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Overtaking Trajectory Assessment Utilizing Data from Driving Simulator

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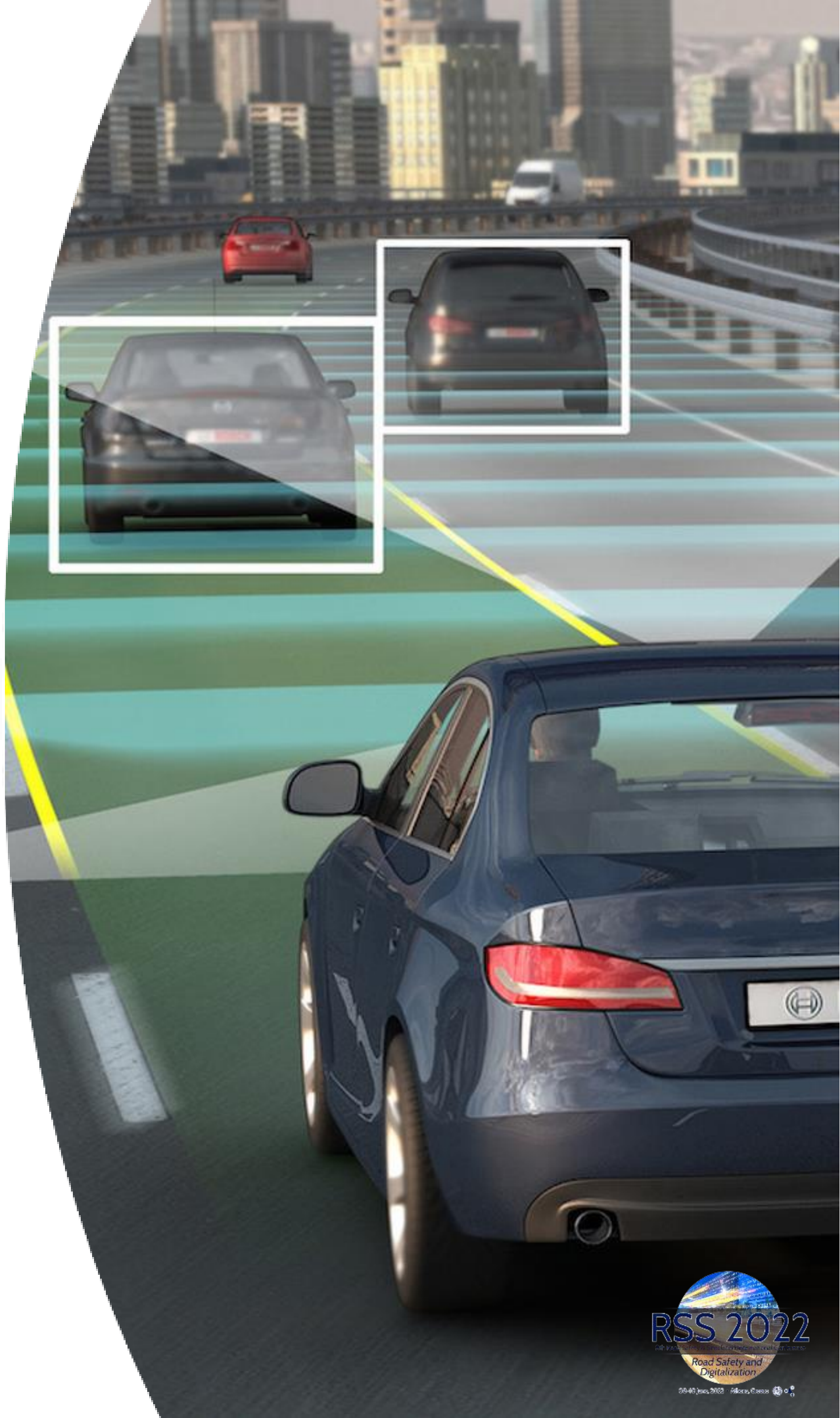
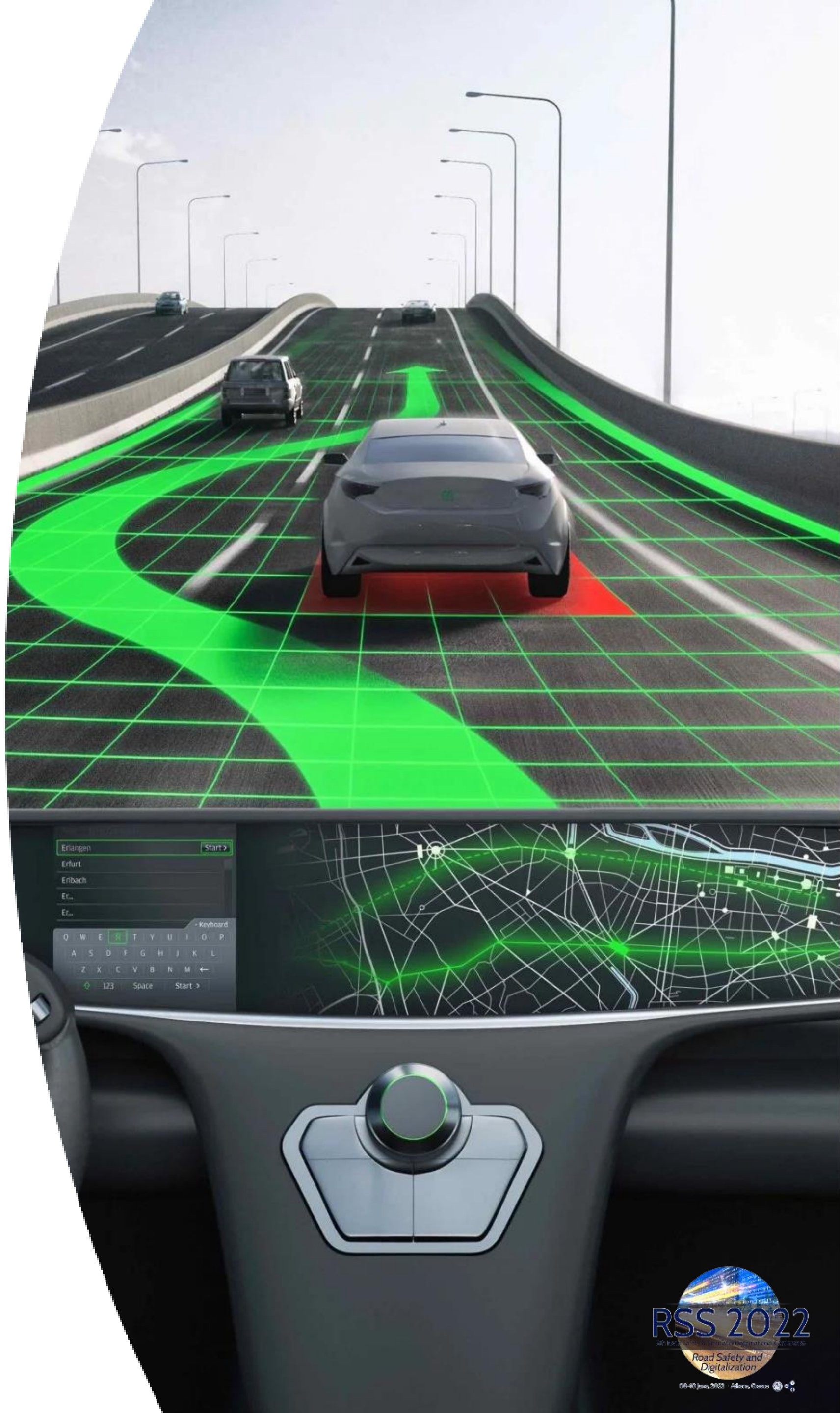
Introduction (1/2)

- The provision of **passing maneuvers** is regarded a key safety priority during the geometric and operational design of two lane rural roads.
- **Accidents** associated with **failure** during the **passing process** are reported as mostly **severe**
  - **head-on collisions** between the passing and the opposing vehicle
  - **same direction collisions** between the passing and the passed vehicle
- Roadways with **limited** passing opportunities
  - motivate certain drivers to make **risky passing attempts** in passing zones
  - **Passing attempts** on road segments **not intended** for passing



Introduction (2/2)

- The forthcoming Advanced Driver Assistance Systems (ADAS) in the near future are expected to:
  - address more **accurately** the **passing process**
  - **standardize** vehicle passing **path**.
- Various geometric curves have been proposed in the past:
  - polynomial trajectory curves
  - quadratic Bessel curves
  - Trapezoidal curves
  - Spiral curves
- Complex curves are hard to be adopted from vehicles in terms of **road-engineering**.
- **Utilization** of simpler **curves** that respond better in terms of **vehicle dynamics**.



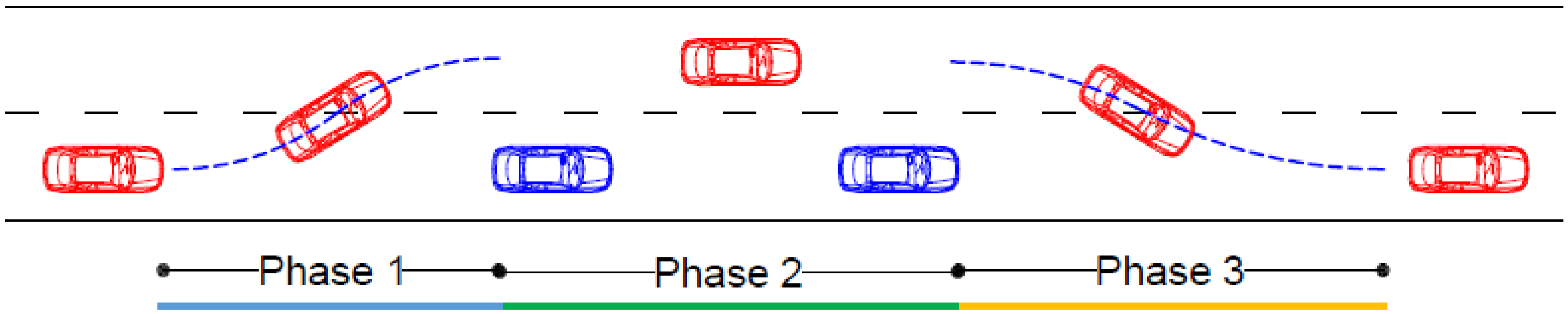
Problem Statement

- The present research aims to develop a **new mathematical model** for the overtaking maneuver that incorporates two pairs of **consecutive reverse curves**.
- The **assessment** is based on:
  - Driving simulator experiment
  - Vehicle dynamics model
- Determination of passing path **geometry** through driving simulator **experiment**.
- Assessment of **vehicle** critical **acceleration** performance through vehicle dynamics model.

Methodology (1/2)

- The analysis assumes:
  - free flow conditions.
  - the passing maneuvers were performed on tangent sections of two lane rural roads.
  - accelerated passing maneuvers.
  - the opposing vehicle was ignored.

- Passing maneuvers comprise of 3 Phases (Figure):
  - Phase 1 (1st reverse curve): movement from the original driving lane to the opposing lane
  - Phase 2: the vehicle travels along the opposing lane (tangent)
  - Phase 3: return to the original lane (2nd reverse curve).



Methodology (2/2)

- The two involved vehicles had different motion characteristics, where the following criteria – assumptions were applied:
  - both vehicles were supposed to **never exceed** the posted **speed** of the roadway
  - passing maneuvers under 2 different posted speed values
    - 70km/h
    - 90km/h
  - 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**
  - the **passing vehicle's speed** value at the starting phase was set **equal** to the relevant speed of the **passed vehicle**

Driving Simulator Experiment (1/2)

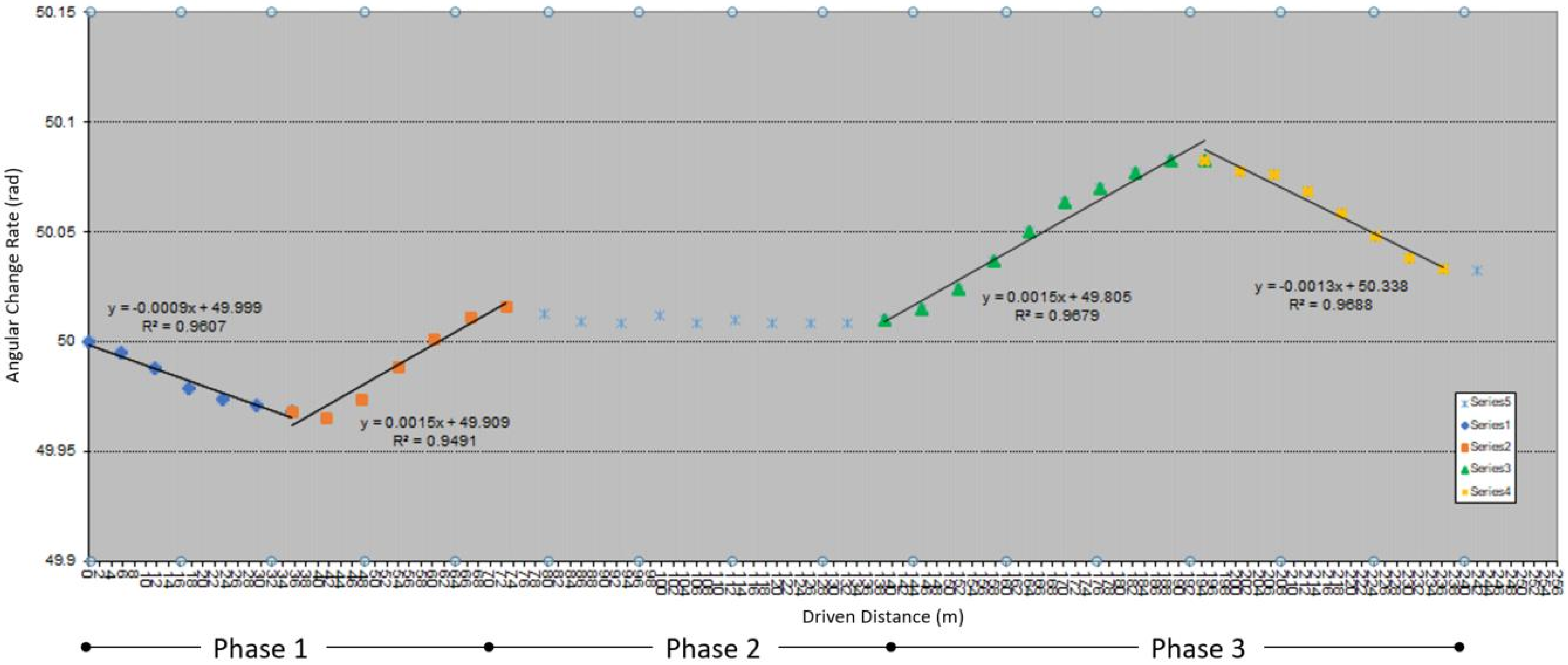
- **Urban** two lane rural **road**
- **Free flow** conditions
- 3.5km long driveway with two lanes (2x4.00m wide), with both tangents and curves.
- The participants were asked to drive **3 times** including one lap for warming up and getting acquainted with the driving environment.
- For every **run**, the participants were able to perform between **2** and **3 passing maneuvers**.
- Overtaking maneuvers **only on tangents**.

Driving Simulator Experiment (2/2)

- The **trajectory** of the passing vehicle was recorded with **high accuracy** (time-frame=0.3sec).
- The trajectory of the impeding vehicle was pre-determined through the algorithm development.
- In total **63 valid** accelerated passing **maneuvers** were recorded:
  - 29 participants aged between 20 to 27 years old.
  - 15 of the participants were males (mean age 24years, experience 6years)
  - 14 females (mean age 23years, experience 3years)
  - no known health or vision problems
  - valid driving license
  - frequent drivers (>5,000km travelled annually)

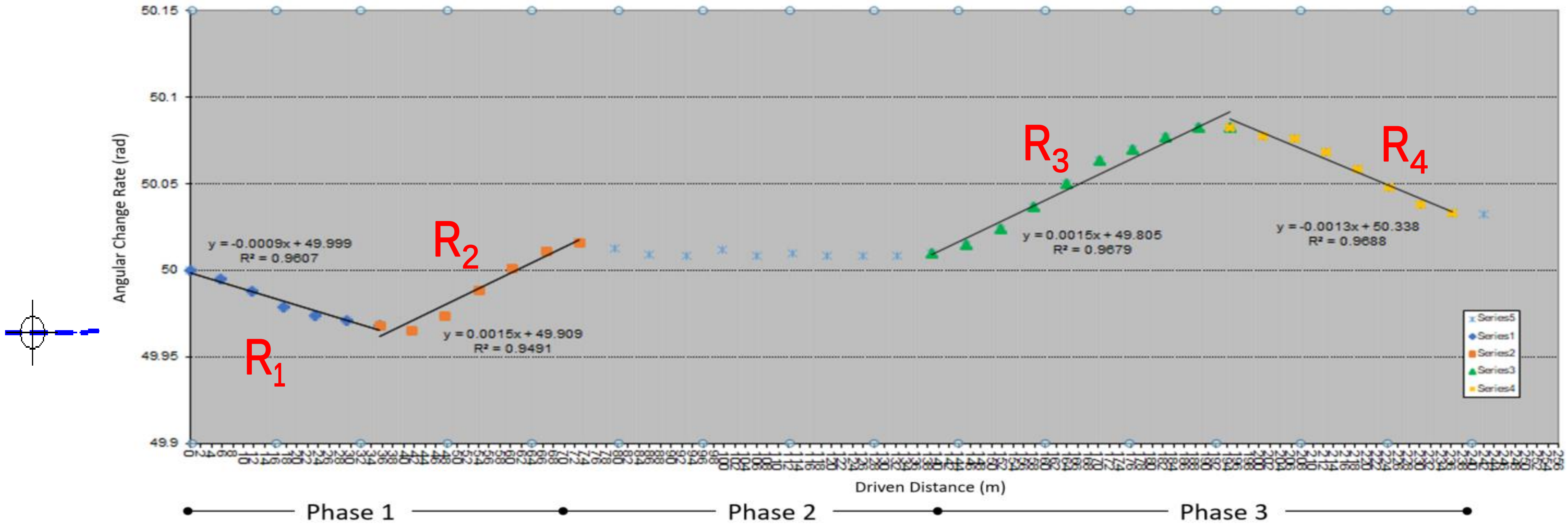
Azimuth Diagram

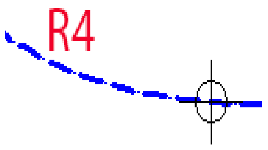
- The geometry of the vehicle trajectories during the passing process was defined by drawing the azimuth diagram, utilizing the x and z coordinates of the vehicle path.



Assigning Curved Paths

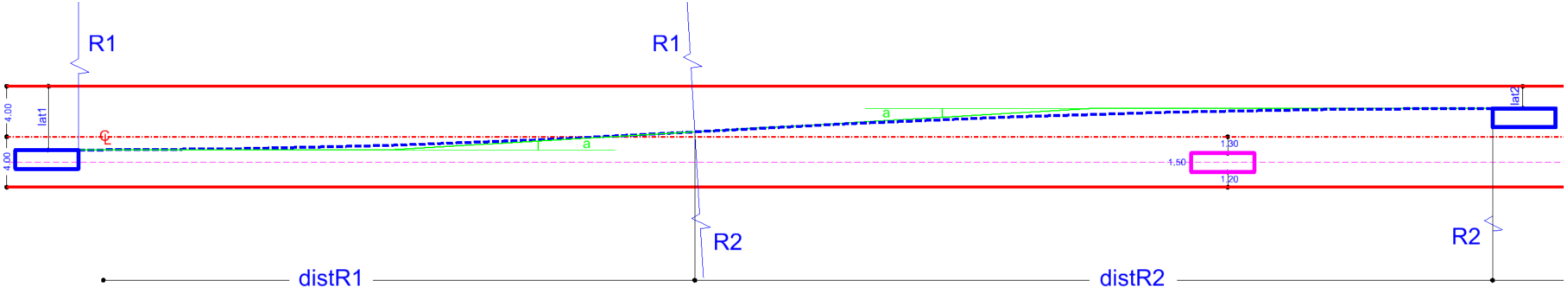
- The azimuth diagram, through regression analysis, defines the angular change rate of the vehicle path along with the driven distance.
- Parallel and inclined lines define tangents and circular arcs respectively.
- For every inclined line, the applied regression analysis revealed an equation (tension line), where the radius of the circular path was defined as: R=1/a (y=ax+b).





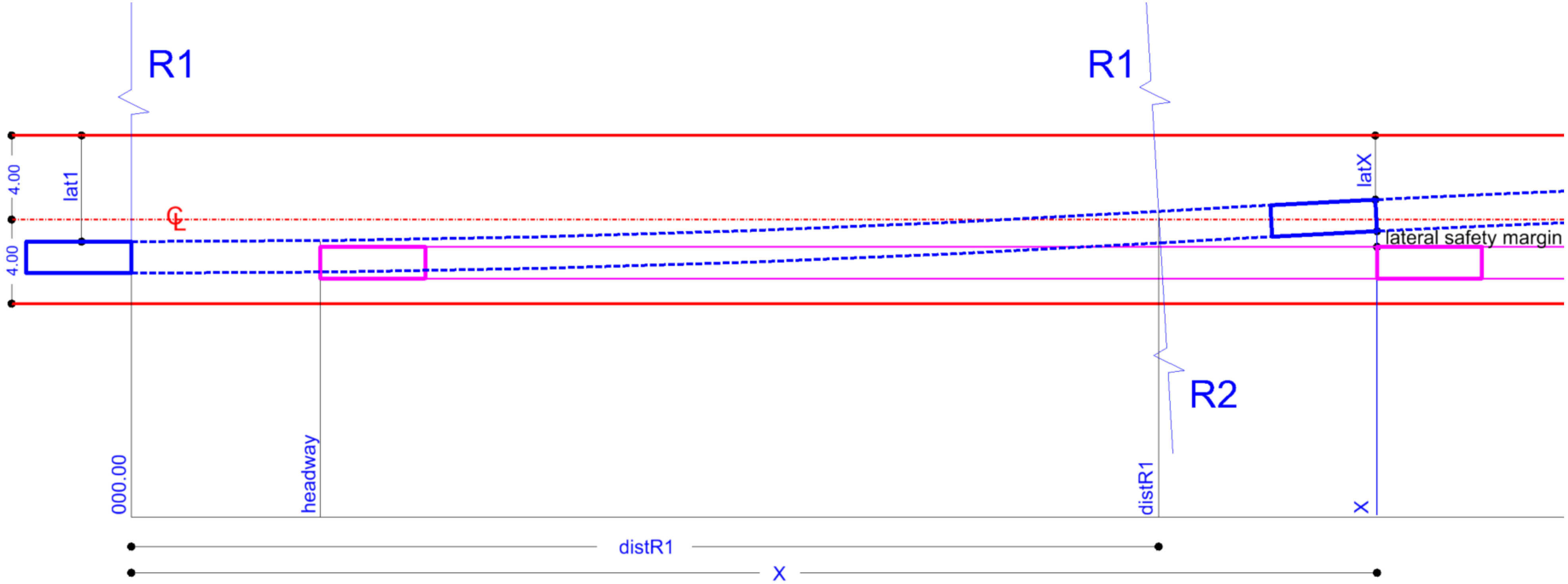
Dynamic Approach (1/4)

- After the radii determination, the paths of both vehicles (passing and impeding) are created with accuracy.
- The present research focused on **three parameters** from dynamic aspect:
  - the **acceleration** of the passing vehicle
  - the distance between the passing and the impeding vehicle, at the start and the end of the maneuver (**headway**).
  - the **lateral distance** between the passing and the impeding vehicle at critical points.



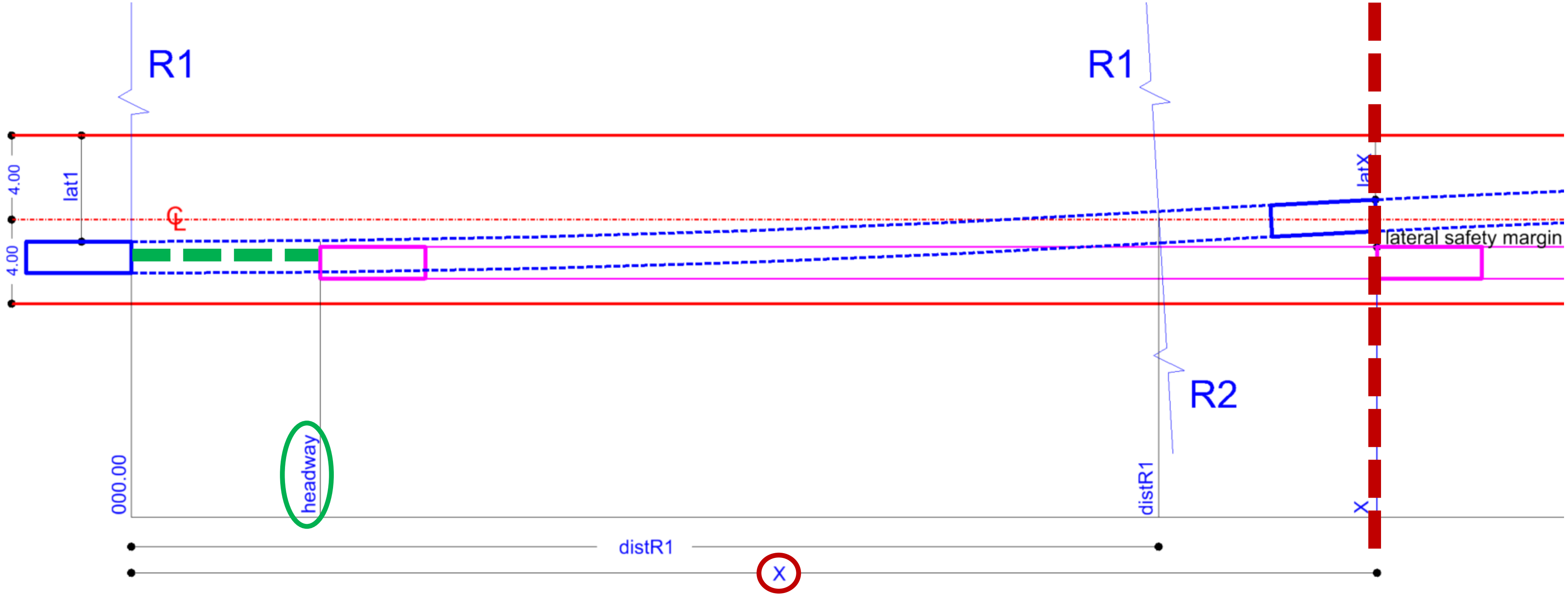
Dynamic Approach (2/4)

- The first step is to correlate the trajectories of the passing and impeding vehicle at every timeframe of their motion.
  - the passing vehicle's motion during the overtaking process was under acceleration mode
  - the impeding vehicle's speed was steady (50km/h and 70km/h).



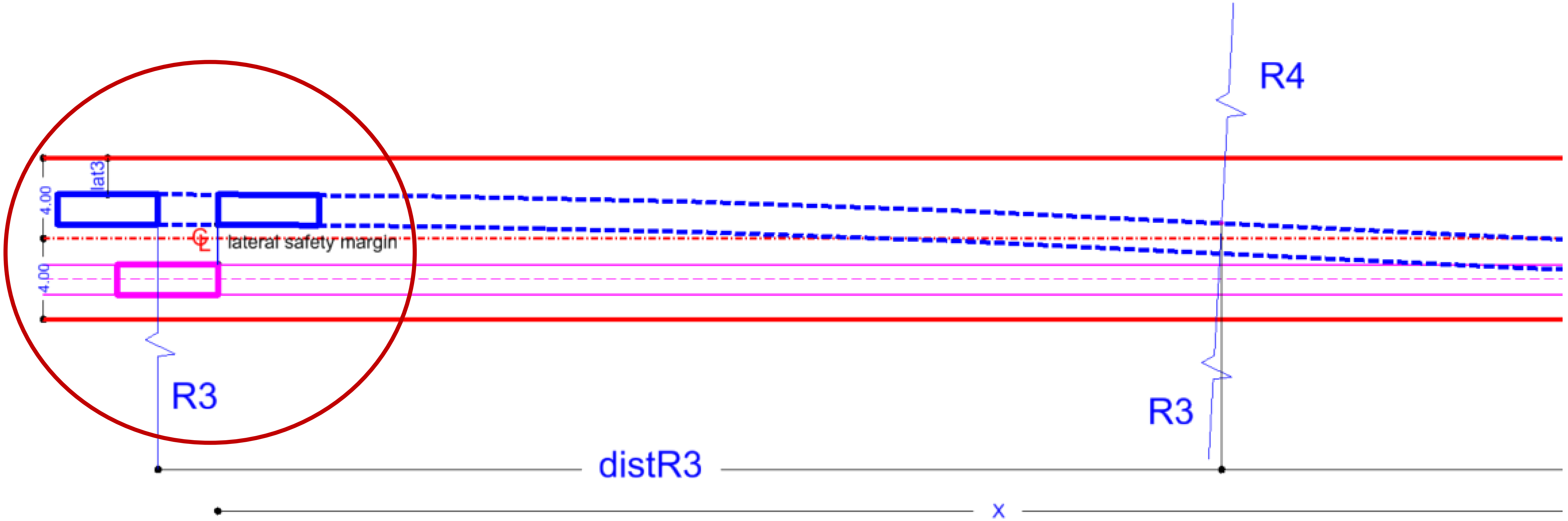
Dynamic Approach (3/4)

- At the starting point of Phase 1 the distance between the two vehicles equals to the **headway** distance.
- During Phase 1, a **key issue** along the passing process is to **avoid path overlap** between the passing and the impeding vehicles, in terms of having a collision (sideswiping each other)
- This incident must be checked at the **point** where the headway **distance** between the passing and the impeding vehicle is **eliminated**.



Dynamic Approach (4/4)

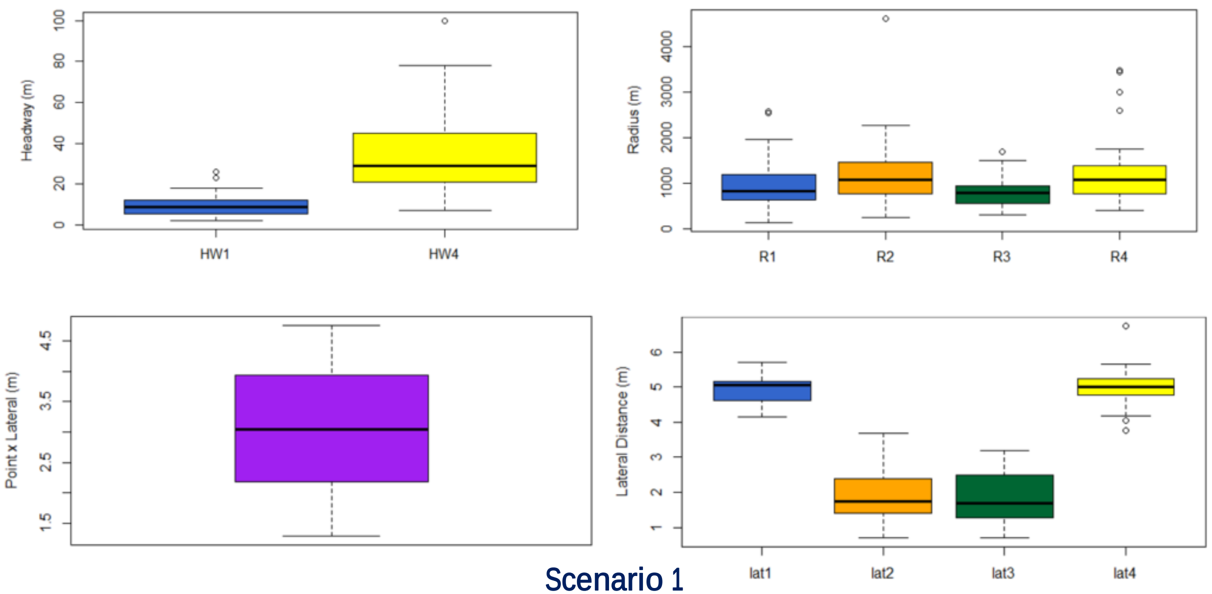
- Similar to Phase 1, during Phase 3 path overlap must be avoided.



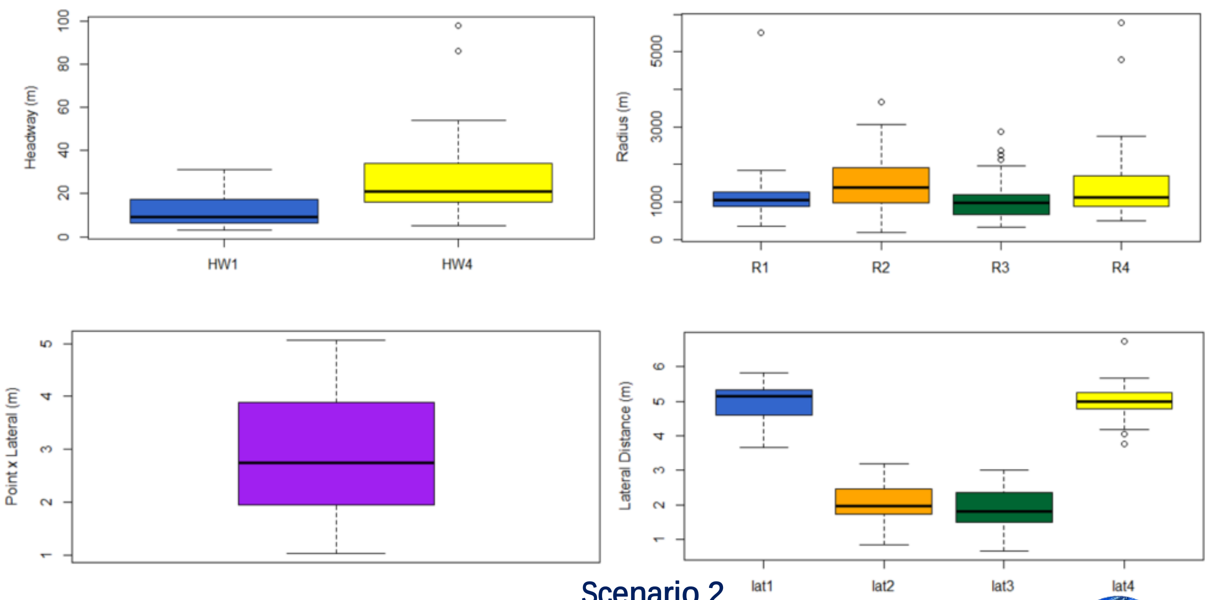
Outputs

- 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 **radii** of each overtaking phase
  - the **headway** distance
  - the path **elimination distance** (X)
  - the **lateral** distance

} **Lateral Safety Margin**



Scenario 1
Posted speed V=70km/h0



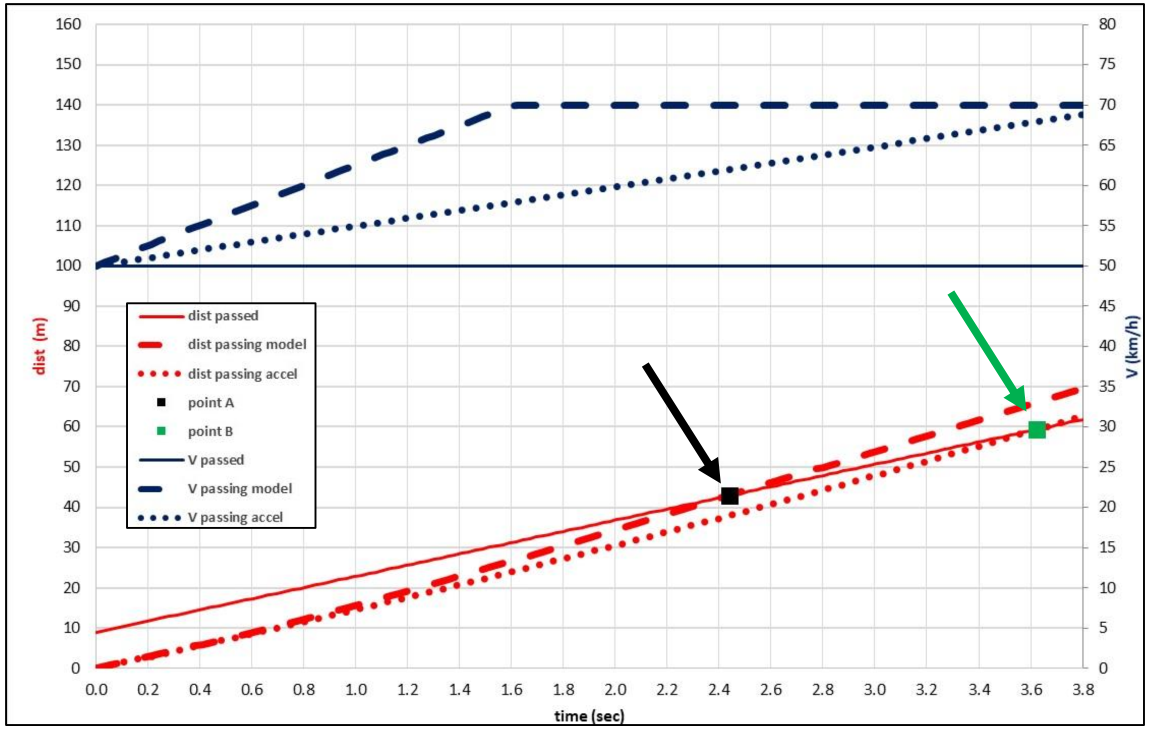
Scenario 2
Posted speed V=90km/h

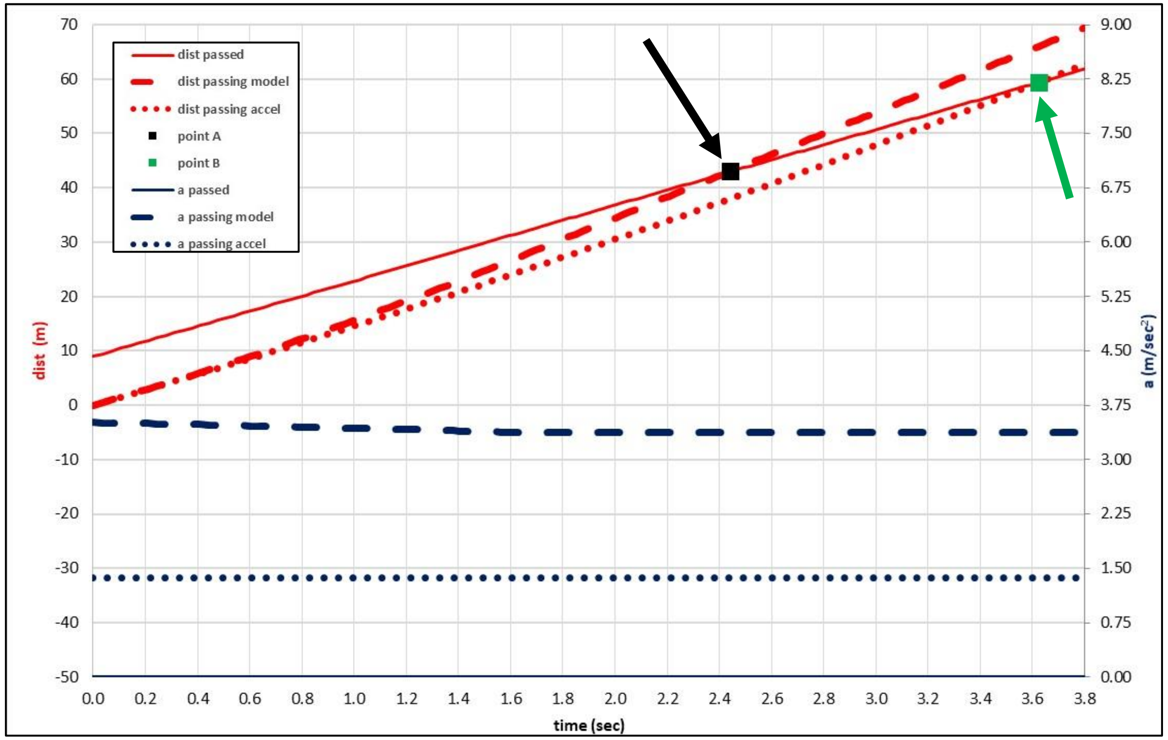
Vehicle Dynamics Model (1/2)

- Although, a validation of acceleration performance is essential.
  - Utilizing vehicle dynamics model (median values).
  - Performance of passing vehicle under real circumstances.
  - The performance of the vehicle was examined under full acceleration utilization.
  - Passing vehicle [C-class passenger car (Toyota CH-R)]
  - Assuming a rather good pavement friction supply set to fmax=0.80.
  - A rather moderate horsepower value of 100hp was assumed.
  - In the vehicle's dynamics model the acceleration is not considered constant.

Vehicle Dynamics Model (2/2)

- Point A indicates the path elimination distance utilizing Vehicle dynamics model
- Point B indicates the path elimination distance according to physics/kinematics.
- DistA<DistB → more conservative → passing vehicle can perform the maneuver!





Conclusions (1/2)

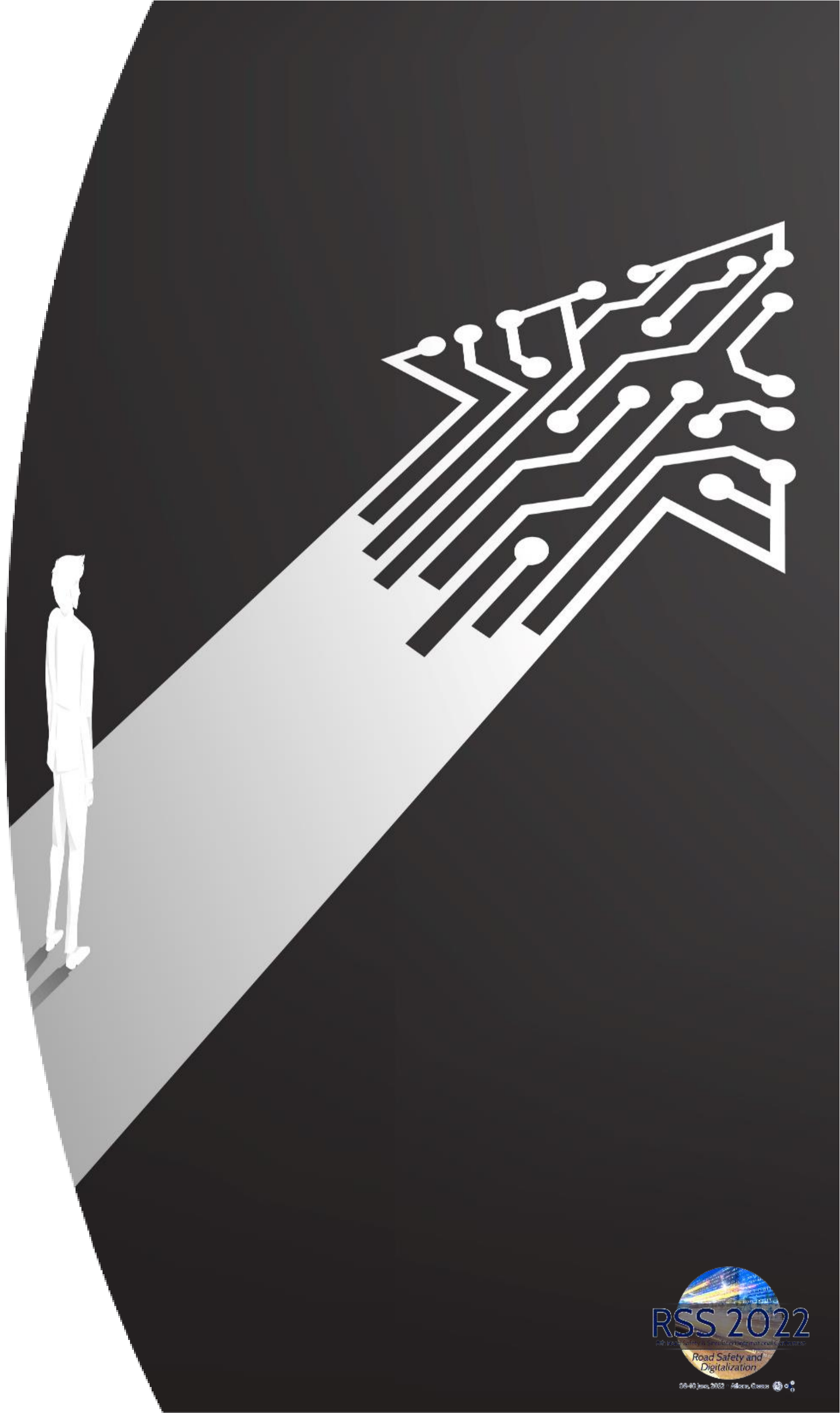
- The paper delivers a safe and realistic representation of the passing process on tangent road sections.
- The assessment is based on a driving simulator experiment and a vehicle dynamics model.
- Utilization of the azimuth diagram
  - Horizontal alignment determination through statistical approach.
- The curved paths were determined:
  - for two posted speed values (70km/h and 90km/h)
  - Impeding (passed) vehicle under steady speed (20km/h below the posted speed values).

Conclusions (2/2)

- A vehicle dynamics model was utilized in order to **assess the feasibility** of **overtaking** under certain acceleration.
- Quantification of:
  - the passing consecutive **curves**,
  - **lateral distances** in each overtaking phase.
  - the **headway** distance.
  - the lateral distance at the critical elimination point (**lateral safety margin**)

Further Research (1/2)

- Quantification of the acceleration rates under:
  - various vehicle **horse-power** utilizations
  - various **pavement frictions** values.
- Separation of the dataset in **aggressive** and **normal** driving behavior
- **Wider sample** of participants in terms of **gender** and **age**.
- Investigation of **more speed values** between the involved vehicles.
- **More speed differences** between the impeding vehicle and the roadway’s posted speed.



Further Research (2/2)

- Passing assessment assuming accelerated motion by the impeding vehicle.
- Capability of obstacles detection on the roadway that might cancel the passing process.
- An imminent challenge is to further improve the described methodology
  - by enabling more sophisticated communication between vehicles (V2V)
  - or between vehicles and road environment (V2I).

Thank you for your attention!!

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