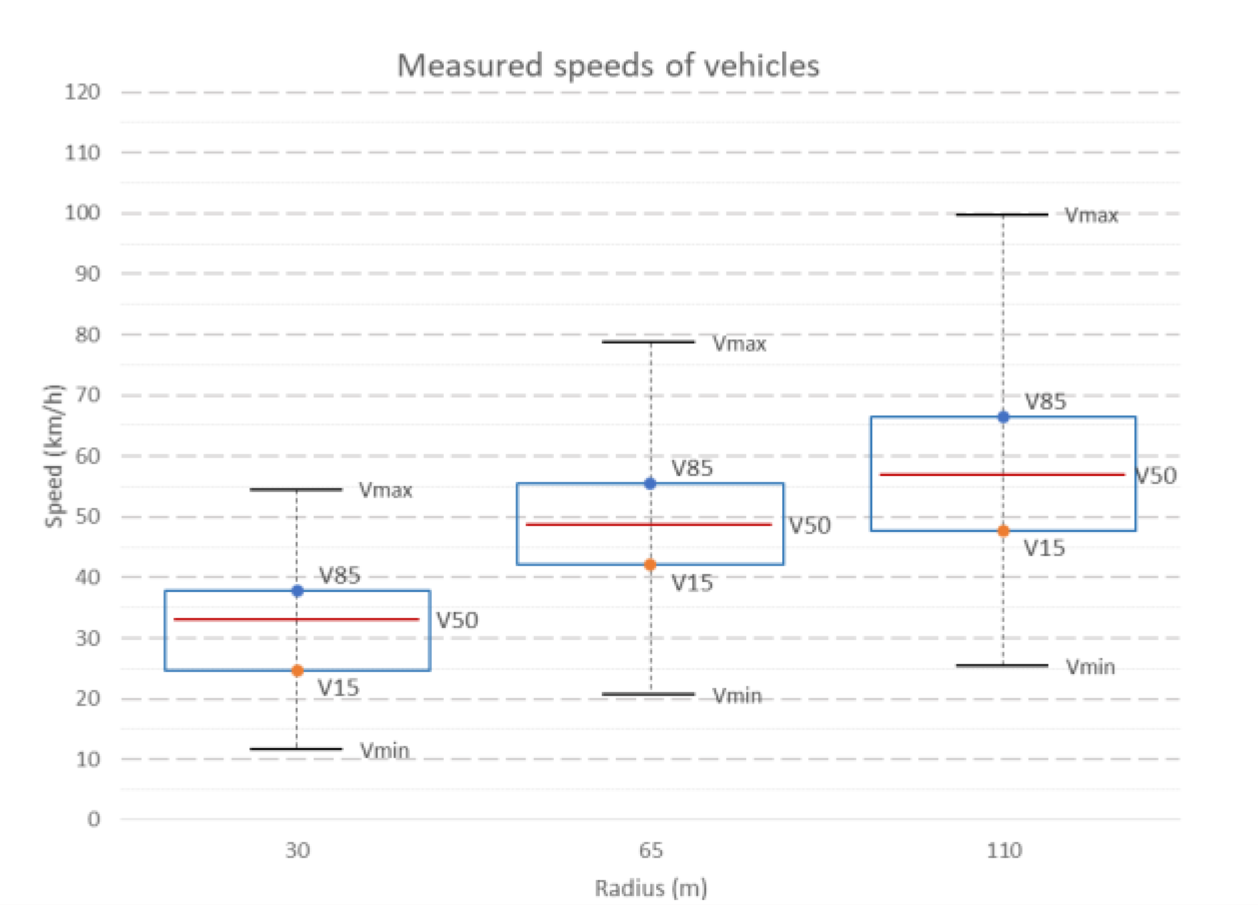


Data Analysis - Speed data processing

Operating speed

- The measurements from ATC-3 position (radius 220m) was ignored due to traffic signalized intersection nearby.
- The operating speed measured for the rest curves summarized:

Operating speed (km/h)				
Measurement spot	**6/7/2018**	**7/7/2018**	**8/7/2018**	**Average**
ATC-1 (R=110 m)	64.43	68.84	65.94	66.40
ATC-2a (R=65 m)	54.78	56.51	54.93	55.41
ATC-2b (R=30 m)	37.24	38.53	37.97	37.91

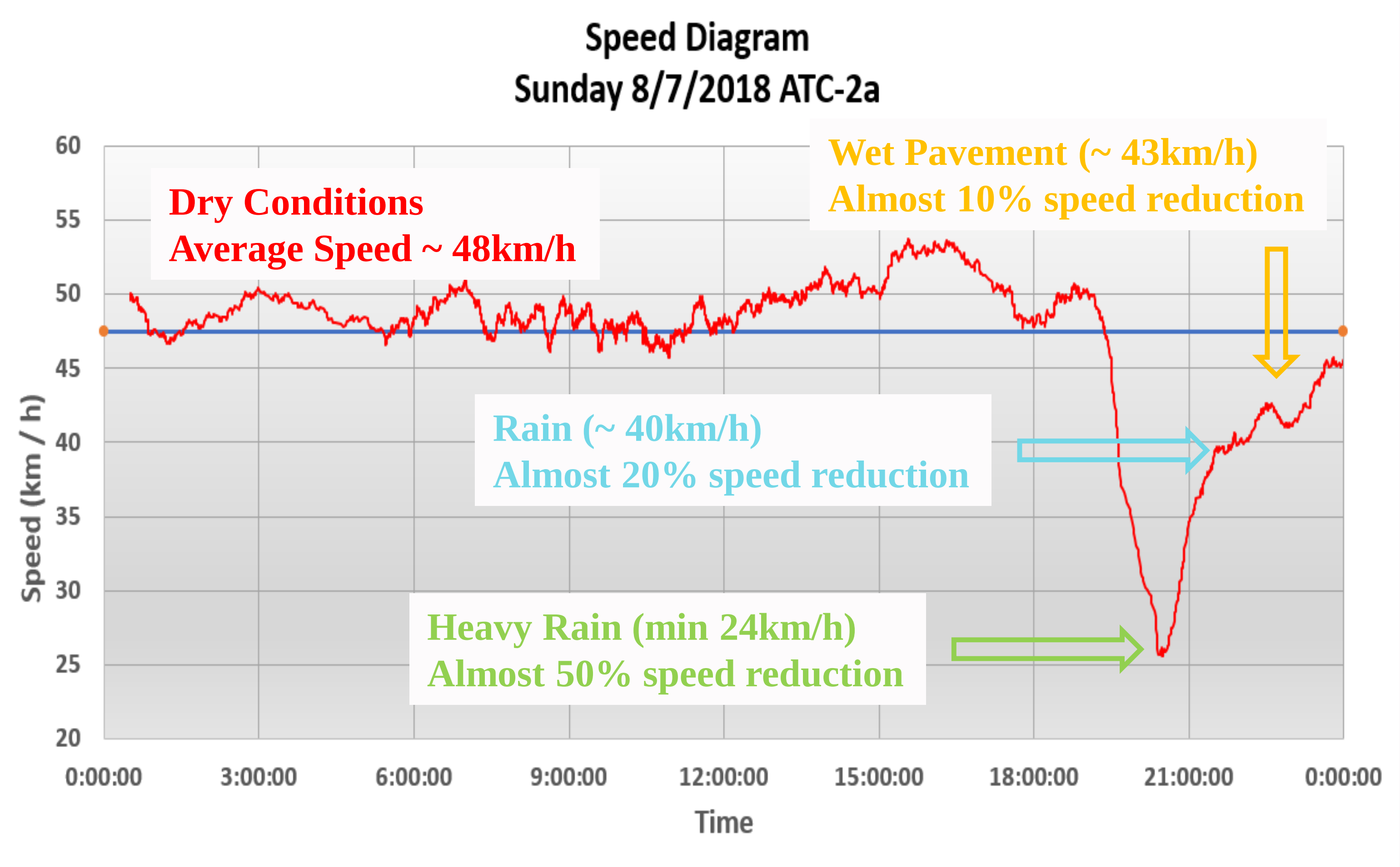


Data Analysis - Speed data processing

Speed variation in respect to weather conditions was investigated

- Meteorological data were collected and there was a sudden rainfall on Sunday.

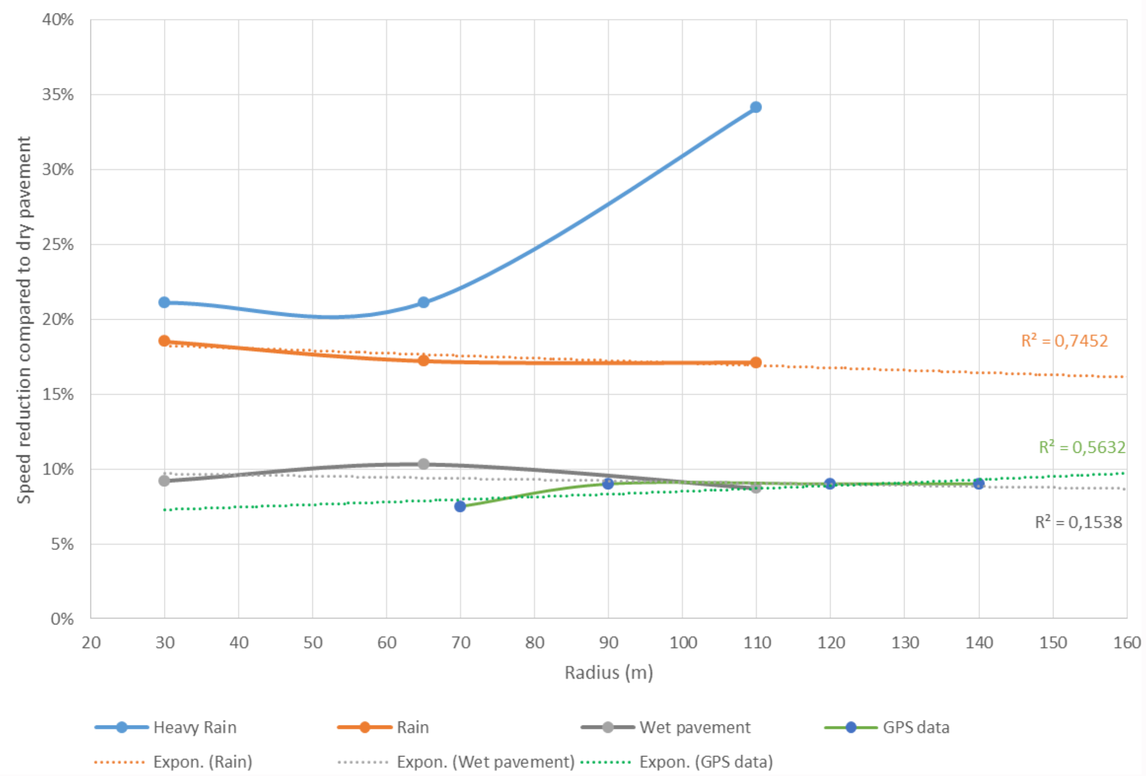
- The weather conditions was classified in 4 categories
    - Dry Pavement (before 19:20)
    - Wet Pavement (after 22:20)
    - Normal Rain (20:20 – 22:20)
    - Heavy Rain (19:20 – 20:20)



Data Analysis - Speed data processing

Speed variation in respect to weather conditions

- The Operating speed depending on the weather conditions is following:
  - A sudden speed decrease in heavy rain period between 22% ~ 34% (max 50% instantly).
  - A slight lower reduction in normal rain conditions between 16% ~ 18%
  - A reduction around 10% in wet pavement conditions.

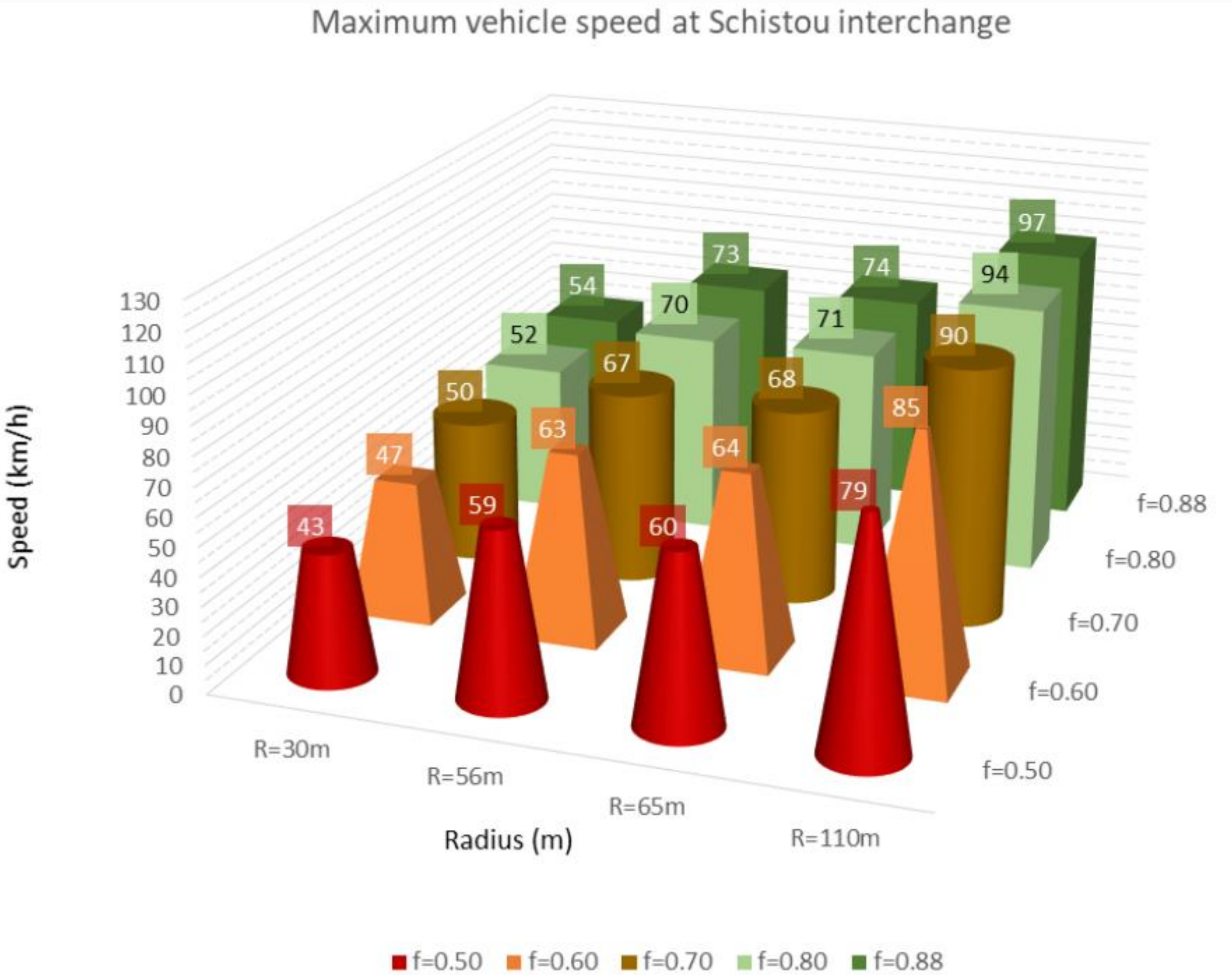


Radius(m)	Speed dry (km/h)	Speed rain (km/h)	Speed wet (km/h)
110	64.6	42.6 (-34.1%)	58.9 (-8.7%)
65	54.2	42.8 (-21.1%)	48.8 (-10.3%)
30	38.9	30.7 (-21.1%)	35.4 (-9.2%)

Data Analysis - Speed data processing

<u>Maximum passing speed through the Vehicle Dynamics Model was investigated</u>

- Based on the test runs on the interchange ramps, the available friction factor of the road surface was measured in dry conditions equal to f=0.88.
- It was found that the lateral acceleration felt by drivers exceeds the comfort limit as defined by AASHTO regulations for all horizontal radius of the interchange.
- For each examined curve, different friction factors were examined ranging from f=0.50 to 0.88 to calculate the maximum passing speed.



Data Analysis - Speed data processing

Maximum passing speed was found through the Vehicle Dynamics Model

- The calculated maximum attainable constant speed was compared to the measured operating speed for each curve.

- In all cases, vehicles maintain a sufficient margin from impending skid speed on dry surface (reduction between 16.2% to 30.6%).

- On wet pavement conditions, speed margins dropped (reduction between 8.4% to 20.5%). Combined with the fact that wet surface increases the chance of vehicle skidding, the possibility of an accident occurring is greater.

Speed difference (km/h) in **dry** surface

Radius (m)	**V_{85}-$V_{max,theory}$**
30	-16.2
65	-18.3
110	-30.6

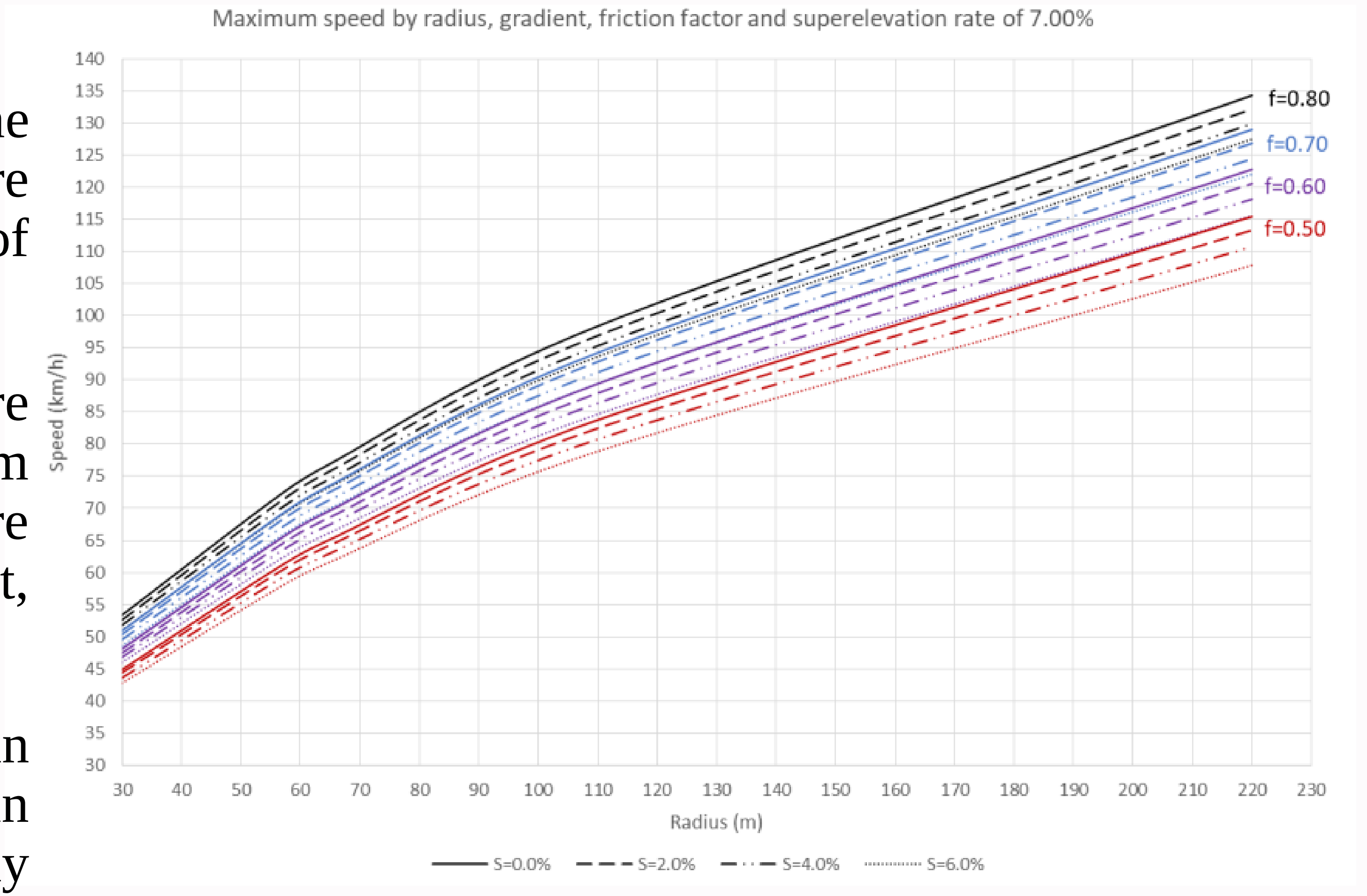
Speed difference (km/h) in **wet** surface

Radius (m)	**V_{85}-$V_{max,theory}$**
30	-8.4
65	-10.2
110	-20.5

Data Analysis - Speed data processing

Maximum constant speed graphs

- The present analysis represents only one example of interchange. More examination is needed in other types of interchanges.
- To assist future studies, graphs were plotted that calculate the maximum attainable speed in respect to curvature (horizontal radius), road gradient, superelevation and friction factor.
- Using these graphs, the researcher can easily assess the safety margins in respect to the measured speeds at any studied interchange,



Conclusions

1. The operation speed is reduced around 10% on wet road surface compared to dry road surface.
2. Measured speed in all horizontal curves of the interchange leads to lateral accelerations outside the comfort limits as defined by US AASHTO design guidelines.
3. Vehicles do not travel at impending skid conditions and maintain a sufficient safety margin in respect to the speed calculated from the lateral friction coefficient requirement.
4. Vehicles maintain a significantly lower safety margin in respect to the speed calculated from the lateral friction requirement on wet pavement surface compared to dry pavement surface.

Subject for further research

- More data collection for similar interchange branches in a wider range of horizontal curves and traffic volumes could be investigated.
- More data collection for other interchange types rather trumpet, such as diamond, cloverleaf etc.
- Additional speed measurements in different weather conditions including:
  - Heavy rain conditions
  - Normal rain conditions
  - Wet and dry pavement conditions
- Additional analysis for heavy vehicles and motorcycles and correlation with the results of passenger cars, taking also into account the traffic composition could be investigated.

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Thank You
for your attention!