CoEXist

Definitions of performance metrics and qualitative indicators

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1 Introduction

The mission of the CoEXist project is to systematically increase the capacity of local authorities and other urban mobility stakeholders to prepare for the transition towards a shared road network with increasing levels of connected and automated vehicles (CAVs), both in terms of vehicle penetration rates and levels of automation using the same road network as conventional vehicles (CVs). The overall outcome of the project is to enable local authorities to confidently proclaim that they are “automation-ready”. The concept of “automation-readiness” should not be misunderstood as an endorsement of the disruptive technologies surrounding CAVs and their impacts, but rather an empowerment of local authorities to critically review the anticipated technological changes and shape the future according to their expectations. Hence, the concept of “automation-readiness” is defined as:

The capability of making structured and informed decisions about the comprehensive deployment of CAVs in a mixed road environment. This capability requires:

- A clear awareness of the technology underpinning CAVs, the different functional uses and business models for CAVs and a high-level understanding of the impacts different deployment scenarios can have on traffic, quality of life and stakeholders involved in local transport planning.
- The institutional capacity to plan for a future with CAVs by using tools that accurately represent CAV behaviour in order to identify the impacts of different CAV deployment scenarios.
- A strategic approach in deploying a wide range of measures that will ensure a deployment of CAVs, which supports higher level mobility goals.

There are large expectations of CAVs to improve traffic and space efficiency, enhance safety and improve mobility for all. These gains of CAVs may only be fulfilled when local authorities have the capability to shape the deployment of CAVs to their needs. Without this capability, CAVs are likely to worsen the urban mobility problems that local authorities are currently facing.

CoEXist address three key steps to achieve Automation-ready transport and road infrastructure planning:

- Automation-ready transport modelling: Develop a validated extension of existing microscopic traffic flow simulation and macroscopic transport modelling tools to include various types of CAVs (passenger cars/light-freight vehicles, automation levels).
- Automation-ready road infrastructure: Create a tool to assess the impact of CAVs on traffic performance, safety, and space demand and development of design recommendations for Automation-ready infrastructure.
- Automation-ready road authorities: Elaboration of eight use cases in four European local authorities, to demonstrate the above tools and to develop concrete Automation-ready infrastructure and policy action plans and recommendations for local authorities.

The extended traffic and transport models and the assessment tool will be demonstrated by applying them to the eight CoEXist use cases.

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1.1 Definition of automation ready infrastructure

To be able assess how automation ready a specific infrastructure is in terms of road and traffic control design, the term automation ready infrastructure or road design needs to be defined. The definition used in CoEXist is

> "An automation ready road infrastructure is an infrastructure that allows the coexistence of automated vehicles, conventional vehicles and non-motorized road users, i.e. an infrastructure that can handle an introduction of automated vehicles without significant decline in traffic performance, space efficiency or traffic safety."

The assessment of effects on traffic performance, space efficiency or traffic safety should be conducted per mode or road user category (e.g. pedestrians, bikes, conventional cars, automated cars, conventional trucks, automated trucks, etc.) to allow the user to define what "without significant decline" imply for different types of modes and road users.

1.2 Aim

The aim of this report is to present definitions of the metrics that will be utilised in CoEXist to assess the effects on traffic performance and space efficiency as well as to present the qualitative assessment approach used to assess potential effects on traffic safety. The definitions will be used as a basis for the development of the assessment tool. The definitions presented in this report may be revised, and the final definitions of the metrics will be presented in deliverable "D3.3: AV-ready hybrid road infrastructure assessment tool".

1.3 Report structure

The report consists of three main chapters. Chapter 2 specifies the traffic performance metrics, chapter 3 describe the space efficiency metrics and chapter 4 present the safety assessment approach. The report ends with conclusions and lessons learnt in chapter 5.

For the specification of the metrics we use a revised version of the metric specification template developed in the H2020 project 'FLOW: Congestion Impact Reduction Analysis Tools Guidelines' presented in D2.4 FLOW Impact Assessment Tool – Guideline (Szabo and Schäfer 2016). However, instead of transport mode we use the term *transport user class* to include both transport mode and vehicle class, e.g. bus, train, walking, cycling, conventional vehicle, automated vehicle, conventional car, automated car, conventional truck, automated bus, etc.

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2 Traffic performance metrics

A guiding principle for the evaluation of the traffic performance is to evaluate it per mode; both to provide a more detailed view than an aggregation over all modes would provide, and to allow the road authority using the assessment tool to prioritize certain modes by having stricter automation readiness thresholds for them. Furthermore, assessment per mode is especially important when considering travel time, since the value of time differs per mode and non-automated modes should be considered separately to ensure that they do not experience significant decline. This do not only apply to non-automated non-motorised road users but also to motorised automated and non-automated vehicles. Hence, it is sometimes of interest to assess impact of conventional non-automated vehicles due to the introduction of automated vehicles separately.

In the definitions presented below, a superscript ‘0’ on a quantity indicates that the quantity is calculated based on the baseline scenario simulations, without any AVs, and a superscript ‘A’ indicates that the quantity is calculated in the scenario to be evaluated, with AVs in the traffic.

2.1 Overview of metrics used in the literature

Traffic performance assessment of different types of ADAS or automated vehicles using traffic models differs to some extent to the traditional common usage of traffic models, i.e. assessment of different road and/or traffic control designs. In impact assessment of ADAS or automated vehicles it is the driver/vehicle population that change and not the infrastructure. Anyhow, the traffic performance metrics of relevance and interest can be expected to be the same. In order to investigate if other types of metrics are used in assessment of ADAS and automated vehicles a literature review was conducted.

Most of the found reports and articles did not discuss which metrics to use or if other metrics should be used for ADAS and automation applications of traffic models. However, we went through the literature found and noted which metrics that were utilized. The review was not aiming to give a complete description but to illustrate commonly utilized traffic performance metrics in traffic model investigations of automated vehicles. Hence, there might be other metrics used and there might be additional usage of the metrics listed in this deliverable. The traffic performance metrics that were found to be used in traffic model investigations of ADAS and automated vehicles in the literature are

- Delay related
    - Total (e.g. Bierstedt 2014, Klunder, Li, and Minderhoud 2009, Minelli, Izadpanah, and Razavi 2015, Burghout, Rigole, and Andréasson 2015)
    - Average (e.g. Bierstedt 2014, Deluka Tibljaš et al. 2018, Kesting 2008, Khan et al. 2014, Klunder, Li, and Minderhoud 2009, Le Vine, Zolfaghari, and Polak 2015, Wagner 2016, Hegeman, Tapani, and Hoogendoorn 2009)
    - Standard deviation (e.g. Le Vine, Zolfaghari, and Polak 2015)
    - Percentiles (e.g. Le Vine, Zolfaghari, and Polak 2015)

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- Travel time related
    - Total (e.g. Bierstedt 2014, Bose and Ioannou 1998)
    - Average (e.g. Kesting 2008, Aria, Olstam, and Schwietering 2016, Hegeman, Tapani, and Hoogendoorn 2009)
    - Per distance (e.g. Bierstedt 2014))
- Speed related
    - Average (e.g. Bierstedt 2014, Deluka Tibljaš et al. 2018, Kerner 2016, Kesting 2008, Klunder, Li, and Minderhoud 2009, Ntousakis, Nikolos, and Papageorgiou 2015, Van Arem, Van Driel, and Visser 2006, van Driel and van Arem 2010, Aria, Olstam, and Schwietering 2016)
    - Standard deviation (e.g. Deluka Tibljaš et al. 2018, Klunder, Li, and Minderhoud 2009, Aria, Olstam, and Schwietering 2016)
    - Profiles (e.g. Bose and Ioannou 1999, Bose and Ioannou 2003, Davis 2007, Kikuchi, Uno, and Tanaka 2003, Laquai et al. 2013, Van Arem, Van Driel, and Visser 2006, van Driel and van Arem 2010)
- Capacity related
    - Capacity/Throughput (e.g. Bose and Ioannou 1998, Kesting, Treiber, and Helbing 2010, Klunder, Li, and Minderhoud 2009, Le Vine, Zolfaghari, and Polak 2015, Mahmassani et al. 2018b, a, Motamedidehkordi, Margreiter, and Benz 2016, Talebpour and Mahmassani 2016, Van Arem, Van Driel, and Visser 2006, VanderWerf et al. 2002)
    - Number of vehicles served (e.g. Bierstedt 2014)
    - Volume-to-capacity (e.g. Liu et al. 2017)
    - Probability of breakdown (e.g. Kerner 2016, Kesting 2008, Kesting, Treiber, and Helbing 2010, Mahmassani et al. 2018b)
- Density or spacing between vehicles (e.g.Klunder, Li, and Minderhoud 2009, Ntousakis, Nikolos, and Papageorgiou 2015, Rajamani et al. 2005, Aria, Olstam, and Schwietering 2016)
- Speed-density relationship (e.g. Kesting 2008, Liu et al. 2017, Talebpour and Mahmassani 2016)
- Stability (e.g. Bose and Ioannou 1999, Bose and Ioannou 2003, Kikuchi, Uno, and Tanaka 2003, Mahmassani et al. 2018b, Rajamani et al. 2005, Talebpour and Mahmassani 2016)
- Shock wave related
    - Propagation speed of congestion (e.g. Mahmassani et al. 2018b, Motamedidehkordi, Margreiter, and Benz 2016)

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- Number of shock waves (e.g. Mahmassani et al. 2018b, Van Arem, Van Driel, and Visser 2006)

- Strong decelerations (e.g. Khan et al. 2014)
- Lane change frequency / lane utilization (e.g. Khan et al. 2014, Liu et al. 2017)
- Queue length (e.g. Deluka Tibljaš et al. 2018)
- Vehicle kilometers travelled (e.g. Martinez and Viegas 2017, Burghout, Rigole, and Andréasson 2015, Fagnant and Kockelman 2018, Moreno et al. 2018)
- Modal split (e.g. Minelli, Izadpanah, and Razavi 2015, Moreno et al. 2018)

The conclusion from the literature review is that there are in principle only one report (Mahmassani et al. 2018a) that discuss what metrics to use for evaluation of the introduction of automated vehicles. Furthermore, the metrics used in the reports and articles that we scanned do not deviate from the metrics commonly used for assessing traffic performance from traffic models. Travel time, delay, speed and capacity are common traffic performance metrics used in microscopic simulation studies, while total travel time, vehicle kilometres travelled, and modal split are common metrics in macroscopic traffic assignment studies.

2.2 Choice of metrics

The traffic performance metrics that are planned to be included in the CoEXist assessment tool for assessment of automation readiness are

- Served Demand Ratio (SDR)
- Average travel time (ATT)
- Average individual travel time per distance (AITTD)
- Average delay (AD)
- Vehicle kilometres travelled (VKT)
- Person kilometres travelled (PKT)
- Vehicle Hours Travelled (VHT)
- Person hours travelled (PHT)

The relevance of each metric and how they are calculated are described in sections 2.3-2.10.

2.3 Served Demand Ratio

Performance metric: Served demand ratio (SDR)
Description of metric
Relevance
SDR indicates if the demand exceeds the capacity for the analysed period. This is an important indicator since the introduction of CAVs or infrastructural changes may reduce the capacity and lead to congestion that does not dissolve before the end of the analysis period, which may critically affect the interpretation of other metrics. This metric is only relevant for microscopic use cases since all demand are per definition served in a

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macroscopic traffic assignment model.

Definition

$$SDR_c = \frac{served\ demand\ of\ user\ class\ c}{total\ demand\ of\ user\ class\ c}$$

Assessment approach for automation readiness

$$\frac{SDR_c^A - SDR_c^0}{SDR_c^0}$$

Unit

Unitless

Calculation procedure

Assessed transport user classes[1]

Micro:

- Walking and Cycling;
- Conventional Vehicles: Car, Truck, Bus and Minibus;
- Automated Vehicles: Car, Truck, Bus, and Minibus;

Macro: Not applicable

Calculation rules

The total demand is the input demand during the analysis period and the served demand is the number of travellers reaching their destination during the analysis period, which is given as output from the microscopic model. Assumes a warm up period of sufficient length. The demand can be measured in number of travellers or vehicles, depending on available information.

Sources for required input data

Micro:

- The total amount of vehicles that reaches their destination is given in the network performance evaluation file by Vissim, denoted as VEHARR.
- The total demand is described in the traffic input.

Macro:

- Not applicable to macroscopic models since the SDR equals one by definition.

Further remarks

If the SDR is significantly below one, the effects of congestion measured by other metrics will be underestimated, since part of the congestion is moved to after the analysis period. It is strongly recommended to define the analysis period such that $SDR \approx 1$ at least in the baseline scenario, and if possible in all scenarios. It is also important to have a sufficiently extended warm up period, that allows steady state to develop before the first vehicles that are included in the SDR calculation enter the network.

Not applicable to macroscopic models since the SDR equals one by definition.

[1] The term *transport user class* is used to include both transport mode and vehicle class, e.g. bus, train, walking, cycling, conventional vehicle, automated vehicle, conventional car, automated car, conventional truck, automated bus, etc

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2.4 Average travel time

Performance metric: Average travel time (ATT)
Description of metric
Relevance
ATT is a standard and intuitive metric of the performance of the traffic system, and there is no reason to believe that it will become irrelevant when the transport system becomes automated. However, the generalized cost per unit time is likely to differ between modes, so averaging the travel time over modes should only be done with care. The choice of average travel time instead of total travel time is due to the need for mode specific comparisons between scenarios with different demand of the mode, especially the travel time of conventional cars as their fraction of the fleet decreases.
Definition
Micro: $ATT_c = \frac{1}{N_c}\sum_{n=1}^{N_c} t_{nc}$ t_{nc}: Travel time of individual n in transport user class c. N_c: Number of travellers in transport user class c that reaches their destination during the analysis period. Macro: In a macroscopic transport model, all travellers will reach their destination. Since no individual level travel time is available but a travel time over OD level, the average travel time per traveller will be calculated as: $ATT_c = \frac{\sum_{i=1}^{I}\sum_{j=1}^{J} t_{ijc}^{cur} \times D_{ijc}}{\sum_{i=1}^{I}\sum_{j=1}^{J} D_{ijc}}$ i: Index of origin zone. j: Index of destination zone. I: Set of all origin zones. J: Set of all destination zones. D_{ijc}: Demand of transport user class c from origin zone i to destination zone j. t_{ijc}^{cur}: Travel time of transport use class c from origin zone i to destination zone j on the loaded (congested) network.
Assessment approach for automation readiness
$-\left(\frac{ATT_c^A - ATT_c^0}{ATT_c^0}\right)$ Including only non-automated modes.
Unit
Seconds
Calculation procedure
Assessed transport user classes[2]
Micro:

[2] The term *transport user class* is used to include both transport mode and vehicle class, e.g. bus, train, walking, cycling, conventional vehicle, automated vehicle, conventional car, automated car, conventional truck, automated bus, etc

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- Walking and Cycling;
- Conventional Vehicles: Car, Truck, Bus and Minibus;
- Automated Vehicles: Car, Truck, Bus, and Minibus;

Macro:
- Conventional Car, Automated Car, Car (sum of Conventional Car and Automated Car),
- Truck,
- All vehicles (sum of Conventional Car, Automated Car and Truck).

Calculation rules

The travel time of individual vehicles are given by the simulation. Only vehicles reaching their destination during the analysis period is included, and their whole travel time is counted, including any portion of it that occurs during the warm up period. Hence, a long enough warm-up period is required.

For the macro use cases,
The travel time between origins and destinations on the loaded (congested) network are given by the macroscopic traffic assignment. The demand matrix D_{ijc} for each transport user class m is the input of the model, thus is available. It is, however, important to note that not all OD pairs defined in the model will be used since some OD pairs are trips from a peripheral zone to a peripheral zone where the network coded near these peripheral zones is often simplified. This means that travel time t_{ijc}^{cur} for these OD pairs will be unrealistic. It is recommended that only OD pairs within the detailed coded network should be used.

Sources for required input data

Micro:

The vehicle records provide:
- Mode type of each vehicle, VEHTYPE
- The total time in network for each vehicle, TMINNNETTOT
- Time stamps of trajectory, SIMSEC

Macro:
- Type of travel mode. It is given by the Transport system ID.
- Selection set of OD pairs that are within detailed coded network.
- The travel time between OD for a given transport user class. It is given by the PrT skim where the skimmed travel time matrix can be calculated on the loaded (congested) network, tcur.
- The demand between OD for a given transport user class. It is given by the input demand matrix or available from the demand model.

Further remarks

One of the reasons for the importance of ATT as a performance metric is that the travel time constitute a significant fraction of the cost of a trip when included in CBAs and similar analyses. However, when CAVs are introduced, they will most likely follow the speed limits, and thus get a higher ATT than conventional vehicles that routinely speeds. This effect is of course real and should be considered, but the users of the CAVs are likely to be aware of this design feature and values the benefits of the automation higher than the increased TT. Thus, it is questionable if the increased ATT for CAVs compared to conventional vehicles should be treated as a cost or a negative effect of the introduction of CAVs (unless also the benefits, which are hard to estimate, are included). Thus, only the travel time of non-automated vehicles are included in the evaluation of automation readiness.

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2.5 Average individual travel time per distance

Performance metric: Average individual travel time per distance (AITTD)
Description of metric
Relevance
If the studied network includes routes with differing lengths, there is a risk that the ATT gets dominated by effects on the long routes. Complementing the ATT with the AITTD enables detection of increased travel times on short routes, thus providing a more complete view. In addition, AITTD is completely constrained to the analysis period.
Definition
$AITTD_c = \frac{1}{N_c}\sum_{n=1}^{N_c}\frac{t_{nc}}{d_{nc}}$ t_{nc}: Travel time of individual n in transport user class c, including only time within the analysis period, d_{nc}: Travelled distance of individual n in transport user class c, including only distance travelled within the analysis period, N_c: Number of travellers in transport user class c, during the analysis period. In a macroscopic transport model, the measure will be calculated as: $AITTD_c = \frac{\sum_{i=1}^{I}\sum_{j=1}^{J}\frac{t_{ijm}^{cur} \times D_{ic}}{d_{ijc}}}{\sum_{i=1}^{I}\sum_{j=1}^{J} D_{ijc}}$ I: Set of all origin zones. J: Set of all destination zones. D_{ijc}: Demand of transport user class c from origin zone i to destination zone j, t_{ijc}^{cur}: Travel time on the loaded (congested) network. d_{ijc}: Skimmed trip distance from origin zone *i* to destination zone *j* by transport user class *c*.
Assessment approach for automation readiness
$-\left(\frac{AITTD_c^A - AITTD_c^0}{AITTD_c^0}\right)$
Unit
seconds/meter
Calculation procedure
Assessed transport user classes[3]
Micro: • Walking and Cycling; • Conventional Vehicles: Car, Truck, Bus and Minibus; • Automated Vehicles: Car, Truck, Bus, and Minibus;

[3] The term *transport user class* is used to include both transport mode and vehicle class, e.g. bus, train, walking, cycling, conventional vehicle, automated vehicle, conventional car, automated car, conventional truck, automated bus, etc

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Macro: • Conventional Car, Automated Car, Car (sum of Conventional Car and Automated Car), • Truck, • All vehicles (sum of Conventional Car, Automated Car and Truck).
Calculation rules
The travel time and travelled distance of individual vehicles are given by the simulation, and only the part of the travel time experienced by travellers within the analysis period is included. For macro use cases, the travel time and travel distance on the OD level is directly available from the PrT skim. It is important to know that the distance must be calculated as the mean distance over all paths from the equilibrium network. At the equilibrium stage, several paths will be used for travellers from a given OD where the travel time of these paths will be similar due to the equilibrium while the travel distance may differ significantly. Therefore, it is recommended to skim distance of all the paths and take the weighted mean value.
Sources for required input data
Micro: • Mode type of each vehicle, VEHTYPE • The total time in network for each vehicle, TMINNNETTOT • The travelled distance of each vehicle, DistTravTot • Time stamps of trajectory, SIMSEC Macro: • Type of transport user class . It is given by the Transport system ID. • Selection set of OD pairs that are within the detailed coded network. • The travel time between OD for a given transport user class. It is given by the PrT skim where the skimmed travel time matrix can be calculated on the loaded (congested) network, t_{cur}. • The travel distance matrix between OD for a given transport user class. It is given by the PrT skim where the skimmed travel distance matrix can be calculated on the loaded (congested) network, *DIS* • The demand between OD for a given transport user class. It is given by the input demand matrix.
Further remarks
The AITTD should not be confused with the average travel time per distance, which is the ratio of the total travel time to the total travelled distance, that is, the inverse of the mean speed. There is a need for both ATT and AITTD: Since AITTD is the arithmetic mean of individual average travel times per distance, it weighs all road users equally, regardless their distance travelled in the network; this may or may not be suitable, depending on the circumstances. Also, the AITTD is less sensitive than ATT to measures that change the trip lengths.

2.6 Average delay

Performance metric: Average delay (AD)
Description of metric
Relevance
Delay is the primary metric for traffic inefficiency, and there are no indications that it will be made irrelevant by the introduction of CAVs. It complements ATT and AITTD by considering that CAVs have a lower desired speed

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than conventional vehicles. Thus, CAVs will have a longer travel time, due to their lower desired speed, which will be captured by the ATT, but only increased travel time relative to their travel time at the desired speed is included in the delay.
Definition
The delay of a road user is defined as the difference between the actual travel time and the travel time in an empty network. To avoid running extra simulations with each road user through an empty network, assuming static route choice, the delay is approximated by $AD_c = \frac{\Delta t}{N_c} \sum_{n=1}^{N_c} \sum_{i_n=0}^{T_n} \left(1 - \frac{v_{i_n}}{{v^T}_{i_n}}\right)$ Δt: Time step size i_n: Time step index of road user n T_n: Number of timesteps within the analysis period for road user n v_{i_n}: Speed of road user n at time step i_n ${v^T}_{i_n}$: Theoretical speed of road user n at time step i_n; the theoretical speed equals the desired speed everywhere except when the desired speed changes, then it is adapted to be equal to the speed of a free vehicle adapting its speed from the old to the new desired speed. N_c: Number of road users in transport user class c In the macro case, the concept of delay can vary between different contexts. Since the users are constantly changing routes to minimize the impedance (travel time in most cases). The routes used for a given OD pair on the unloaded network may be very different from the ones in the loaded network. The delay of a given OD pair therefore may refer to the travel time difference caused by the fact that travelers on this OD pair change route. In the macro case, we suggest calculating average delay using the following formula: $AD_c = \frac{\sum_{i=1}^{I} \sum_{j=1}^{J} (t_{ijc}^{cur} - t_{ijc}^{0}) \times D_{ijc}}{\sum_{i=1}^{I} \sum_{j=1}^{J} D_{ijc}}$ i: Index of origin zone. *J:* Index of destination zone. I Set of all origin zones. J Set of all destination zones. D_{ijc}: Demand of transport user class c from origin zone i to destination zone j. t_{ijc}^{cur}: Travel time of transport user class c from origin zone i to destination zone j on the loaded (congested) network. t_{ijc}^{0}: Travel time on the unloaded network. It is important to note that t_{ijm}^{0} should be calculated by skimming the unloaded network (using t_{ijc}^{0} as the path search criterion) not the loaded network (using impedance or t_{ijc}^{cur} as the path search criterion).
Assessment approach
$-\left(\frac{AD_c^A - AD_c^0}{AD_c^0}\right)$
Unit
Seconds

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Calculation procedure

Assessed transport user classes[4]

Micro:

- Walking and Cycling;
- Conventional Vehicles: Car, Truck, Bus and Minibus;
- Automated Vehicles: Car, Truck, Bus, and Minibus;

Macro:

- Conventional Car, Automated Car, Car (sum of Conventional Car and Automated Car),
- Truck,
- All vehicles (sum of Conventional Car, Automated Car and Truck).

Calculation rules

Vissim calculates the cumulative delay of each entity and stores it in the driver or pedestrian records.

For the macro use cases, the travel time between origins and destinations on the loaded (congested) network are given by the macroscopic traffic assignment. The demand matrix D_{ijm} for each mode m is the input of the model, thus is available. It is, however, important to note that not all OD pairs defined in the model will be used since some OD pairs are trips from a peripheral zone to a peripheral zone where the network coded near these peripheral zones is often simplified. This means that travel time t_{ijm}^{cur} for these OD pairs will be unrealistic. It is recommended that only OD pairs within the detailed coded network should be used.

It is important to note that t_{ijm}^{0} should be calculated by skimming the unloaded network (using t_{ijm}^{0} as the path search criterion) not the loaded network (using impedance or t_{ijm}^{cur} as the path search criterion).

Sources for required input data

Micro:

- The delay of each vehicle, DELAYTM
- The vehicle type, VEHTYPE

Macro:

- Type of transport user class is given by the Transport system ID.
- Selection set of OD pairs that are within detailed coded network.
- The travel time between OD for a given transport user class. It is given by the PrT skim where the skimmed travel time matrix can be calculated on the loaded (congested) network, t_{cur}.
- The travel time matrix between OD for a given transport user class. It is given by the PrT skim where the skimmed travel time matrix can be calculated on the unloaded (free flow) network, t_0
- The demand between OD for a given transport user class. It is given by the input demand matrix.

Further remarks

[4] The term *transport user class* is used to include both transport mode and vehicle class, e.g. bus, train, walking, cycling, conventional vehicle, automated vehicle, conventional car, automated car, conventional truck, automated bus, etc

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2.7 Vehicle kilometres travelled

Performance metric: Vehicle kilometres travelled (VKT)
Description of metric
Relevance
Vehicle kilometres travelled (VKT) is the primary metric that is relevant for accessibility assessed in macroscopic models. A dramatical increase in VKT of all travellers modelled in the macroscopic model would indicate a substantial change in travellers' destination choice and route choice, indicating that travellers tend to travel to destinations that are further away. However, if the destination choice is fixed in the macroscopic model, the relationship between the introduction of CAVs and VKT becomes less intuitive and straightforward. VKT of CAVs, is of less interest in this case compared to the VKT of all transport user classes since total number of vehicles per transport user class depend on the penetration rate. However, VKT of a specific transport user class such as Car in total (sum of CAVs and CVs) can be of interest.
Definition
In a macroscopic transport model where both demand and supply are modelled, the mode choice and destination choice will depend on the (congested) travel time and/or distance between each OD pair. The introduction of CAVs will have a direct impact on travel time resulting in a change of destination choice and mode choice that leads to a change in VKT. VKT is calculated as: $VKT_m = \sum_{c=1}^{M_c} \sum_{i=1}^{I} \sum_{j=1}^{J} d_{ijc} \times D_{ijc}$ *c*: index of transport user class. m: index of travel mode. M_C: number of transport user class *c* can constitute a specific mode (e.g. conventional and automated cars that together constitute the mode car). i: Index of origin zone. j: Index of destination zone. I: Set of all origin zones. J: Set of all destination zones. d_{ijc}: skimmed distance of transport user class *c* from origin zone *i* to destination zone *j*. D_{ijc}: Demand of transport user class *c* from origin zone *i* to destination zone *j*.
Assessment approach
$-\left(\frac{VKT_m^A - VKT_m^0}{VKT_m^0}\right)$
Unit
Vehicle kilometres
Calculation procedure
Assessed transport user classes[5]
Micro: • Not relevant

[5] The term *transport user class* is used to include both transport mode and vehicle class, e.g. bus, train, walking, cycling, conventional vehicle, automated vehicle, conventional car, automated car, conventional truck, automated bus, etc

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Macro: • Car, Truck, Bus, Train. Separation into conventional and automated vehicles is not of interest.
Calculation rules
Micro: Not relevant Macro: For the macro use cases, the demand matrix D_{ijc} for each transport user class c is the input of the model, thus is available. It is, however, important to note that not all OD pairs defined in the model will be used since some OD pairs are trips from a peripheral zone to a peripheral zone where the network coded near these peripheral zones is often simplified. This means that travel time and the skimmed travel distance for these OD pairs will be unrealistic. It is recommended that only OD pairs within the detailed coded network should be used. It is important to know that the skimmed distance must be calculated as the mean distance over all paths from the equilibrium network. At the equilibrium stage, several paths will be used for travellers from a given OD where the travel time of these paths will be similar due to the equilibrium while the travel distance may differ significantly. Therefore, it is recommended to skim distance of all the paths and take the weighted mean value.
Sources for required input data
Micro: • The metric is not relevant for micro cases Macro: • Type of transport user class. It is given by the Transport system ID. • Selection set of OD pairs that are within detailed coded network. • The travel distance matrix between OD for a given transport user class. It is given by the PrT skim where the skimmed travel distance matrix can be calculated on the loaded (congested) network, *DIS* • The demand between OD for a given transport user class. It is given by the input demand matrix or available from the demand model.
Further remarks
Only interesting for macroscopic use cases

2.8 Person kilometres travelled

Performance metric: Person kilometres travelled (PKT)
Description of metric
Relevance
Person kilometres travelled (PKT) is a primary metric that is relevant for accessibility assessed in macroscopic models. A dramatical change in PKT of all travellers modelled in the macroscopic model would indicate a substantial change in travellers' destination choice and route choice, indicating that travellers tend to travel to destinations that are further away. However, if the destination choice is fixed in the macroscopic model, the relationship between the introduction of CAVs and PKT becomes less intuitive and straightforward. PKT of CAVs, is of less interest in this case compared to the PKT of all modes since total number of vehicles per mode depend on the penetration rate. In VISUM, the private transport system (PrT) in principal uses vehicle as unit while the public transport system (PuT) uses passenger as unit. In the PrT system, if it is assumed that each vehicle carries

only one person (occupancy rate is 1) then PKT is equivalent as VKT. If it is assumed otherwise or there is a demand model explicitly modelling number of individuals per vehicle, PKT could provide insights other than VKT. For the PuT system, PKT is the standard indicator while VKT is often less intuitive. VKT of CAVs, is of less interest in this case compared to the VKT of all vehicle classes since total number of vehicles per vehicle class depend on the penetration rate. However, VKT of a specific transport user class such as Car in total (sum of CAVs and CVs) can be of interest.

Definition

In a macroscopic transport model where both demand and supply are modelled, the mode choice and destination choice will depend on the (congested) travel time and/or distance between each OD pair. The introduction of CAVs will have a direct impact on travel time resulting in a change of destination choice and mode choice that leads to a change in PKT. PKT is calculated similarly as VKT as:

$$PKT_m = \sum_{c=1}^{M_c} O_c \times \left(\sum_{i=1}^{I} \sum_{j=1}^{J} d_{ijc} \times D_{ijc} \right)$$

c: index of transport user class.
m: index of travel mode.
M_c: number of transport user class *c* can constitute a specific mode (e.g. conventional and automated cars that together constitute the mode car).
i: Index of origin zone.
j: Index of destination zone.
I: Set of all origin zones.
J: Set of all destination zones.
d_{ijc}: skimmed distance of transport user class *c* from origin zone i to destination zone j.
D_{ijc}: Demand of transport user class *c* from origin zone *i* to destination zone *j*.
O_c: occupancy rate of transport user class *c*.

Assessment approach

$$-\left(\frac{PKT_c^A - PKT_c^0}{PKT_c^0}\right)$$

Unit

Vehicle kilometres

Calculation procedure

Assessed transport user classes[6]

Micro:

- Not relevant

Macro:

- Car, Truck, Bus, Train. Separation into conventional and automated vehicles is not of interest.

Calculation rules

Micro: Not relevant

Macro:

[6] The term *transport user class* is used to include both transport mode and vehicle class, e.g. bus, train, walking, cycling, conventional vehicle, automated vehicle, conventional car, automated car, conventional truck, automated bus, etc

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For the macro use cases, the demand matrix D_{ijc} for each transport user class c is the input of the model, thus is available. It is, however, important to note that not all OD pairs defined in the model will be used since some OD pairs are trips from a peripheral zone to a peripheral zone where the network coded near these peripheral zones is often simplified. This means that travel time and the skimmed travel distance for these OD pairs will be unrealistic. It is recommended that only OD pairs within the detailed coded network should be used. It is important to know that the skimmed distance must be calculated as the mean distance over all paths from the equilibrium network. At the equilibrium stage, several paths will be used for travellers from a given OD where the travel time of these paths will be similar due to the equilibrium while the travel distance may differ significantly. Therefore, it is recommended to skim distance of all the paths and take the weighted mean value.
Sources for required input data
Micro: • The metric is not relevant for micro cases Macro: • Type of transport user class. It is given by the Transport system ID. • Selection set of OD pairs that are within detailed coded network. • The travel distance matrix between OD for a given transport user class. It is given by the PrT skim where the skimmed travel distance matrix can be calculated on the loaded (congested) network, *DIS* • The demand between OD for a given transport user class. It is given by the input demand matrix or available from the demand model. • The occupancy rate O_c is an input of each transport user class and thus is available. In the situation where occupancy rate is modelled in a more careful manner, corresponding occupancy rate at specific OD level or trip level should be used.
Further remarks
Only interesting for macroscopic use cases

2.9 Vehicle hours travelled

Performance metric: Person hours travelled (VHT)
Description of metric
Relevance
VHT is the primary metric of overall congestion level assessed in macroscopic models. An increase in VHT of all vehicles would indicate an increased congestion level. Intuitively, VHT has a relationship with the penetration rate of CAVs as the introduction of CAVs directly impacts the network capacity, congestion level and travel time between OD pairs. VHT of CAVs is also of less interest in this case compared to the VHT of all vehicle classes since total number of vehicles per vehicle class depend on the penetration rate. However, VHT of a specific transport user class such as Car in total (sum of CAVs and CVs) can be of interest.
Definition
Micro: $VHT_m = \sum_{m=1}^{M} \sum_{i=1}^{I_m} t_{im}$ t_{nm}: Travel time of vehicle i in mode m.

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m: index of transport mode. I_m: number of vehicles in mode m that reach their destination during the analysis period. Macro: $VHT_m = \sum_{c=1}^{M_c} \sum_{i=1}^{I} \sum_{j=1}^{J} t_{ijc}^{cur} \times D_{ijc}$ c: index of transport user class. m: index of travel mode. M_c: number of transport user class *c* can constitute a specific mode (e.g. conventional and automated cars that together constitute the mode car). i: Index of origin zone. j: Index of destination zone. I: Set of all origin zones. J: Set of all destination zones. t_{ijc}^{cur}: Travel time of transport user class *c* from origin zone *i* to destination zone *j* on the loaded (congested) network. D_{ijm}: Demand of mode *m* from origin zone *i* to destination zone *j*.
Assessment approach
$-\left(\frac{VHT_m^A - VHT_m^0}{VHT_m^0}\right)$
Unit
Hours
Calculation procedure
Assessed transport user classes[7]
Micro: • Total, Cars, Trucks, Bus, Minibus, Walking and Cycling. Separation into conventional and automated vehicles is not of interest Macro: • Car, Truck, Bus, Train. Separation into conventional and automated vehicles is not of interest
Calculation rules
Macro: For the macro use cases, the demand matrix D_{ijc} for each transport user class c is the input of the model, thus is available. It is, however, important to note that not all OD pairs defined in the model will be used since some OD pairs are trips from a peripheral zone to a peripheral zone where the network coded near these peripheral zones is often simplified. This means that travel time and the skimmed travel distance for these OD pairs will be unrealistic. It is recommended that only OD pairs within the detailed coded network should be used.
Sources for required input data
Macro: • Type of transport user class. It is given by the Transport system ID. • Selection set of OD pairs that are within detailed coded network.

[7] The term *transport user class* is used to include both transport mode and vehicle class, e.g. bus, train, walking, cycling, conventional vehicle, automated vehicle, conventional car, automated car, conventional truck, automated bus, etc

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- The travel time between OD for a given transport user class. It is given by the PrT skim where the skimmed travel time matrix can be calculated on the loaded (congested) network, t_{cur}.
- The demand between OD for a given transport user class. It is given by the input demand matrix or available from the demand model.

Further remarks

2.10 Person hours travelled

Performance metric: Person hours travelled (PHT)
Description of metric
Relevance
PHT is also the primary metric of overall congestion level assessed in macroscopic models. PHT has many similarities as VHT but the fundamental difference lies on how travel unit is defined and modelled in each transport system. In VISUM, the private transport system (PrT) in principal uses vehicle as unit while the public transport system (PuT) uses passenger as unit. In the PrT system, if it is assumed that each vehicle carries only one person (occupancy rate is 1) then PHT is equivalent as VHT. If it is assumed otherwise or there is a demand model explicitly modelling number of individuals per vehicle, PHT could provide insights other than VHT. For the PuT system, PHT is the standard indicator while VHT is often less intuitive. VHT of CAVs is also of less interest in this case compared to the VHT of all vehicle classes since total number of vehicles per transport user class depend on the penetration rate. However, VHT of a specific transport mode such as Car in total (sum of CAVs and CVs) can be of interest.
Definition

Micro:

$$PHT_m = \sum_{m=1}^{M} \sum_{n=1}^{N_m} t_{nm}$$

t_{nm}: Travel time of individual n in mode m.
N_m: Number of travellers in mode m that reaches their destination during the analysis period.
m: index of transport mode.

Macro:

$$PHT_m = \sum_{c=1}^{M_c} O_{mc} \times \left(\sum_{i=1}^{I} \sum_{j=1}^{J} t_{ijc}^{cur} \times D_{ijc} \right)$$

c: index of transport user class.
m: index of transport mode.
M_c: number of transport user class c can constitute a specific mode (e.g. conventional and automated cars that together constitute the mode car).
i: Index of origin zone.
j: Index of destination zone.
I: Set of all origin zones.
J: Set of all destination zones.
t_{ijc}^{cur}: Travel time of transport user class *c* from origin zone *i* to destination zone *j* on the loaded (congested) network.

D_{ijc}: Demand of transport user class *c* from origin zone *i* to destination zone *j*.
O_c: occupancy rate of transport user class *c*.

Assessment approach

$$-\left(\frac{PHT_m^A - PHT_m^0}{PHT_m^0}\right)$$

Unit

Hours

Calculation procedure

Assessed transport user classes[8]

Micro:

- Total, Cars, Trucks, Bus, Minibus, Walking and Cycling. Separation into conventional and automated vehicles is not of interest

Macro:

- Car, Truck, Bus, Train. Separation into conventional and automated vehicles is not of interest

Calculation rules

Macro:
For the macro use cases, the demand matrix D_{ijc} for each transport user class c is the input of the model, thus is available. It is, however, important to note that not all OD pairs defined in the model will be used since some OD pairs are trips from a peripheral zone to a peripheral zone where the network coded near these peripheral zones is often simplified. This means that travel time and the skimmed travel distance for these OD pairs will be unrealistic. It is recommended that only OD pairs within the detailed coded network should be used.

Sources for required input data

Macro:

- Type of transport user class. It is given by the Transport system ID.
- Selection set of OD pairs that are within detailed coded network.
- The travel time between OD for a given transport user class. It is given by the PrT skim where the skimmed travel time matrix can be calculated on the loaded (congested) network, t_{cur}.
- The demand between OD for a given transport user class. It is given by the input demand matrix or available from the demand model.
- The occupancy rate O_c is an input of each transport user class and thus is available. In the situation where occupancy rate is modelled in a more careful manner. The corresponding occupancy rate at specific OD level or trip level should be used.

Further remarks

[8] The term *transport user class* is used to include both transport mode and vehicle class, e.g. bus, train, walking, cycling, conventional vehicle, automated vehicle, conventional car, automated car, conventional truck, automated bus, etc

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3 Space efficiency metrics

Space efficiency metrics aim to capture how efficiently the available road space is used for different scenarios of coexistence of CAVs and conventional vehicles on, and for different road network design and operation.

It is often hypothesised that the introduction of CAVs will allow for a more efficient use of the road space due to shorter headways, better cooperation, reduced lateral lane width required, and thus may permit a reduction of the space dedicated to motorised transportation. The space saved could then be reallocated to other modes or used differently altogether. However, given the many forms CAV operation may take, and various degrees of mixes of CAVs of different capabilities as well as conventional vehicles that may co-exist for a significant period of time, this may or may not be the case depending on how these various vehicle classes mix and interact with each other and the road infrastructure.

3.1 Overview of metrics used in the literature

The use of space efficiency metrics in transport models is not yet common, and relatively few references exist that define and use such metrics, mostly because two-dimensional behaviour modelling capabilities are currently limited (and 3D mostly absent). Below are a couple of references where space-efficiency metrics are used.

Szell (2018) evaluates the special efficiency of various transport modes using a polygon packing algorithm applied to Open Street Map car parking spaces to evaluate their spatial efficiency in m^2 He goes on to compare the distribution of car, vehicle and bicycle space reservations for various cities around the world.

Fang et al. (2013) define a space-time use efficiency metric based on vehicle trajectories (introducing the notion of space-time cubes), which they use to evaluate the efficiency of a proposed pedestrian evacuation optimisation algorithm.

3.2 Choice of metrics

In this section two main metrics are proposed, the Average Space Claim for a specific vehicle class, as well as the Average Space Time Footprint. A vehicle class is defined by the type of vehicle (e.g. truck or car) as well as its CAV capabilities (e.g. conventional, Cautious CAV, All-knowing CAV).

The first metric, Average Space Claim, consists of the average space that a vehicle belonging to that vehicle class given its length (in m) and the headway it requires ahead of it, to guarantee safe operation. The Average Space Time Footprint of a vehicle class extends the space claim notion to also account for the time that the vehicle is requiring this space.

Both metrics can be formulated in one, two or three dimensions, but given the lack of detailed information from simulation models on required widths (and vehicle height is completely absent in current simulation modelling software) we only define the one dimensional versions here.

Both metrics can be extended to their two-dimensional or three-dimensional equivalents by taking into account the required lane-width (currently not available as an output from VISSIM or other microscopic models), and possibly required height for 3D versions.

A further extension of the metrics could be to define them per passenger, rather than per vehicle.

Both metrics can also be normalised with the total available road space for the Average Space Claim, and for the Average Space Time Footprint by both the total available road space as well as the total time of study.

In addition to the metrics defined below, the provided Matlab script calculates standard deviations and coefficients of variance of the space claim and space-time footprint.

3.3 Space claim

Performance metric: Average Space claim (ASC)
Description of metric
Relevance
The average vehicle space claim indicates the average space that is 'occupied' by a vehicle as it moves through the network. The average space claim has the following properties: • The space occupied by a moving vehicle is not only the length of the vehicle itself, but also includes the required headway in front of it. • This headway depends on the speed, safe stopping distance and the assumed reaction time: typically between 0.8 and 2.0 s for common values • It takes into account the vehicle's **required headway**, not the actual one (which may be smaller (e.g. after a merge) or larger (in case of free-flow conditions).
Definition
The instantaneous space claim [in meter] SC_{i_n} of an individual vehicle n is defined as the sum of the length of the vehicle and the required headway at time step i_n given its current speed v_{i_n}. The instantaneous space claim is calculated as $SC_{i_n} = l_n + h_{i_n}(v_{i_n})$ v_{i_n}: Speed of vehicle n at time step i_n (in meters per second) h_{i_n}: headway of vehicle n at time step i_n (in meters) l_n : length of vehicle n (in meters) The **average space claim** (in meters) for transport user class c: ASC_c is defined as the average space claim, for all vehicles n of vehicle class c, for all time periods $i_n \epsilon\, T_n$ that the vehicle was in the network. The average space claim is calculated as: $ASC_c = \frac{\sum_n \sum_{i_n} SC_{i_n}}{N_c T_n}$ N_c : Number of vehicles of class c T_n : Number of time intervals vehicle n was in the network

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Assessment approach for automation readiness
$-\frac{ASC_c^A - ASC_c^0}{ASC_c^0}$
Unit
Meter (m)
Calculation procedure
Assessed transport user classes[9]
Micro: Car, Truck, Bus, Minibus; Conventional: Car, Truck, Bus and Minibus; Automated: Car, Truck, Bus, and Minibus; Macro: Not applicable
Calculation rules
The metrics are computed from the Vissim FZH file through the Matlab script provided
Sources for required input data
Micro: • FZH output files from VISSIM simulation runs. Using VTYPE, VLENGTH, SAFEDISTANCE attributes Macro: • Not applicable
Further remarks
• This metric can be extended into a two-dimensional metric (unit: m^2) if relevant required width is available from the simulation models This metric can also be extended into value per passenger (unit: m), if the simulation models vehicle passengers and passenger occupancy of vehicles is reported in the output (FZH) file

3.4 Space time footprint

Performance metric: Space time footprint (STF)
Description of metric
Relevance
Space time footprint characterizes the space claimed by a vehicle while moving through the network. It is sensitive to both the space claim of the vehicle and it's speed (the time it spends in the network). The smaller the average space-time footprint for a vehicle class, the more efficiently the vehicles use the available space and time (they use less space and/or use it for a shorter amount of time)
Definition

[9] The term *transport user class* is used to include both transport mode and vehicle class, e.g. bus, train, walking, cycling, conventional vehicle, automated vehicle, conventional car, automated car, conventional truck, automated bus, etc

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The space-time footprint for a vehicle [in meter x seconds] STF_n of an individual vehicle n is defined as the sum of the instantaneous vehicle space claim SC_{i_n} over all time steps i_n that the vehicle is in the network, times the time step length (duration) $\|i_n\|$. The space-time footprint for a vehicle is calculated as $STF_n = \|i_n\| \cdot \sum_{i_n} SC_{i_n}$ $\|i_n\|$: the length (duration) of time interval i_n in seconds (s) The **average space-time footprint for a vehicle class** [in meters x seconds] for transport user class c: $ASTFP_c$ is defined as the average for all vehicles n of vehicle class c, for all time periods i_n: $ASTF_c = \frac{\sum_n STF_n}{N_c}$
Assessment approach for automation readiness
$-\frac{STF_c^A - STF_c^0}{STF_c^0}$
Unit
Second·Meter
Calculation procedure
Assessed transport user classes[10]
Micro: Conventional: Car, Truck, Bus and Minibus; Automated: Car, truck, Bus, and Minibus Macro:
Calculation rules
The metrics can be computed from the VISSIM file through the provided Matlab script, based on the FZH vehicle output files.
Sources for required input data
Micro: • FZH output files from VISSIM simulation runs. Using SIMSEC, VTYPE, VLENGTH, SAFEDISTANCE attributes. Macro: • Not applicable
Further remarks
• This metric can be extended into a two-dimensional metric (unit: $m^2 \cdot s$) if relevant required width is available from the simulation models • This metric can also be extended into value per passenger (unit: $m \cdot s$), if the simulation models vehicle passengers and passenger occupancy of vehicles is reported in the output (FZH) file

[10] The term *transport user class* is used to include both transport mode and vehicle class, e.g. bus, train, walking, cycling, conventional vehicle, automated vehicle, conventional car, automated car, conventional truck, automated bus, etc

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4 Qualitative safety assessment approach

Connected & automated vehicles (CAVs) safety is generated a lot of interest from the transportation industry, policymakers, and the public as well. Determining how safe CAVs should be before allowing them on the roads will influence how CAVs are introduced into the market and therefore how cities need to prepare for this entry (Kalra and Groves 2017).

Road safety relies traditionally on accident statistics as main data source. For many reasons, such as the lack of data, the fact that accidents are rare events and often the result of a series of unhappy realisations of many small probabilities; current road safety studies are challenging (Laureshyn et al. 2010). Therefore, studying CAVs safety, for which extremely few data are available and a good part relies on imagination of what CAVs will be, can only be extremely challenging!

Some attempt at accident analysis can however be found: Dixit, Chand, and Nair (2016), for example, studied the number of disengagements and the reaction times for data collected in California between September 2014 and November 2015. Favarò et al. (2017) studied the accident reports from data collected between September 2014 and March 2017 from the same database in California (Favarò et al. 2017). However, all these articles are relying on very few data, their results and conclusions are, therefore, lacking statistical significance.

Another approach for quantifying safety impacts, based on results of microscopic simulation, is the so-called surrogate safety assessment model (SSAM)[11]. It automatically identifies safety conflicts based on trajectory data of the simulation and calculates several indicators, so called surrogate safety measures, for each of the conflicts. Based on thresholds for surrogate safety measures or correlations between surrogate safety measures and accident indicators, it is then possible to quantify the accident situation for the analysed road site. A US team (Kockelman et al. 2016) has been running a very similar study to what CoEXist is aiming at and estimated how many crashes per year are likely to occur on different road configurations given different rates of AV market penetration. However, many limitations are linked to the use of SSAM such as the fact that conflict analysis is sensitive to the model:

- The number of conflicts is very sensible to the model: a change in the way one draws the links has an influence on the number of conflicts;
- The model in Vissim might not be an accurate model of AV behaviour[12];
- One needs to define thresholds without data available to define them,
- It could end up very time-consuming for the cities/the modellers to perform such an analysis for a very rough output
- It focuses on one type of source of accident: vehicles crashes.

For all the reasons mentioned above, SSAM has not been chosen for the impact assessment developed in CoEXist but a third approach, similar to the one presented by Rösener et al. in their article (Rösener et al. 2018). The approach focuses on the analysis of driving functions. Scenarios which are potentially

[11] SSAM has been developed by the Federal Highway Administration (FHWA)
[12] The way automated cars are modelled in PTV Vissim is to best of the current knowledge and the data made available within the project. There is however no possible calibration since there are no actual automated cars on the road at this point of time. The accuracy of the model can therefore at the moment not be verified.

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affected by the respective driving function are identified. Afterwards the impact of the respective driving function on accidents (severity and number of accidents) of the respective scenarios are analysed by accident simulations. Finally, the impacts of each driving function are extrapolated on national level. This approach has recently been applied to Germany to assess the impacts of driving functions on German roads. The results of these studies will be published soon, hence not available for CoEXist.

Since assessing safety impacts quantitively is problematic, the project partners of CoEXist have been working on a qualitative assessment instead, following the general ideas of the above-mentioned approach but not going that much into detail: Conflict situations incorporating boundary conditions such as road environment, road characteristics, type of accident, etc. which are potentially addressed by the driving functions are identified and a qualitative assessment of the impacts of each driving function on road safety is carried out.

4.1 Approach and main assumptions

4.1.1 Driving functions

In the literature one can read many claims such as “In Europe and the United States, about 90-95% of road crashes are due to human errors” (Fagnant and Kockelman 2015). The hope is that by replacing human drivers by automated cars, one could decrease the number of accidents by the same share. Obviously, that is assuming that the human errors are not going to be replaced by new types of error. [UT18]

In the present work, it is considered that human drivers will be step by step replaced by automated cars through driving functions. What differentiates today’s cars from automated cars are that the driving functions will be more and more sophisticated and have more and more control over the vehicle. 21 driving functions that are thought to be representative have been chosen as shown in Table 1.

Table 1 Driving function chosen for the safety assessment tool with their definition and corresponding SAE Level [SA14]

Driving functions	Definition	SAE Levels
Lane change assist (LCA)	The system monitors the areas to the left and right of the car and up to 50 metres behind it and warns you of a potentially hazardous situation by means of flashing warning lights in the exterior mirrors. These systems are not always performant for side collisions (Svensson 2015).	**Level 0**
Park distance control (PDC)	The park distance control supports the driver to manoeuvre into tight spaces and reduce stress by informing him of the distance from obstacles by means of ultrasonic or, depending on vehicle, optical signals (Svensson 2015).	

Lane departure warning (LDW)	Lane Departure Warning helps to prevent accidents caused by unintentionally wandering out of lane and represents a major safety gain on motorways and major trunk roads. If there is an indication that the vehicle is about to leave the lane unintentionally (without using the blinkers), the system alerts the driver visually and in some cases by means of a signal on the steering wheel (Svensson 2015).	
Forward collision warning (FCW)	The Front Collision Warning monitoring system uses a radar sensor to detect situations where the distance to the vehicle in front is critical and helps to reduce the vehicle's stopping distance. In dangerous situations the system alerts the driver by means of visual and acoustic signals and/or with a warning jolt of the brakes. Front Collision Warning operates independently of the ACC automatic distance control. Forward collision warning best detects vehicles in front of you. However, not all features will be capable of detecting motorcycles, bicycles, pedestrians, some farm machineries and other vehicles smaller than a car (Svensson 2015).	
Blind Spot Monitoring	Blind spot monitoring detects objects in the driver's blind spot and informs/warns them of a potential collision when they intend to change lanes. Optimised for motorway, does not work well for very fast speed vehicles and slow-moving vehicles like VRUs (VDA Magazine 2015).	
Intelligent speed assist	Intelligent Speed Assist (ISA) is a safety technology that alerts drivers when they exceed the speed limit. ISA activates when a driver exceeds the posted speed limit for a section of road by a set speed (e.g. 2km/h or more). Audio and visual warnings remind the driver if they are going too fast. ISA can also be fitted with a speed limiting function which increases the pressure on the accelerator when you exceed the posted speed limit, making it harder to accelerate (Svensson 2015).	
Adaptive cruise control (ACC)	The cruise control system with "***Adaptive*** distance control ACC" uses a distance sensor to measure the distance and speed relative to vehicles driving ahead, usually using perception information coming from cameras and lasers. The driver sets the speed and the required time gap with buttons on the multifunction steering wheel or with the steering column stalk (depending on model). The target and actual distance from following traffic can be shown as a comparison in the multifunction display. Does not have the capability to stop the car on its own, only to reduce the speed (Svensson 2015).	**Level 1**

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Park assist (PA)	Park assist automatically steers the car into parallel and bay parking spaces, and out of parallel parking spaces. The system assists the driver by automatically carrying out the optimum steering movements to reverse-park on the ideal line. The measurement of the parking space, the allocation of the starting position and the steering movements are automatically undertaken by park assist – all the driver must do is operate the accelerator and the brake. This means that the driver always retains control of the car (Svensson 2015).	
ACC including stop & go	Adaptive Cruise Control with stop & go function includes automatic distance control (control range 0–250 km/h) and, within the limits of the system, detects a preceding vehicle. It maintains a safe distance by automatically applying the brakes and accelerating. In slow-moving traffic and congestion, it governs braking and acceleration (Svensson 2015).	
Lane keeping assist (LKA)	Lane keeping assist has a typical speed range comprised between 65 and 180 km/h [VD19]. The system detects the lane markings and works out the position of the vehicle. If the car starts to drift off lane, the LKA takes corrective action. If the maximum action it can take is not enough to stay in lane, or the speed falls below 65 km/h LKA function warns the driver (e.g. with a vibration of the steering wheel). Then it's up to the driver to take correcting action (Svensson 2015).	
Vulnerable road users safety systems	Vulnerable road users (VRU) detection systems are mostly used for urban environment. VRUs are considered vulnerable road users, since they are not protected and even not aware about the dangerous situations. The pedestrian detection can be classified like a collision warning system (CWS, Level 0). However, since the reaction time of the driver is slow (around 2 seconds), these systems usually have access to the brake system (longitudinal control). For speed around 40 km/h (Svensson 2015).	
Park assistance	Partial automated parking into and out of a parking space, working on public parking area or in private garage. Via smartphone or key parking process is started, vehicle accomplishes parking manoeuvres by itself. The driver can be located outside of the vehicle, but must constantly monitor the system, and stop the parking manoeuvre if required (Svensson 2015).	**Level 2**
Traffic jam assist	The function controls the vehicle longitudinal and lateral to follow the traffic flow in low speeds (ca. 50 km). The system can be seen as an extension of the ACC with Stop & Go functionality (Svensson 2015).	
Highway driving assistant	The driving function "highway driving" assumes lateral and longitudinal control during highly automated driving on motorways up to 180 km/h. The driver must consciously activate the system but does not have to monitor it at all times. Under certain circumstances the system prompts the driver to resume control. No lane changes possible (can be completed by an automatic lane change for speed range of 60 to 130 km/h, not considered here) (VDA Magazine 2015).	

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Traffic jam chauffeur	Conditional automated driving in traffic jam up to 70 km/h on motorways and motorway similar roads. The system can be activated, if traffic jam scenario exists. It detects slow driving vehicle in front and then handles the vehicle both longitudinal and lateral. Driver must deliberately activate the system but does not have to monitor the system constantly. Driver can at all times override of switch off the system. Note: There is no take over request to the driver from the system (Svensson 2015).	**level 3**
Highway chauffeur	Conditional Automated Driving up to 130 km/h on motorways or motorway similar roads. From entrance to exit, on all lanes, incl. overtaking. The driver must deliberately activate the system but does not have to monitor the system constantly. The driver can at all times override or switch off the system. The system can request the driver to take over within a specific time, if automation gets to its system limits (Svensson 2015).	
Parking garage pilot	Highly Automated parking includes manoeuvring to and from parking place (driverless valet parking). In parking garage, the driver does not have to monitor the system constantly and may leave once the system is active. Via smartphone or key parking maneuverer and return of the vehicle is initiated (Svensson 2015).	**Level 4**
Motorway pilot	Automated Driving up to 130 km/h on motorways or motorway similar roads from entrance to exit, on all lanes, incl. overtaking. The driver must deliberately activate the system but does not have to monitor the system constantly. The driver can at all times override or switch off the system. There are no requests from the system to the driver to take over when the systems are in normal operation area (i.e. on the motorway). Depending on the deployment of cooperative systems ad-hoc convoys could also be created if V2V communication is available (Svensson 2015).	
Arterial pilot	Highly automated driving up to limitation speedon arterial roads. The system can be activated by the driver on defined road segments, in all traffic conditions, without lane change in the first phase. The driver can at all-time override or switch off the system. This system handles with very dynamic scenarios, including: pedestrian, motorcycles, bikes, etc. (Svensson 2015)	
Urban pilot	Highly automated driving up to limitation speed, in urban areas. The system can be activated by the driver on defined road segments, in all traffic conditions, without lane change in the first phase. The driver can at all-time override or switch off the system. This system handles with very dynamic scenarios, including: pedestrian, motorcycles, bikes, etc. (Svensson 2015)	

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Fully automated private vehicles	The fully automated vehicle should be able to handle all driving from point A to B, without any input from the passenger. The driver can at all-time override or switch off the system. (Svensson 2015)	**Level 5**

To avoid counting the same function several times, it is important to identify how the different driving functions are linked as shown in Figure 1.

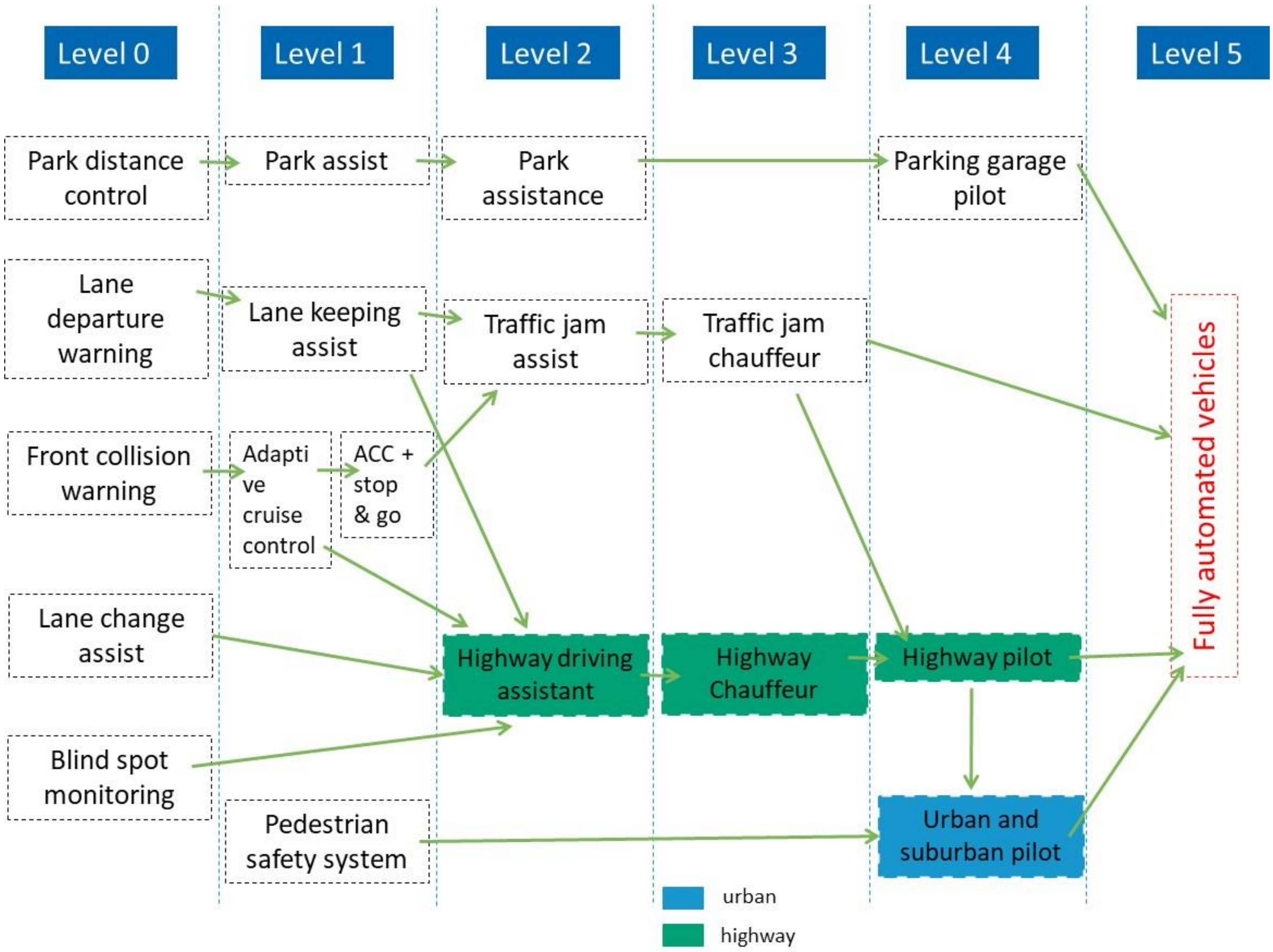

Figure 1 Link between the driving functions used in the CoEXist safety impact assessment

4.1.2 Types of accident

One way of assessing safety is to have a look at conflict situations. There is no harmonized accident type classification used in Europe. However, there are European projects reflecting on this, such as

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SafetyNET[13]. In the SafetyNET project, a classification based on types of accident and the German approach (so called GDV[14]) has been published. The 7 types of accident are explained in the Table 2 (See Appendix A – Types of accident for a complete description of all subcategories).

Table 2 The 7 types of accident and their definition. All the definitions are taken from [RE08]

	Type of accident	Definition
1	**Driving accident**	The accident occurred due to loss of control over the vehicle (because of not adapted speed or erroneous evaluation of the run of the road or the road condition or similar), without the involvement of other road users. But as a result of uncontrolled vehicle movement this could have led to a crash with another road user.
2	**Turning off accident**	The accident occurred due to a conflict between a turning off road user and a road user coming from the same direction or the opposite direction (pedestrians included!) at crossings, junctions, access to properties or parking lots.
3	**Turning-in / Crossing accident**	The accident occurred due to a conflict between a turning in or crossing road user without priority and a vehicle with priority at crossings, junctions, access to properties or parking lots.
4	**Pedestrian accident**	The accident occurred due to a conflict between a vehicle and a pedestrian on the road unless he was walking in lateral direction and unless the vehicle was turning in. This is also applicable if the pedestrian was not hit.
5	**Accident with parking vehicles**	The accident occurred due to a conflict between a moving vehicle and a vehicle which is parking, has stopped or is manoeuvring to park or stop.
6	**Accident in lateral traffic**	The accident occurred due to a conflict between road users moving in the same or in the opposite direction unless this conflict applies to another type of accident.
7	**Other accident type**	Accident that cannot be assigned to the types 1 – 6. Examples: Turning around, backing up, two parking vehicles, objects or animals on the road, sudden vehicle damage.

"To determine the accident type, only the conflict situation which led to the accident is important. If and how road users collided (the accident manner) is of no importance for the determination of the accident type. The mistake of the road users (the accident cause) is basically never of importance. If for example an accident occurs due to a conflict between vehicle and a pedestrian crossing the road, it is a pedestrian accident. This is independent of the following course of the accident (e.g. if the pedestrian was hit or not, if the car leaves the road due to an avoidance manoeuvre, or if the car was hit by following traffic due to

[13] http://erso.swov.nl/safetynet/content/safetynet.htm

[14] Gesamtverband der Deutschen Versicherungswirtschaft

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harsh braking) and independent of who is to blame for the accident (e.g. if the pedestrian or the vehicle had priority)." [RE08]

This classification does not perfectly fit CoEXist's purposes, mostly because driving functions are not aimed at solving specific types of accident, making the assessment of the efficacity of a driving function on a specific type of accident sometimes difficult. It however presents the tremendous advantage to be well illustrated, understandable and complete.

4.1.3 Road environments

The safety assessment tool presented in this document relies on the expected influence of the driving functions on the type of accident. Since not all driving functions and not all types of accident are applicable in all road environments, one should also take the road environment into account. In the CoEXist project, 4 road environments are considered (see Table 3):

Table 3 The 4 road environments considered in CoEXist and their definition [OI18]

Road environment	Definition
Motorway	Multi lane roads with physical barriers between directions and grade separated intersections.
Arterial	Single or multilane roads with at grade intersections (mainly larger type of intersections as signalized intersections or roundabouts). Bicycle and pedestrian traffic are clearly separated from the vehicle traffic either by physical barriers or medians. Vehicle, bikes and pedestrian interact at intersections.
Urban Street	Single or multi lane roads with at grade intersections (also stop or yield regulated intersection). No clear separation between vehicle traffic and pedestrian and bicycle traffic. Walkways and bikeways directly at the side of the vehicle lanes.
Shared Space	Vehicle, bicycles and pedestrian share the same space, which can be unstructured or semi-structured

4.1.4 The approach

The approach of the safety assessment is depicted in Figure 2. The approach relies on evaluating the expected impact of the driving function on accident types in combination with the road environment.

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Figure 2 Basic approach of the safety assessment tool

Due to the high uncertainty linked with estimating the impact of CAVs on road safety completed with a lack of data, a qualitative impact assessment has been chosen. Furthermore, the accident types – driving functions evaluation contains only neutral or positive rating, since it is unexpected that driving functions that are, at least in the long run, jeopardising safety will be brought to the market. The possibility that driving functions enhance the occurrence of some accident type cannot be excluded, but none could be identified at this time, a negative rating is however not excluded and a modification anytime possible.

An additional assumption is that the more advanced the function, the more safety will be achieved. This assumption stems from the fact that technical failures or misjudgement from the CAVs are not taken into account within CoEXist. Therefore, a driving function with level 3 and control over the vehicle is safer than a driving function level 0 that generates only warnings and does not have any control over the car. Furthermore, neither weather nor road conditions are included. It is however important to bear them in mind as they are both of extreme importance for the well-working of the sensors.

Furthermore, the qualitative assessment described so far does not consider potential positive or negative safety impacts on neither the surrounding conventional vehicles which are not equipped with the respective driving function nor other road users as pedestrians or bicyclists. To consider these effects which – especially in case of low penetration rates of CAV – might be the determining factor for the safety impacts of a driving function, an overall function has been developed representing those effects.

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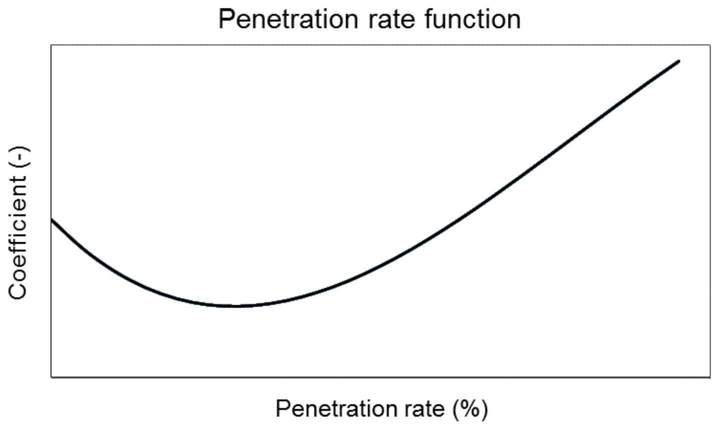

Figure 3 Correction function – could still be modify in the next months

Although the function describing the impacts of the penetration rate is not defined in detail (see Figure 3) it covers the following aspects: The introduction of CAVs with low penetration rates would lead to higher uncertainty and a deterioration of human drivers' road safety because of unexpected behaviours of the CAVs. This assumption might become plausible if one thinks about CAVs following the all-knowing or rail safe driving logic[15]: Their driving behaviour will differ widely from the one of conventional vehicles. Furthermore, it is assumed that human drivers would learn to adapt their own behaviour with increasing penetration rates to cope with the behaviour and driving manoeuvres of CAVs. Therefore, it is assumed that road safety for conventional vehicles increases with increasing CAVs penetration rate. The assumption is strong and relies on the current vision one can have. Ways to validate this assumption are currently under discussion which means that modifications could still take place. Furthermore, this function might be refined according to new knowledge gained over time.

By combining the evaluation of the driving functions and the penetration rate function for relevant conflict situations, a qualitative impact assessment is generated, giving an indication of the change in road safety one could expect.

4.2 Results

The results will be calculated, converted in a qualitative indication and displayed separately for each road environment and each stage of coexistence as shown in the table below

Table 4 Results

	Introductory	Established	Prevalent
Motorway			
Arterial road			
Urban road			
Shared space			

[15] For more details about the driving logics, please see annex A of D1.4 Scenario specification for eight use cases (Olstam and Johansson 2018)

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The result reflects the percentage of improvement of the safety of the traffic situation and will take into account, among others, the typed of conflict relevant for the scenario, the effect of the driving functions on safety, the penetration rate of the automated vehicles, the correction function. The exact calculation will be explained in the deliverable D3.3

4.3 Further work

In the next months, the safety assessment tool will be further developed based on the approach explained above. The embedment of the tool into the CoEXist approach needs to be further adjusted, and then the tool itself will be set-up. The final version of the safety assessment approach will be described in the Deliverable D3.3: AV-ready hybrid road infrastructure assessment tool.

5 Conclusions and lessons learnt

Earlier conducted traffic model experiments of introduction of ADAS or automated vehicles seems to utilise the same type of traffic performance metrics used for traditional level-of-service analysis of different road designs or traffic control measures. The focus in CoEXist have been on finding metrics that in capture traffic system effects in a good way, e.g. travel time, delay and vehicle kilometres travelled. More detailed analysis will probably require additional metrics as throughput, probability of breakdown, etc. However, since the aim of CoEXist is to build the capacity of urban road authorities with respect to the introduction of automated vehicles the COEXist assessment tool should be straightforward to apply and give an overall assessment, which of course might indicate that more detailed analysis is required.

To assess whether the current space used for road traffic could be decreased one would need to actually conducting several traffic model experiments applying measures as removing lanes or reallocating road space between different modes. The suggested space efficiency metrics aim to give indications on how efficiently the available road space is used and thereby give an indication on whether the space for road traffic might be able to be reduced. Few metrics for space efficiency have so far been developed and the metric suggested are novel but need to be applied to several use cases in order to evaluate their usefulness.

Assessment of traffic safety of a mixed traffic stream with both conventional and automated vehicles is difficult. Our conclusion is that it’s today difficult to conduct quantitative estimations of safety benefits. Current tools for trajectory-based calculations to estimate conflicts and conflicts severity are all based on thresholds for what’s safety critical for human drivers (e.g. safety critical time to collision or post-encroachment times). Automated vehicle will probably be able to operate in a safer way and the thresholds would therefore need to be adjusted but there are no or only limited data for conducting such an adjustment. Furthermore, the relationship between conflicts estimation from traffic simulation models and real accidents are not strong and most probably not applicable for a mixed traffic stream. Therefore, we have chosen to suggest an approach for a qualitative assessment of traffic safety. This approach will not be able to give detail results on the traffic safety effects for each use case based on the outputs from the traffic models. It will instead give indications on the potential safety benefits for the types of road environments that is present in the use case.

Experience tell us that the metric definitions might be revised during the implementation in the assessment tool. Therefore, the final definitions of the metrics will be presented together with the description of the tool in deliverable “D3.3: AV-ready hybrid road infrastructure assessment tool”.

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7 Partners

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Appendix A – Types of accident

Extract from Deliverable 5.5 of the SafetyNet Project [RE08]

5.2 Type 1: Driving Accident

Definition: A driving accident occurred when the driver loses control over his vehicle because he chose the wrong speed according to the run of the road, the road profile, the road gradient or because he realised the run of the road or a change in profile too late.
Driving accidents are not always single vehicle accidents where the vehicle leaves the road. A driving accident can also lead to a collision with other road users.

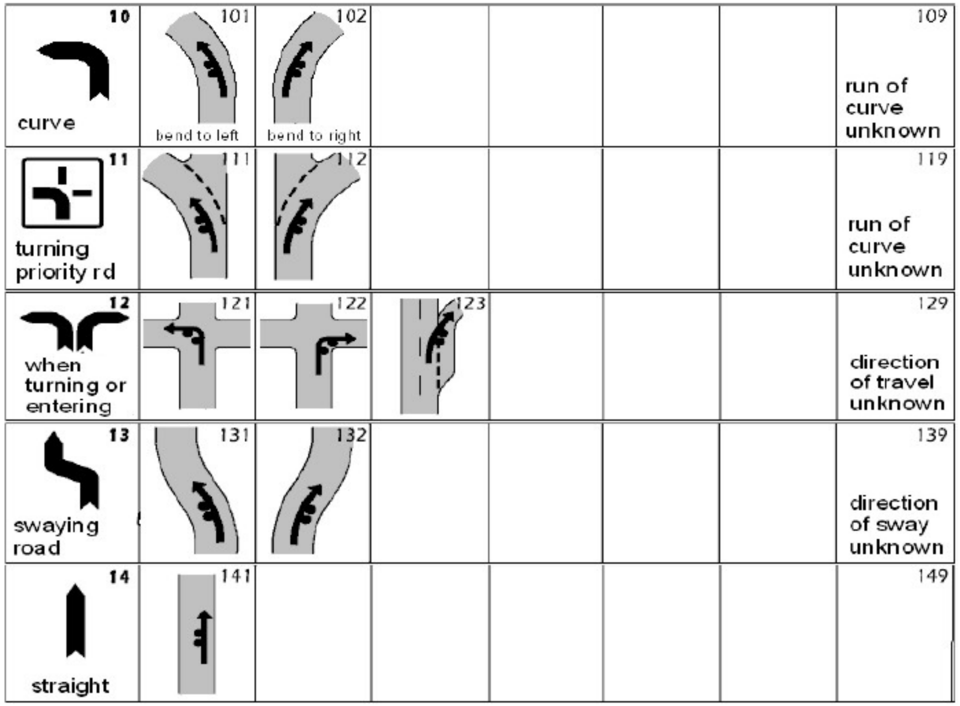
Type 10
In a curve

Type 11
In a curve with turning priority

Type 12
Turning in or off to another road

Type 13
At a swaying road

Type 14
On a straight road



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Accident Classification System (GDV)

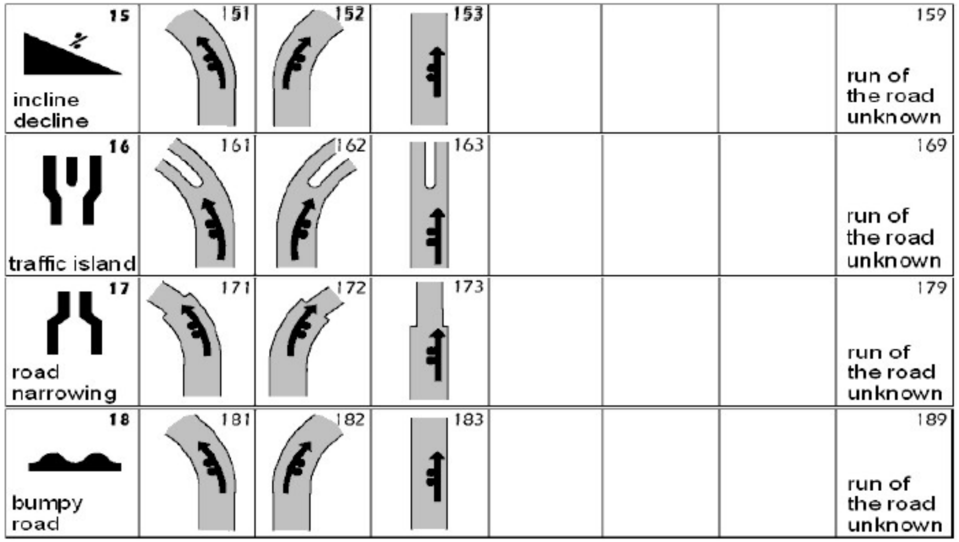
Type 15
…gradient

Type 16
…traffic island

Type 17
… road narrowing

Type 18
… uneven road

Type 19
… other driving accidents



Other driving accidents 199

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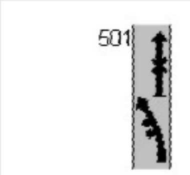
Accident Classification System (GDV)

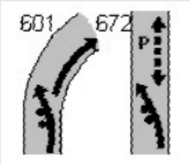
Type 1 : Special cases

Note:
Expressions in the accident description like "… started to skid" or "…run off the road" do not necessarily mean that it is a driving accident.



If a driver loses control over his vehicle, attempting to avoid a vehicle parking on the same side, it is an "accident with parking vehicles" (501).

If the driver attempted to avoid a broken down vehicle, it is an "other accident type" (742).



It is an "accident in lateral traffic" if a driver attempted to avoid a pedestrian (672) or a slowly moving vehicle (601). This is independent of the fact if there was a collision with the accident causer as a result of the conflict situation, or if there was a collision with another road user or if the vehicle ran of the road.

If a driver loses control over his vehicle because of too high speed when turning off, it is a "driving accident".

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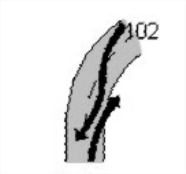
Accident Classification System (GDV)



If a driver cuts the curve and this results into an accident with head on traffic, then it is a "driving accident".

If a non priority vehicle (vehicle having to wait) turns in to a superior road too fast and therefore loses control over his vehicle, it is a "driving accident" unless there is a conflict with a priority vehicle.

If a driver loses control over his vehicle because of a dizzy spell, falling asleep or because he is heavily distracted (e.g. searching a fallen down cigarette) or because of a sudden technical defect on the vehicle (e.g. a bursting tyre), it is an "other accident type"

If a driver loses control over his vehicle as a result of crosswinds, it is a "driving accident"

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5.3 Type 2: Turning off Accident

Definition: A turning accident occurred when there was a conflict between a turning road user and a road user coming from the same direction or the opposite direction (pedestrians included!). This applies at crossings, junctions of roads and farm tracks as well as access to properties or parking lots.

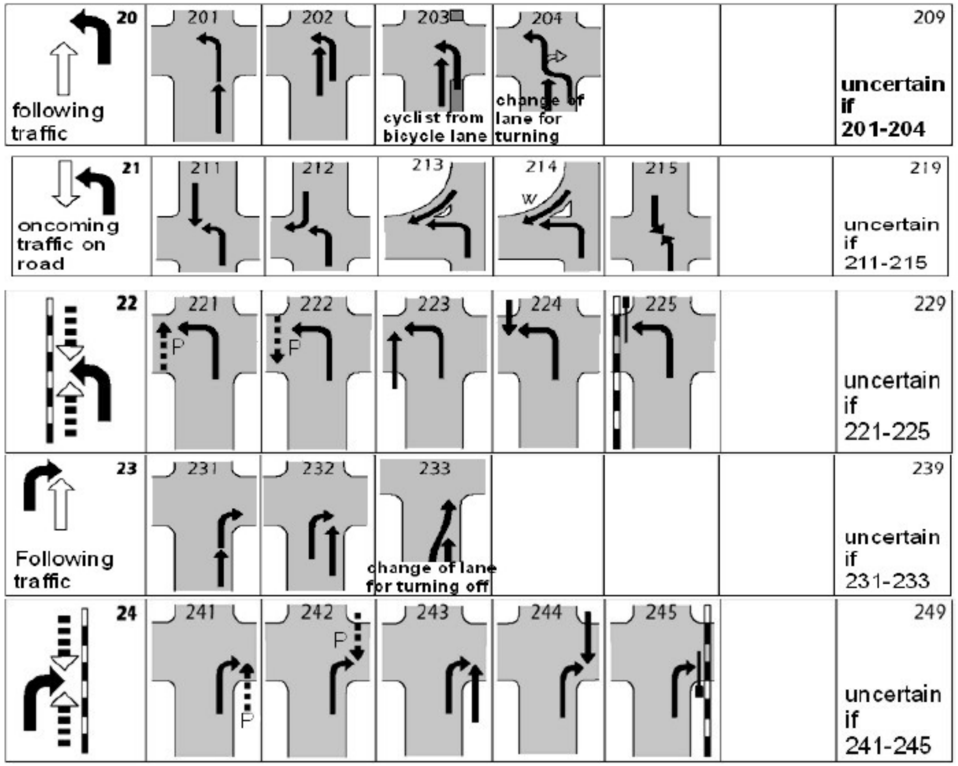
Type 20
Conflict between a vehicle turning off to the left and following traffic

Type 21
Conflict between a vehicle turning off to the left and oncoming traffic

Type 22
Conflict between a vehicle turning off to the left and a vehicle from a special path/track or a pedestrian going to the same or opposite direction

Type 23
Conflict between a vehicle turning off to the right and following traffic

Type 24
Conflict between a vehicle turning off to the right and a veh. from a special path/track or a pedestrian moving in to the same or opposite direction



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Type 25
Conflict between two turning off vehicles, moving along side in the same direction.

Type 26
Conflict between a turning off vehicle and a vehicle without priority, waiting at the headed road of the turning veh.

Type 27
Conflict between a turning off veh. from a priority rd and another road user at a traffic junct. with a turning priority road.

Type 28
Conflict between a turning off veh. and another rd user coming from the same or the opposite direction when the turning traffic is regul. by traffic lights.

Type 29
Other turning off accidents

Other turning off accidents 299

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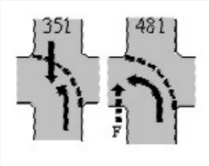
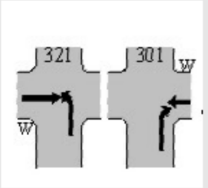
Type 2 : Special cases

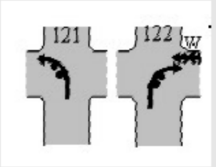
Note:
A road user following a turning priority road is not turning off. Also a conflict between a road user turning off the priority road and a waiting non priority vehicle behaving accordingly is a type 2 accident (turning off accident).



Is there a conflict between a vehicle following a turning priority road and a non priority vehicle or a pedestrian crossing the road, it is a "turning in / crossing accident" (351) or a "pedestrian accident" (481). This is not a turning off accident.



If while turning off there is a conflict with a non priority vehicle because the vehicle has entered too far into the superior road (321) or is too far left (301), then it is a type 3 accident (turning in / crossing accident)



If the driver of a turning off vehicle looses control over his vehicle when turning off because of too high speed (121) (and hits for example a waiting non priority vehicle (122)), it is a type 1 accident (driving accident).

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CoEXist

5.4 Type 3: Turning in / crossing accident

Definition: A turning in / crossing accident occurred due to a conflict between a turning in or crossing road user without priority and a vehicle with priority. This applies at crossings, junctions of roads and farm tracks as well as access to properties or parking lots.

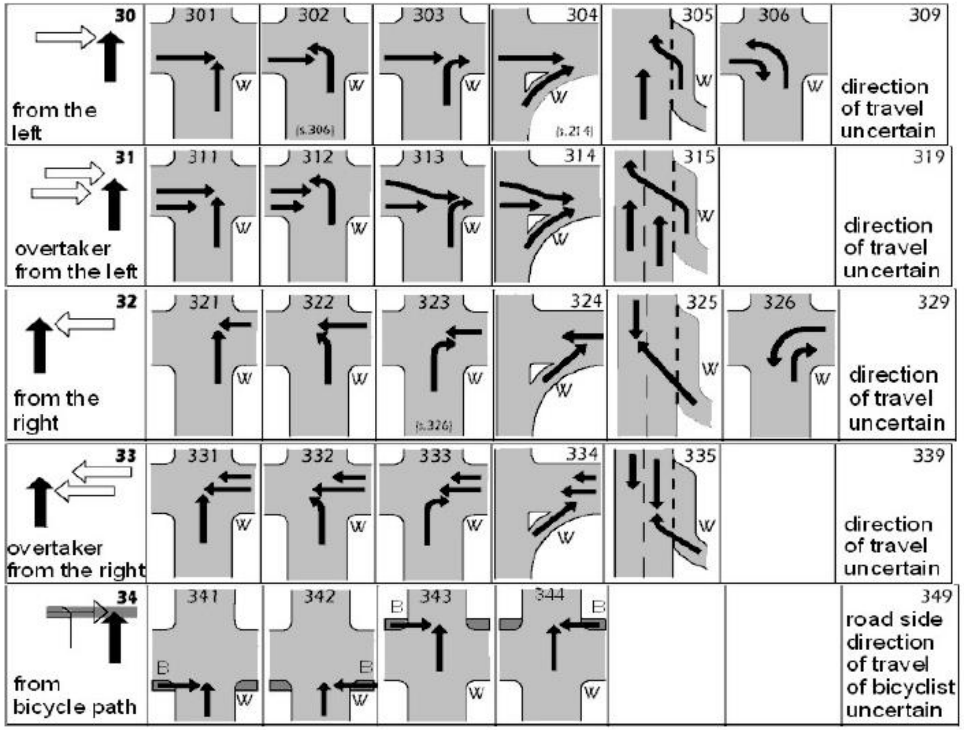
Type 30
Conflict between a non priority vehicle and a priority vehicle coming from the left, which is not overtaking.

Type 31
Conflict between a non priority vehicle and a priority vehicle coming from the left, which is overtaking.

Type 32
Conflict between a non priority vehicle and a priority vehicle coming from the right, which is not overtaking.

Type 33
Conflict between a non priority vehicle and a priority vehicle coming from the right, which is overtaking.

Type 34
Conflict between a non priority vehicle and a bicyclist with priority coming from a bicycle path.



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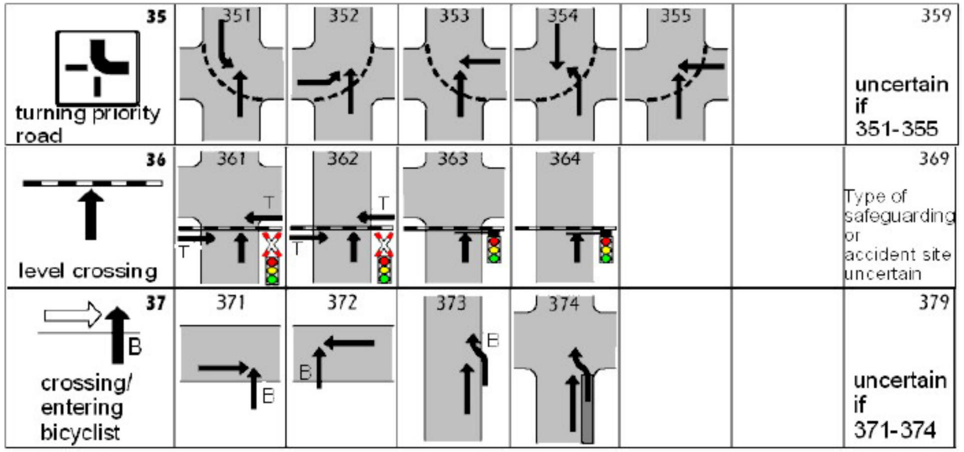
Accident Classification System (GDV)

Type 35
Conflict between a non priority vehicle and a priority vehilce on a turning priority road.

Type 36
Conflict between vehicle and a railway vehicle at a level crossing. (Unless it is a turning off accident)

Type 37
Conflict between a vehicle and a bicyclist coming from a parallel bicycle path who is turning in to or crossing the road.



Type 39
Other turning in / crossing accidents

Other turning in / crossing accidents 399

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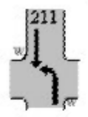
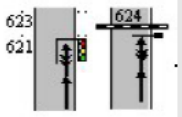
Type 3 : Special cases

Note:
It makes no difference, whether the obligation to give way was expressed by signs, traffic lights or by a general rule (e.g. traffic from the right has priority).



If a road user without priority wants to turn left at a crossing and crashes with on coming traffic it is a type 2 accident (turning off accident).

If a road user without priority, while turning in onto a superior road leaves the road because of e.g. not adapted speed or an icy road, without there being a conflict with a priority vehicle, it is a type 1 accident (driving accident).



Is there a conflict between a non priority vehicle which is stopping, braking or going slowly because it has to wait and between a vehicle from the following traffic, it is a type 6 accident (accident in lateral traffic).

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5.5 Type 4: Pedestrian Accident

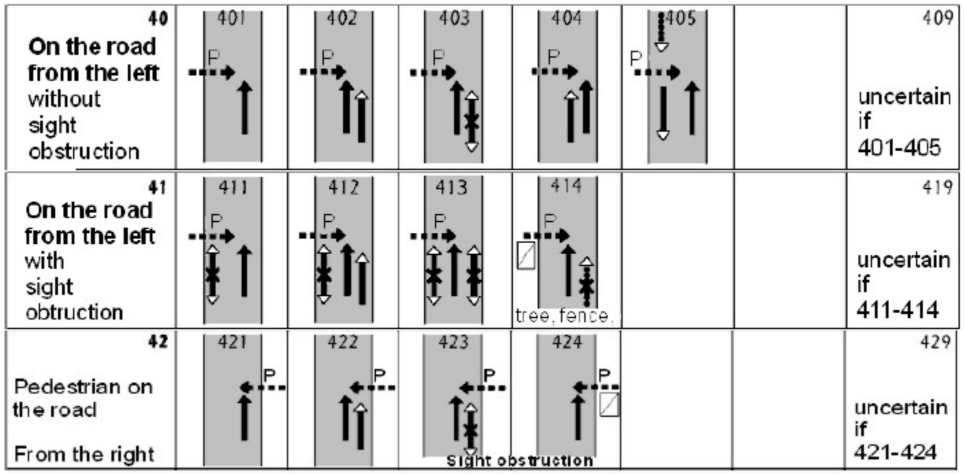
Definition: A pedestrian accident has occurred due to a conflict between a pedestrian crossing the road and a vehicle unless the vehicle was turning off. This is independent of whether the accident occurred at a place without special pedestrian crossing facilities or at a zebra crossing or similar.

Type 40
Conflict between a pedestrian coming from the left and a vehicle.
(Unless type 41)

Type 41
Conflict between a pedestrian coming from the left and a vehicle which had an obstructed line of sight by parking vehicle, tree, fence ....

Type 42
Conflict between a pedestrian coming from the right and a vehicle.

No Junction



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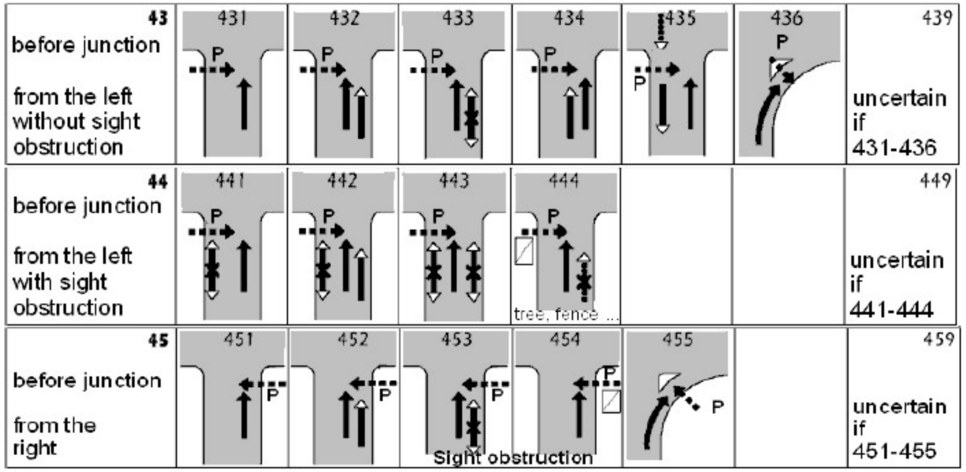
Before a Junction

Type 43
Conflict between a pedestrian coming from the left and a vehicle.
(Unless type 44)

Type 44
Conflict between a pedestrian coming from the left and a vehicle which had an obstructed line of sight by parking vehicle, tree, fence ….

Type 45
Conflict between a pedestrian coming from the right and a vehicle.



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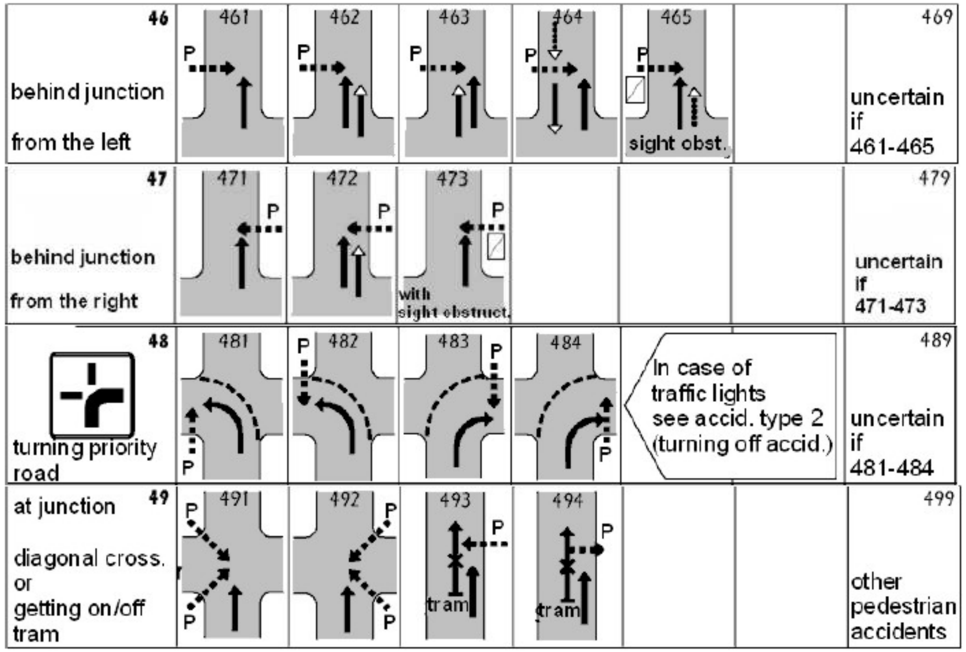
Behind a Junction

Type 46
Conflict between a pedestrian coming from the left and a vehicle.

Type 47
Conflict between a pedestrian coming from the right and a vehicle

Type 48
Conflict between a pedestrian and a vehicle following a turning priority road.

Type 49
Conflict between a vehicle and a pedestrian crossing a junction diagonally, or getting on/off a tram.
As well as other pedestrian accidents.



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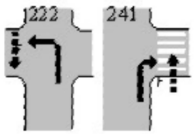
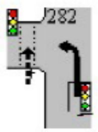
Type 4 : Special cases

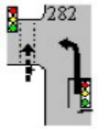
Note:
An accident is also a type 4 accident (pedestrian accident) if the conflict causing pedestrian was not hit. This includes accidents, where the conflict was caused by pedestrians that were e.g. playing, getting in or out of a car, but were not walking in lateral direction.



If at a crossing a pedestrian crosses the access road of a turning off vehicle and this results in a conflict, then it is a type 2 accident (turning off accident)



If such a conflict occurs at a crossing with traffic lights – even with a turning off signal – it is also a type 2 accident (turning off accident)



If somebody is getting out of the car and this results in a conflict between this pedestrian and another vehicle, it is a type 4 accident (pedestrian accident)

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5.6 Type 5: Accident with parking traffic

Definition: An accident with standing traffic occurred due to a conflict between a vehicle from moving traffic and a vehicle which is parking, has stopped or is manoeuvring to park or stop. This is independent of whether stopping/parking was permitted or not.

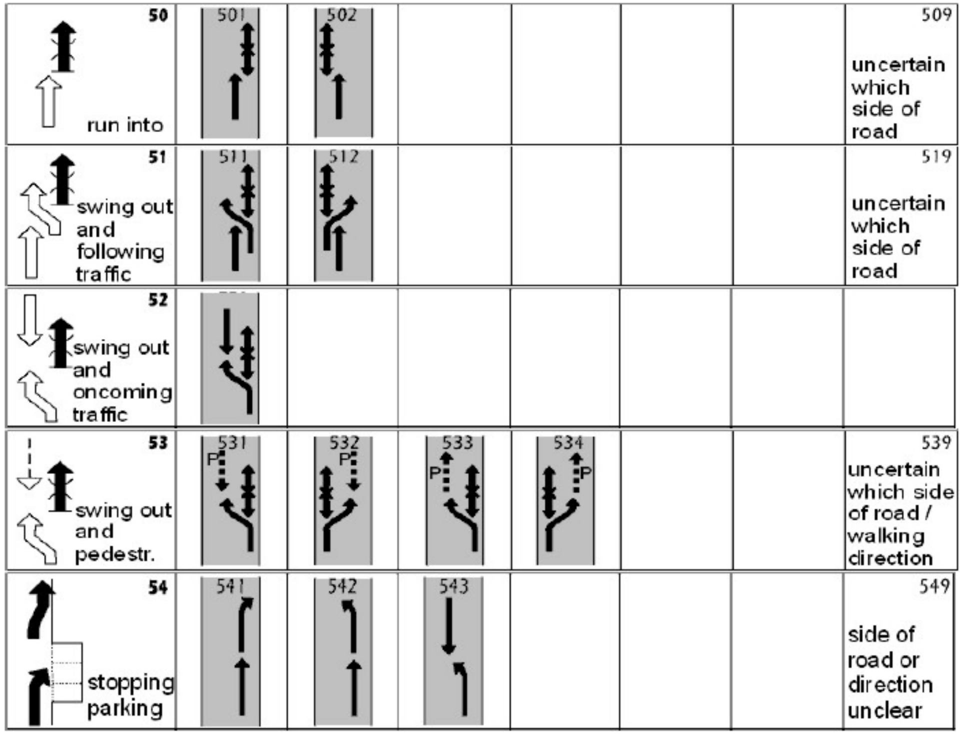
Type 50
Conflict between a vehicle and a parking vehicle in front.

Type 51
Conflict between a vehicle swinging out to avoid a parking vehicle and a following vehicle.

Type 52
Conflict between a vehicle swinging out to avoid a parking vehicle and an oncoming vehicle.

Type 53
Conflict between a vehicle swinging out to avoid a parking vehicle and a pedestrian.

Type 54
Conflict between a vehicle which is stopping to park or entering a parking space and a vehicle of the moving traffic.



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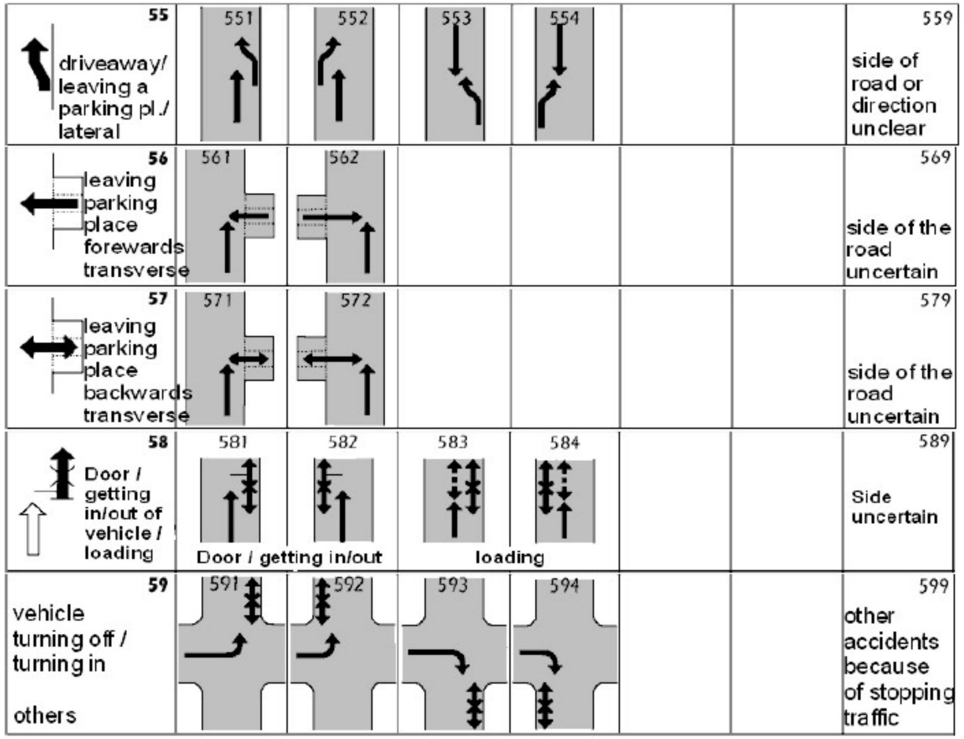
Type 55
Conflict between a vehicle driving away or leaving a lateral parking space and a vehicle of the moving traffic.

Type 56
Conflict between vehicle leaving a transverse parking space forewards and a vehicle of the moving traffic.

Type 57
Conflict between vehicle leaving a transverse parking space backwards and a vehicle of the moving traffic.

Type 58
Conflict because of opening a vehicle door, getting into /out of the vehicle or loading.

Type 59
Conflict between a turning vehicle and a parking vehicle which is located at the headed path – as well as other accidents with parking vehicles.



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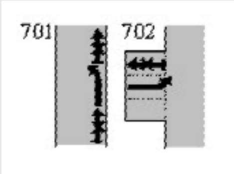
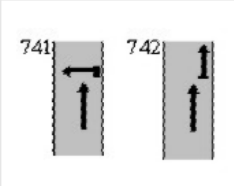
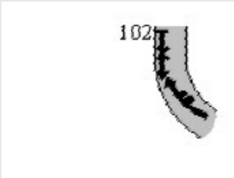
Type 5 : Special cases



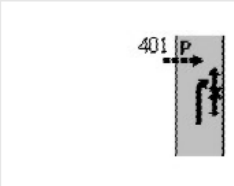
If the accident occurred with a vehicle manoeuvring to enter or leave a parking space and a standing vehicle, the accident is a type 7 accident (Other accident).



A vehicle brakes because of another broken down (or crashed) vehicle and is hit by a following vehicle. In this case it is a type 7 accident (Other accident).



If a standing/parking vehicle is hit, it need not always be a type 5 accident (accident with parking vehicles): For example if a driver looses control over his vehicle (e.g. in a curve, due to not adapted speed) and then collides with a parked vehicle, it is a type 1 accident (driving accident)



If a driver of a vehicle collides with a parked vehicle due to harsh braking because of a crossing pedestrian, the accident is a type 4 accident (pedestrian accident)

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5.7 Type 6: Accident in lateral traffic

Definition: The accident in lateral traffic occurred due to a conflict between road users moving in the same or in the opposite direction. This applies unless the conflict is the result of a conflict corresponding to another accident type.

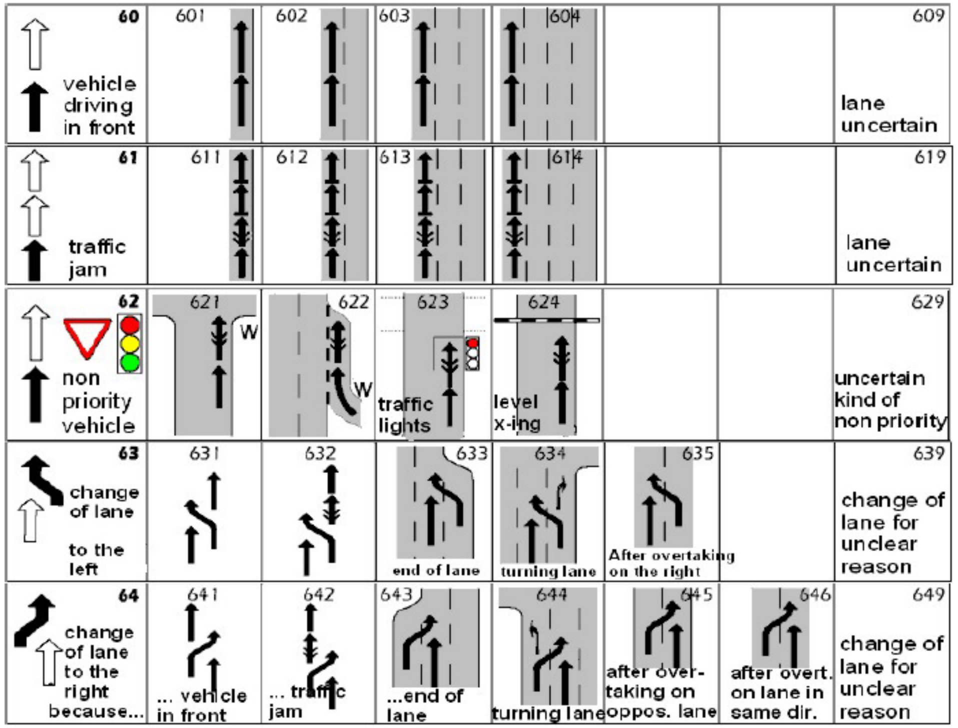
Type 60
Conflict between a vehicle and another vehicle driving in front on the same lane.

Type 61
Conflict between a vehicle which is braking, standing or going slow due to a traffic jam and a following vehicle.

Type 62
Conflict between a veh. wh. is braking, standing or going slow due to traffic or non priority and a following vehicle.

Type 63
Conflict between a vehicle which is changing lanes to the left and a following vehicle on the lane alongside.

Type 64
Conflict between a vehicle which is changing lanes to the right and a following vehicle on the lane alongside.



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Accident Classification System (GDV)

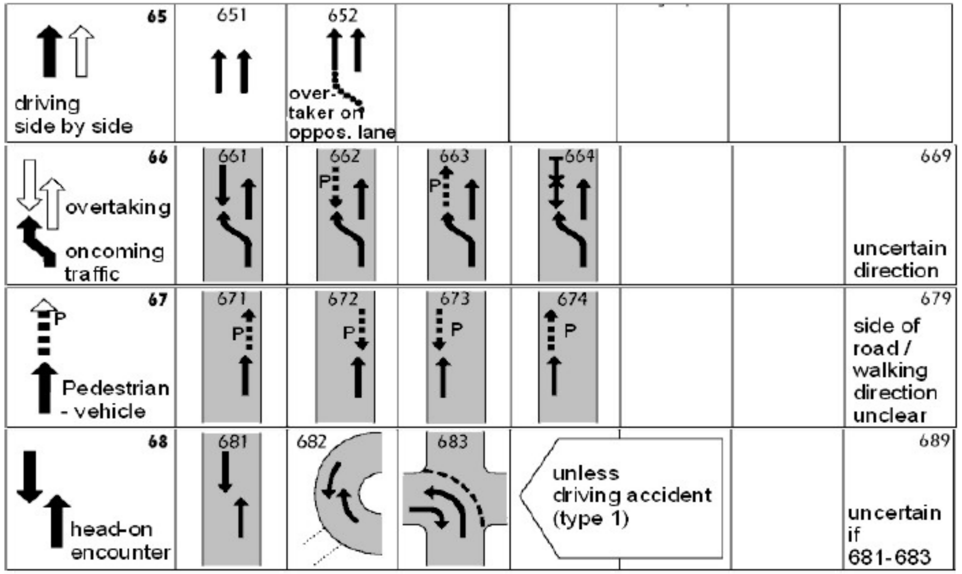
Type 65
Conflict between two vehicles, side by side, going in the same direction.

Type 66
Conflict between an overtaking vehicle and a vehicle from oncoming traffic, a pedestrian or a parking vehicle.

Type 67
Conflict between vehicle which is not overtaking and a pedestrian on the same lane.

Type 68
Conflict between two head-on encountering vehicles.

Type 69
Other accidents in lateral traffic.



Other accidents in lateral traffic 699

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5.8 Type 7: Other Accident Type

Definition: Other accidents are accidents that cannot be assigned to the accident types 1-6. Examples: Turning around, backing up, accidents between two parking vehicles, objects or animals on the road, sudden vehicle defects.

Type 70 Accident with two parking vehicles.	70 Parker-Parker	701	702	703 at car park				709 uncertain if 701-703
Type 71 Accident while backing up or rolling back. Unless manoeuvring to park	71 backing up	711 driving	712 rolling	713 P	714 backing out	715		719 uncertain if 711-715
Type 72 Accident due to a u-turn.	72 u-turn	721	722	723	724			729 uncertain if 721-724
Type 73 Accident due to a not fixed object.	73 not fixed object	731 load	732 other					

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Type 74 Accident due to a broken down vehicle.	74 broken down vehicle	741 accident	742 break down					749 uncertain if 741 or 742
Type 75 Accident due to an animal on the road.	75 Animal	751 wild animal	752 unattended domestic animal	753 attended domestic animal				759 uncertain if 751-753
Type 76 Accident due to a sudden physical disability of a road user.	76 sudden physical disability	761 falling asleep	762 dizzy spell	763 other (not alcohol)				
Type 77 Accident due to a sudden technical defect on the vehicle.	77 sudden vehicle damage	771 tyre	772 windscreen	773 brakes	774 steering	775 other damage		

Type 79
All other accidents

Other accidents 799

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