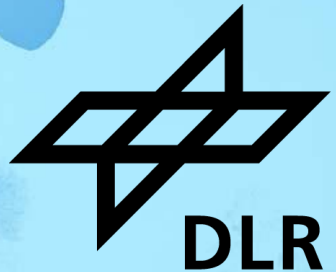


# **SPORE – COMPARISON OF PEDESTRIAN, BICYCLE AND CAR SIMULATOR**

4th HCVRU Sim Workshop 10.04.2025



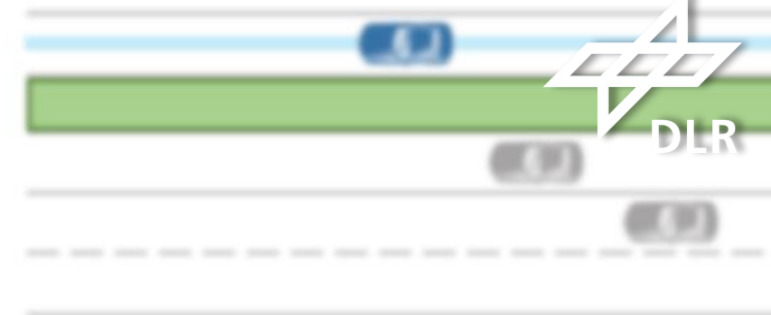
Event 08 – Overtake Pedestrian Grass Verges



Event 06 – Overtake Bicycle Grass Verges



Event 05 – Overtake Vehicle Grass Verges



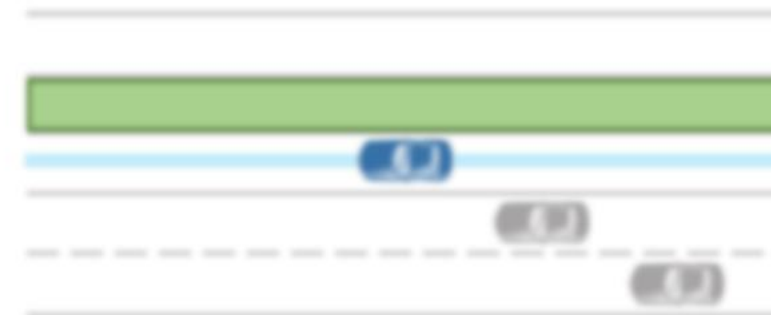
Event 07 – Overtake Pedestrian



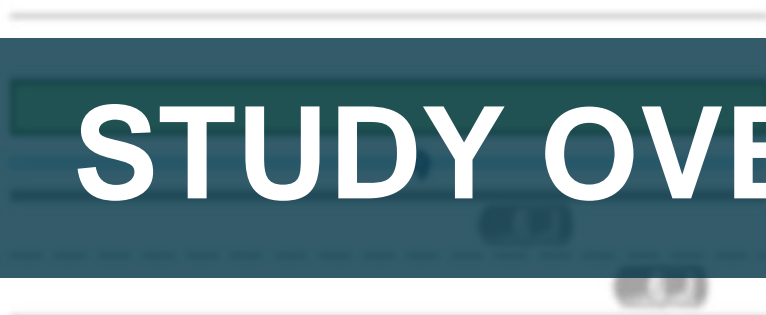
Event 04 – Overtake Bicycle



Event 03 – Overtake Vehicle



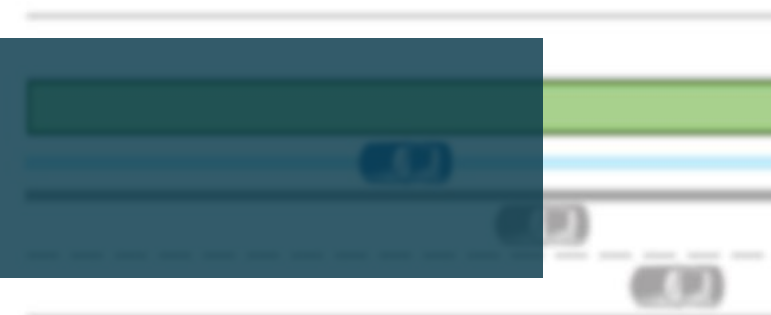
Event 08 – Overtake Pedestrian Barrier



Event 05 – Overtake Bicycle Barrier

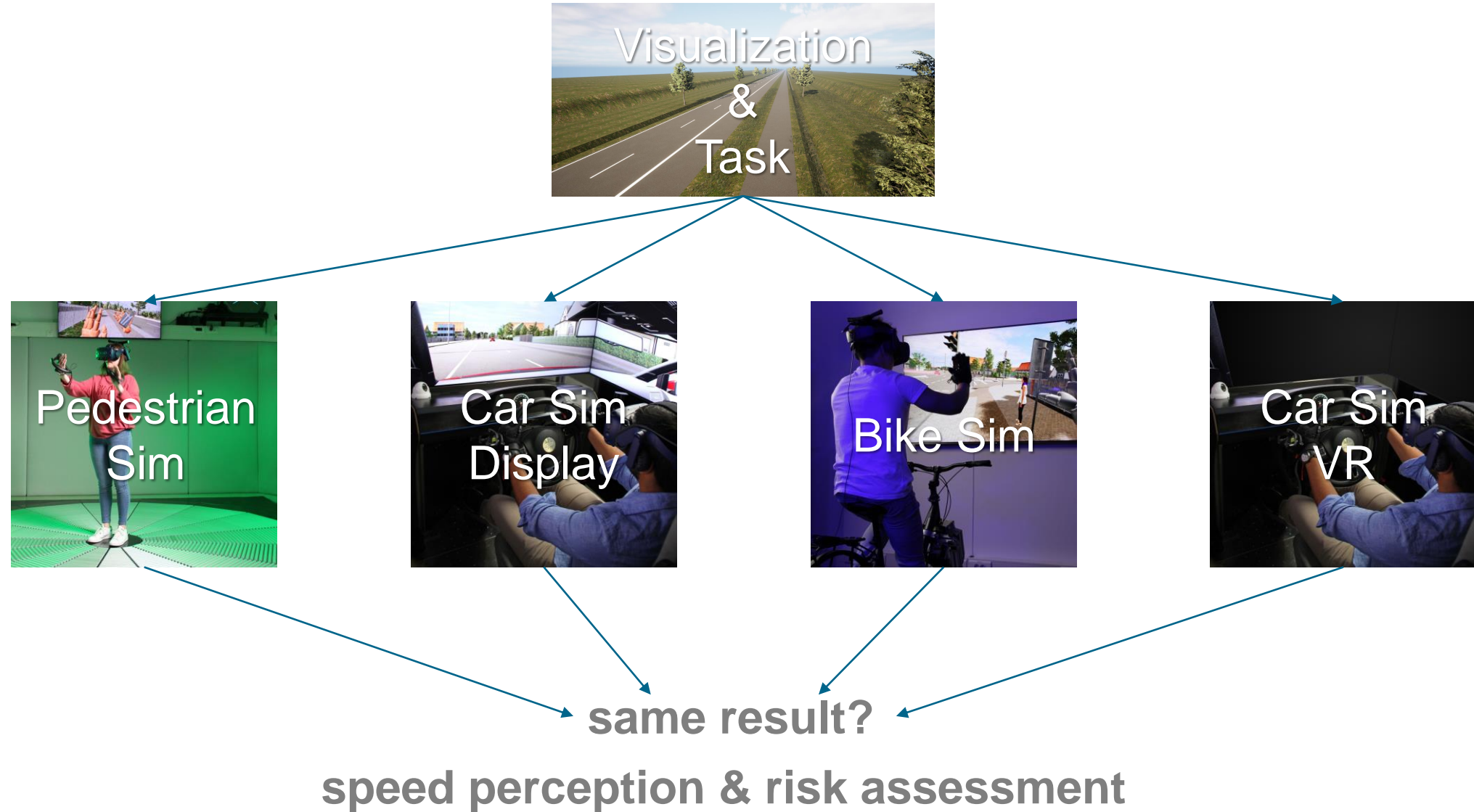


Event 02 – Overtake Vehicle Barrier



# STUDY OVERVIEW

# General Question



- Does the simulator type influence the collected data?
- Do some simulators generate more realistic behavior than others?
  - What would be the implications for multi user scenarios?
- How can we improve the simulation and/or the simulator to generate more realistic user behavior?





|              |           |     |     |     |     |     |     |     |     |     |     |     |     |
|--------------|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Erdbeere     | CarSim VR | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 | 201 | 202 | 203 | 204 |
|              | BikeSim   | 205 | 206 | 207 | 208 | 209 | 210 | 211 | 212 | 213 | 214 | 215 | 216 |
|              | CarSim    | 217 | 218 | 219 | 220 | 221 | 222 | 223 | 224 | 225 | 226 | 227 | 228 |
|              | PedSim    | 229 | 230 | 231 | 232 | 233 | 234 | 235 | 236 | 237 | 238 | 239 | 240 |
| Heidelbeere  | CarSim VR | 241 | 242 | 243 | 244 | 245 | 246 | 247 | 248 | 249 | 250 | 251 | 252 |
|              | PedSim    | 253 | 254 | 255 | 256 | 257 | 258 | 259 | 260 | 261 | 262 | 263 | 264 |
|              | BikeSim   | 265 | 266 | 267 | 268 | 269 | 270 | 271 | 272 | 273 | 274 | 275 | 276 |
|              | CarSim    | 277 | 278 | 279 | 280 | 281 | 282 | 283 | 284 | 285 | 286 | 287 | 288 |
| Himbeere     | BikeSim   | 289 | 290 | 291 | 292 | 293 | 294 | 295 | 296 | 297 | 298 | 299 | 300 |
|              | PedSim    | 301 | 302 | 303 | 304 | 305 | 306 | 307 | 308 | 309 | 310 | 311 | 312 |
|              | CarSim VR | 313 | 314 | 315 | 316 | 317 | 318 | 319 | 320 | 321 | 322 | 323 | 324 |
|              | CarSim    | 325 | 326 | 327 | 328 | 329 | 330 | 331 | 332 | 333 | 334 | 335 | 336 |
| Kirsche      | PedSim    | 337 | 338 | 339 | 340 | 341 | 342 | 343 | 344 | 345 | 346 | 347 | 348 |
|              | CarSim VR | 349 | 350 | 351 | 352 | 353 | 354 | 355 | 356 | 357 | 358 | 359 | 360 |
|              | CarSim    | 361 | 362 | 363 | 364 | 365 | 366 | 367 | 368 | 369 | 370 | 371 | 372 |
|              | BikeSim   | 373 | 374 | 375 | 376 | 377 | 378 | 379 | 380 | 381 | 382 | 383 | 384 |
| Mirabelle    | CarSim VR | 385 | 386 | 387 | 388 | 389 | 390 | 391 | 392 | 393 | 394 | 395 | 396 |
|              | CarSim    | 397 | 398 | 399 | 400 | 401 | 402 | 403 | 404 | 405 | 406 | 407 | 408 |
|              | BikeSim   | 409 | 410 | 411 | 412 | 413 | 414 | 415 | 416 | 417 | 418 | 419 | 420 |
|              | PedSim    | 421 | 422 | 423 | 424 | 425 | 426 | 427 | 428 | 429 | 430 | 431 | 432 |
| Stachelbeere | BikeSim   | 433 | 434 | 435 | 436 | 437 | 438 | 439 | 440 | 441 | 442 | 443 | 444 |
|              | PedSim    | 445 | 446 | 447 | 448 | 449 | 450 | 451 | 452 | 453 | 454 | 455 | 456 |
|              | CarSim    | 457 | 458 | 459 | 460 | 461 | 462 | 463 | 464 | 465 | 466 | 467 | 468 |
|              | CarSim VR | 469 | 470 | 471 | 472 | 473 | 474 | 475 | 476 | 477 | 478 | 479 | 480 |
| Pflaume      | CarSim    | 481 | 482 | 483 | 484 | 485 | 486 | 487 | 488 | 489 | 490 | 491 | 492 |
|              | CarSim VR | 493 | 494 | 495 | 496 | 497 | 498 | 499 | 500 | 501 | 502 | 503 | 504 |
|              | CarSim    | 505 | 506 | 507 | 508 | 509 | 510 | 511 | 512 | 513 | 514 | 515 | 516 |
|              | PedSim    | 517 | 518 | 519 | 520 | 521 | 522 | 523 | 524 | 525 | 526 | 527 | 528 |
| Feige        | PedSim    | 529 | 530 | 531 | 532 | 533 | 534 | 535 | 536 | 537 | 538 | 539 | 540 |
|              | BikeSim   | 541 | 542 | 543 | 544 | 545 | 546 | 547 | 548 | 549 | 550 | 551 | 552 |
|              | CarSim VR | 553 | 554 | 555 | 556 | 557 | 558 | 559 | 560 | 561 | 562 | 563 | 564 |
|              | CarSim    | 565 | 566 | 567 | 568 | 569 | 570 | 571 | 572 | 573 | 574 | 575 | 576 |

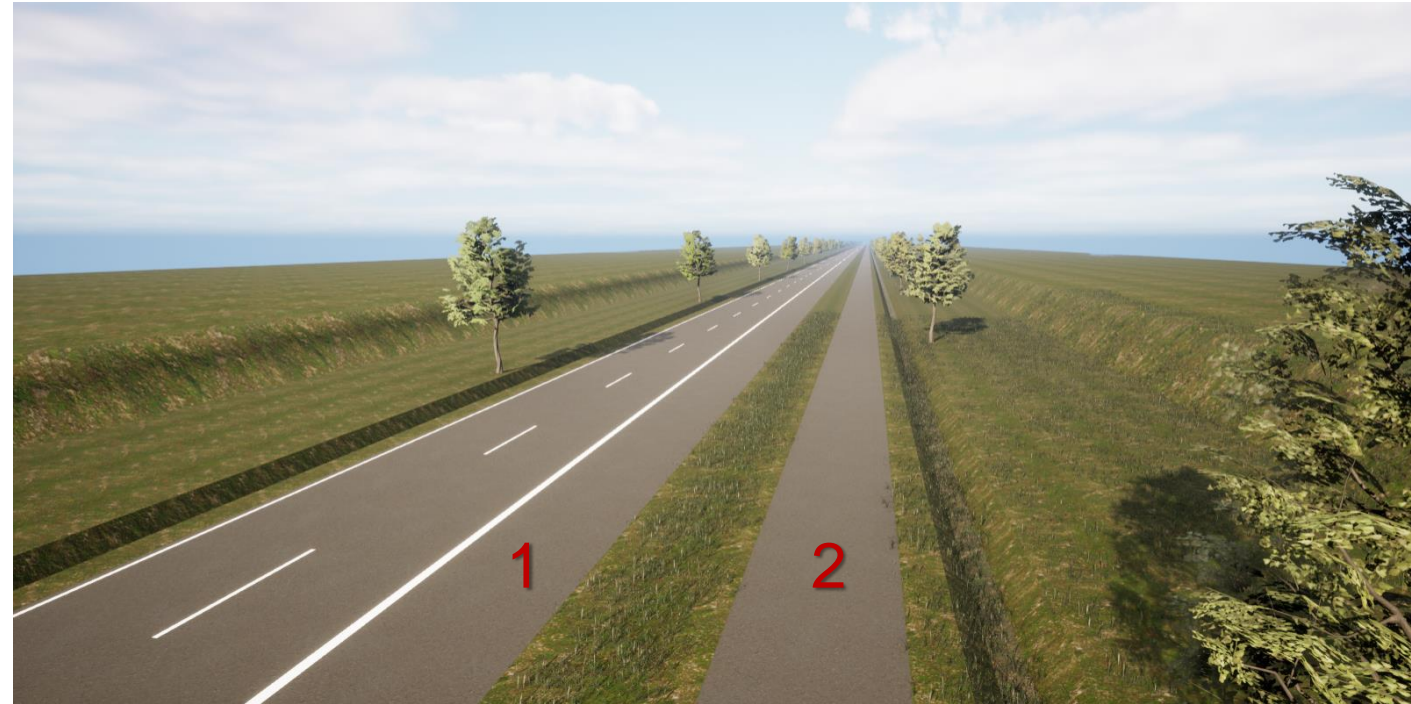
# METHOD & STUDY DESIGN

# Simulators and Virtual Environment



## MoSAIC Simulators

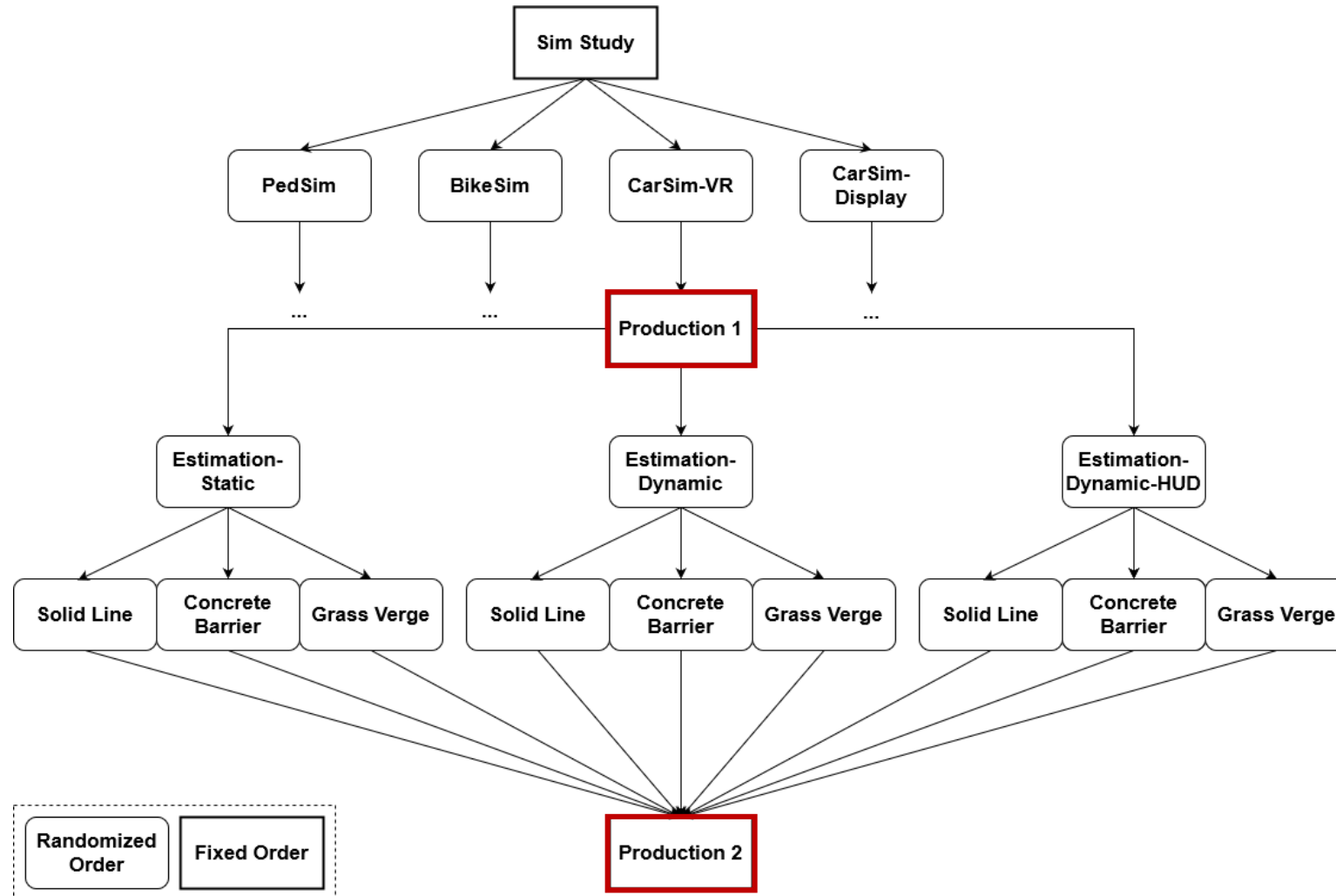
- Bike Simulator
- Pedestrian Simulator
- Car Simulator VR
- Car Simulator Display



## Virtual Environment

- Unreal Engine 5.1
- Variation:
  - Position EGO (1,2)
  - Concrete barrier

# Procedure





# Overtaking and self-produced Speed



Aspired and constant speeds for production and estimation method per simulator

| PedSim | BikeSim | CarSimVR | CarSimDisplay |
|--------|---------|----------|---------------|
| 3 km/h | 15 km/h | 50 km/h  | 50 km/h       |

Overtaking speeds in each simulator

| Simulator     | V1 | V2  | V3  | V4  | V5  |
|---------------|----|-----|-----|-----|-----|
| PedSim        | 10 | 20  | 50  | 80  | 100 |
| BikeSim       | 30 | 50  | 70  | 80  | 130 |
| CarSimVR      | 80 | 100 | 120 | 130 | 180 |
| CarSimDisplay | 80 | 100 | 120 | 130 | 180 |



# Balancing

| ID  | Bezeichnung | Sim       | Training | Production | Estimation | Estimation | Estimation | Estimation | Estimation | Estimation | Estimation | Estimation | Estimation | Production |
|-----|-------------|-----------|----------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| 1   | Apfel       | CarSim    | 1        | 2          | 3          | 4          | 5          | 6          | 7          | 8          | 9          | 10         | 11         | 12         |
|     |             | CarSim VR | 13       | 14         | 15         | 16         | 17         | 18         | 19         | 20         | 21         | 22         | 23         | 24         |
|     |             | BikeSim   | 25       | 26         | 27         | 28         | 29         | 30         | 31         | 32         | 33         | 34         | 35         | 36         |
|     |             | PedSim    | 37       | 38         | 39         | 40         | 41         | 42         | 43         | 44         | 45         | 46         | 47         | 48         |
| 2   | Aprikose    | BikeSim   | 49       | 50         | 51         | 52         | 53         | 54         | 55         | 56         | 57         | 58         | 59         | 60         |
|     |             | CarSim    | 61       | 62         | 63         | 64         | 65         | 66         | 67         | 68         | 69         | 70         | 71         | 72         |
|     |             | CarSim VR | 73       | 74         | 75         | 76         | 77         | 78         | 79         | 80         | 81         | 82         | 83         | 84         |
|     |             | PedSim    | 85       | 86         | 87         | 88         | 89         | 90         | 91         | 92         | 93         | 94         | 95         | 96         |
| 3   | Birne       | PedSim    | 97       | 98         | 99         | 100        | 101        | 102        | 103        | 104        | 105        | 106        | 107        | 108        |
|     |             | CarSim    | 109      | 110        | 111        | 112        | 113        | 114        | 115        | 116        | 117        | 118        | 119        | 120        |
|     |             | BikeSim   | 121      | 122        | 123        | 124        | 125        | 126        | 127        | 128        | 129        | 130        | 131        | 132        |
|     |             | CarSim VR | 133      | 134        | 135        | 136        | 137        | 138        | 139        | 140        | 141        | 142        | 143        | 144        |
| ... |             |           |          |            |            |            |            |            |            |            |            |            |            |            |
| 32  | Physalis    | PedSim    | 1489     | 1490       | 1491       | 1492       | 1493       | 1494       | 1495       | 1496       | 1497       | 1498       | 1499       | 1500       |
|     |             | BikeSim   | 1501     | 1502       | 1503       | 1504       | 1505       | 1506       | 1507       | 1508       | 1509       | 1510       | 1511       | 1512       |
|     |             | CarSim VR | 1513     | 1514       | 1515       | 1516       | 1517       | 1518       | 1519       | 1520       | 1521       | 1522       | 1523       | 1524       |
|     |             | CarSim    | 1525     | 1526       | 1527       | 1528       | 1529       | 1530       | 1531       | 1532       | 1533       | 1534       | 1535       | 1536       |

- 32 test subjects
- 48 Runs per subject
- 1536 runs in total
- Fully balanced estimation method (static, dynamic, dynamic with HUD)

| Randomisierung Streckenreihenfolge der Estimation Methoden |               |   |   |   | Kombination (rot = doppelt) |
|--|---------------|---|---|---|-----------------------------|
| 1  | Apfel         | 1 | 2 | 3 | 123                         |
| 2  | Aprikose      | 2 | 4 | 5 | 245                         |
| 3  | Birne         | 3 | 6 | 1 | 361                         |
| 4  | Brombeere     | 4 | 1 | 2 | 412                         |
| 5  | Erdbeere      | 5 | 3 | 4 | 534                         |
| 6  | Heidelbeere   | 6 | 5 | 1 | 651                         |
| 7  | Himbeere      | 1 | 3 | 6 | 136                         |
| 8  | Kirsche       | 2 | 6 | 4 | 264                         |
| 9  | Mirabelle     | 3 | 2 | 1 | 321                         |
| 10   | Stachelbeere  | 4 | 6 | 5 | 465                         |
| 11   | Pflaume       | 5 | 4 | 3 | 543                         |
| 12   | Feige         | 6 | 1 | 2 | 612                         |
| 13   | Papaya        | 1 | 5 | 6 | 156                         |
| 14   | Weintraube    | 2 | 3 | 4 | 234                         |
| 15   | Pfirsich      | 3 | 5 | 2 | 352                         |
| 16   | Pfirsich2     | 4 | 5 | 6 | 456                         |
| 17   | Granatapfel   | 5 | 2 | 1 | 521                         |
| 18   | Quitte        | 1 | 3 | 4 | 134                         |
| 19   | Sternfrucht   | 1 | 4 | 2 | 142                         |
| 20   | Zitrone       | 2 | 6 | 3 | 263                         |
| 21   | Orange        | 3 | 1 | 6 | 316                         |
| 22   | Mandarine     | 4 | 3 | 5 | 435                         |
| 23   | Banane        | 5 | 6 | 3 | 563                         |
| 24   | Ananas        | 6 | 2 | 5 | 625                         |
| 25   | Birne         | 6 | 1 | 5 | 615                         |
| 26   | Dattel        | 2 | 1 | 4 | 214                         |
| 27   | Drachenfrucht | 3 | 4 | 6 | 346                         |
| 28   | Kiwi          | 4 | 5 | 1 | 451                         |
| 29   | Limette       | 5 | 4 | 2 | 542                         |
| 30   | Mango         | 6 | 2 | 3 | 623                         |
| 31   | Melone        | 1 | 4 | 6 | 146                         |
| 32   | Melone        | 2 | 3 | 5 | 235                         |
| Häufigkeiten   |               |   |   |   | =                           |
| Strecken-Kombinationen (Insgesamt)                         | 1             | 6 | 5 | 5 | 16                          |
|  | 2             | 6 | 5 | 5 | 16                          |
|  | 3             | 5 | 6 | 5 | 16                          |
|  | 4             | 5 | 6 | 5 | 16                          |
|  | 5             | 5 | 5 | 6 | 16                          |
|  | 6             | 5 | 5 | 6 | 16                          |

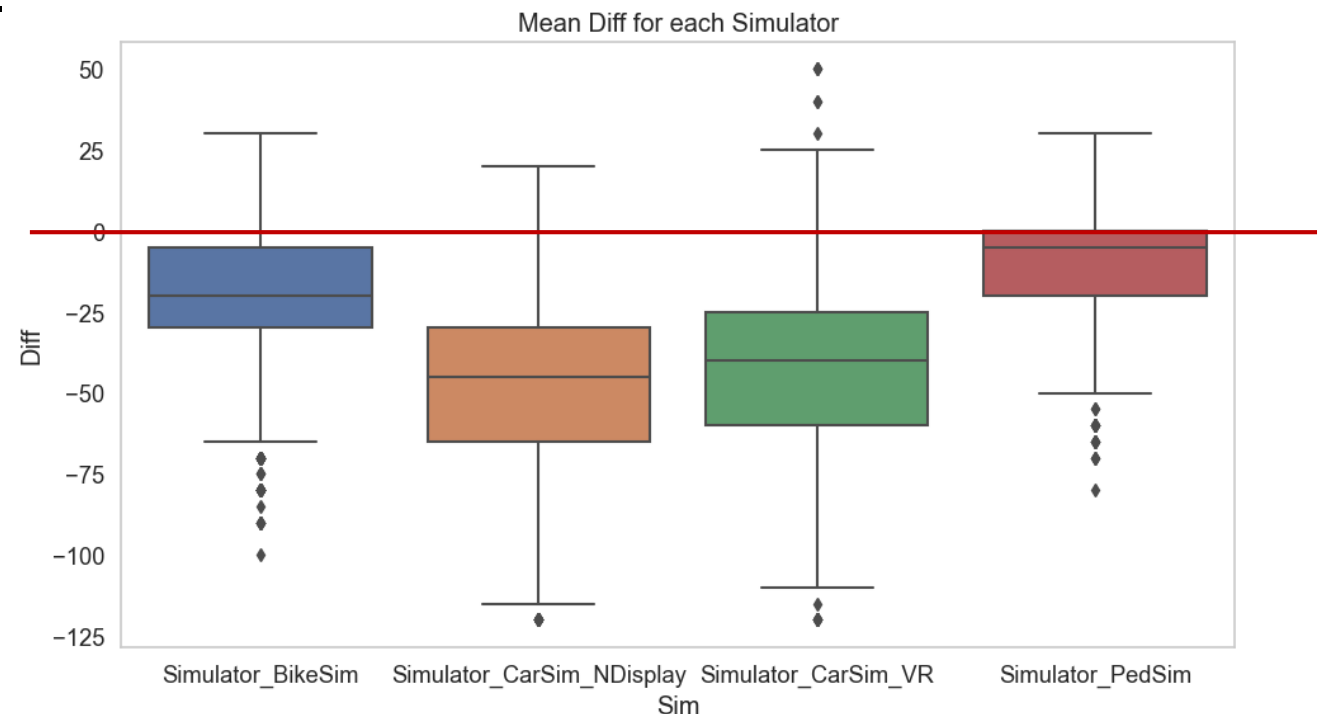
- Before the study
  - Immersive Tendencies Questionnaire
- During each simulator run
  - Speed Assessment (verbal)
- After each simulation
  - Risk Assessment Questions
  - Presence Questionnaire
  - Simulator Sickness Questionnaire
  - Visual Comfort Questionnaire
- After the study
  - Demographical Questionnaire



# RESULTS AND FUTURE PROJEKTS

# Deviation between Estimate and Actual Speed per Sim

- No surprise: Subjects perform poorly when assessing speeds of overtaking road users
- Better performance in VRU simulators (bc of lower overtaking speeds)
- Subjects tend to massively under-estimate overtaking vehicles

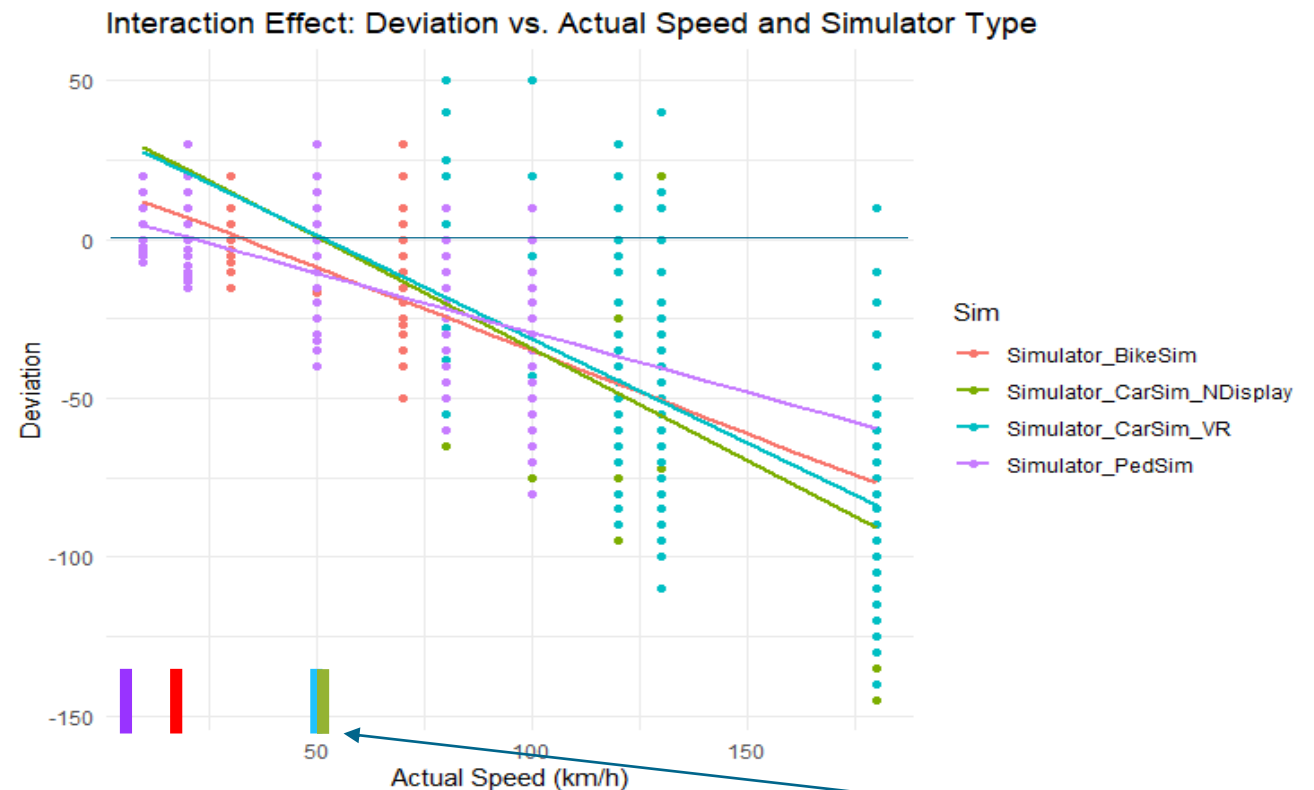




# Deviation vs. Actual Speed and Simulator

- Caution by interpretation of „corners trends“
- Overestimation at low speeds and underestimation at high speeds
- Sweet spot around 80 km/h

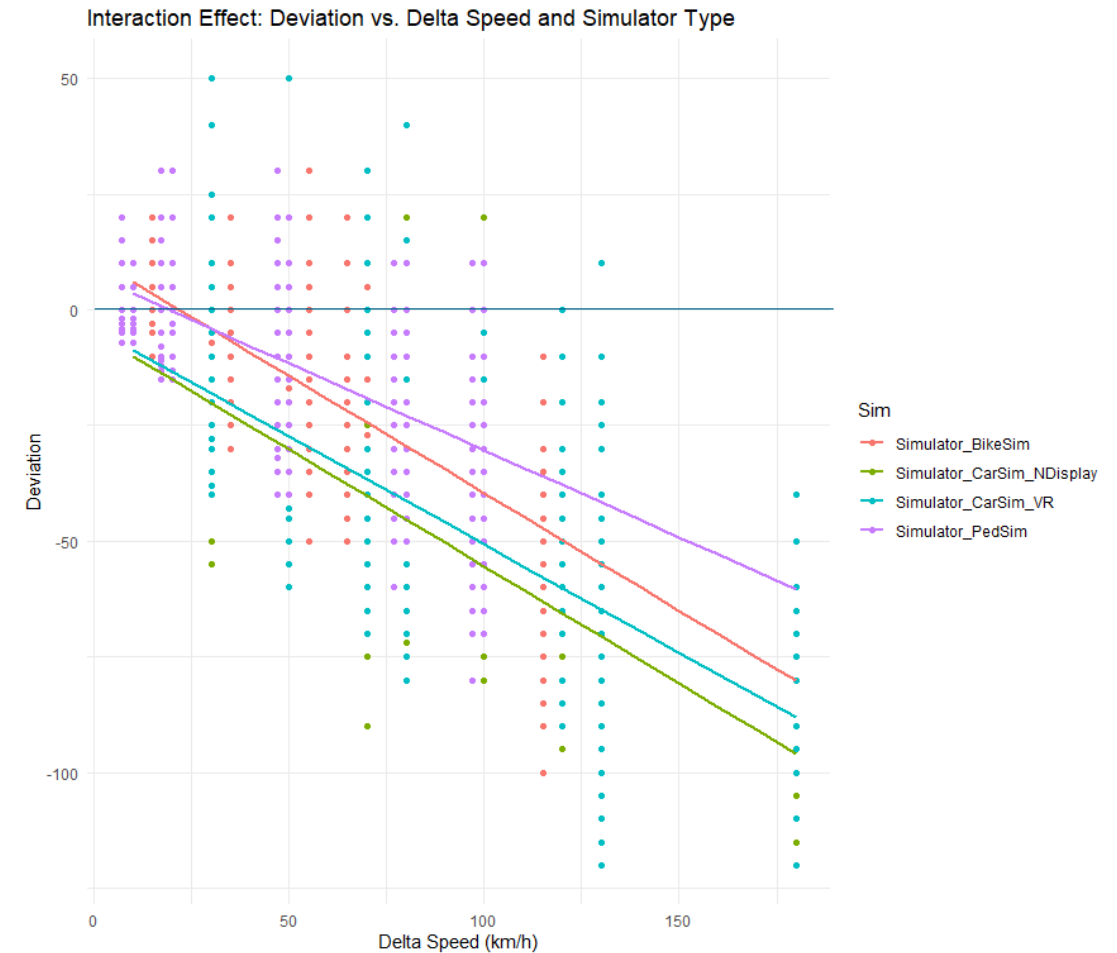
→ Actual speed



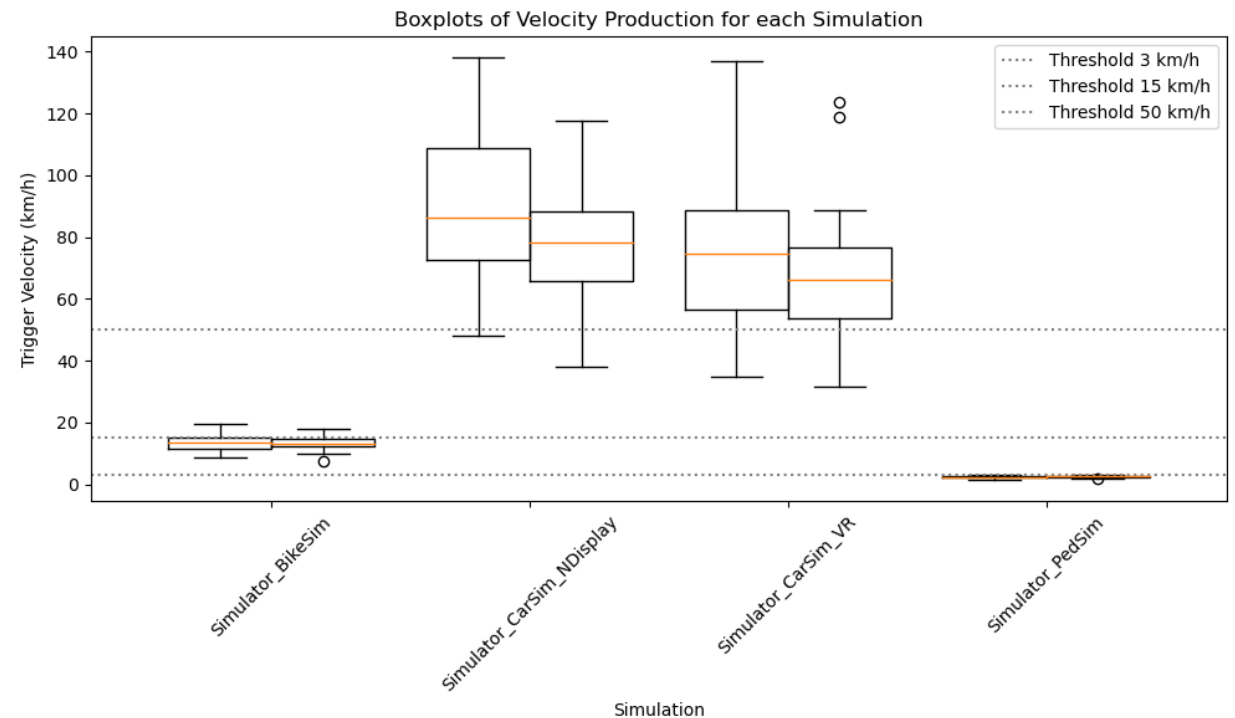
# Deviation vs. Delta Speed and Simulator

→ Delta speed

- Noticable differences between speed perception per simulator
- Subjets perform better in VRU simulators
- VR headset performs better than display condition

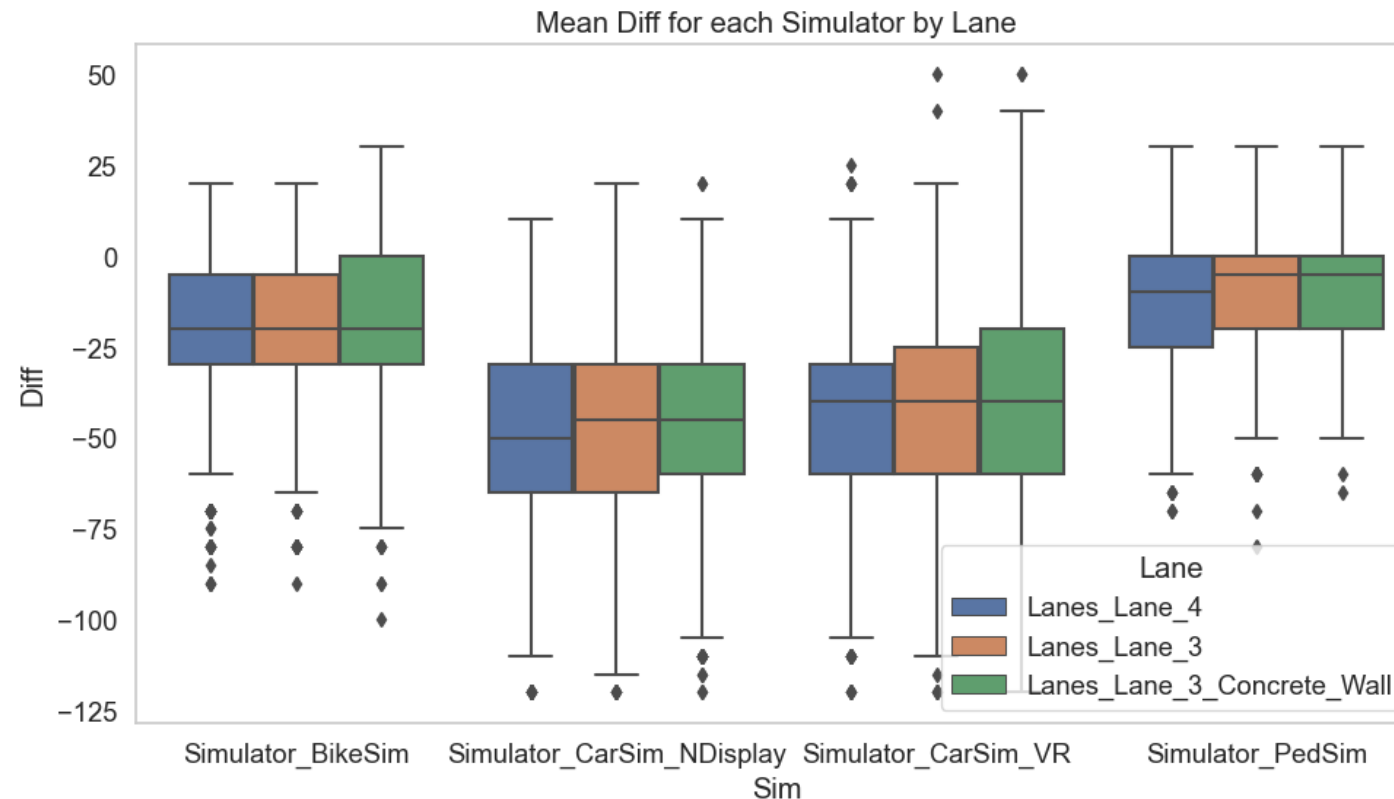


- Overestimation of self produced speed in VRU simulators
- Underestimation in car simulators
- Learning effect in car simulators
- Better performance with HMD



# Deviation between Estimate and Actual Speed per Sim by Lane

- No significant influence of overtaking distance/risk assessment
- Underestimation and higher risk assessment don't cancel each other out





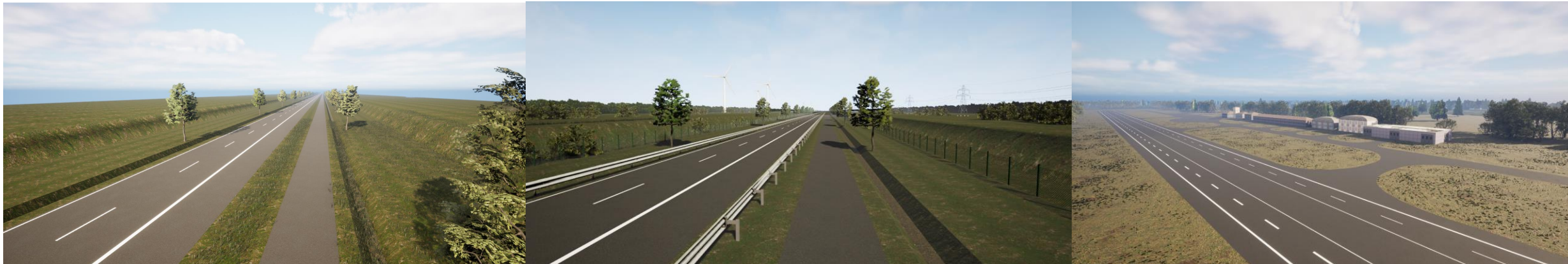
# NEXT STEPS

## ■ SPoRe2 – Sim Study

- Acoustics
- Display resolution
- Object density
- Geometrical field of view
- Marking width

## ■ SPoRe3 – Real Test Track

- Risk assessment
- Distance estimations
- Marking width



**Thanks for your  
Attention!**

# Scenarios



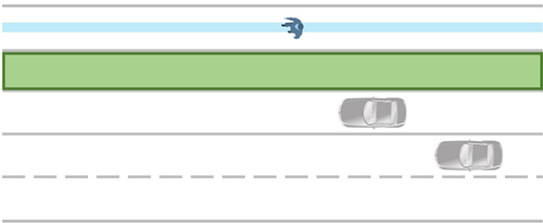
Pedestrian

Bike

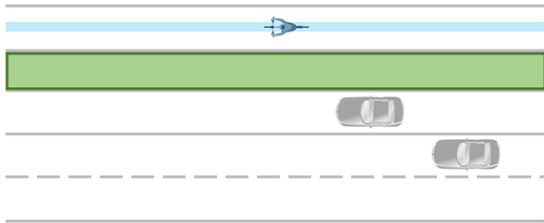
Car

Grass Verge

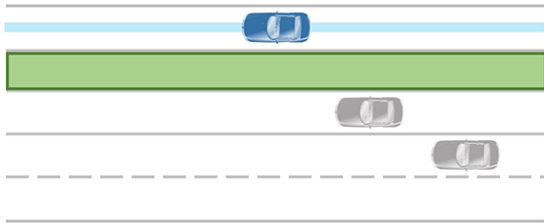
Event 09 – Overtake Pedestrian Grass Verge



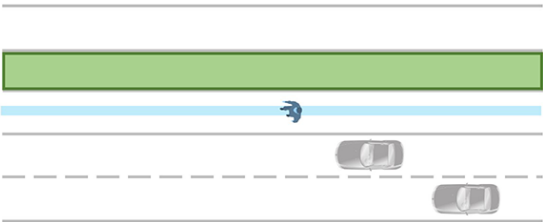
Event 06 – Overtake Bicycle Grass Verge



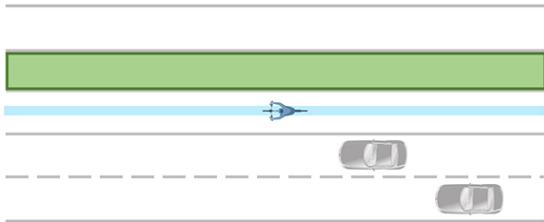
Event 03 – Overtake Vehicle Grass Verge



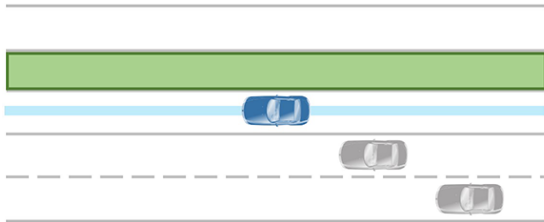
Event 07 – Overtake Pedestrian



Event 04 – Overtake Bicycle

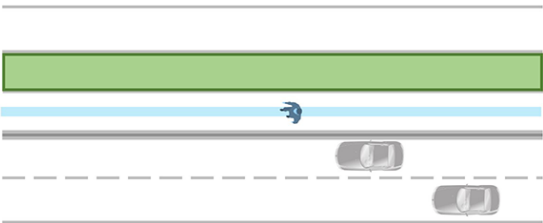


Event 01 – Overtake Vehicle

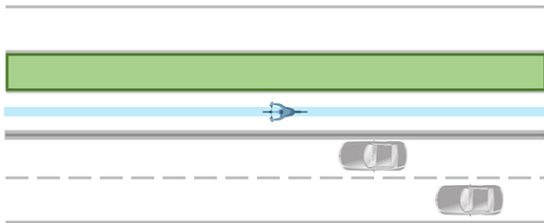


Solid Line

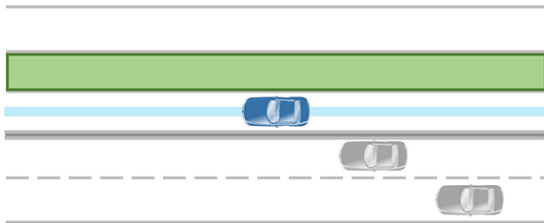
Event 08 – Overtake Pedestrian Barrier



Event 05 – Overtake Bicycle Barrier



Event 02 – Overtake Vehicle Barrier



Concrete Barrier