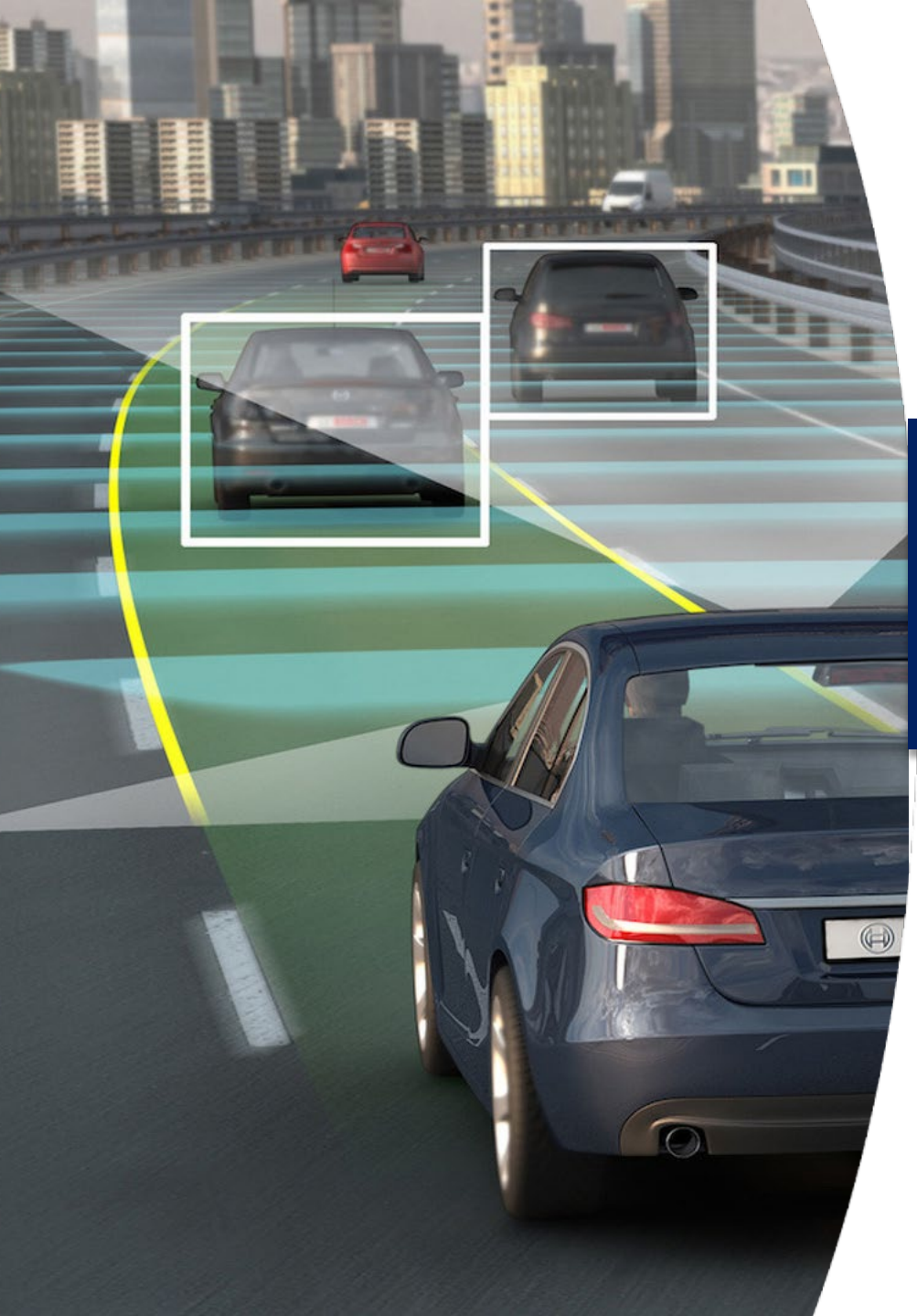

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Defining Vehicle Passing Trajectories utilizing GNSS Data

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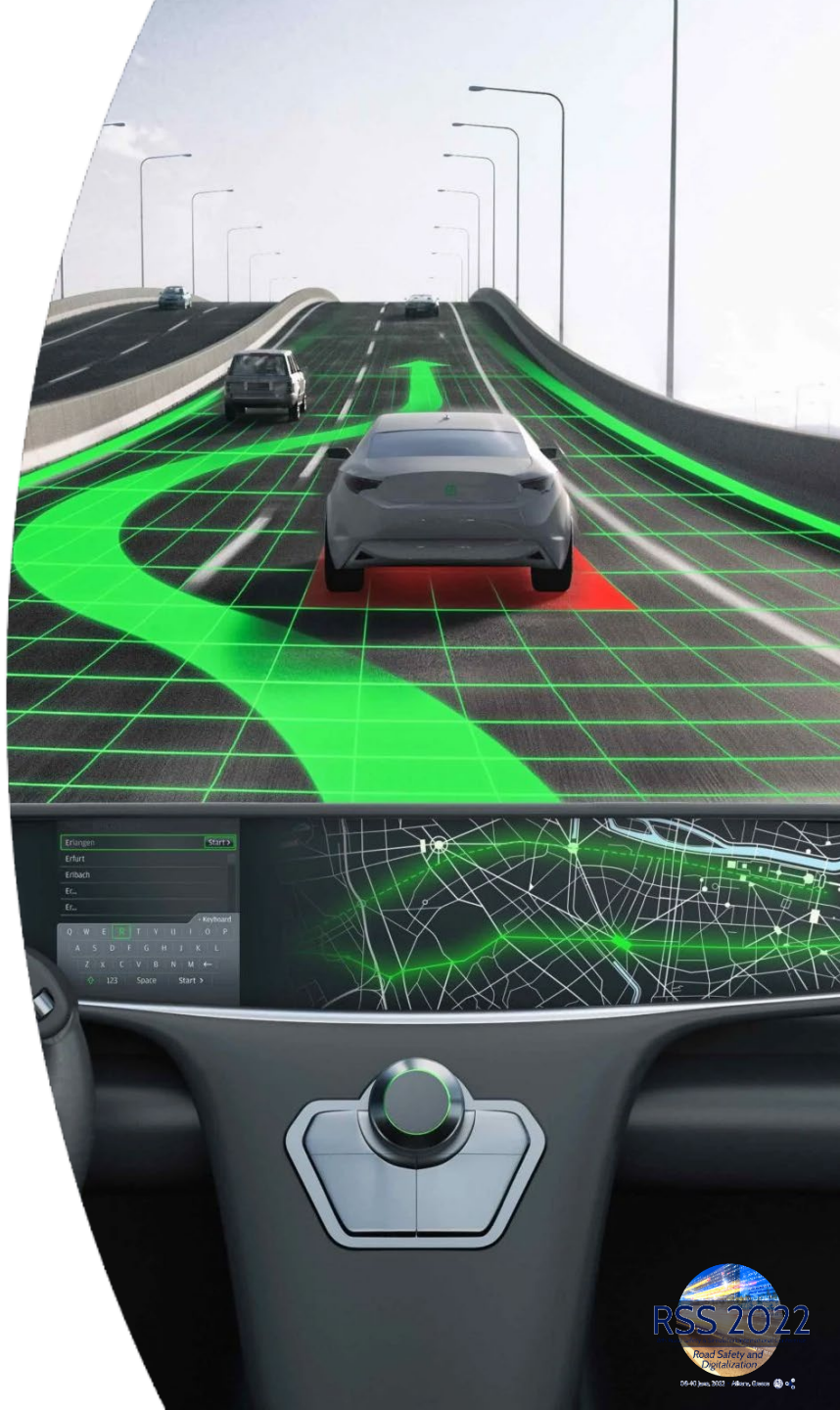
Introduction

- Overtaking
  - not yet adequately modeled
  - remains a cutting edge research topic
- Overtaking process is comprised of two successive lane changing maneuvers
- In total three distinct, successive and independent maneuvers:
  - left lane change
  - tangent motion
  - right lane change
- The overtaking and lane change maneuvers are not clearly distinguished in the existing literature

Problem Statement

- Various geometric curves have been proposed in the past:
  - polynomial expressions
  - circular arcs
  - sigmoids
  - spiral arcs (clothoids)

- The forthcoming Advanced Driver Assistance Systems (ADAS) in the near future are expected to:
  - address more accurately the passing process
  - standardize vehicle passing path

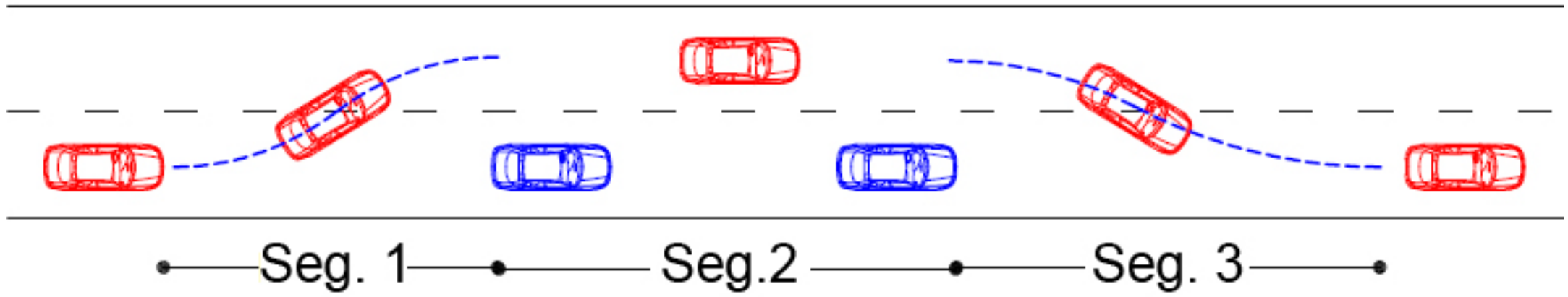


Methodology

- The present research aims to develop a new mathematical model for the overtaking maneuver that incorporates a series of successive parametric spiral arcs
  - spiral curves are mathematical curves with a linearly changing curvature profile widely utilized in current road design practice
- A field-driving experiment was conducted to record passing maneuvers by means of GNSS receivers
- Overtaking trajectory database was created
  - quantification of the spiral curves geometry
  - design of predictive models

Overtaking Maneuvers

- Passing maneuvers comprise of 3 segments
  - segment 1 (1st reverse curve set)
    vehicle motion from the original driving lane to the opposing lane
  - segment 2: vehicle travels along the opposing lane (tangent)
  - segment 3: return to the original lane (2nd reverse curve set)
    vehicle motion from the original driving lane



Criteria (1/2)

- The analysis assumes:
  - free flow conditions
  - overtaking maneuvers performed on tangent sections
  - opposing vehicle was ignored
  - passing and passed vehicle were supposed to never exceed the posted speed of the roadway
    - $V_{posted1}$ = 90km/h
    - $V_{posted2}$ = 110km/h

Criteria (2/2)

- The two involved vehicles had different motion characteristics
  - the motion of the passed vehicle was under steady state conditions with a speed value 20km/h below the posted speed of the roadway
  - the passing vehicle's motion during the overtaking process was under acceleration mode, but respecting the posted speed
  - the passing vehicle's speed value at the starting phase was set equal to the relevant speed of the passed vehicle

Data Collection Process (1/2)

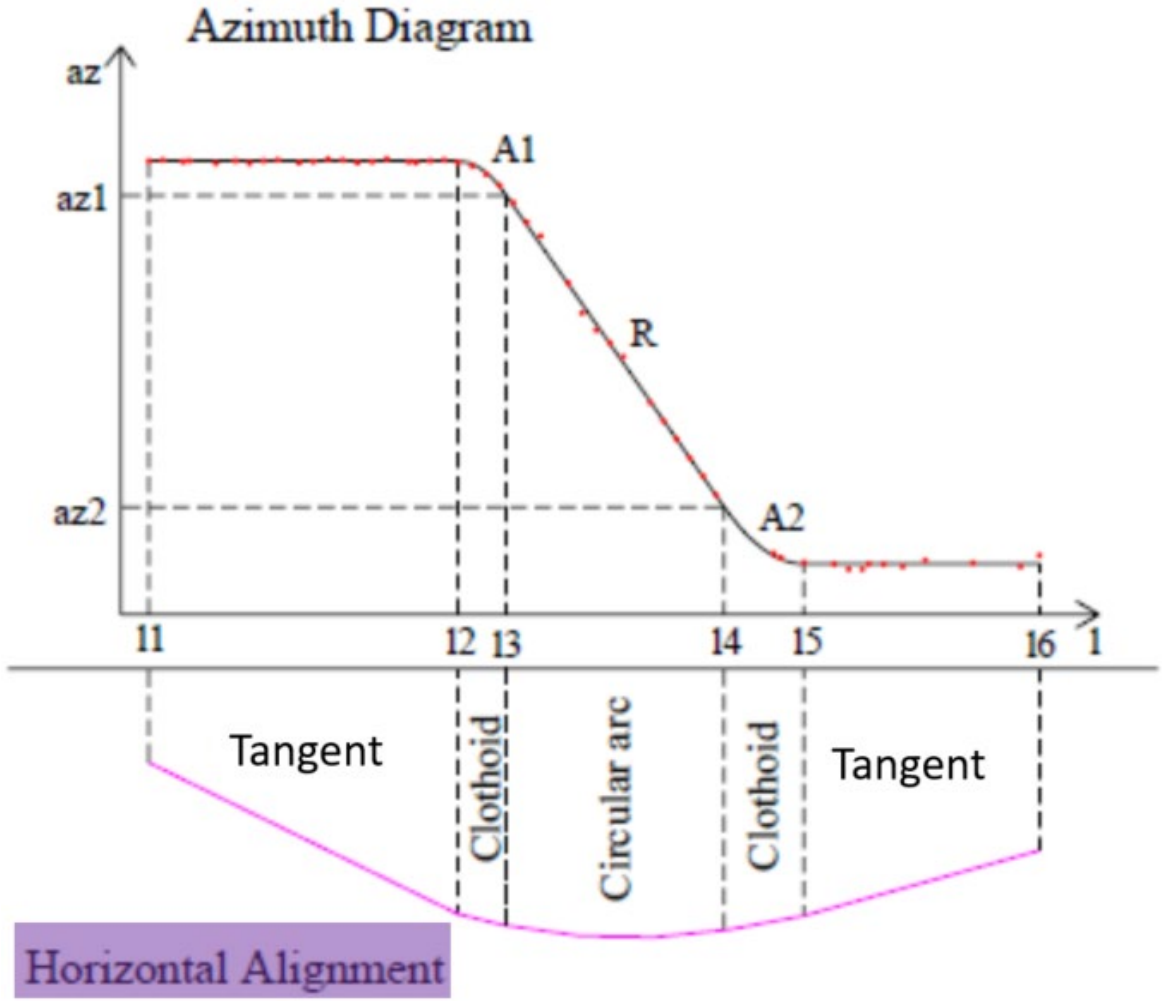
- Urban divided freeway for safety reasons
- 16km long driveway with three lanes (3x3.50m wide) per direction of travel, with both tangents and curves
- The participants were asked to drive 3 times including one lap for warming up and getting acquainted with the driving environment
- For every run (22min duration) the participants were able to perform between 7 and 9 passing maneuvers

Data Collection Process (2/2)

- The trajectories of both the passing and the impeding vehicles were recorded with high accuracy, using a GPS receiver mounted at the roof of each vehicle
- Utilization of low-cost, u-blox type, GNSS receivers:
  - all-weather devices
  - designed especially for field measurements
- In total 170 valid accelerated passing maneuvers were recorded:
  - 32 participants aged between 21 to 58 years old
  - 19 male participants (mean age 27years, experience 8years)
  - 13 female participants (mean age 24years, experience 4years)
  - no known health or vision problems
  - valid driving license
  - frequent drivers

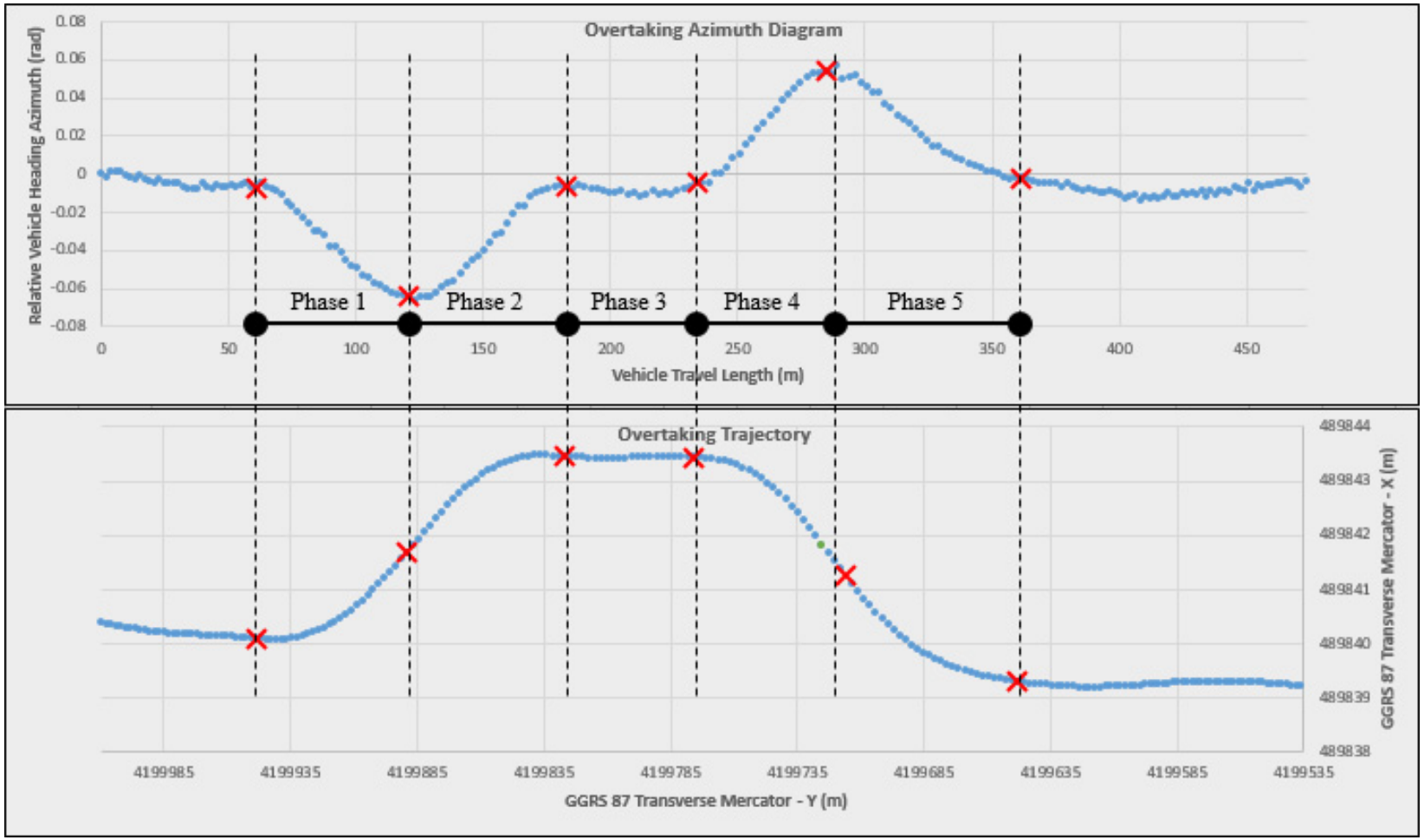
Overtaking Trajectory Determination

- Azimuth Diagram defines the angular change rate of the vehicle path along with driven distance
  - tangents: horizontal line
  - circle arc: inclined line
  - clothoid: parabola



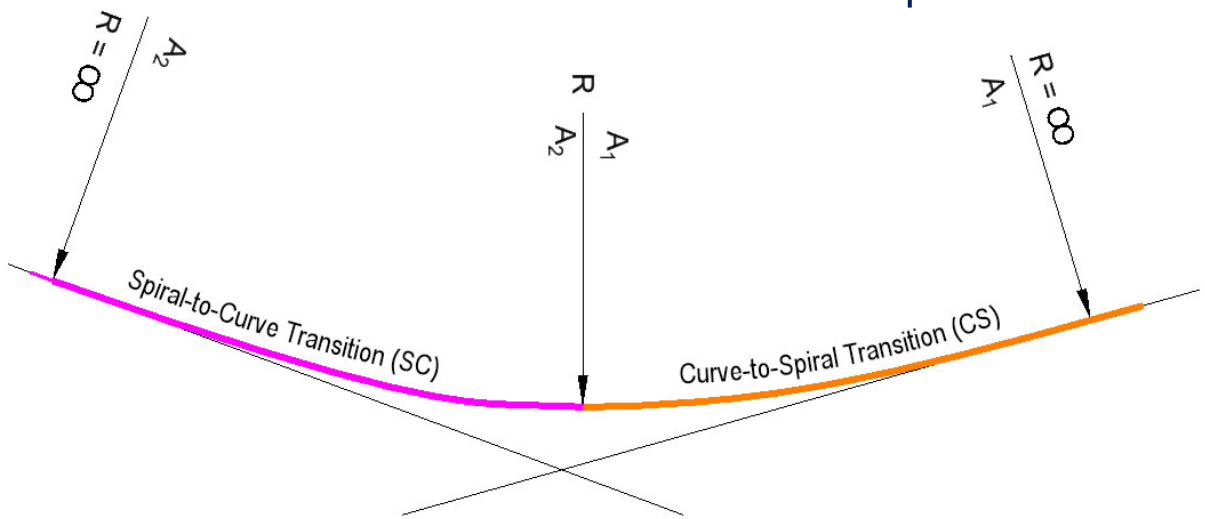
Azimuth Diagram

- Overtaking trajectory vs overtaking azimuth diagram



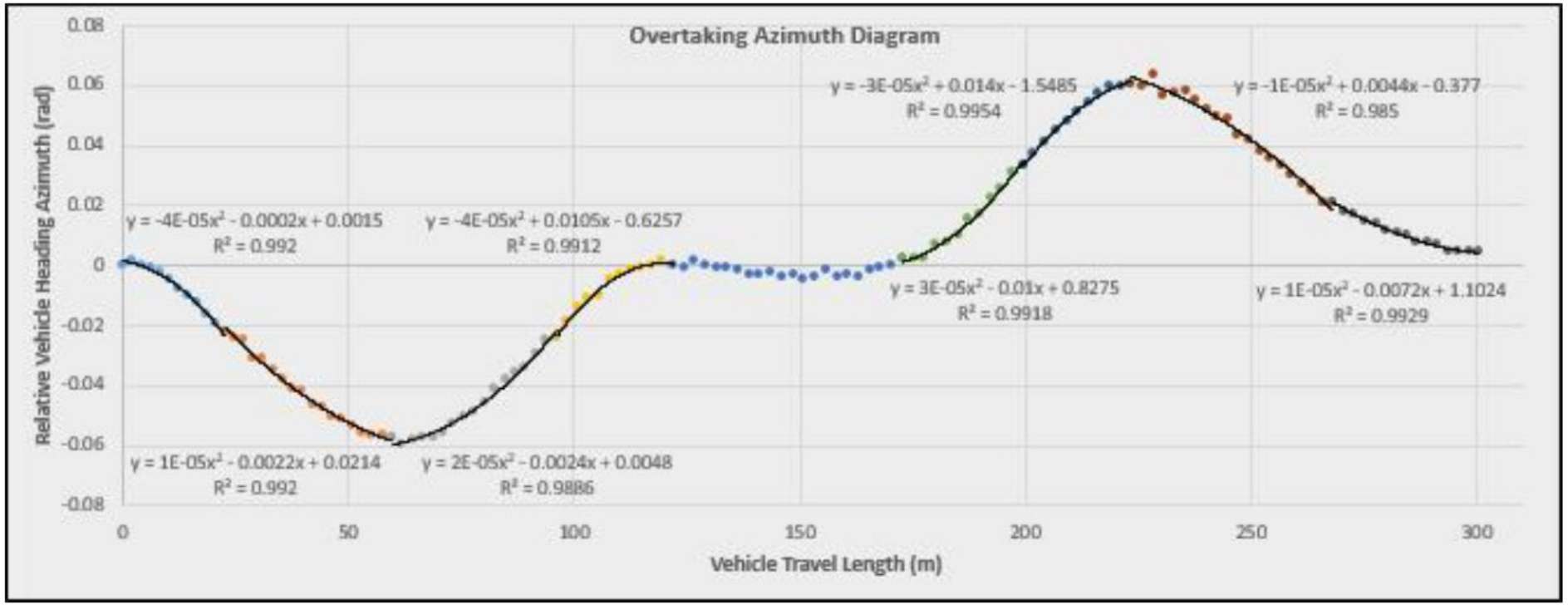
Assigning Spiral Curves

- Spiral curves are mathematical curves with a linearly changing curvature profile widely utilized in current road design practice
- For every phase, it was decided to adopt a sequence of curve consisting of entry spiral – circular arc – exit spiral
- Circular arc length elimination → successive spiral lengths
- Such an assumption is not far from the reality, since during an overtaking process the driver constantly alters the steering angle of the vehicle
- A lane shift maneuver was considered to consist of four consecutive spiral curves



Overtaking Geometry Determination

- Regression analysis to define overtaking geometry
- Determination of
  - entry spiral
  - point radius
  - exit spiral



Dynamic Approach

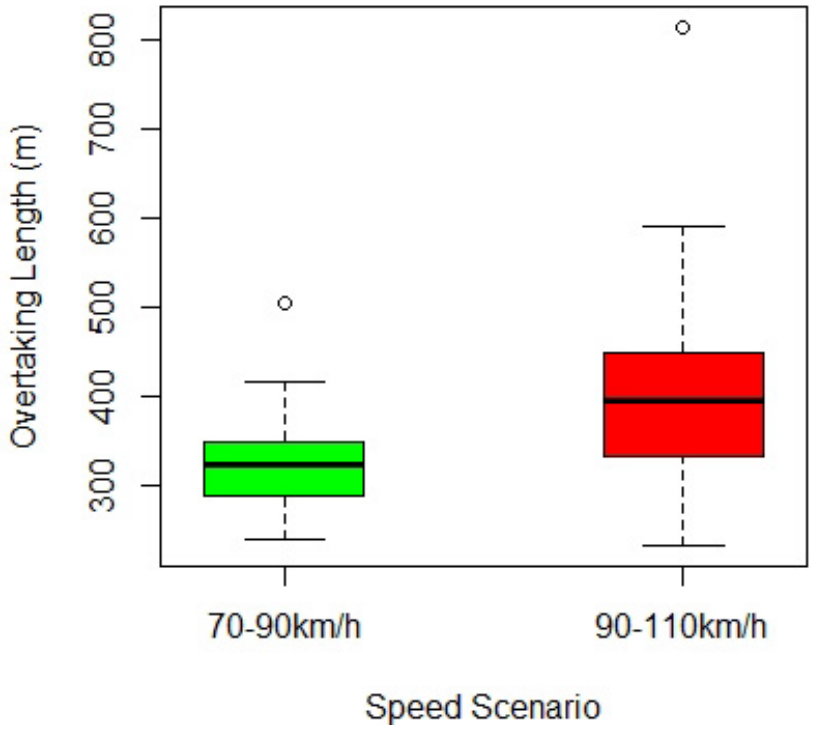
- The present research is focused on defining:
  - the geometry of the passing vehicle
  - the distance between the passing and impeding vehicle, at the start of the maneuver (headway)

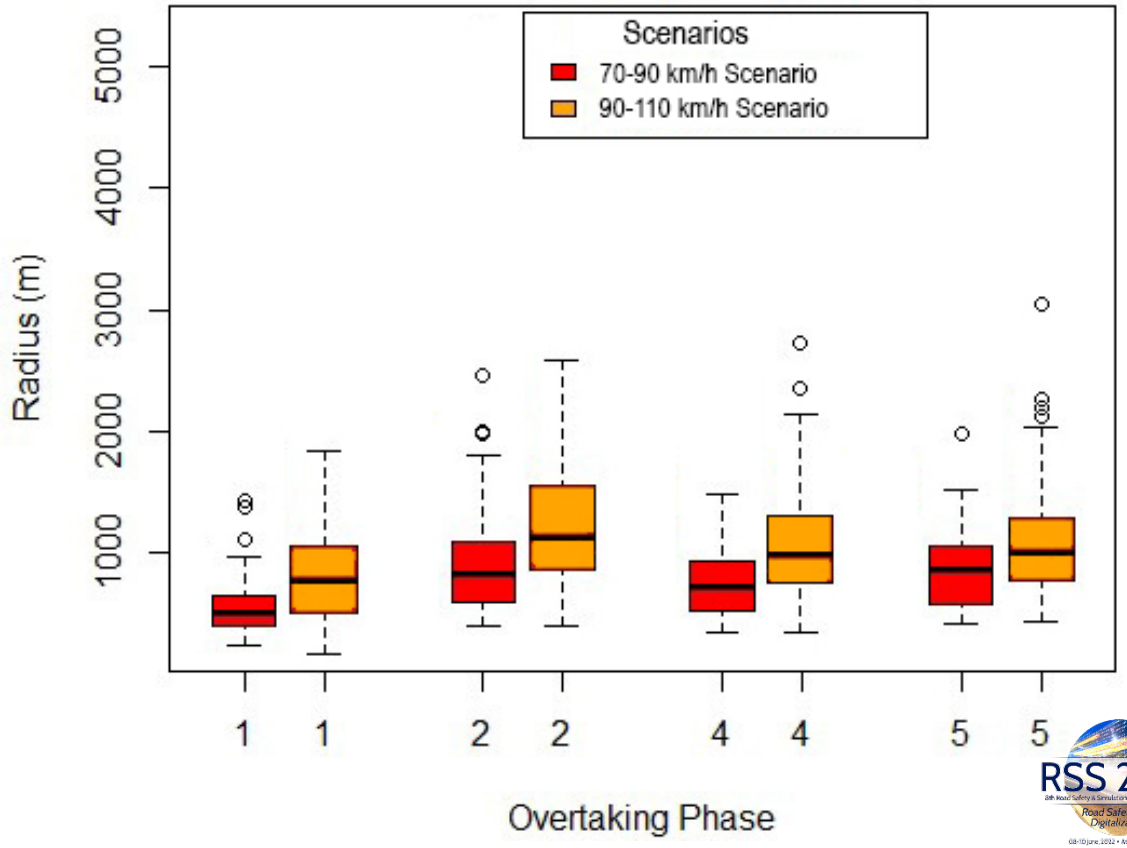
- For each of the five overtaking phases the mean acceleration of the passing vehicle was calculated

- The headway was calculated at the starting point of the overtaking (start of Phase 1)

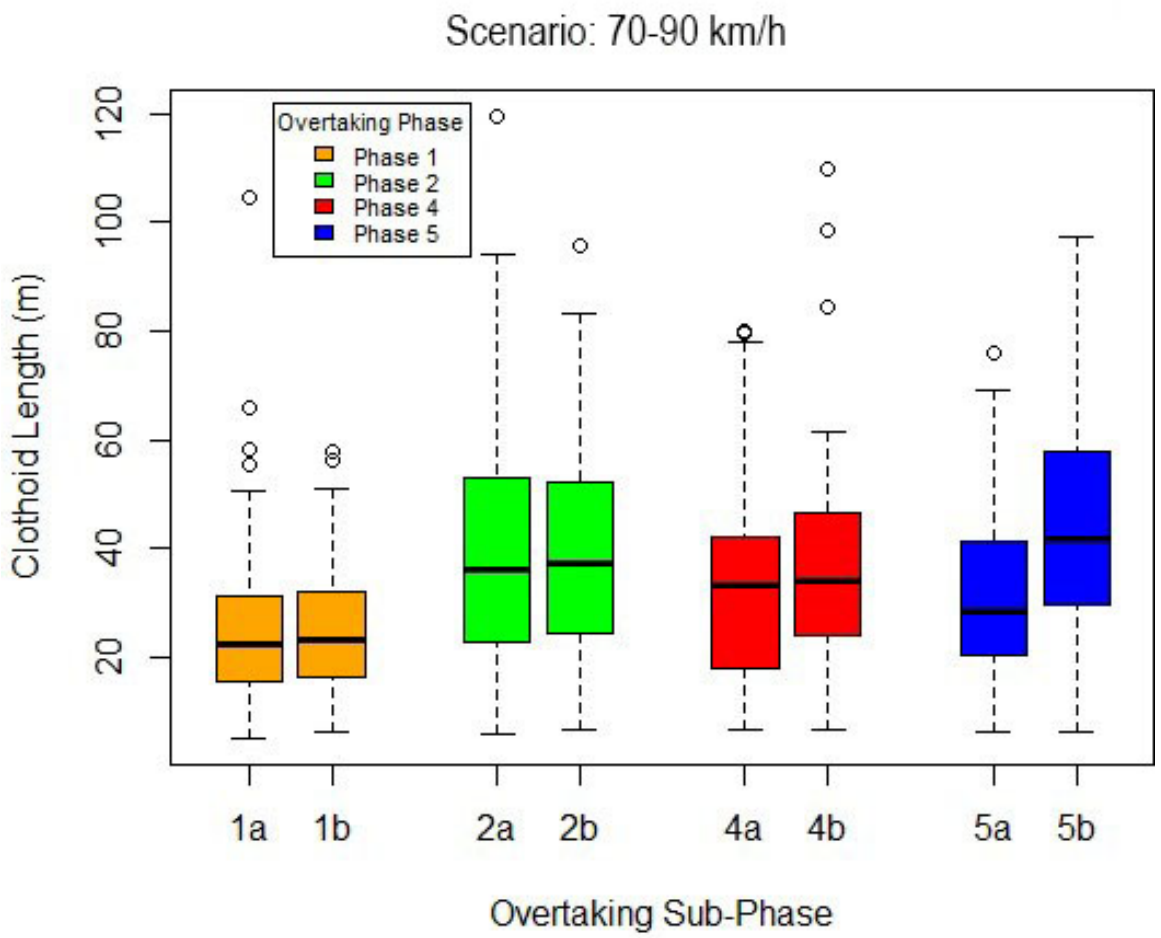
Outputs (1/2)

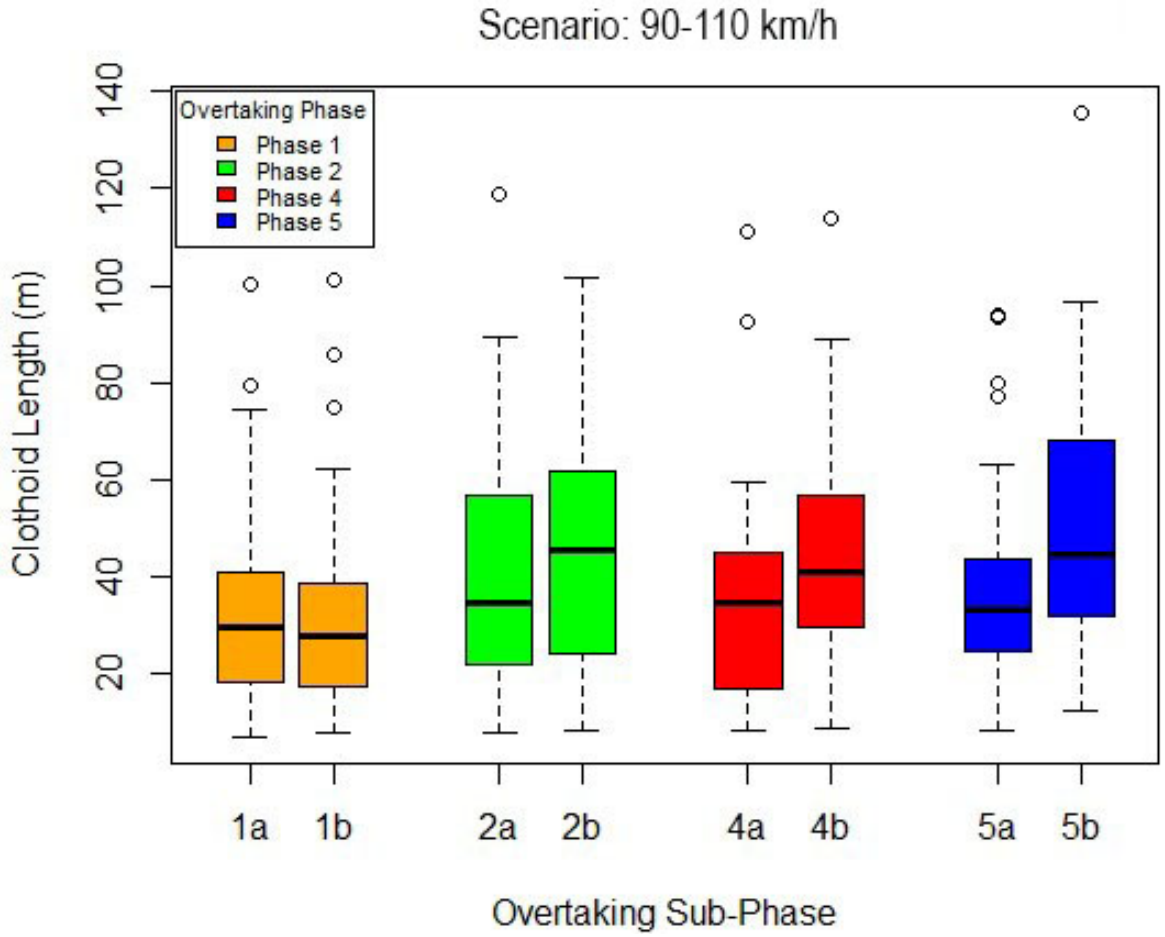
- Aiming to standardize the passing maneuver, for both posted speed values, special emphasis was given to the median values of the boxplot output data, which included:
  - the length and point radii of each overtaking phase
  - the total length of the overtaking procedure





Outputs (2/2)


Scenario: 70-90 km/h
Overtaking Phase
Phase 1
Phase 2
Phase 4
Phase 5
Clothoid Length (m)
20
40
60
80
100
120
1a
1b
2a
2b
4a
4b
5a
5b
Overtaking Sub-Phase


Scenario: 90-110 km/h
Overtaking Phase
Phase 1
Phase 2
Phase 4
Phase 5
Clothoid Length (m)
20
40
60
80
100
120
140
1a
1b
2a
2b
4a
4b
5a
5b
Overtaking Sub-Phase

Conclusions (1/2)

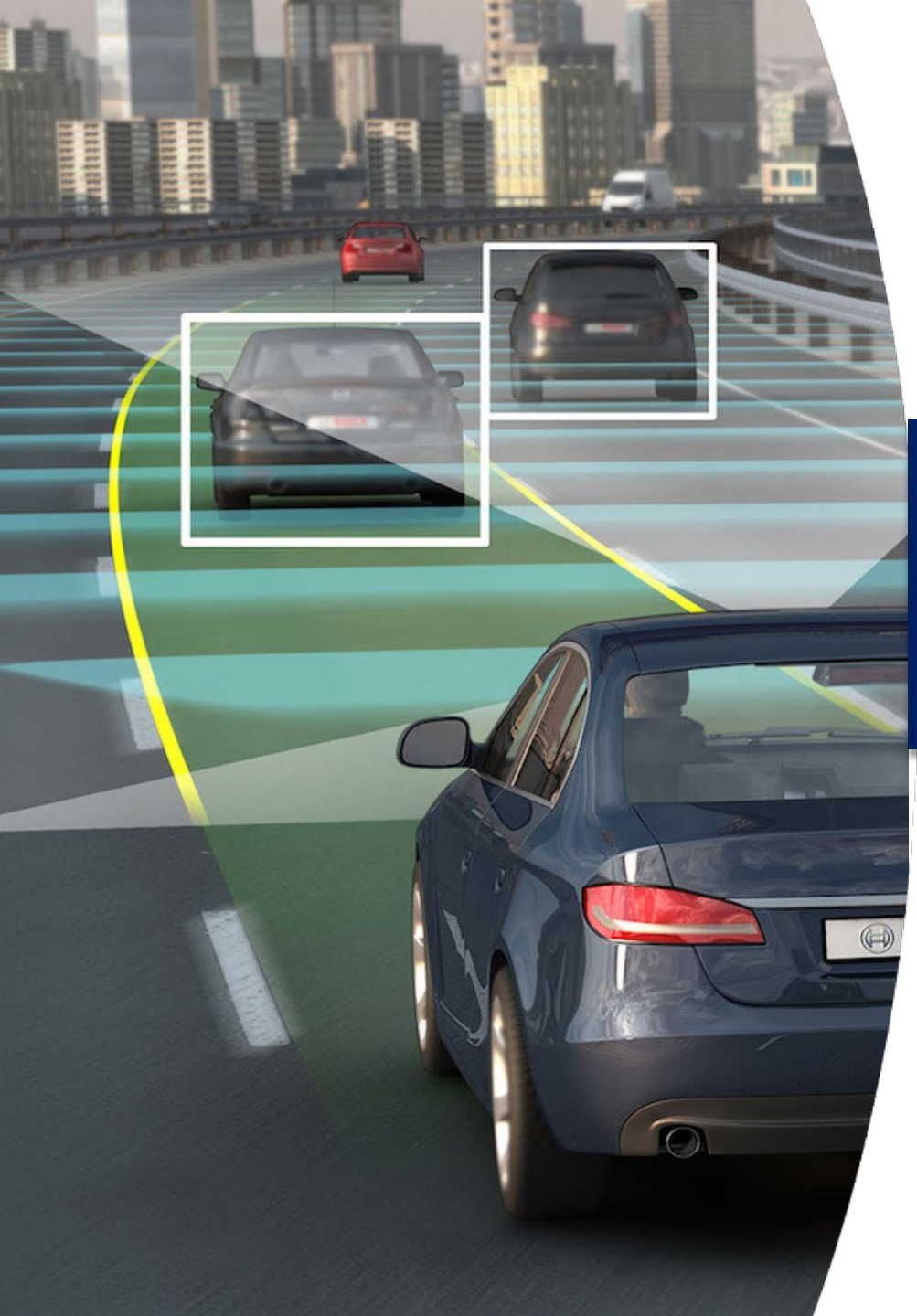
- The speed increases along with the total length required to complete the overtaking maneuver
- The total time required to complete the overtaking remains more or less constant, regardless of the speed of the two vehicles participating in the maneuver procedure
- The acceleration of the passing vehicle, during the first two phases, was approximately the same in both examined speed scenarios

Conclusions (2/2)

- The passing vehicle accelerated during Phase 1 and Phase 2 overtaking
- During Phase 3 zero acceleration was reported, the vehicle had reached the maximum speed limit (posted speed/+20km/h compared to impeding vehicle)
- The utilization of spiral curves
  - delivers very high coefficients of determination values (R^2>95%) for all examined cases
  - ensures the continuity of the curvature diagram during the overtaking procedure
  - is strongly recommended to standardize the trajectory of an overtaking maneuver

Further Research

- Integration of the lateral distance between the passing and the impeding vehicle (lateral safety margin)
- Separation of the dataset
  - aggressive driving behavior
  - normal driving behavior
- Overtaking process can be standardised and therefore deployed in existing ADAS
  - normalise overtaking length
  - determine vehicle's steering angle
  - assess emergency situations



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