RSS 2022
8th Road Safety & Simulation International Conference
Road Safety and Digitalization
08-10 June 2022 • Athens, Greece

Estimation and safety validation of a roundabout gap-acceptance model in a simulated environment

Evangelos Paschalidis , Albert Solernou, Mohamed Hasan, Gustav Markkula, He Wang, Richard Romano

8th Road Safety & Simulation International Conference, 08-10 June 2022, Athens, Greece

VeriCAV
VERIFICATION OF CONNECTED AND AUTONOMOUS VEHICLES

UNIVERSITY OF LEEDS
Institute for Transport Studies

Outline

- Motivation - aim
- Methodological approach
- Data – Data process
- Modelling approach
- Model – simulation analysis (estimates, SSM)
- Next steps

Motivation - Aim

- Virtual intelligent traffic is essential for an immersive experience in a driving simulator

- Heterogeneity in driver behaviour is not captured in smaller scale interactions

<u>Roundabouts</u>

- Advantages:
    - Intersection control without traffic lights
    - Minimisation of conflict locations

- Driving behaviour: gap-acceptance & critical headway

- Majority of gap-acceptance model – simplification of critical gap

- Aim: model – more rigorous critical gap approach

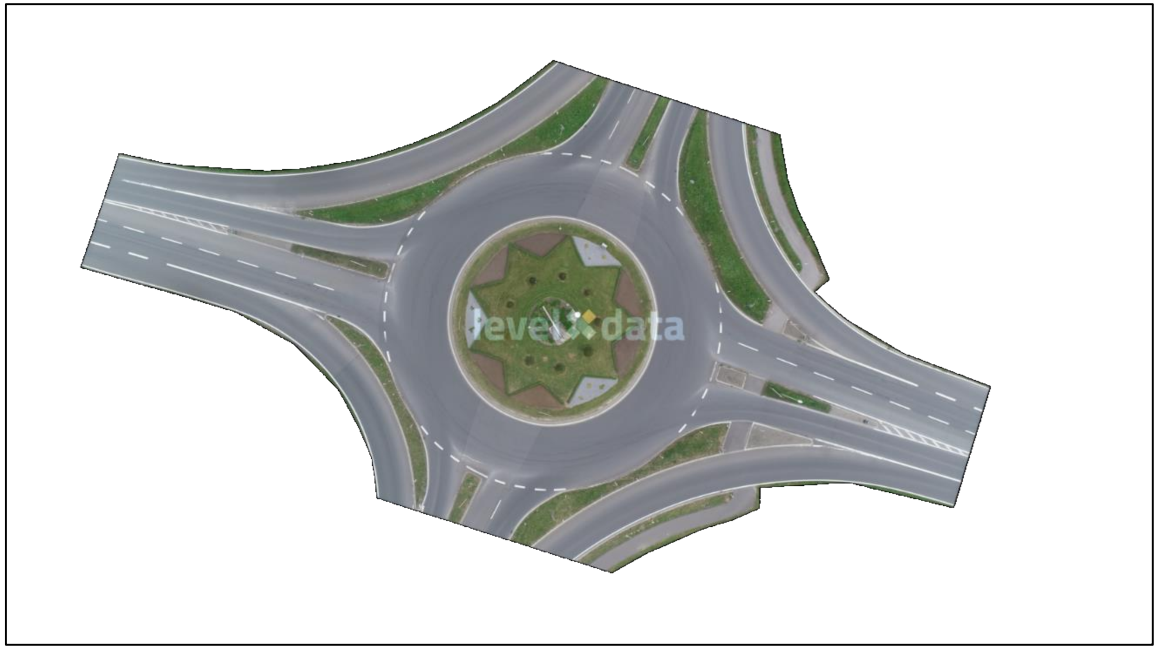
Methodological approach

- Step 1: Roundabout gap-acceptance model estimation
  - Base critical gap model

- Step 2: Model evaluation in a simulation environment
  - Implementation in SmartActors
  - Traffic throughput and safety evaluation (SSM)
  - Comparison to the base critical gap model

Data

- Data: round drone data set
- Location: Germany (Neuweiler roundabout - Aachen)
- 22 Smaller data sets (7 – 20 mins each, mean approx. 16 mins)
- No lane markings - used as either single or dual-lane

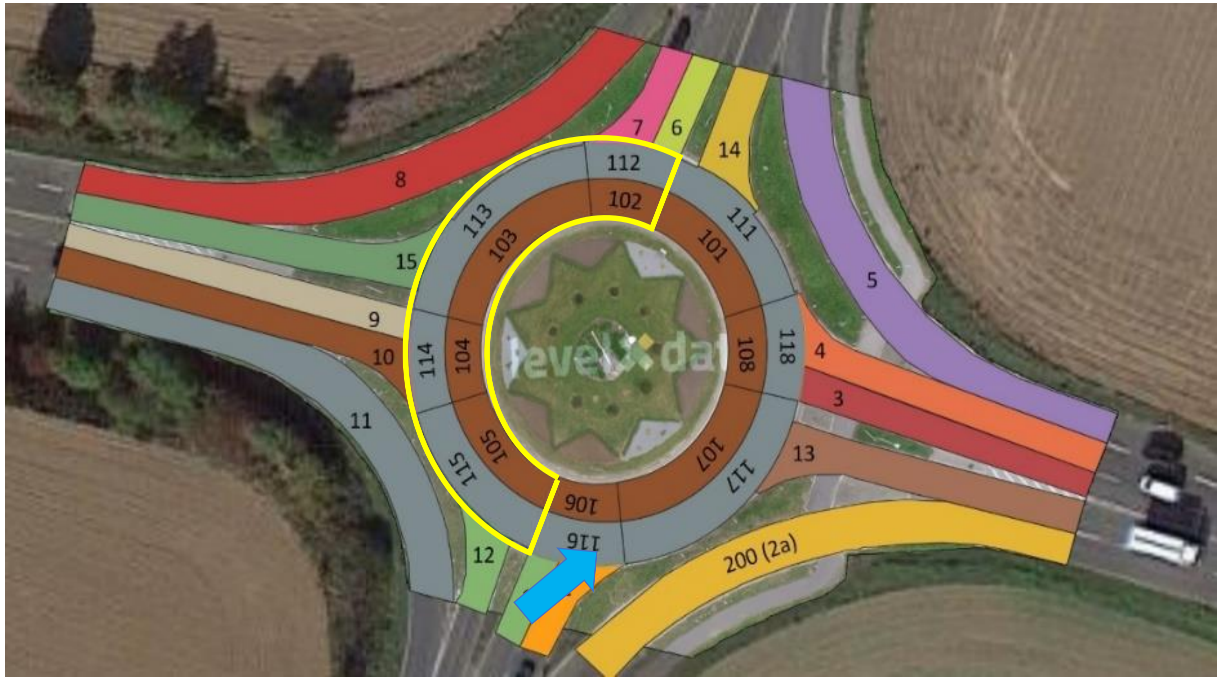


Source [Krajewski et al., 2020]

Data process

<u>Infrastructure process</u>

- Areas: (a) entrance lanes, (b) roundabout, (c) conflict zones (d) exit lanes
- Entrance lanes: (a) inner (e.g. 1), (b) outer (e.g. 2)
- Roundabout: (a) inner (e.g. 105), (b) outer (e.g. 115)



<u>Gap outcomes</u>

- (a) No circulating, (b) one circulating, (c) two circulating vehicles
- Gap-acceptance process – distance to roundabout 0.5 m
- Exiting vehicles included
- Final data set (4,100 vehicles, 12,390 observations)

Modelling approach

- Critical-gap

$$G_{nt}^{cr,\,g} = e^{(X_{nt}\beta_g + \varepsilon_{nt})}$$

- Probability of single gap acceptance

$$P_n(\text{accept gap}) = P_n[G_{nt} \geq G_{nt}^{cr}]$$

$$P_{nt}^{GA} = P_n[G_{nt} \geq G_{nt}^{cr}] = \Phi\left[\frac{\ln(G_{nt}) - (\beta_g X_{nt})}{\sigma_g}\right]$$

- Total gap acceptance probability

$$P_n(\text{accept gap}) = P_n(\text{accept near gap})P_n(\text{accept far gap}) = P_n[G_{nt}^{near} \geq G_{nt}^{cr\ near}]P_n\left[G_{nt}^{far} \geq G_{nt}^{cr,\ far}\right]$$

- $G_{nt}^{cr,\,g}$ is the critical gap of driver n, at time t
- X_{nt} is a vector of explanatory variables that affect the critical gap
- β_g is a vector of parameters to be estimated
- ε_{nt} is an independent and identically normally distributed disturbance term: $N(0,\sigma_g^2)$
- $g \in$ (near, far)

Modelling approach

- Gap-acceptance probability – No vehicles condition

$$P_{nt}^{GA} = \frac{e^{(\delta X_{nt})}}{1+e^{(\delta X_{nt})}}$$

- k = a: one circulating vehicle
- k = b: two circulating vehicles
- k = c: no circulating vehicles

- Total probability

$$P_{nt}^{GA} = \left(P_{nt}^{GA,\,k=a}\right)(k=a) + \left(P_{nt}^{GA,\,k=b}\right)(k=b) + \left(P_{nt}^{GA,\,k=c}\right)(k=c)$$

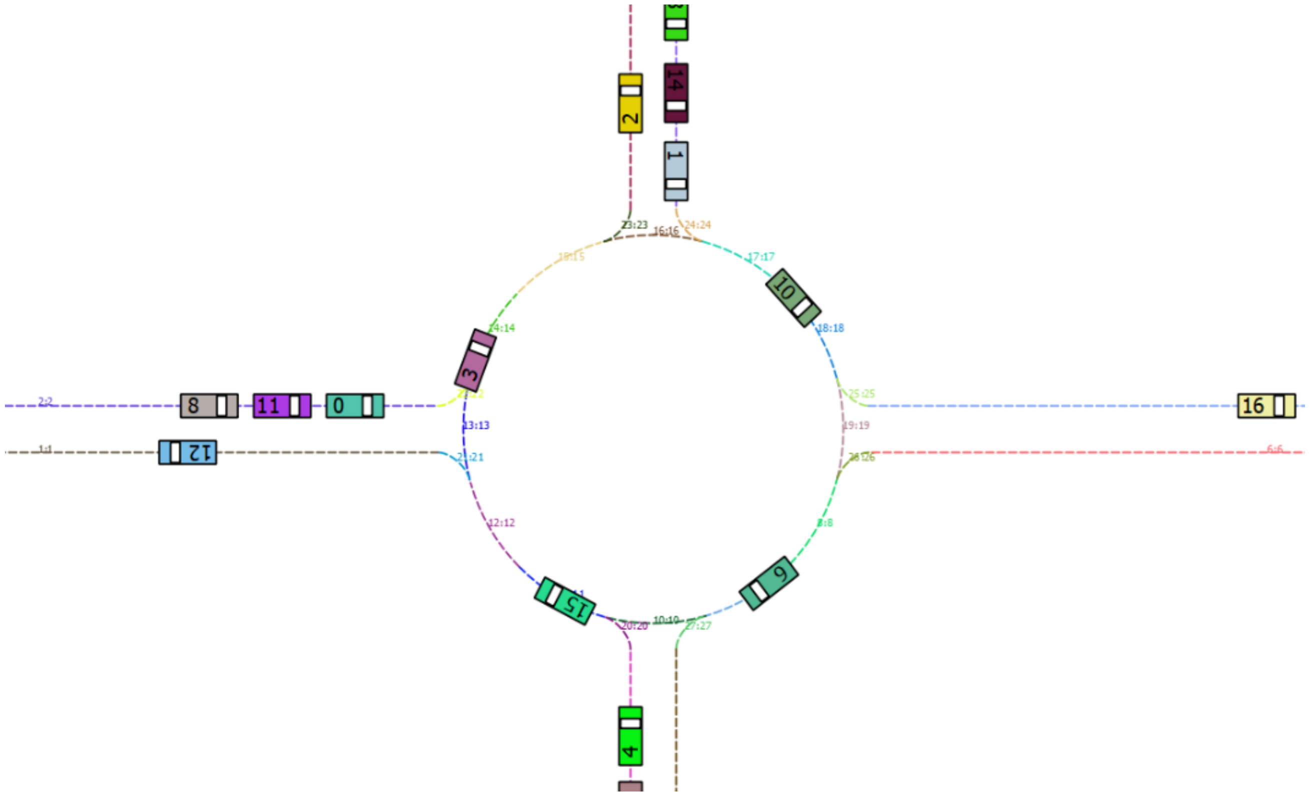
- Likelihood function

$$L_n = P_n\left(D_{1n}, D_{2n}, \ldots, D_{T_n n}\right) = \prod_{t=1}^{T_n} P_{nt}^{GA}$$

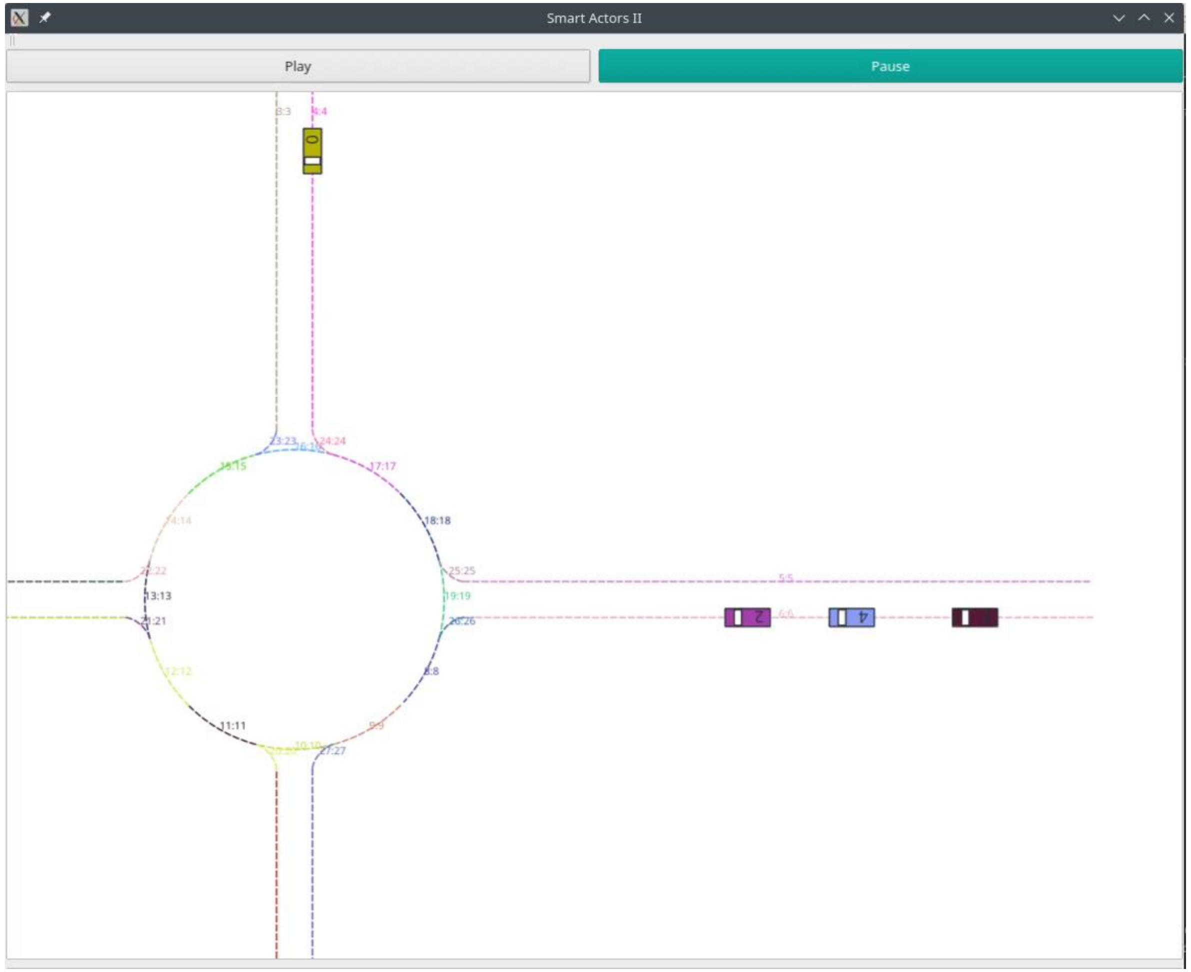
Results – Parameter estimates

One circulating vehicle		
Variable	**Parameter**	**t-ratio**
Constant	0.015	0.07
Inner lane dummy (subject vehicle)	-0.424	-3.21
Inner zone circulating vehicle dummy	0.117	0.29
Subject speed (m/s)	-0.534	-8.89
Circulating vehicle speed (m/s) - Outer zone	0.097	3.60
Circulating vehicle speed (m/s) - Inner zone	0.082	1.62
Circulating vehicle distance (m) - Outer zone	6.157	3.29
Circulating vehicle distance (m) - Inner zone	4.925	3.01
Vehicle in the outer roundabout conflict zone	0.980	8.88
Vehicle in the inner roundabout conflict zone	0.977	13.95
Motorcycle circulating vehicle dummy	0.433	1.90
Heavy circulating vehicle dummy	0.206	2.45
σ^{outer}	3.779	7.73
σ^{inner}	2.826	6.26

Simulation analysis



Simulation analysis



Results – Simulation analysis

- Simulation:
  - 6 levels of P_{cr}
  - 3 levels of speed
  - Each scenario – 10 simulations, 60 mins each

P_{cr}	Conflicts total	Crashes total	Conflicts average	Crashes average	Average speed (m/s)	Average traffic
High speed results (30m/s road, 20m/s roundabout)						
0.4	264	1	26.4	0.1	8.75	2370.3
0.5	243	25	24.3	2.5	8.70	2022.9
0.6	245	24	24.5	2.4	8.67	1933.6
0.7	231	25	23.1	2.5	8.67	1931.6
0.8	235	26	23.5	2.6	8.67	1934.3
0.9	231	21	23.1	2.1	8.67	1929.4
Medium speed results (20m/s road, 15m/s roundabout)						
0.4	14	0	1.4	0	6.73	1991.2
0.5	28	0	2.8	0	6.72	1685.4
0.6	31	0	3.1	0	6.70	1563.6
0.7	22	0	2.2	0	6.70	1564
0.8	22	0	2.2	0	6.70	1551.1
0.9	34	0	3.4	0	6.70	1553.2
Slow speed results (15m/s road, 7m/s roundabout)						
0.4	3020	0	302	0	3.20	1379.6
0.5	1810	0	181	0	3.21	1163.5
0.6	1765	0	176.5	0	3.21	1049.9
0.7	1881	0	188.1	0	3.21	998.4
0.8	1907	0	190.7	0	3.21	994.5
0.9	1981	0	198.1	0	3.21	999.1

Results – Surrogate Safety Measures

- Surrogate Safety Measures - Surrogate Safety Assessment Model
  - Conflict critical values: TTC, 1.5 s; PET, 5s

- Time-to-collision (TTC):
  - Higher speed → shorter TTC but marginal significance or no significance
  - Probability level did not affect TTC for the same speed condition

- Post Encroachment Time (PET):
  - “Medium speed” condition – higher PET values
  - Probability level did not affect TTC for the same speed condition

Results – Base model

- Base model: constant-only model

$$G_{nt}^{cr,\,g} = e^{(a_g + \varepsilon_{nt})}$$

- Base model – higher traffic, higher number of conflicts and crashes
- Base model – significantly smaller TTC compared to proposed model
- Base model – significantly smaller PET compared to proposed model

Next steps

- Approaching behaviour
  - Approach speed
  - Impact of lead vehicle
  - Distance to merge (0.5 m threshold)

- Gap-related issues
  - Impact of “inner” circulating vehicle
  - Gap correlation and (unobserved heterogeneity)
  - Impact of more vehicles (not only the closest)

- Model validation
  - Road layout similar to raw data
  - Different implementation of P_{cr}
  - Critical headway model implementation

Consortium

VeriCAV
VERIFICATION OF CONNECTED AND AUTONOMOUS VEHICLES

A HORIBA COMPANY MIRA

CATAPULT Connected Places

UNIVERSITY OF LEEDS

aimsun.

VeriCAV is supported by

Centre for Connected
& Autonomous Vehicles

UKRI Innovate UK

Questions?