A Driving Simulator Study to Evaluate the Effects of Different Types of Median Separation on Driving Performance on 2+1 Roads

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INTRODUCTION

INCREASE OF TRAFFIC VOLUMES → SAFETY AND TRAFFIC PERFORMANCE ON TWO-LANE ROADS HAVE BEEN DECREASING → INCREASE OF DELAYES AND CRASHES

1 LANE
PER DIRECTION

INCREASING THE NUMBER OF LANES

OPERATING PERFORMANCE × SAFETY PERFORMANCE

ECONOMICALLY INCONVENIENT SOLUTION

2 LANES
PER DIRECTION

ADDITION OF ONE LANE, WHICH ALTERNATES BETWEEN THE TWO DIRECTIONS

«2+1 ROADS»

2+1 Roads

- Three lanes on a single carriageway

- Two lanes in one direction, one lane in the opposite direction

- The two-lane section alternates with the one-lane section at set intervals

Merging area

Non-critical changeover

Additional lane

Critical changeover
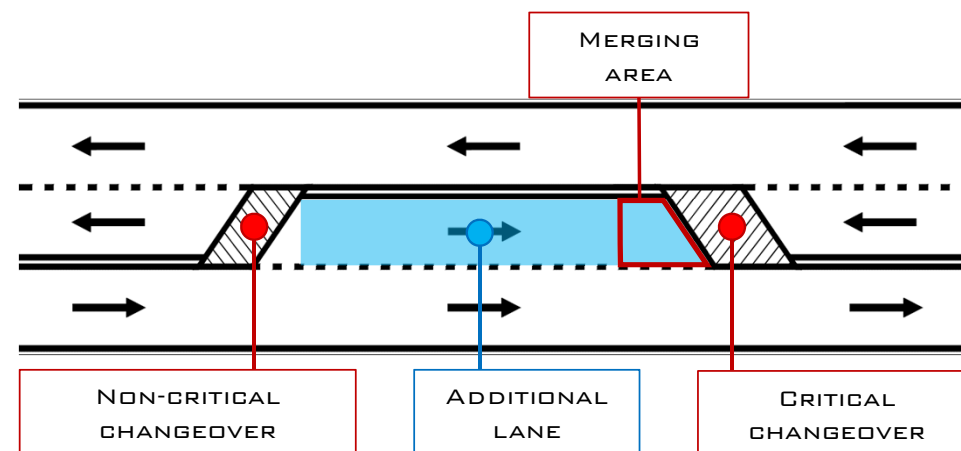
EUROPE   OTHER COUNTRIES

- Poland
- Sweden
- Finland
- Germany
- Spain

- USA
- China
- South Korea
- New Zealand

Design guidelines based on the **scientific literature**, which confirms the **benefits** of the 2+1 configuration

HIGHWAY CAPACITY MANUAL

ROADSIDE DESIGN GUIDE

RSS 2022
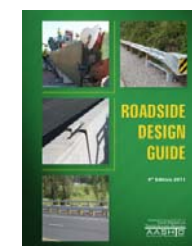
2+1 Roads

TRAFFIC PERFORMANCE

Speed increase and delay reduction

Increase of the passing rates

Reduction of platooning

improvement of operating conditions and reduction of driver's discomfort levels

SAFETY PERFORMANCE

Before-after studies show a reduction of crashes

Not taken into account in the scientific literature

human factors and driving performance are not considered

DESIGN PARAMETERS

Position in the road network and spacing

Cross-section dimensions (lanes, median width, ...)

Geometrical features of changeovers

Passing lane length, merging length

Median separation type

Merging configuration

Gap in the literature

MEDIAN SEPARATION

MEDIAN SEPARATION TYPES

- No vehicle redirection:
  - No physical separators
  - Delineators
- Vehicle redirection:
  - Median barriers

MERGING CONFIGURATIONS AT THE END OF THE ADDITIONAL LANE

- Road markings only
- Use of road signs
- Cable barriers
- Merging lengths

Objectives

The research project is aimed at investigating the human factors and driving behavior with the use of driving simulation and micro-simulation

Roma Tre University
Department of Engineering

Cracow University Of Technology
Faculty of Civil Engineering

University of Catania
Civil Engineering and Architecture Department

Lund University
Department of Technology and Society

1. Innovative design guidelines based on road safety and operations

2. behavioral models for traffic micro-simulation

Driving simulation studies developed:

1. Analysis of driving behavior for different geometric and operating conditions
   investigation of: traffic volume, merging length, passing lane length

2. Analysis of driving behavior for different types of median separation
   investigation of: median separation type, passing lane length

3. Analysis of driving behavior for different merging configurations
   investigation of: merging configuration, passing lane length

Method – Driving Simulator

The experiments were carried out using the driving simulator at Roma Tre University
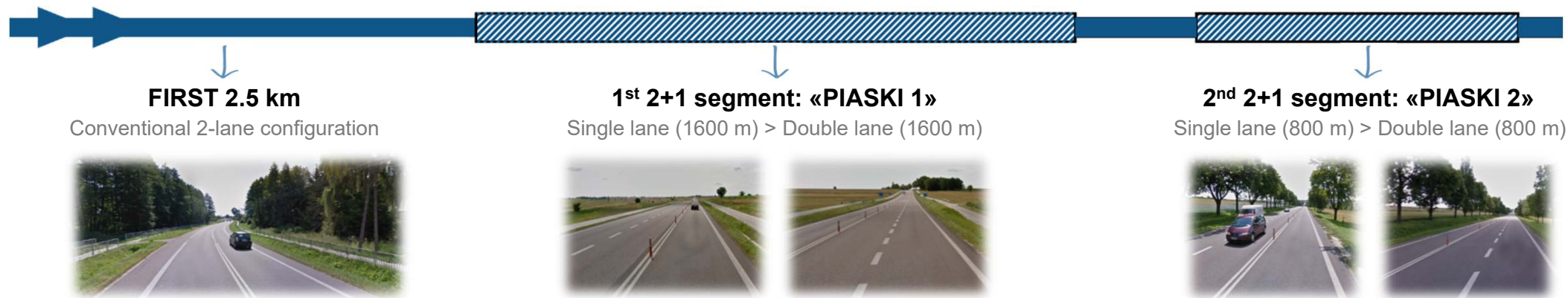

- ✓ One curved screen projection (180° UFOV), manual gear, steering wheel, pedals

- ✓ It is inserted in a real car in order to get the best feeling of realism and it is completed with an odometer and three rear-view mirrors

- ✓ High resolution of the visual scene with a refresh rate up to 60 Hz. The data recording system acquired more than 40 parameters

- ✓ Sound system (engine and other vehicles), eye tracking system and other tools for psychophysical measures

This set-up provides a realistic view of the road and surrounding environment and allows to take into account human factors, using an effective interdisciplinary and multidisciplinary approach.

METHOD – SCENARIO

THE **SCENARIO** IS BASED ON THE «DK 17» ROAD, IN THE MUNICIPALITY OF PIASKI IN POLAND.
THE **TRAFFIC VOLUME** WAS EXACTLY IMPLEMENTED IN THE SIMULATED ENVIRONMENT ACCORDING TO ON-SITE MEASUREMENTS, AND WAS UNCHANGED AMONG THE DIFFERENT TESTS AND SCENARIOS IMPLEMENTED.

FIRST 2.5 km
Conventional 2-lane configuration

1st 2+1 segment: «PIASKI 1»
Single lane (1600 m) > Double lane (1600 m)

2nd 2+1 segment: «PIASKI 2»
Single lane (800 m) > Double lane (800 m)

CONFIGURATIONS OF MEDIAN SEPARATION TYPES

a) Type 1: Double solid lines

b) Type 2: Reflective elements

c) Type 3: Flexible guideposts

d) Type 4: Cable barriers

Method – Sample of Drivers and Procedure

The sample of **participants** consisted of forty-six drivers, forty-one after validation of data, 16 women and 25 men, mean age of 28.6 years (SD = 6.8 years), ranging between 22 and 41 years.

The sample of drivers was tested using four drives of the scenario to investigate the effects of the different types of median separation on driving and traffic performance on the 2+1 road. The sequence of drives was randomly selected in order to avoid any repetitive influences.

Each participant drove the scenario four times on two different days. After a preliminary drive of a training scenario to help the participant familiarizing with the tool, the participant was then given a brief explanation of how 2+1 roads work as well as a general description of the scenario they will be driving.

Following the driving tests, each driver was required to fill in a digital questionnaire that consisted in evaluating his or her thoughts on the perceived safety of each type of median separation encountered in the simulations (with the use of screenshots from the scenario).

METHOD – DATA COLLECTION

1. EFFECTS ON DRIVING PERFORMANCE

Influence of the independent variables on the dependent variables

SPEED

S_1: beginning of the 2+1 lane

S_2: beginning of the lane-change maneuver

S_{av}: average speed along 2+1 lane

POSITION

P: beginning of the lane-change maneuver

LP_{av1}: average lateral position along 2+1 lane

LP_{av2}: average lateral position along the right lane

ACCELERATION

a_{avg}: average acceleration along 2+1 lane

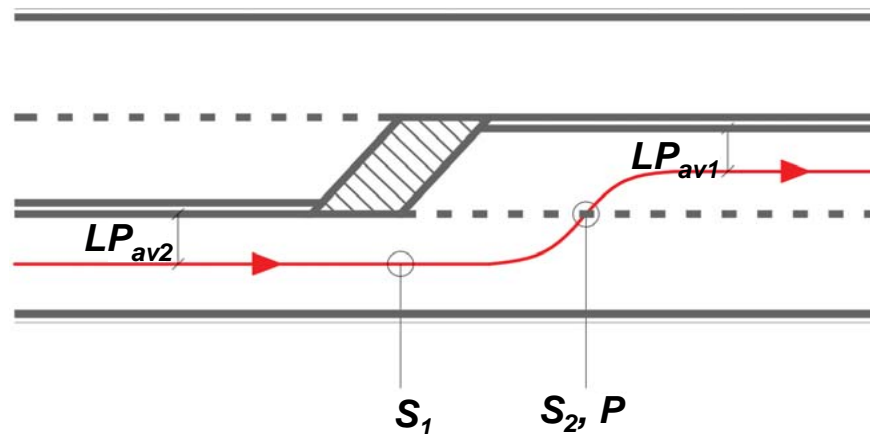a_{max}: maximum acceleration along 2+1 lane

... TO STUDY DRIVING BEHAVIOR AT THE **BEGINNING OF THE 2+1 SEGMENTS**, ON THE **SINGLE-LANE SEGMENTS** AND WHILE **PASSING** SLOWER VEHICLES

2. EFFECTS ON TRAFFIC PERFORMANCE

Speed increase and delay reduction

3. SUBJECTIVE MEASURES
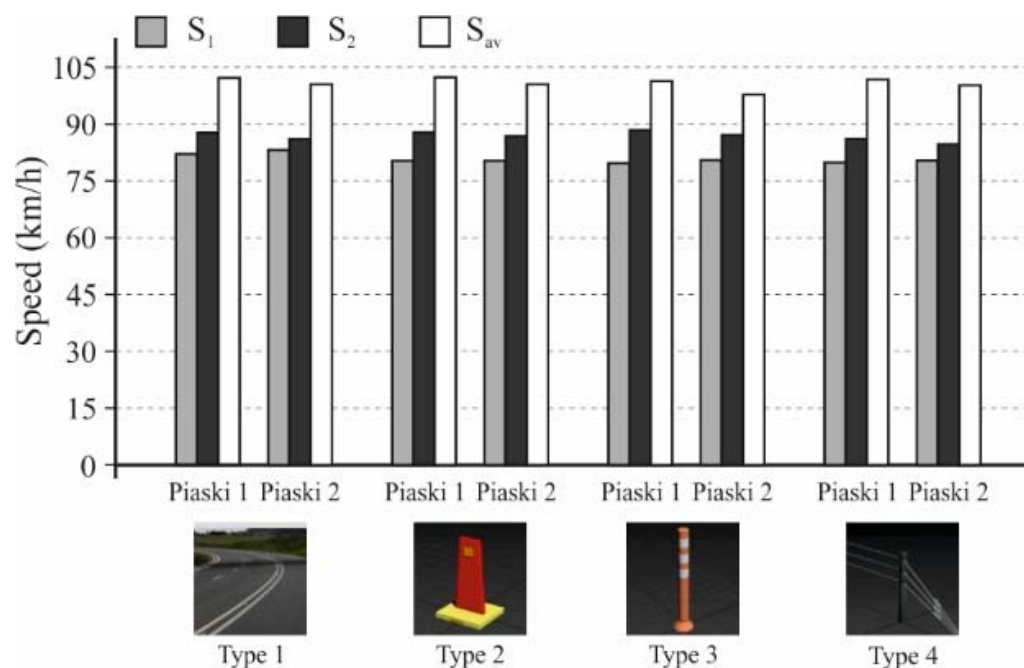
Screen-based questionnaire

EFFECTS ON DRIVING PERFORMANCE

Variable	Median Separation Type				F	p
	Type 1	Type 2	Type 3	Type 4		
PIASKI 1						
S_1	82.1	80.3	79.7	79.9	1.22	0.305
S_2	87.8	87.8	88.5	86.1	0.75	0.524
S_{av}	102.2	102.4	101.4	101.8	-	0.967
P	45.5	55.8	61.1	62.2	-	0.101
LP_{av1}	1.6	1.6	1.6	1.8	**10.30**	**0.000**
LP_{av2}	1.8	1.8	1.9	2.0	-	**0.007**
a_{av}	0.03	0.05	0.06	-0.01	-	**0.000**
a_{max}	1.66	1.70	1.76	1.60	-	0.921
PIASKI 2						
S_1	83.2	80.3	80.5	80.4	-	0.299
S_2	86.1	86.8	87.1	84.7	1.09	0.355
S_{av}	101.9	100.5	97.8	100.3	1.70	0.170
P	27.6	41.4	54.0	39.8	-	**0.006**
LP_{av1}	1.6	1.7	1.7	1.9	-	**0.000**
LP_{av2}	1.7	1.9	1.9	1.9	-	**0.000**
a_{av}	-0.02	0.001	-0.02	-0.01	-	0.982
a_{max}	1.48	1.60	1.57	1.55	-	0.793

EFFECTS OF MEDIAN SEPARATION TYPE ON SPEED

NO STATISTICALLY SIGNIFICANT DIFFERENCES

THE DIFFERENT MEDIAN SEPARATION TYPES HAVE **SMALL EFFECTS** ON DRIVERS' SPEED

AVERAGE SPEED

DOUBLE SOLID LINES = 101.57 KM/H

REFLECTIVE ELEMENTS = 100.72 KM/H

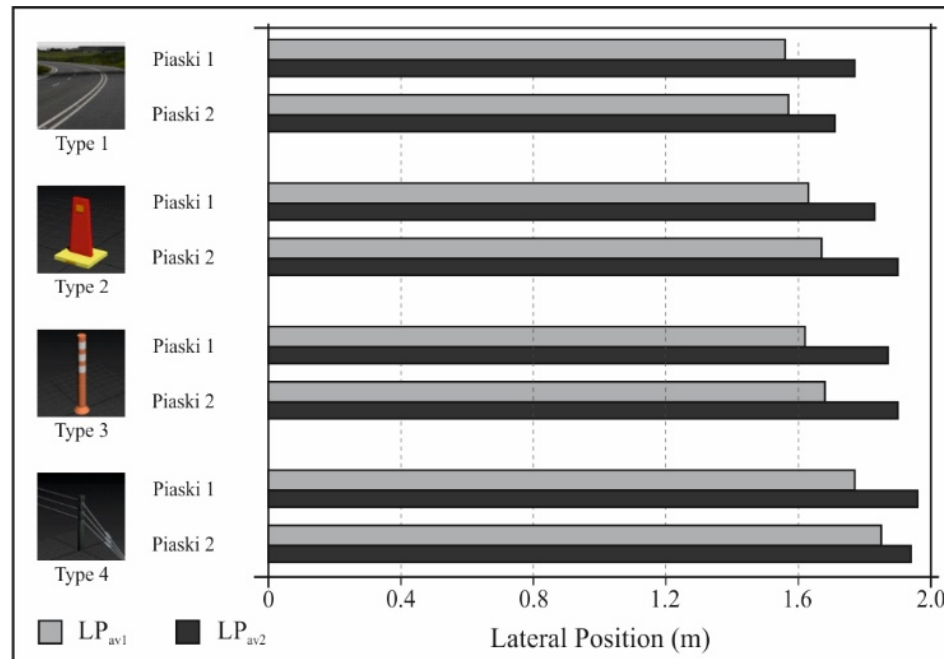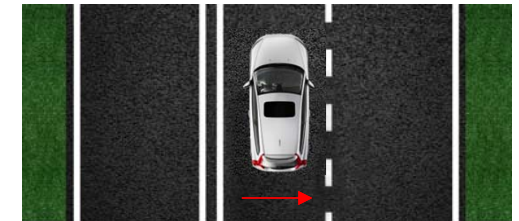FLEXIBLE GUIDEPOSTS = 99.91 KM/H

CABLE BARRIERS = 101.05 KM/H

Type 1   Type 2   Type 3   Type 4

EFFECTS ON DRIVING PERFORMANCE

EFFECTS OF MEDIAN SEPARATION TYPE ON LATERAL POSITION

Variable	Median Separation Type				F	p
	Type 1	Type 2	Type 3	Type 4		
PIASKI 1						
S_1	82.1	80.3	79.7	79.9	1.22	0.305
S_2	87.8	87.8	88.5	86.1	0.75	0.524
S_{av}	102.2	102.4	101.4	101.8	-	0.967
P	45.5	55.8	61.1	62.2	-	0.101
LP_{av1}	1.6	1.6	1.6	1.8	**10.30**	**0.000**
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S_{av}	101.9	100.5	97.8	100.3	1.70	0.170
P	27.6	41.4	54.0	39.8	-	**0.006**
LP_{av1}	1.6	1.7	1.7	1.9	-	**0.000**
LP_{av2}	1.7	1.9	1.9	1.9	-	**0.000**
a_{av}	-0.02	0.001	-0.02	-0.01	-	0.982
a_{max}	1.48	1.60	1.57	1.55	-	0.793

STATISTICALLY SIGNIFICANT DIFFERENCES

An **INCREASE** IN THE OVERALL DIMENSIONS OF THE MEDIAN SEPARATORS CAUSES **GREATER DEVIATIONS** TO THE RIGHT OF THE VEHICLE TRAJECTORIES

DIFFERENT **RISK PERCEPTION**

SAME PHENOMENON IN THE SINGLE-LANE SEGMENTS

LATERAL POSITION

DOUBLE SOLID LINES = 1.56 M

REFLECTIVE ELEMENTS = 1.65 M

FLEXIBLE GUIDEPOSTS = 1.65 M

CABLE BARRIERS = 1.81 M

Effects on Traffic Performance

increase in speed

Separation type	Lane length	Average speed variation [km/h]	Average speed in the passing lane [km/h]
Type 1	1600 m 800 m	+ 10.92 + 10.28	101.75 101.40
Type 2	1600 m 860 m	+ 10.68 + 9.06	101.64 99.79
Type 3	1600 m 860 m	+ 10.20 + 9.07	101.55 98.28
Type 4	1600 m 860 m	+ 10.48 + 9.85	101.81 100.29

✓ Average speed increases between 9 and 11 km/h

Greater benefits for longer additional lanes

reduction of ptsf (*percent time spent following*)

Separation type	Travel time [s]	PTSF variation [%]
Type 1	275.52	-9.18
Type 2	278.05	-8.34
Type 3	278.54	-8.18
Type 4	278.01	-8.36

✓ Average reduction between 8.18% and 9.18%

The results are in line with the previous literature findings

Country	Median barrier	Average speed variation [km/h]	Average speed in the passing lane [km/h]	PTSF variation [%]
Sweden [21]	Yes	+2	-	-
Sweden [21]	No	+4	-	-
Sweden [3]	Yes	+10	-	-
Finland [1]	Yes	+1	-	-
Finland [16]	No	-	100 ÷ 130	-
Germany [1]	No	+5 to +10	100 ÷ 130	-
Germany [13]	No	-	-	-15
South Korea [7]	No	+20 (one section)	100 ÷ 130	-8.3 (one section)
Poland [23]	No	+10 (one section)	-	-
Japan [12]	Yes	+8 to +14 (simulation)	-	-
United States [1]	No	+1 to +10 (simulation)	-	-28 to -15
United States [10]	No	"Modest"	-	-

Subjective Measures

QUESTIONS THAT THE PARTICIPANT HAD TO REPLY AFTER THE TESTS, USING A NUMERICAL VALUE FROM 1 TO 5:

Q1: Do you consider this type of median separation to be safe? (1: not safe, 5: very safe);

Q2: Did the separation elements influence your speed in the additional passing lane? (1: little, 5: great);

Q3: Did the separation elements influence your position in the additional passing lane? (1: little, 5: great);

Q4: Did the separation elements influence your speed in the regular lane? (1: little influence, 5: great influence);

Q5: Did the separation elements influence your position in the regular lane? (1: little influence, 5: great influence).

Questions	Median separation type				
	Type 1	Type 2	Type 3	Type 4	p-value
Q1	**2.54**	**2.85**	**3.22**	**4.00**	**0.000**
Q2	2.70	2.56	2.76	2.96	0.503
Q3	2.74	2.72	2.93	3.04	0.541
Q4	2.11	2.06	2.20	2.30	0.530
Q5	2.28	2.11	2.30	2.46	0.500

Results show that drivers consider cable barriers to be the safest median separation solution among those tested, with road markings only being the least safe

CONCLUSIONS

Median separation	Main effects on driving behavior	Operation and safety features	Notes
Road markings only	✗ Vehicle trajectories closer to the opposite traffic flow	✓ No installation costs ✓ Very little maintenance required ✗ No redirection of errant vehicles	Increases traffic performance compared to two-lane configurations but maintains the risk of head-on collisions
Non-containing objects	✓ Vehicle trajectories close to the lane center	✓ Little maintenance required ✗ No redirection of errant vehicles	Should be preferable to road markings only for better delineation and safer trajectories
Cable barriers	~ Great vehicle trajectory deviations to the right	✓ Mitigate the risk of head-on collisions ~ Increase in PDO crashes ~ Higher costs and maintenance	Best safety performance, but requires wider passing lanes and wider median to accommodate deflections

✓ GREATER OPERATIONAL BENEFITS → PASSING LANE LENGTH

PROPOSED GUIDELINE:

L > 1000 M

FUTURE RESEARCH

DRIVING SIMULATION

- FUTURE STUDIES WILL FURTHER VALIDATE CURRENT FINDINGS

- WIDER FIELD OF ANALYSES IN OTHER FEATURES:

  - EFFECTS OF DIFFERENT OPERATING CONDITIONS (LOS) BEFORE THE 2+1 SEGMENTS

  - FURTHER MODIFICATIONS OF THE GEOMETRICAL ELEMENTS (LANE WIDTH, CHANGEOVERS, MERGING AREA,...)

  - FURTHER CONFIGURATIONS OF TRAFFIC (VOLUME AND COMPOSITION)

TRAFFIC MICRO-SIMULATION

- IN-DEPTH ANALYSIS OF **TRAFFIC AND SAFETY PERFORMANCE**:

  - SAFETY ANALYSIS IN MICROSIMULATION

  - ANALYSIS OF PLATOONING

  - CAPACITY ASSESSMENT

  - ASSESSMENTS OF THE SPACING BETWEEN DIFFERENT 2+1 SEGMENTS ON A ROAD NETWORK LEVEL

USING THE BEHAVIORAL MODELS OBTAINED FROM DRIVING SIMULATION

Thanks

for your attention

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