CoEXist

D3.3 Tools for assessing the traffic impacts of automated vehicles

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1 Introduction

A key goal of the CoEXist project is to enable local road authorities and other urban mobility stakeholders to evaluate the impact of the introduction of connected and automated vehicles (CAVs). One part of achieving this goal is the development of extended traffic models able to model traffic with various mixes of different types of CAVs, as presented in CoEXist deliverables D2.10/D2.11 and D2.7/D2.8. However, there are large uncertainties associated not only with the behaviour of the automated vehicles and the reactions of non-automated road users to the CAVs, but also the rate of introduction of various types of CAVs into the vehicle fleet. These uncertainties make interpreting the output of traffic models significantly harder.

The aim of this document is to present the approach that has been used in CoEXist, that in a structured and sound way can be used by road authorities to assess the traffic impact of automation on a given road design, traffic controllers, regulations, etc. The traffic performance and space efficiency assessment approach utilizes outputs from automation-ready transport modelling tools as input. The traffic models are applied to a set of consistent experiments with respect to penetration rates and different mixes of AV classes, as described in deliverable D3.1. Relevant performance metrics, presented in deliverable D3.2, are calculated from the model outputs and used to assess the traffic impact of automation in terms of traffic performance for different infrastructure designs. An essential functionality of the assessment approach is to consider and visualize effects of the large uncertainties with respect to how different types of AVs might behave and which mixes of different types of AVs that are likely to CoEXist at different stages of the transition period towards full automation.

Assessing traffic safety based on traffic models is difficult and in addition to the traffic performance and space efficiency assessment tool, two different safety assessment tools are developed: one qualitative safety assessment approach, which assess potential safety effects in relation to the accident types and automation functions that are relevant for an infrastructure design; and one more detailed safety assessment approach based on safety inspections. These two safety assessment approaches are not relying on the results of modelling tools and can be used independently

1.1 Structure of the deliverable

This deliverable consists of five different parts of which this report is one part. The other parts are:

- Scripts for calculation of the traffic performance and space efficiency metrics specified in D3.2 (Olstam et al., 2019) based on outputs from a microscopic traffic simulation model
- A spreadsheet-based tool for calculation of use-case specific impacts on traffic performance and space efficiency based on microscopic traffic simulation outputs (Traffic performance and space efficiency assessment tool - micro.xlsm)
- A spreadsheet-based tool for calculation of use-case specific impacts on traffic performance based on macroscopic traffic model outputs (Traffic performance assessment tool – macro.xlsm + assessment_tool_input.xlsx)
- A spreadsheet-based tool for qualitative safety estimations of traffic safety effects of different AV-functions for a specific use-case (Qualitative safety assessment tool.xlsx)

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The scripts and the spreadsheet-based tools are available for download at the CoEXist webpage, https://www.h2020-coexist.eu/.

1.2 Relation to other CoEXist deliverables

The assessment tool presented in this report constitute an important step in achieving the CoEXist goal of enabling automation-ready transportation and road infrastructure planning. The tool uses the output of the models presented in D2.10 / D2.11 (Sukennik, 2020a, Sukennik, 2020b) and D2.7 / D2.8 (Sonnleitner and Friedrich, 2018, Sonnleitner and Friedrich, 2020) to assess the traffic impact of automation in terms of the metrics presented in D3.2 (Olstam et al., 2019). The models and the assessment tool are applied to the eight CoEXist use cases specified in D1.3 (Olstam and Johansson, 2018a), D1.4 (Olstam and Johansson, 2018b), through applications of the experimental designs specified in D3.1 (Olstam, 2018) to the use case models presented in D4.1 (Liu and Olstam, 2018), with the results of the assessment tool for the eight use cases that will be presented in D4.3.

1.3 Outline

As described in section 1.1, the tool presented in this report consist of several components. These can be grouped into two parts: the quantitative evaluation of traffic performance and space efficiency, and the qualitative assessment of traffic safety effects. In chapter 2 the traffic performance and space efficiency part, both for macroscopic and microscopic models, is presented, including required inputs, produced output, and a detailed step-by-step guide to applying the tool. Also, a brief discussion on the limitations of the tool and some conclusions are provided. In chapter 3 the qualitative traffic safety assessment part of the assessment tool is presented, including a description of the general approach to qualitative safety assessment taken, a discussion around the assumptions underlying the tool, and a description of how it is meant to be applied. A more detailed safety assessment approach based on safety inspections is presented in chapter 4.

2 Traffic performance and space efficiency assessment tool

2.1 Metrics and thresholds for traffic impact of automation

Previous studies that have been conducted with a focus on automation or ADAS (Advanced Driver Assistance Systems) show that the metrics of interest do not differ much from those used in traditional applications of traffic modelling. This indicates that all the usual metrics may be suitable to measure the traffic performance implications of the automation. However, when applying metrics to calculate a performance difference, care must be taken to compare the metrics for corresponding classes of road users. Various travel time-based metrics are commonly used to evaluate traffic performance. In this case the problem is twofold: firstly, value of time for automated vehicles is likely to differ, possibly significantly, from that of other road users due to the possibility to engage in other activities during the ride. Thus, comparing the travel time for all cars, including AVs, to a baseline with no AVs may result in a misleading

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quantification of the traffic impact of automation. Therefore, it is recommended to mainly consider the effects on the traffic performance of non-automated modes when evaluating the traffic impact of automation on traffic performance. An important effect of this is also that total delay for conventional cars is problematic to use as a metric of the traffic impact of automation, since the number of conventional cars decreases when the penetration rate of automated cars increases. Thus, averaged metrics are used instead of total.

Many road authorities have policies to prioritize active modes above private cars in traffic planning. This often implies that a road authority can accept a marginal decline in traffic performance for private cars to achieve an improvement for pedestrians and cyclists. However, the details of such policies differ between road authorities. To allow road authorities to define thresholds of acceptable decline for different modes and road users, the assessment of traffic impact of automation should be conducted per mode or road user category (e.g. pedestrians, bikes, conventional cars, automated cars, etc.). For example, in order to ensure that the introduction of AVs do not counteract mobility goals on prioritization of walking, cycling and public transport over private cars.

To summarize, the traffic impact of automation on traffic performance is assessed by comparing the relative improvement in a performance metric for a specific road user category for a case with a specific penetration rate and mix of AVs with the baseline case of no AVs. This relative improvement is then compared to the road authority requirements, e.g. no acceptance on decrease in improvement for pedestrians, bikes or buses but 5% decrease in performance for cars.

2.2 Handling uncertainties related to the transition period

Traffic models have traditionally been applied to investigate traffic performance of different road or traffic control designs. In such applications the driver population is assumed to be constant for all investigated design alternatives. When assessing the traffic impact of automation, it is instead the infrastructure that is constant and the driver population that changes. The pace of changes of the mix of driving behaviours is highly uncertain. Thus, there is a need to consider several possible AV behaviours and that these different types of AVs might CoEXist. The combinations of penetration rates for several types of AVs lead to a large space of possibilities, too large for exhaustive exploration to be feasible. To confine the possible combinations of penetration rates it is assumed that both penetration rate of AVs and the level of automation will increase during the transition period towards full automation. That is, as time goes by, the penetration rate of AVs will increase, *and* the AVs will become more capable. This reduces the two-dimensional space of possibilities to a one-dimensional space. Furthermore, we explore the resulting space in steps as described below.

When conducting investigations of the transition period the mixes of different AVs should be taken into consideration. Depending on the assumptions made on the behaviour of AVs the resulting estimate of capacity, delay, travel time, etc. will vary significantly. The transition period is therefore suggested to be divided into a limited set of stages (not defined in terms of specific number of years in the future, but rather by the level of automation). In CoEXist three stages have been defined and are presented in the bullet points below. For more information on the different stages and what type of AV mixes to be expected in the different stages see D3.1.

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- Introductory: Automated driving has been introduced, but most vehicles are conventional cars. Automated driving is in general significantly constrained by limitations (real or perceived) in the technology.
- Established: Automated driving has been established as an important mode in some areas. Conventional driving still dominates in some road environments due to limitations (real or perceived) in the technology.
- Prevalent: Automated driving is the norm, but conventional driving is still present.

Further it is recommended to define a set of consistent experiments within each stage. These experiments should specify which penetration rates and which mixes of different AV behaviour that can be expected to be present during each stage. The experiments can, and should if necessary, also include variations of other uncertain variables as e.g. transport demand and behavioural adaptation of non-automated road users. The result of this is an experimental design defining each experiment/scenario that is being conducted. Details about the experimental design are presented in D3.1 (Olstam, 2018) and section 2.5.2 gives an overview of the experimental design and the functionality of it in the traffic performance and space efficiency assessment tool.

Traffic model runs are conducted for all the combinations of uncertain factors specified by the experimental design and the output is used to calculate the traffic impact of automation, i.e. the relative improvement in the performance metrics for each case with AVs and compare it to the baseline without any AVs. The comparisons of interest are shown in figure 1.

The results from the simulation experiments belonging to the same stage of CoEXistence can be seen as “samples” of the traffic impact of automation during that stage. The traffic impact of automation at a specific stage is presented in terms of the median, the minimum, and the maximum values for that stage, to compactly represent the results, including the uncertainty. In order to determine whether the traffic impact of automation is acceptable at a given stage, these values can be compared to the acceptable thresholds defined by the cities or road authorities.

The aim of the traffic performance and space efficiency assessment tool is to present the expected traffic impact of automation for each stage in a comprehensible manner, clearly showing the impact on traffic performance and space efficiency and it’s relation to the mobility goals that are defined by the cities and road authorities.

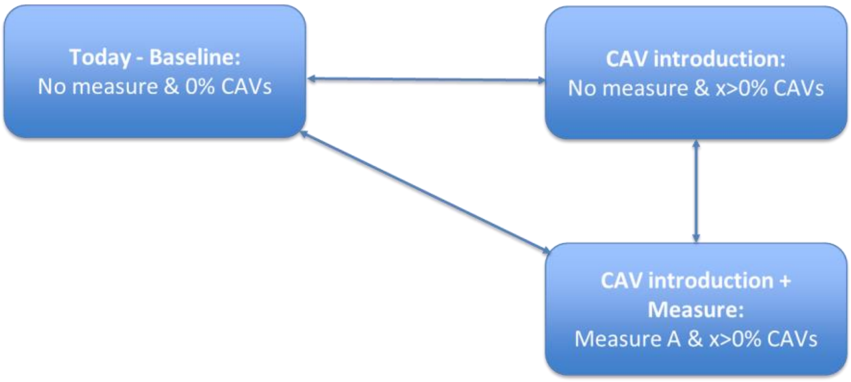

Figure 1 Relevant comparisons for assessment of the traffic impact of automation

The comparisons are made with the baseline to see if there's any relative improvement, for the defined metrics, by the introduction of CAVs. The same comparison is done for the cases where CAV's are introduced together with potential infrastructural measures to be investigated. The tool then allows for a visual comparison between the cases with only CAVs and with CAVs and the implemented measure.

2.3 Tool structure overview

The assessment tool is excel based and all calculations are done with formulas or array formulas. Macros are applied in order to import the experimental design and to import metric values. For micro simulation cases, a script has been provided to extract the metric values from the simulations. As for macro cases there is a template where values can be imported from the several skim matrices. Due to the properties of excel the tool is "sheet/tab based" where the different sheets are colour coded, representing different functionalities within the tool. There are two versions of the tool where one is meant to be used for analysis with microscopic models and the other for cases where macroscopic models have been applied.

Both of the tools have introductory sheets providing the user with necessary base information about CoEXist, and a small compact step by step guide on how to use the tool. Both the tools are similar to each other in regard to design and the methodology used in order to assess the traffic impact of automation. However, there are some differences that are clarified in the upcoming sections.

2.4 Development process

As the final version of the tool is going to be accessible for external parties one important aspect of the tool is its usability. To ensure user friendliness and eliminating any potential bugs or faults, several versions of the tool have been circulated to the parties involved in CoEXist. This has allowed for preliminary tests of the tool and also allowed actual end users to give feedback on both design and functionality. The development process is illustrated in figure 2.

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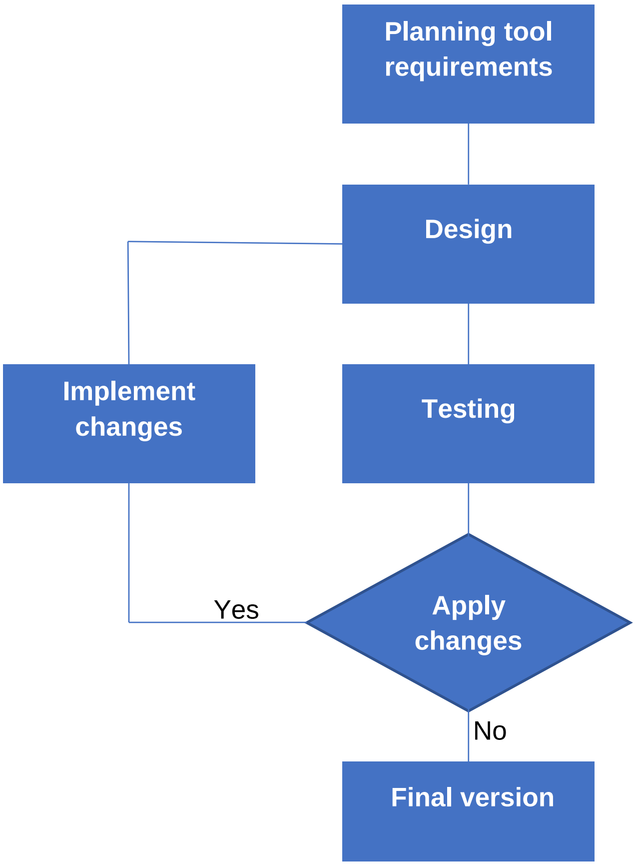

Figure 2 Development process

The iterative process of testing the tool showed to be beneficial, as feedback from the parties has given insight in lacking features of the early versions as well as design recommendations. Some of the implemented changes during the development process are listed in the bullet list below.

- Added functionality for importing data generated from both microscopic and macroscopic models.
- Added comparison flexibility, allowing the user to compare any two experiments.
- Increased user control over figure details.
- Colour scheme changes.

2.5 Input

The input to the tool can be classified into two different types of input.

1. ***The experimental design:*** which gives information of each individual experiment and defines the order of the experiments in the scenario management structure in Vissim and Visum.
2. ***Numeric inputs:*** which are the results from each experiment and gives information of the networks performance given a specific configuration.

Both the macro and micro version of the tool utilizes an experimental design and numeric inputs for further calculations and assessment of the traffic impact of automation in the studied area. There is also a python script developed to extract performance metrics from micro simulations performed in Vissim. Extraction of the relevant values in Visum, on the other hand, is done manually.

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2.5.1 Considered metrics

The evaluation is done with regards to specified metrics defined within CoEXist, presented in D3.2 (Olstam et al., 2019) and summarized in the bullet lists below.

For microscopic models:

- Served demand ratio
- Average travel time
- Average travel time per distance unit
- Average delay
- Vehicle hours travelled
- Person hours travelled
- Average space claim
- Average space time footprint
- Average space time utilisation

For macroscopic models:

- Average travel time
- Average travel time per distance unit
- Average delay
- Vehicle hours travelled
- Person hours travelled
- Vehicle kilometres travelled
- Person kilometres travelled

The tool is limited to assess the traffic impact of automation at a site with the presented metrics as a base.

2.5.2 Experimental design

There are many uncertainties related to autonomous vehicles and the introduction of them into the traffic system. As mentioned in section 2.2 an experimental design is created in order to systematically capture a large space of potential future scenarios.

In the experimental design, different experiments are set up in order to be able to make an assessment of the studied area. The experimental design determines the number of experiments needed and the configuration that should be applied to each experiment.

Each experiment configuration in the experimental design is, and needs to be, unique since the tool utilizes this feature when performing calculations. The variables of an experimental design are presented in the bullet list below:

- **AV penetration rate configuration:** Penetration rate of AV for each transport user class, is dependent on the stage of automation. It is stated in combination with the actual stage. Where the stage is described in text and the penetration rates in parenthesis.

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- **AV-class configuration:** The AV-class is dependent on the stage of automation. It is stated in combination with the stage where the stage is described in text and the ratios of the different AV-classes are given in the parenthesis.
- **Demand configuration:** The traffic demand, stated as a number, should be described further in another sheet in the same file or in a separate document.
- **Non automated road user behaviour:** How the behaviour of non-AV road users is changed due to introduction of automated vehicles is stated as not changed (normal), aggressive or passive behaviour. The definition of each non-AV behaviour is case specific and should also be described in a separate sheet in the same excel file or in a separate document.
- **Measures:** Potential measure to be investigated (i.e. legislation or infrastructural changes). The measures are also stated as numbers or ***"no"*** and should also be described in another sheet in the same excel file or in a separate document.

The other function of the experimental design is to define the order of how simulations are carried out in Vissim. This is of importance since the different metrics that are used for the assessment need to be associated with the corresponding experiment. For a more detailed overview on how this could be structured see Appendix A. Figure 21 and Figure 22 show an example of how the experimental design could be structured.

Penetration rate conf.	Av-class configuration	Demand Configuration	Non-Av behavior	Measure
Today (No AV)(0-0-0)	Today (No AV)	1	Normal	no
Today (No AV)(0-0-0)	Today (No AV)	2	Normal	no
Introductory (20-20-0)	Introductory (80-20-0)	1	Normal	no
Introductory (20-20-0)	Introductory (80-20-0)	2	Normal	no
Established (50-50-0)	Established(10-80-10)	1	Normal	no
Established (50-50-0)	Established(10-80-10)	2	Normal	no
Prevalent (70-70-0)	Prevalent(0-20-80)	1	Normal	no
Prevalent (70-70-0)	Prevalent(0-20-80)	2	Normal	no
Introductory (20-20-0)	Introductory (80-20-0)	1	Normal	1
Introductory (20-20-0)	Introductory (80-20-0)	2	Normal	1
Established (50-50-0)	Established(10-80-10)	1	Normal	1
Established (50-50-0)	Established(10-80-10)	2	Normal	1
Prevalent (70-70-0)	Prevalent(0-20-80)	1	Normal	1
Prevalent (70-70-0)	Prevalent(0-20-80)	2	Normal	1

Figure 3 Example 1 of experimental design sorted on measure

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Penetration rate conf.	Av-class configuration	Demand Configuration	Non-Av behavior	Measure
Today (No AV)(0-0-0)	Today (No AV)	1	Normal	no
Today (No AV)(0-0-0)	Today (No AV)	2	Normal	no
Introductory (20-20-0)	Introductory (80-20-0)	1	Normal	no
Introductory (20-20-0)	Introductory (80-20-0)	2	Normal	no
Introductory (20-20-0)	Introductory (80-20-0)	1	Normal	1
Introductory (20-20-0)	Introductory (80-20-0)	2	Normal	1
Established (50-50-0)	Established(10-80-10)	1	Normal	no
Established (50-50-0)	Established(10-80-10)	2	Normal	no
Established (50-50-0)	Established(10-80-10)	1	Normal	1
Established (50-50-0)	Established(10-80-10)	2	Normal	1
Prevalent (70-70-0)	Prevalent(0-20-80)	1	Normal	no
Prevalent (70-70-0)	Prevalent(0-20-80)	2	Normal	no
Prevalent (70-70-0)	Prevalent(0-20-80)	1	Normal	1
Prevalent (70-70-0)	Prevalent(0-20-80)	2	Normal	1

Figure 4 Example 2 on experimental design sorted on stage

2.5.3 Value extraction script (Micro)

Scripts for extraction of the different metrics have been developed, partly to facilitate the workflow for the different parties involved in the project, but also to ensure that the metrics are computed coherently throughout the different use cases in the project. By following the instructions given in Appendix A it is possible to get the relevant metrics that are needed when using the tool. The values for each metric are given in an excel file which corresponds to the 4 input sheets in the tool. These are named ***"Traffic Performance Input data", "Traffic Performance STD", "Space Efficiency Input data", and "Space efficiency STD".*** In addition, one tab in the output from the script gives additional columns with the number of served vehicles which are used in the tab named ***"Quality check"***. For details on how to use the scripts read appendix A.

2.5.4 Value extraction (Macro)

For the macroscopic cases a template of how to structure the values of the metrics is provided. The template is excel based and named ***"assessment_tool_input.xlsx"***. Using the template is not mandatory as values can be pasted directly into the tool by the user. However, structuring the performance metrics from the macroscopic model in the template allows the user to utilise the built-in function to import the values from the ***"assessment_tool_input.xlsx"***.

2.6 Output

Since there are two versions of the tool where each version corresponds to either an assessment of a microscopic simulation case or a macroscopic simulation case there's also some differences in the output from the two tools. The expected output from both of the tools is explained in this section.

2.6.1 Quality check (micro)

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As stated in section 2.5.1 one of the performance-metrics in a microsimulation case is the served demand ratio. Together with a calculation of how many simulation iterations are needed, these two values establish a form of initial check, indicating if the capacity of the network is enough and if more simulation iterations per experiments are needed.

2.6.2 Automation Impact (micro/macro)

As the main purpose of the tool is to assess the traffic impact of automation at an investigated site, the relative improvement of performance metrics compared to the baseline for each experiment is presented in the sheet ***"Automation impact".*** The tool will automatically generate the relative improvement considering the default baseline, which in general would be the present network with the same demand configuration and non-AV behaviour, see Figure 1 for clarification. However, the tool provides a possibility of adding a customised baseline, meaning that the user can select any of the experiments as a baseline.

2.6.3 Score Cards (micro/macro)

The traffic impact of automation is computed for each transport user class, metric, and experiment. In order to give the user an overview of the metrics and transport user class of interest, the tool provides the user with score cards. The function of these is to give a range of the traffic impact of automation in each stage, for each measure, metric and transport user class. Each score card generates a mean and median value along with the minimum and maximum value of each stage, and the selected measure, metric and transport user class. In addition, there is also an option to select a relative improvement threshold which would indicate the minimum accepted level of the traffic impact of automation for the specific case.

In the sheets next to each score card there are sheets providing the user with figures which visualises the median relative improvement as bars and the min and max values as error bars. The threshold of minimal accepted level of improvement is depicted in the figures as a horizontal line over each group of bar/bar.

The limitation to the score cards lies in how many performance measures, transport user classes or measures that can be portraited in the same figures, as for now the limit is set to eight.

The difference between the score cards lies in how they relate to the layout of the figures and how the relative improvement threshold is set. Score card 1 generates figures where all three stages are visualized together, and one threshold is set over the three stages. In contrast, score card 2 generates figures for each stage where the threshold level can be set independently for each stage, metric, measure and transport user class.

2.7 Other possibilities

In general, the tool can be considered to be rather static and confined to do the comparisons that are defined within the CoEXist project. This could be considered a drawback of the tool, since other comparisons could be of interest. In order to enable some flexibility in what experiments that are compared to each other there's a ***"Customised Baseline"*** column which can be used.

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As each experiment generates a unique key, this can be used in order to define a new baseline which is then possible to select for computations of the relative difference between the defined performance indicators.

2.8 Step by step guide

To compliment the overview of the tool, a detailed step by step guide on how to use the tool is presented in this section. Following each step thoroughly is crucial in order to get the desired output, putting information in the wrong cell or in the wrong format into the tool, will cause errors or give results that are wrong which in turn will lead to misinterpretations.

2.8.1 Step 0

Before starting with the actual tool, there's a couple of prerequisites that need to be fulfilled.

1. Create an experimental design in accordance with section 2.5.2.
2. Run simulations. Use scenario management functionality in Vissim/Visum and let each experiment be configurated so that it matches each row in the experimental design.
3. **Micro**: Extract vehicle/pedestrian records from Vissim. Specifications on what attributes that are needed can be found in table 3 in Appendix A.
   Macro: Extract relevant skim matrices.
4. **Micro:** Run the provided python script to calculate traffic performance and space efficiency metrics and get a new file called ***"Assessment_tool_input.xlsx".***
   Macro: Fill the template ***"Assessment_tool_input.xlsx"*** with values from macro simulations.
5. Save the tool, the experimental design and your "***Assessment_tool_input.xlsx"*** in the same folder.
6. Create a copy of the tool, just in case.
7. Open the assessment tool.

2.8.2 Step 1a

1. In the info tab of the tool, insert the name of your experimental design. The name has to be correct otherwise the tool will fail in importing the experimental design.
2. Go to the tab named ***"Generate Data"*** *and press the two buttons that are there for importing the necessary data.*
3. Copy all the experiments except the baseline experiments and paste them in the tab "***Automation Impact"***, starting in **column B**.
4. Type the stage, ***"Introductory"***, ***"Established"***, or ***"Prevalent"*** in the corresponding row in column A. It is important that the stages are typed in correctly and that there are no spaces in the beginning of, or at the end of each word.

2.8.3 Step 1b

Micro:

1. Assuming that the provided python script has been executed and the data has been imported correctly into the tool the user can now go to the tab ***"Quality check"*** and insert the demand of

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each experiment. This has to be done manually and is used in order to calculate the ***"SDR"*** (served demand ratio). The default threshold for accepted SDR is set to 0.9 but can be changed by the user in cell R3.

2. Cell T3, U3 and V3 are dedicated to the parameter values used to calculate number of simulation iterations needed according to equation (1).

   In this step there might be a risk of the number of simulations iterations being too little and therefore new simulations may be carried out.

$$n = \left(\frac{s_i * t_{\alpha/2}}{\bar{x}_i * \epsilon}\right)^2 \qquad (1)$$

where:
$n =$ the number of iterations needed
$s_i =$ standard deviation of measure i
$t_{\alpha/2} =$ critical t value from t − distribution table for confidence level of $\alpha/2$
$\epsilon =$ percental error margin

Macro:

Step 1b is not relevant for any macro case.

2.8.4 Step 2

1. Assuming that everything in step 1b passes the initial checks, the next step is to choose what metrics, modes and measures to analyse. These are selected in drop down lists in the different score cards which are located under the tabs ***"Score Card 1"*** and ***"Score Card 2".***
2. Next the relative improvement threshold is chosen. In ***"Score Card 1"*** the relative improvement threshold is located in column E. Selecting a threshold here will affect the figures connected to this score card where the relative improvement threshold spans over the 3 stages. In contrast, the relative improvement threshold in ***"Score Card 2"*** is located in columns G, M and S. The threshold is here chosen for each stage and selecting a threshold here will have an effect on the figures associated with this specific score card.

2.9 Discussion

2.9.1 Tool limitations

Even though the tool has been completed successfully and has increased its functionality since the initial versions, there are still some limitations with regards to the technical capabilities and also in the assessment of the traffic impact of autonomous vehicles.

Firstly, the tool can handle a maximum of 200 experiments, which is approximately 50 experiments per stage, (Today, Introductory, Established, and Prevalent). For the needs within the project this has been enough since no use case has more than 200 experiments in its experimental design. However, there might be a need of handling a larger number of experiments in other projects. In case more experiments

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are needed, it is possible to extend the areas where the computations are made. This will have no other effect on the tool except allowing it to handle an extended number of experiments.

The score cards and figures are limited to display 8 results from each stage of coexistence and shows the impact of the introduction of autonomous vehicles in regard to the traffic performance and space efficiency metrices defined in D3.2. As the approach for the qualitative safety assessment differs from the one applied here to the traffic performance and space efficiency metrics, this is done in a separate tool. For more details on the qualitative safety assessment see chapter 3.

2.9.2 Conclusions

The traffic performance and space efficiency assessment tool is essentially a practical application of the theoretical approach, described in section 2.2, of how to assess the potential impact that autonomous vehicles are going to have on a given site. The iterative development process in which different versions of the tool have been tested have contributed to the implementation of features that were not originally considered and have increased the functionality of the tool, resulting in a user friendly excel based interface.

An important strength of the assessment approach and the implementation of the tool is that it is not CoEXist specific, meaning that practitioners within the field can apply the assessment approach and the developed tools to their specific use cases, using common microscopic and macroscopic modelling tools.

The tool produces results in the form of score cards and figures showing the relative improvement of specified metrics per stage and transport user class, illustrating two aspects of the impact that automated vehicles can potentially have on the transportation system.

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3 Qualitative safety assessment approach

Connected & automated vehicles' (CAVs) safety is generating 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 onto 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 very few data are available and a large part relies on projections of what CAVs will be, can only be extremely challenging!

Some attempts of accident analysis can however be found: Dixit et al. (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)[1]. 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: small changes in the geometric specification of road links has an influence on the number of conflicts.
- The model in Vissim might not be an accurate model of AV behaviour[2].
- 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 in Rösener et al. (2018), has been selected. The approach focuses on the analysis of driving functions. Scenarios which are potentially affected by the

[1] SSAM has been developed by the Federal Highway Administration (FHWA)
[2] 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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respective driving function are identified. Afterwards the impacts 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 that are identified and a qualitative assessment of the impacts of each driving function on road safety is carried out.

3.1 Approach and main assumptions

3.1.1 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 (Utrainen, 2018).

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 is that the driving functions will be more and more sophisticated and have more and more control over the vehicle. 22 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 (SAE International, 2018)

Driving function	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).	

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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 forward 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 (FCW) 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 (ISA)	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 (VDA, 2019). 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).	
Automatic emergency steering & autonomous emergency braking (AES & ABS)	The automatic emergency steering & autonomous emergency braking systems can apply emergency braking when it determines that an accident is unavoidable, helping the driver to avoid a potential collision. When the system detects the risk of collision with an obstacle in front that cannot be avoided by braking only, it determines a direction without an obstacle (an escape zone). It then automatically steers the vehicle to help avoid a collision. The primary goal of the technology is to prevent crashes by detecting a potential conflict and alerting the driver, and, in many systems, aiding in brake application or automatically applying the brakes.	**Level 2**
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).	

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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).	
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).	
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).	**Level 4**
Arterial pilot	Highly automated driving up to limitation speed on 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)	

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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)	
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 to each other as shown in Figure 5.

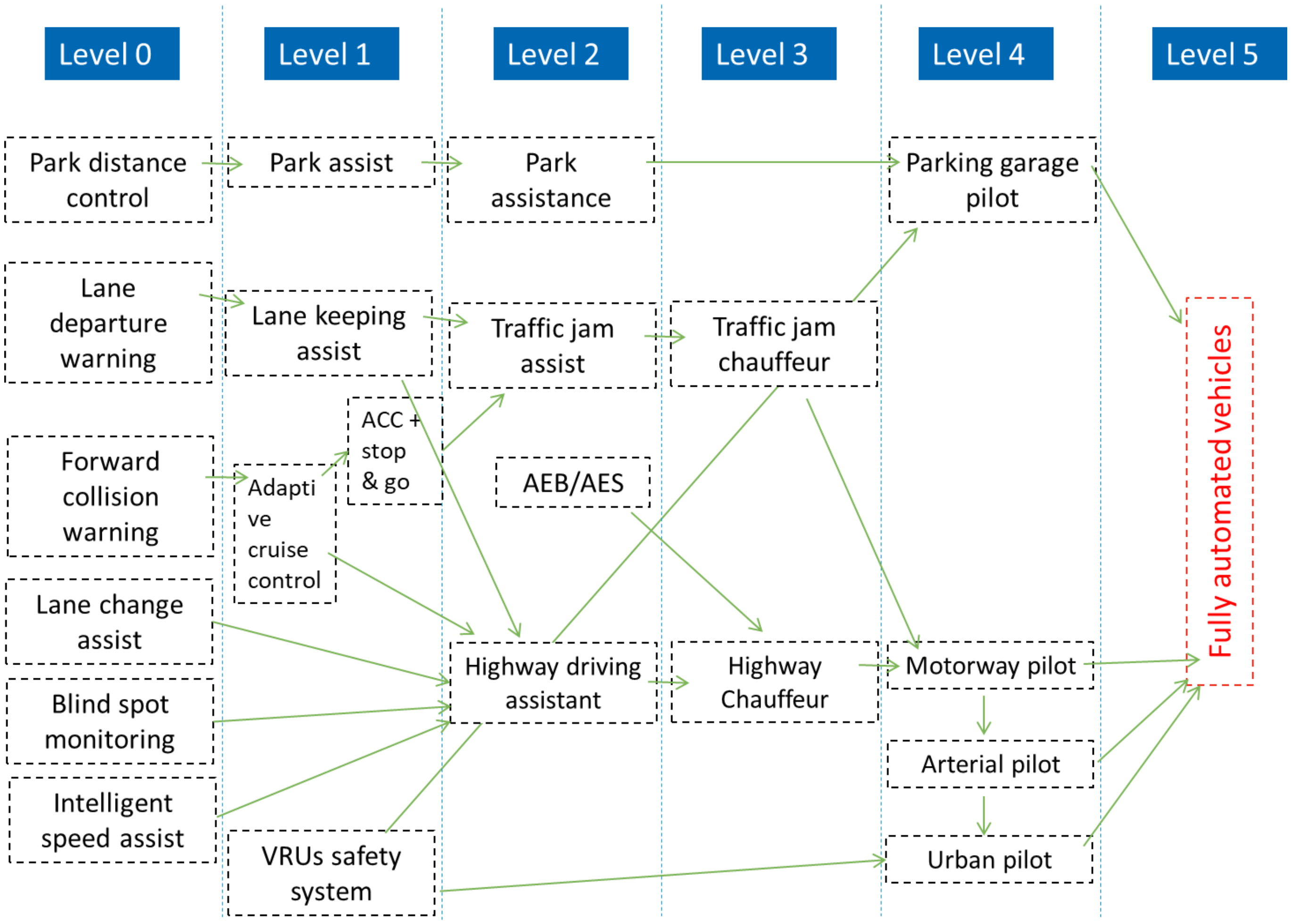

Figure 5 Link between the driving functions used in the CoEXist safety impact assessment

The figure illustrates how driving functions are included as parts of other more advanced functions. For example: Blind spot monitoring is included in highway driving assistant and highway driving assistant is

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included in highway chauffeur. It is important to consider this when evaluating the impacts of a combination of driving functions.

3.1.2 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 SafetyNET[3]. In the SafetyNET project, a classification based on types of accident and the German approach (so called GDV[4]) has been published. The 7 types of accident are explained in Table 2 (See Appendix B – 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 Reed and Morris (2008)

	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.

[3] http://erso.swov.nl/safetynet/content/safetynet.htm
[4] Gesamtverband der Deutschen Versicherungswirtschaft

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"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 harsh braking) and independent of who is to blame for the accident (e.g. if the pedestrian or the vehicle had priority)." (Reed and Morris, 2008)

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.

3.1.3 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, four road environments are considered (see Table 3):

Table 3 The four road environments considered in CoEXist and their definition (Olstam and Johansson, 2018b)

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. Vehicles, bicycles and pedestrians 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

3.1.4 The approach

The approach of the safety assessment is depicted in Figure 6. 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 6 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 almost 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 is, however, not excluded and has been identified for very few cases.

Two approaches linked to each other: the second one being the extension of the first one, are described in the present document.

3.2 The safety assessment tool

The safety assessment tool relies on what has been described in part 3.1.It is an excel based advanced filter for displaying the results.

The user can select which accident types and driving functions are relevant for its use case and display the results for each road environment.

This is done in 3 steps:

1. Select the relevant type of accident based on facts or educated guesses on which types of accident are recurrent in the area covered by the use case.
2. Select the relevant driving functions – the one of interest for the use case.
3. Display the results.

The tool is implemented in a Visual basic for applications (VBA) program, which is fetching the results from a database and giving an indication if the driving function is expected to have a positive, neutral or negative impact on an accident situation for each road environment with the help of the four pictograms shown in Table 4:

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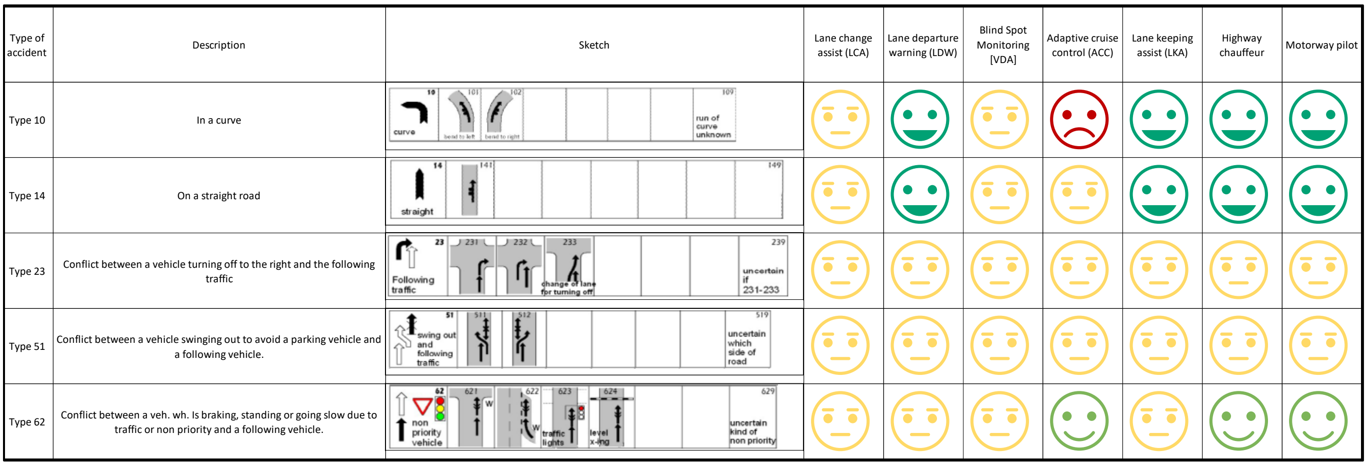
Table 4 Pictograms used in the road safety impact assessment tool and their meaning

Pictogram				
Meaning	The road safety could be negatively impacted	The road safety is not expected to be impacted	The road safety could be positively impacted	The road safety could be very positively impacted

The database contains the information of the influence of the driving functions on each type of accident for each road environment. The database has been developed by Charlotte Fléchon and Alexander Dahl (PTV Group) and Johan Olstam and Niklas Strand (VTI) based on estimation to the best of their knowledge. Modifications based on experience or gain of knowledge are expected. The tool gives the results in the form shown in Figure 7:



Type of accident	Description	Sketch	Lane change assist (LCA)	Lane departure warning (LDW)	Blind Spot Monitoring [VDA]	Adaptive cruise control (ACC)	Lane keeping assist (LKA)	Highway chauffeur	Motorway pilot
Type 10	In a curve	10 curve; 101 bend to left; 102 bend to right; 109 run of curve unknown							
Type 14	On a straight road	14 straight; 141; 149							
Type 23	Conflict between a vehicle turning off to the right and the following traffic	23 Following traffic; 231; 232; 233 change of lane for turning off; 239 uncertain if 231-233							
Type 51	Conflict between a vehicle swinging out to avoid a parking vehicle and a following vehicle.	51 swing out and following traffic; 511; 512; 519 uncertain which side of road							
Type 62	Conflict between a veh. wh. Is braking, standing or going slow due to traffic or non priority and a following vehicle.	62 non priority vehicle; 621 W; 622 W; 623 traffic lights; 624 level x-ing; 629 uncertain kind of non priority							

Figure 7 Screenshot of the road safety impact assessment tool

The tool described above is the tool that has been chosen for the impact assessment of the use cases studied in the CoEXist project.

The following part describes the reflections on an extended tool, more sophisticated, that has not been chosen for CoEXist because of the lack of information to calibrate and validate it. However, since such a concept could be interesting for further research, it has been decided to describe it in the present document.

3.3 Concepts for an extended tool

As mentioned, the safety aspects of traffic are in general challenging to study due to reasons mentioned in section 3. Due to the lack of data with regards to CAVs in every aspect there is no reason to assume

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that this task would be less challenging. Nevertheless, a method for a safety assessment has been developed.

One of the limitations of the qualitative assessment described above is that it 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.

In order 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. As the approach described in the upcoming sections is a concept, no tool has been developed taking this approach into consideration. This is merely a framework of how such an approach could be used when performing an assessment of the safety aspect when CAV's are introduced to the system.

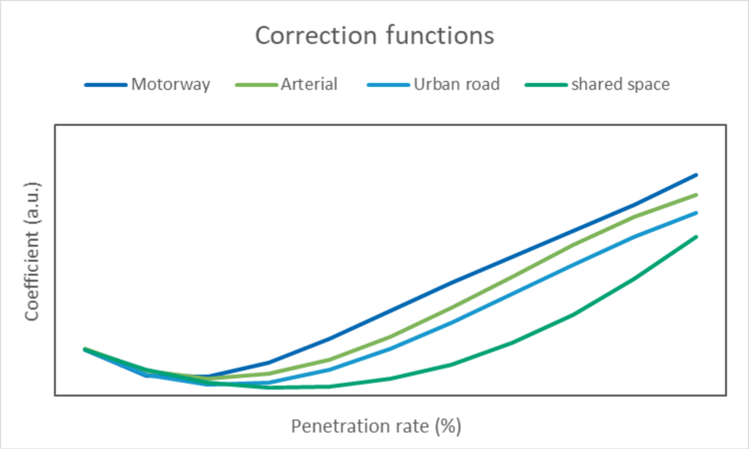

Figure 8 Correction functions for the 4 road environments

The function describing the impacts of the penetration rate is not defined in detail (see Figure 8), although 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[5]: 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 an educated guess, which means that the functions are not exact but should reflect a trend that is seen as one of many possibilities of what could happen with the introduction of automated cars on different road environments. Furthermore, this function might be refined according to new knowledge gained over time.

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

[5] For more details about the driving logics, please see annex A of D1.4 Scenario specification for eight use cases Olstam, J. and Johansson, F. 2018b. D1.4 Scenario specifications for eight use cases. Deliverable D1.4 of the CoEXist Project.

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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.

It is assumed that the more complex the environment the later and slower the increase of safety will take place and the probability of an accident will remain higher. This doesn't reflect the gravity of the accidents.

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.

3.3.1 Embedding of the tool into the CoEXist approach

The assessment tool should also fit to the way the use cases and the scenarios are planned within CoEXist.

First of all, the driving logics are expected to have an influence on the safety, mostly during the transition period. Indeed, if a car is very cautious, one can expect less accident or lighter accidents than if the vehicle is forcing its way. For this reason, each driving logics has a factor whose value has been given arbitrarily, the highest being for the rail-safe driving behaviour and the lowest for all-knowing. Manual driving is assigned a factor of one, since it is the "reference". Table 1 from deliverable D1.4 has been taken as basis to link the road environment and AV classes to the driving logics.

Table 5 Driving logic for the different road types and AV classes – taken from D1.4

Road type	Basic AV	Intermediate AV	Advanced AV
Motorway	C	N	AK
Arterial	C	C	AK
Urban Street	M	C	N
Shared space	M	RS	C

The penetration rates are also linked to the AV classes, using the same procedure as in D1.4 for example:

Table 6 Example for the scenario table, showing the penetration rate parameter that could be used in an extended tool

Scenarios	Stage	AV penetration	basic AV	Intermediate AV	Advanced AV
1	Introductory	25%	70%	30%	0%
2	Introductory	25%	70%	30%	0%
3	Introductory	25%	70%	30%	0%
4	Established	50%	0%	50%	50%
5	Established	50%	0%	50%	50%

The safety impact assessment tool is, therefore, embedding the concept of driving logics, stages of coexistence and AV classes developed in the project.

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3.3.2 Results

The results could then be calculated, converted in a qualitative indication and displayed separately for each road environment and each stage of coexistence as shown in the Table 7 below.

Table 7 Results

	Introductory	Established	Prevalent
Motorway			
Arterial road			
Urban road			
Shared space			

The result reflects the improvement of the safety of the traffic situation and is taking into account, among others, the type 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 procedure is explained in section 3.3.4. The results are displayed in a qualitative manner, the possible results are: -, 0, +, ++, +++. – reflects a negative impact and +++ a very positive impact.

3.3.3 What the user would need to do

The user must evaluate the importance of each type of accident for the use case he is studying. His evaluation is either based on available accident data, or if none are available on his estimation.

For each type of accident and each road environment, the user must enter a weight as shown in Figure 9. This weight can be derived from the number of accidents or if not available an estimate.

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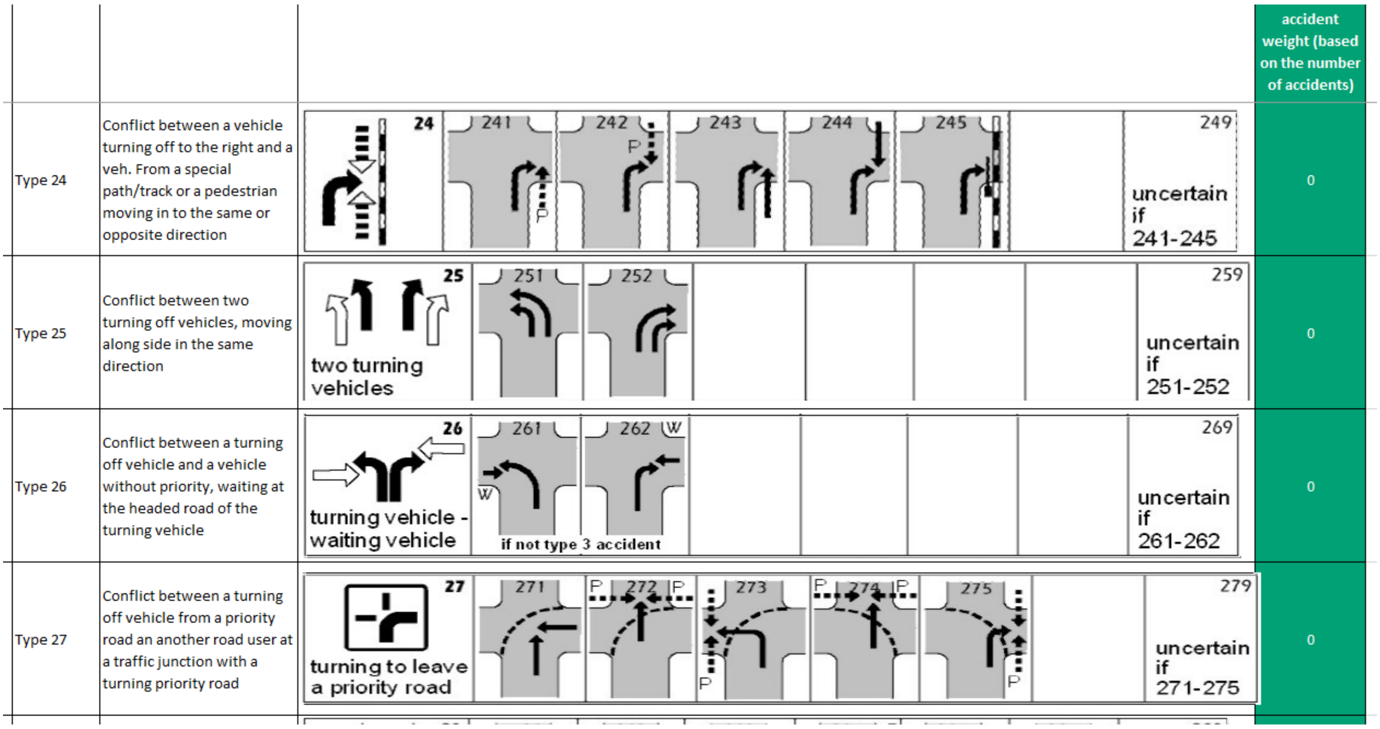

			accident weight (based on the number of accidents)
Type 24	Conflict between a vehicle turning off to the right and a veh. From a special path/track or a pedestrian moving in to the same or opposite direction	24; 241; 242 P; 243; 244; 245; 249 uncertain if 241-245	0
Type 25	Conflict between two turning off vehicles, moving along side in the same direction	25 two turning vehicles; 251; 252; 259 uncertain if 251-252	0
Type 26	Conflict between a turning off vehicle and a vehicle without priority, waiting at the headed road of the turning vehicle	26 turning vehicle - waiting vehicle; 261 W; 262 W; if not type 3 accident; 269 uncertain if 261-262	0
Type 27	Conflict between a turning off vehicle from a priority road an another road user at a traffic junction with a turning priority road	27 turning to leave a priority road; 271; 272 P P; 273 P; 274 P P; 275 P; 279 uncertain if 271-275	0

Figure 9 Screenshot of the table that must be fill in by the user depending on the type of accident recurrent for the studied use case.

Additionally, the user needs to define which driving functions he wants as reference and for the different AV classes as shown in Figure 10. Instead of or in addition to AV classes, it is possible to work with a personalised profile.

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			AV classes			
	Driving functions	Reference / conventional car	AV basics	AV intermediate	AV advanced	Personnalised
Level 0	Lane change assist (LCA)	0,2	0	0	0	0
	Park distance control (PDC)	0,2	0	0	0	0
	Lane departure warning (LDW)	0,05	0	0	0	0
	Forward collision warning (FCW)	0,25	0	0	0	0
	Blind Spot monitoring	0,1	0	0	0	0
	Intelligent speed assist	0,03	0	0	0	0
Level 1	Adaptive cruise control (ACC)	0,3	0	0	0	0
	Parks assist (PA)	0	0	0	0	0
	ACC including stop & go	0	0	0	0	0
	Lane keeping assist (LKA)	0	0	0	0	0
	VRUs safety systems	0	0	0	0	0
Level 2	AEB/AES	0	0	0	0	0
	Park assistance	0	0	0	0	0
	Traffic jam assist	0	0	0	0	0
	Highway driving assistant	0	0	0	0	0
Level 3	Traffic jam chauffeur	0	0	0	0	0
	Highway chauffeur	0	0	0	0	0
Level 4	Parking garage pilot	0	0,3	0,5	0,7	0
	Motorway pilot	0	0,5	0,7	0,9	0
	Arterial pilot	0	0,2	0,5	0,7	0
	Urban pilot	0	0	0,3	0,5	0
Level 5	Fully automated private vehicles	0	0	0	0	1

Figure 10 Driving function specification.

Finally, the user needs to fill in the scenarios with their penetration rates as shown in Table 6. The tool is, therefore, fairly easy to fill in for the user.

3.3.4 Metric specification

The approach explained in the parts above, can be summarised in the metric specification table as followed

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Safety metric: Gain in safety of the traffic situation

Description of metric

Relevance

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)

Definition

Estimation of the improvement of the safety of the traffic situation.

Assessment approach

Safety of the situation studied / safety of the reference

Measurand

(-)

Calculation procedure

Assessed transport mode

Motorised transport mode equipped with the selected driving functions

Calculation rules

Estimation of the improvement of the safety of the traffic situation $\boldsymbol{S^r_{CO}}$ is calculated separately for each combination of stage of coexistence **CO** and road environment **r**:

$$S^r_{CO} = \frac{f^r(p_{CO}) \times [p_{CO} \times \sum_{AVC}(p_{AVC,CO} \times b^r_{AVC} \times \sum_{acc}(w_{acc} \times g^r_{AVC,acc})) + (1 - p_{CO}) \times b^r_{REF} \times \sum_{acc}(w_{acc} \times g^r_{REF,ac}}{b^r_{REF} \times \sum_{acc}(w_{acc} \times g^r_{REF,acc})}$$

With:

r: road environment [see D1.4 (Olstam and Johansson, 2018b)]:

- 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. Vehicles, bicycles and pedestrians 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: Vehicles, bicycles and pedestrians share the same space, which can be unstructured or semi-structured.

CO: stage of coexistence [see D1.4 (Olstam and Johansson, 2018b)]:

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- Introductory: Automated driving has been introduced, but most vehicles are conventional cars. Automated driving is in general significantly constrained by limitations (real or perceived) in the technology.
- Established: Automated driving has been established as an important mode in some areas. Conventional driving still dominates some areas due to limitations (real or perceived) in the technology.
- Prevalent: Automated driving is the norm, but conventional driving is still present.

AVC: AV classes (see D1.4 (Olstam and Johansson, 2018b)) includes personalised

- Basic: First generation of AVs with SAE[6] level 4 capabilities only for one directional traffic environment with physical separation with active modes. The behaviour is in general quite cautious and risk minimizing. Basic AVs will not have dedicated devices for vehicle communication and cooperating functions.
- Intermediate: Second generation of AVs with level 4 capabilities in some road environments and driving context. The behaviour at more complicated road environments and driving context is still cautious and risk minimizing while the behaviour at less complicated road environments and driving
- Advanced: The third generation of AVs with level 4 capabilities in most road environments and driving context. The behaviour and how cautious the behaviour is, vary depending on road environment and driving context. Advanced AVs will have dedicated devices for vehicle communication and cooperating functions but are not depending on them.
- Personalised: defined by the user. These cars are considered to be automated cars.

The different AV classes are reflected by different relevant AV functions.

$\boldsymbol{P_{CO}}$: penetration rate of the automated vehicles (AVs) for the stage of coexistence **CO** considered. [If $\boldsymbol{p_{CV}}$ is the penetration rate of conventional vehicle, then $p_{CV} + p_{CO} = 1$]

$\boldsymbol{f_r}$: **correction function** (-) specific for each road environment and reflecting:

- the introduction of CAVs with low penetration rates will lead to higher uncertainty and a deterioration of human drivers' road safety because of unexpected behaviours of the CAVs.
- Human drivers will learn to adapt their own behaviour with increasing penetration rate to cope with the behaviour and driving manoeuvres of the CAVs
- CAVs will also be improved and better anticipate human behaviour. it should be kept in mind that when an accident occurs involving a CAVs, the driving logic of at least the whole fleet of vehicles of the same brand can be improved at once, while a human driver will learn only for himself.
- Therefore, it is assumed that road safety for conventional vehicles increase with increasing CAVs penetration rate.

$\boldsymbol{p_{AVC,CO}}$ penetration rate of the automated cars in the AV class considered in the stage of coexistence considered.

[6] SAE International. 2018. Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, J3016_201806. SAE International. https://saemobilus.sae.org/content/j3016_201806.

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acc: type of accident. There are 68 types of accidents based on deliverable 5.5 in the SafetyNET project (Reed and Morris, 2008). $\boldsymbol{w_{acc}}$: accident weight per accident type (-) estimated by the city or known from accident data the sum of the weights should be equal to one: $$\sum_{i \in acc} w_i = 1$$ $\boldsymbol{n_{avf}}$ proportion of vehicles equipped with the driving function **avf** $\boldsymbol{g^r_{AVC,acc}}$: influence of the driving function (-) It is a factor calculated based on the expected gain in safety of the relevant driving functions for each type of accident in the considered road environment. The driving functions **AVF** are either set by the AV class selected or tailored (=personalised). $$g^r_{AVC,acc} = \sum_{avf \in AVF_{AVC}} g^r_{acc,avf} \times n_{avf\,AVC}$$ $\boldsymbol{g^r_{REF,acc}}$: influence of the reference, similar to $\boldsymbol{g^r_{AVC,acc}}$ but for the reference driving functions. $$g^r_{REF,acc} = \sum_{avf \in AVF_{REF}} g^r_{acc,avf} \times n_{avf\,REF}$$ $\boldsymbol{b^r_{AVC}}$: safety factor related to the behaviour profile of the AV class considered. Can be set for each combination of AV class and road environment $\boldsymbol{b^r_{REF}}$: safety factor related to the behaviour profile of the reference. (Set to 1 by default)
Sources for required input data
• $\boldsymbol{w_{acc}}$: accident weight per accident type (-) estimated by the city or known from accident data • $\boldsymbol{P_{CO}}$: penetration rate of the automated vehicles (AVs) for the stage of coexistence **CO** considered. [If $\boldsymbol{p_{CV}}$ is the penetration rate of conventional vehicle, then $p_{CV} + p_{CO} = 1$] – given by the user • $\boldsymbol{p_{AVC,CO}}$ penetration rate of the automated cars in the AV class considered in the stage of coexistence considered – given by the user • $\boldsymbol{n_{avf}}$ proportion of vehicles equipped with the driving function **avf** for the reference and the case studied – given by the user
Further remarks

3.3.5 One step deeper: conversion to qualitative assessment and sensitivity analysis

3.3.5.1 Conversion quantitative to qualitative

As already explained previously, the present tool is meant to be a qualitative tool giving a hint on the improvement of safety depending on the current situation, and the driving functions and AV penetration

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rate of interest. Due to the tremendous amount of assumptions made, the results should be taken with extreme care and a qualitative assessment seems more adapted than number for which the interpretation could be misleading.

In order to convert the arbitrary values given from the tool into qualitative values, an estimation of the maximum values for each combination road environment and stage of coexistence has been done.

- Negative values are assigned the sign –
- Values equal to zero are assigned the sign 0
- Values between 0 and 30% of the maximum value are assigned the sign +
- Values between 30% and 70% of the maximum value are assigned the sign ++
- Values higher than 70% of the maximum are assigned the sign +++

3.3.6 Behaviour of the tool as a function of the penetration rate

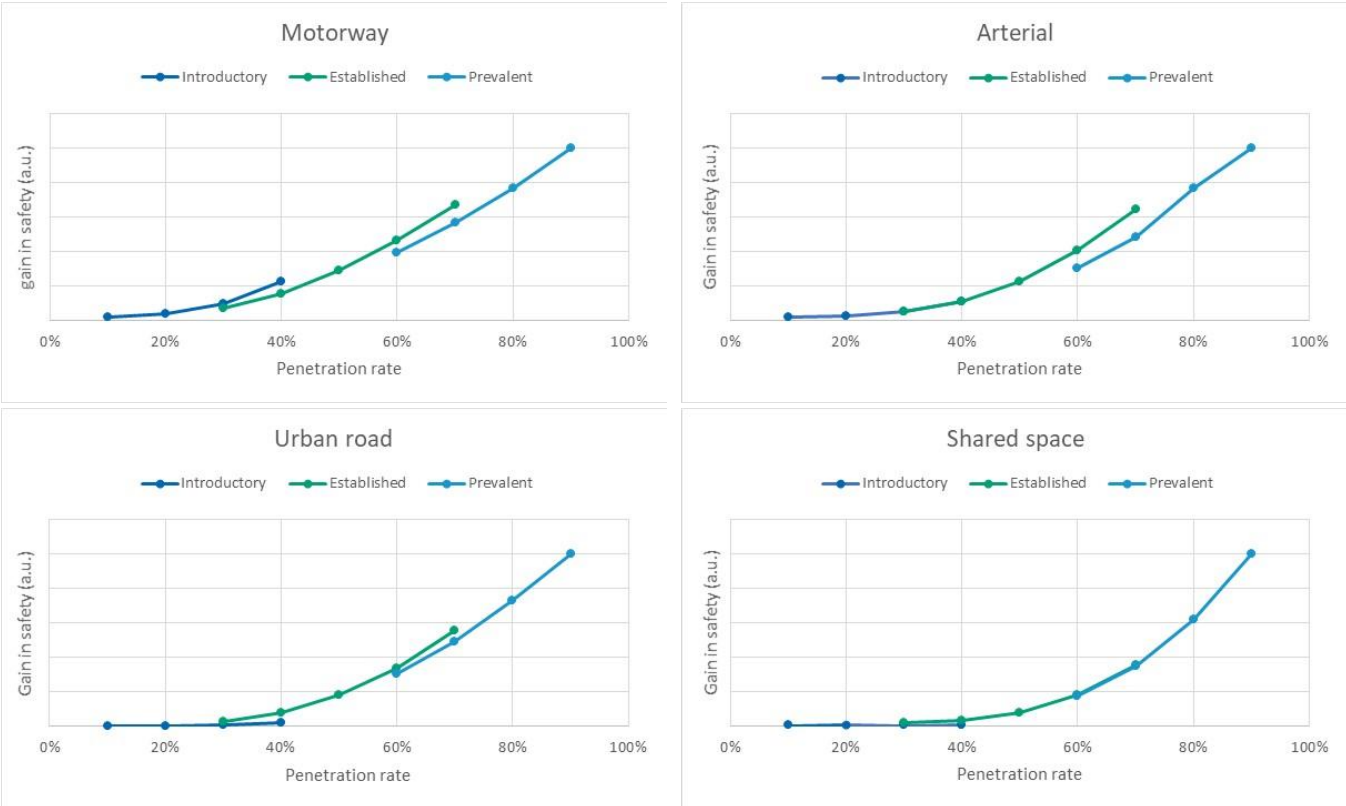

Figure 11 Gain in safety as a function of the penetration rate for the different road environments and stage of coexistence

As shown in Figure 11 and as expected from the correction functions shown in Figure 8, the curves representing the gain of safety as a function of the penetration rate are close to an exponential function. The differences between the stages of coexistence are coming from the different driving logics. The differences between the road environments from the driving logics and the correction function. Each road environment needs to be treated separately since not all type of accident and driving functions are valid on all road environments.

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Disabling the correction function leads to the behaviours shown in Figure 12. The gain in safety is increasing linearly with the penetration rate and the differences between the stages of coexistence is due to the different driving logics.

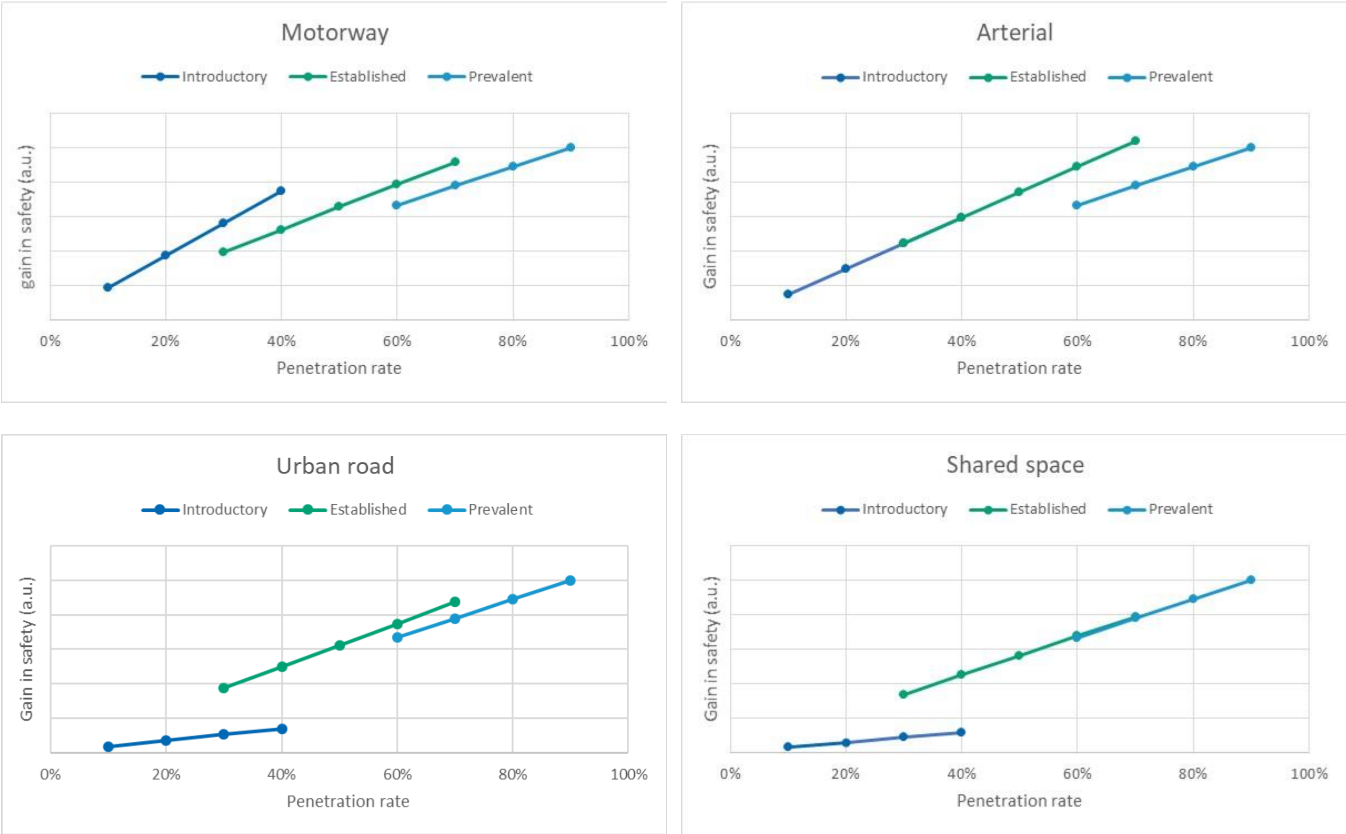

Figure 12 Gain in safety as a function of the penetration rate for the different road environments and stage of coexistence and disabling the correction function

Without driving logic factors the curves in Figure 12 would be continuous and linear.

3.4 Conclusion safety impact assessment tool

The safety impact assessment tool developed within the CoEXist project is relying on many strong assumptions and is a first step toward the assessment of the impacts of the deployment of CAVs on road safety.

The tool provides a prompt answer on what could be the impacts of the driving functions on different types of accident and road environment. Thus, it is an easy tool for cities and stakeholders to use when assessing the potential impacts of automated cars on their roads.

An extended tool has been developed as well and described in the document. However, it has not been used within CoEXist due to a lack of data to calibrate and validate it. This shows, how much work is still needed to be able to assess the impacts of automated cars on road safety.

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4 Safety inspection-based assessment approach

As stated above in chapter 3, a quantitative assessment of the impact of automated vehicles on road safety is challenging. However, in this section, a methodology is proposed which gives a quantitative output of road traffic crash risk for different scenarios, in order to understand to what extent road safety will be affected by gradually reducing the human factor in the road system. The methodology has been developed in cooperation with the consulting firm FRED Engineering (www.fredeng.eu).

This methodology, based on road safety inspections, is deemed to further strengthen CoEXist's results on the matter of road safety assessment, by further developing validated and recognized road safety evaluation techniques to allow the innovative consideration of automated driving effects.

Road safety inspections are nowadays an established procedure (PIARC, 2009) to assess the safety level of a road infrastructure. Though road traffic crashes are due to many different co-causes, road geometry has shown the clearer correlation (PIARC, 2003), proving to be a chief contributing factor. Automation is expected to have an influence on this, because of changes in vehicle behaviours, even without changing road infrastructures, and because of technical limitations and strengths.

Through its aim of using the knowledge of safety inspections to quantify these changes, this activity integrates the qualitative safety assessment approach described in chapter 3.

Three of the CoEXist use cases have been selected to develop and test this innovative approach of safety assessment, one in Gothenburg (use case 1) and two in Helmond (use cases 3 and 4). Their safety status has been quantified and eventual road infrastructure modifications to improve safety recommended. The road safety assessment for the current infrastructures is thus extended to the three use cases scenarios, by evaluating the interaction of automated vehicles with conventional vehicles and with the surrounding environment. The road safety analysis could lead to new solutions to improve road infrastructure for the safe operation of AVs.

By learning from the resultant methodology and the results from its implementation, cities and road authorities will be able to better assess future automation effects on the infrastructures and make informed decisions on its implementation.

4.1 Approach

Figure 13 describes the steps according to which the study has been conducted, including the main activities performed.

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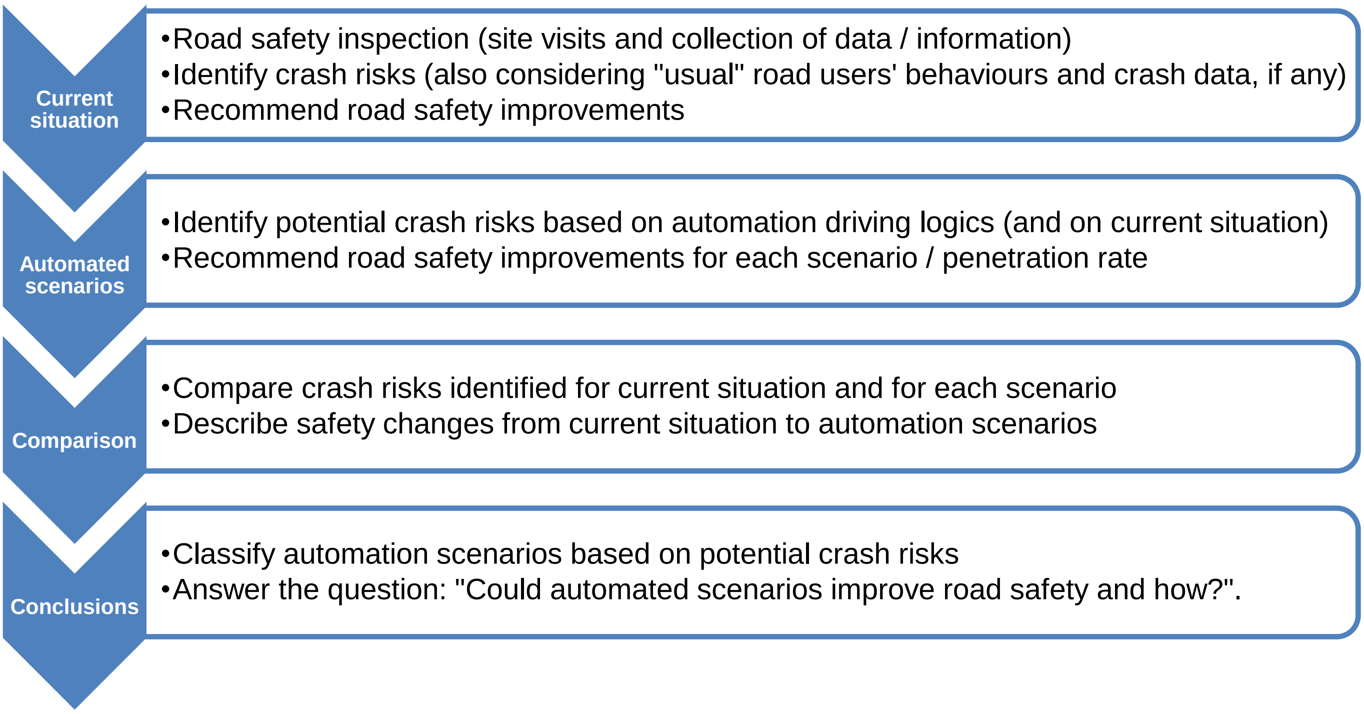

Figure 13 Steps of the safety inspection-based assessment approach

4.1.1 Current situation

A road safety inspection (RSI) of the roads in operation should be undertaken to identify road safety related features and prevent crashes.

According to the European Directive 2008/96/EC “road safety inspection” means an “ordinary periodical verification of the characteristics and defects that require maintenance work for reasons of safety”.

RSI responds to the safety implications of changing conditions on the road network. The road environment is dynamic; it is not fixed over its lifetime. Roadside features are added or removed, materials forming the road deteriorate and are replaced, new developments are built on the road frontage altering access conditions and modifying traffic flows. Changes also occur to our understanding of road safety and road design standards; certain engineering designs that would have been considered safe in the past are not conceivable anymore.

Based on common practices, road safety inspections should be carried out:

- During daylight, in both directions. An inspection by night is advisable if collision records show an unexpected share of crashes during the night.
- At times of normal operation of the road. Unless otherwise required, times when the road environment conditions are abnormal should be avoided, such as when special events are occurring. However, if events are frequent (occurring at least weekly), and if the conditions during those events are considered to affect road safety, then the road should also be driven under those conditions. School-times and commuter congestion are examples of factors which may need consideration if they apply to the road and are significant in terms of safety. However, off-peak conditions should always be considered.

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The RSI should be conducted by a team of at least two experienced practitioners. The benefits of a team approach are that reports are likely more balanced, and the likelihood to miss some road safety issues is lower. In addition, it is strongly recommended that all team members are independent which means not involved in the maintenance or operations' decisions of the road. The inspection is intended to be a fresh, independent look at the road.

The complete RSI process is composed of three different stages.

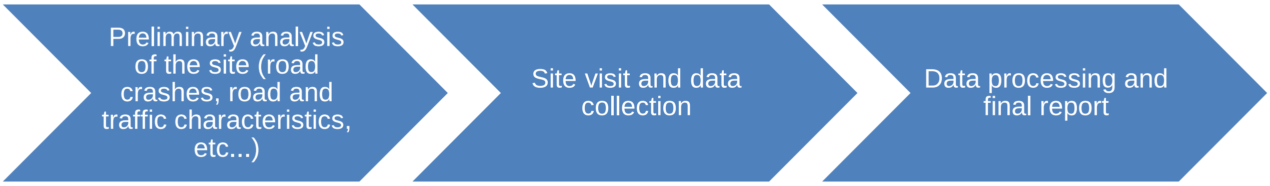

Figure 14 The road safety inspection process

An initial **desktop study** based on the road traffic crash analysis and on data about road and traffic characteristics is necessary, depending on data availability. When no crashes have occurred, it is however useful to have a preliminary idea of the section/site where the visit will be carried out and of the potential hazard points/elements arising from experience in safety inspections, using map resources when available. In case of an intersection, it is also interesting to carry out a conflict study, evaluating all possible situation involving one or more vehicles where there could be imminent danger of a collision if the vehicle movements remain unchanged.

The next step is the **site visit**. Issues cannot be identified only from crash data, crash report forms or photographs. It is essential to carry out a site visit always considering the point of view of different road users ('role play'). For this reason, the inspection is generally carried out with a car. Sometimes, it is also useful to visit the site by walking or using other types of vehicle, depending on the location and the vehicles used mainly by the local people. If deemed necessary and safe, stops are made at dangerous points to carefully assess all risk factors. It is strongly recommended to equip the vehicle with a high-resolution video-camera provided with a GPS device. It allows an easy positioning of the identified issues on a map.

During site visits, it is essential to take notes of what is observed, also using other available equipment[7] to make this activity efficient and effective, so that the following inspection report can be produced more quickly and accurately. The primary purpose of the site visit is to identify any environment and traffic deficiencies which may contribute to risk of road traffic crashes. To ensure that road deficiencies are identified, it is essential that site inspections are carried out in an extremely systematic and purposeful manner.

After the site visit and the collection of all relevant data, a final step of **data processing** follows. During this phase all the information collected is put together, processed and analysed also using the recorded

[7] For instance, FRED Engineering (www.fredeng.eu) has developed an application for Android with the aim of maximizing the effectiveness of road safety audits and inspections (ASIA - Assistant for road Safety Inspections and Audits)

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videos. In this way it is possible to obtain a list of problems and possible dangers that could lead to crashes.

Even when road traffic crash data analysis does not show relevant results, sometimes due to the absence of crashes occurring at that site, it does not mean that the road is safe. In fact, the objective of the road safety inspection is specifically to identify those dangerous elements that could lead to crashes, even if they have not occurred before. It is important to note that RSI is a pro-active methodology, aimed at reducing risks of crashes by anticipating potential road safety issues.

The results of the road traffic crash analysis and the results of the road safety inspections are not always directly correlated (EuroRAP, 2020).

Collision level $\not\Leftrightarrow$ Risk level from road safety

A road traffic crash is a rare event that occurs due to one or more interacting factors, but the risk of having a crash due to road-related problems is always present.

The number of crashes occurred on a section is a consequence not only of road infrastructure characteristics, but also of traffic levels, road user behaviour and the characteristics of the vehicle fleet.

To obtain a crash risk estimation, it is recognised that it must be the result of a combination of three key factors:

- Danger [**D**]: Likelihood that a crash can happen.
- Vulnerability [**V**]: Risk of injury of road users given a crash occurred.
- Exposure [**E**]: Amount of “activity” a user is exposed to a risk.

The resulting (general) formula for risk assessment is as follows:

$$\mathbf{R = D \times V \times E}$$

For this study, no traffic flow changes have been assumed between the current situation and the different scenarios (i.e. the annual average daily traffic is constant), so that the exposure factor can be overlooked. Since the objective is to assess the variation of risk between the current situation and the scenarios, a constant exposure will not influence the final result.

The risk assessment process must be undertaken in a systematic manner in order to produce quantitative risk values which can enable a comparison to be made between the risks associated with different issues at a particular site or, indeed, at different sites. An assessment of risk therefore involves a subjective evaluation of the likely frequency and likely severity of crashes.

The subjective evaluation of the likelihood of crash occurring (i.e. the frequency with which the hazard will cause or contribute to a crash) can be established using the Table 8 in which the values assigned to each likelihood level are indicated.

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Table 8 Frequency of crash occurring

Frequency / likelihood of crash occurring	Equivalent crash frequency	Value
Frequent	More than once for year	**1.0**
Probable	Once every 1 to 4 years	**0.7**
Occasional	Once every 4 to 10 years	**0.4**
Remote	Less than once every 10 years	**0.1**

The severity of a hazard is established based on a subjective assessment of the most likely outcome occurring if the hazard would cause or contribute to a crash.

It is clear that any type of crash has the potential to result in death, so it is important to consider the most typical or realistic outcome rather than the worst possible outcome (because the worst one is always catastrophic). The Table 9 can be used to assess the crash severity that a hazard could cause and it includes the weights that have been assigned to each severity level.

Table 9 Severity of crash occurring

Severity	Equivalent crash severity	Weight
Catastrophic	Causes at least one death (fatal)	**1.0**
Critical	Causes at least one serious injury (severe)	**0.6**
Marginal	Causes at least one minor injury (slight)	**0.3**
Negligible	Material damage only	**0.1**

For each issue identified during the road safety inspection, a value of likelihood and a weight of severity have been assigned and multiplied in order to obtain the risk value (Figure 15).

Figure 15 Risk value calculation for each problem

The list of issues is then reported in the RSI report and for each of them the risk value is indicated. The sum of the risk values of all problems identified represents the final risk of the use case (Figure 16).

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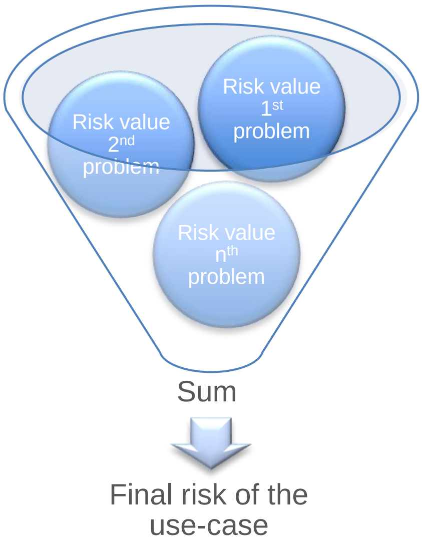

Figure 16 Process for the computation of the final risk of the use-case

As stated before, it is not surprising that on a site/section where no crashes have ever occurred ("low" collision level), during road safety inspections, many high-risk problems are encountered ("high" risk level). The Table 11 shows the interpretations of such cases.

In order to compare the Collision level and the Risk level (RSI), it is necessary to identify the two thresholds that define a high or low risk level section/site as a result of a road safety inspection (Table 10).

Table 10 Correspondence between risk value and risk level

Risk value	Risk level (RSI)
> 0.40	High risk
< 0.10	Low risk

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Table 11 – Interpreting Collision level and Risk level results[8]

Collision level	Risk level (RSI)	Description of the road	Assessment
Coherent cases			
High	**High**	Crash rate is high and road design is likely to be a factor.	Targeted investment improving road infrastructure is highly likely to be cost effective.
Low	**Low**	Inherently safe roads with low crash rates.	Road infrastructure already built and performing to a high standard. Limited potential for further improvement.
Diverging cases			
High	**Low**	Crash rate is high, but road design is unlikely to be a key factor. Crash investigation is necessary to determine causes. Behavioural issues such as speeding, drinking, fatigue, and/or vehicle safety are likely to be factors.	Road investment should aim to ensure crash investigation outcomes are addressed and the basics are maintained to a high standard.
Low	**High**	Road design is inherently unsafe, yet crash rate is low. This could be because road is so dangerous that people take extraordinary care.	Road investment should aim to ensure the basics are at least satisfactory – e.g. good line markings and signage.

With the aim of reducing the risk arising from each problem identified during the road safety inspections, recommendations are suggested.

When possible, depending on the risk entity, recommendations refer to low-cost / short-term road improvements. They are usually related with road infrastructure improvements. However, depending on the issues, also changes in road safety policies and enforcement can be recommended.

Recommendations for improvements, especially when they refer to road infrastructure changes, are made based on best international practices and standards. Referring to the three use cases assessed for CoEXist, reference is made to European standards and eventual EC Directives.

[8] RAP Crash Risk Mapping: Technical Specification, EuroRAP (January 2020)

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4.1.2 Automated scenarios

Starting from the outputs of the road safety inspection (i.e. the current situation with no automated vehicles), it is evaluated if each problem identified will still be present in the scenarios with automated vehicles.

It is important to clarify that, since automated vehicles are a new technology for which there is not yet enough data available concerning their performance on the road and their interaction with other vehicles and road users, the road safety assessment for automated scenarios is more similar to a road safety audit (i.e. an independent safety check relating to the design characteristics of a road infrastructure project).

It is in fact a matter of assessing scenarios that are not yet realised, for which it is necessary to imagine how an automated vehicle "will behave". It is also important to note that for these assessments, the eventual perception errors of AVs are not considered. Assumption is made on a full reliability of technologies used by AVs.

In order to do this, the fundamental principles behind each driving logic and the reactions of automated vehicles consequent to inputs from the surrounding environment in which conventional vehicles and vulnerable users are expected to be present must be considered.

To better understand and assess the roles of the two types of vehicles (conventional and automated) in a crash, two automated vehicles' behaviours have been defined: **Acting** and **Re-acting.**

- **Acting**: the behaviour of the automated vehicle leads to the occurrence of a crash.
- **Re-acting**: the automated vehicle has to react to a dangerous behaviour of a conventional vehicle.

The factors that are taken into account in the assessment of the new road safety risk are: road, vulnerable road users, conventional and automated vehicles (Figure 17).

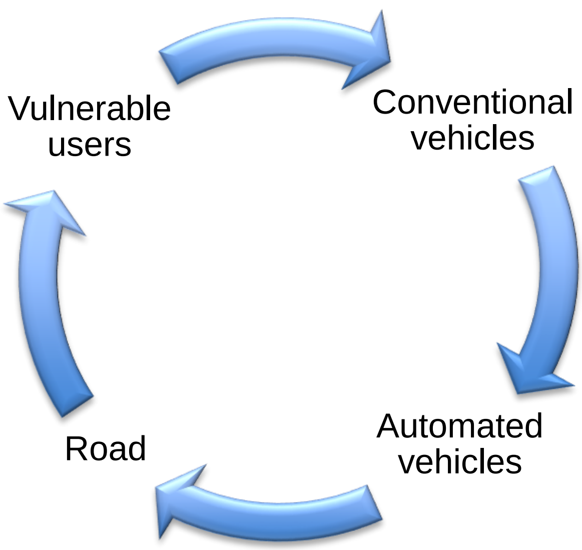

Figure 17 Safety assessment for automated scenarios

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The 14 scenarios used in the microsimulation phase are analysed. They are a combination of different mixes of automated vehicle classes and different penetration rates, as shown below.

Use case 1: Shared space

Table 12 – Scenarios of use case 1

Cars & trucks / Minibuses						
Scenario	**CVs**	**AVs**	**AV class**	**Driving logic**	**AV class**	**Driving logic**
1	45%	55%	100% Intermediate	Cautious	-	-
2	9%	91%	40% Advanced	Cautious	60% Advanced	Normal

Use case 3: Signalised intersection including pedestrians and cyclists

Table 13 - Scenarios of use case 3

Cars & trucks						
Scenario	**CVs**	**AVs**	**AV class**	**Driving logic**	**AV class**	**Driving logic**
1	75%	25%	80% Basic	Cautious	20% Intermediate	Normal
2	75%	25%	20% Basic	Cautious	80% Intermediate	Normal
3	50%	50%	20% Basic	Cautious	80% Intermediate	Normal
4	50%	50%	50% Intermediate	Normal	50% Advanced	All-knowing
5	25%	75%	50% Intermediate	Normal	50% Advanced	All-knowing
6	25%	75%	100% Advanced	All-knowing	-	-

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<u>**Use case 4**: Transition from interurban highway to arterial</u>

Table 14 - Scenarios of use case 4

Cars & trucks						
Scenario	**CVs**	**AVs**	**AV class**	**Driving logic**	**AV class**	**Driving logic**
1	75%	25%	80% Basic	Cautious	20% Intermediate	Normal
2	75%	25%	20% Basic	Cautious	80% Intermediate	Normal
3	50%	50%	20% Basic	Cautious	80% Intermediate	Normal
4	50%	50%	50% Intermediate	Normal	50% Advanced	All-knowing
5	25%	75%	50% Intermediate	Normal	50% Advanced	All-knowing
6	25%	75%	100% Advanced	All-knowing	-	-

Three possible cases may arise at this stage for each scenario:

A. A problem found in the road safety inspection will still be a problem also for automated vehicles. The risk evaluation is revised to assess if it would improve or not. It is examined whether the recommended improvements for the current situation are also suitable to reduce the risk in the scenario with automated vehicles. If not, new countermeasures are suggested.
B. A problem present in the current situation may not be a problem for automated vehicles but will continue to be a problem for normal vehicles. This means that the risk value related to that problem decreases because the likelihood that a crash may occur decreases with the reduction in the number of normal vehicles. The vulnerability is likely to remain unchanged.
C. New problems may arise due to the introduction of automated vehicles driving together with normal vehicles. This is a new factor that changes road safety conditions. A new assessment is therefore required regarding the risk that the automated vehicles may generate against the normal vehicle and vice-versa. In each of the three use-cases, the behaviour of automated vehicles is evaluated, considering all available driving manoeuvres. To each new problem, a risk value is assigned that could change according to the different AVs penetration rates (since the crash likelihood changes with them). Thus, the same problem may have a different risk value in scenarios with different AVs rates. In order to reduce or eliminate the risk arising from each new problem, road infrastructure improvements are suggested.

4.1.3 Comparison

After estimating the risk values for all the problems identified in each scenario, a comparison analysis is made between the final risk value of each scenario and that of the current situation of the specific use case also by calculating the percentage variation in the risk due to the introduction of automated vehicles (Figure 18).

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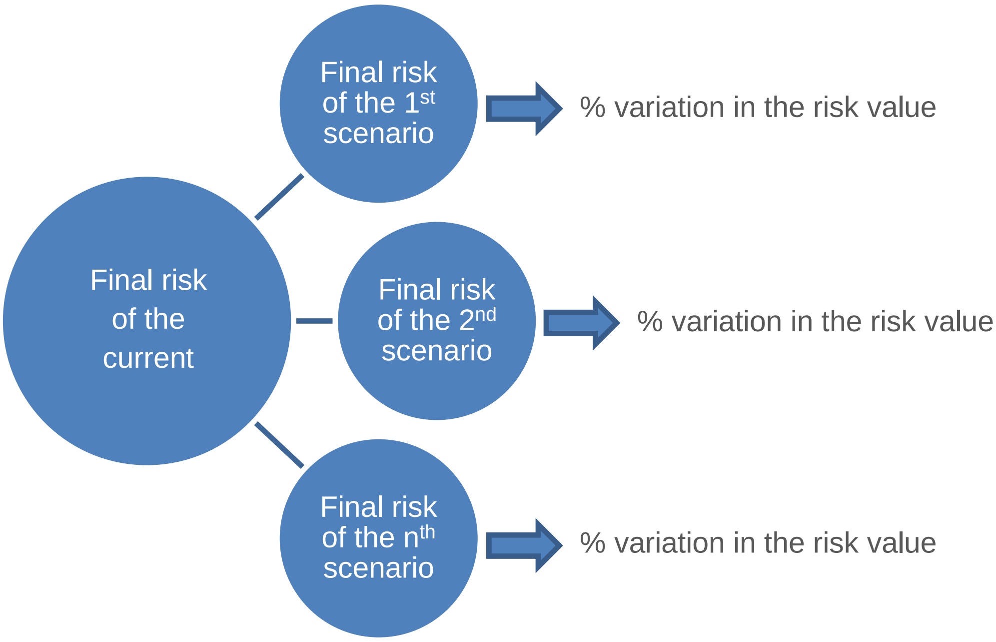

Figure 18 Comparison analysis

The safety changes produced by the introduction of AVs have been explained and a comparison between the AV scenarios performed.

4.1.4 Conclusions

The last part of the study has been focuses on ranking the AVs scenarios based on the risk values obtained. The classification helps understanding which could be the AV scenario allowing to guarantee the highest benefits in terms of road traffic crash risk reduction.

4.2 Overview of the application of the methodology

An example of the methodology application is presented in this section.

After processing of collected information and data (on-field visits), a list of all road safety problems identified on the site/section for the current situation is drafted (see example in the table below). Information include details about the problem, the type of road traffic crash that might occur, and recommendations for elimination or mitigation of the problem. The likelihood of occurrence of the possible road traffic crash and its severity are estimated (based on experts' judgement) and the risk value is calculated according to the risk formulation (Figure 19). This is done for all problems identified.

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Case	Conditions	No.	Location	Problem	Crash type	CVs				
						Recommendation	%	F	S	R
A	Current	A.1	N270 (both directions)	**Dangerous sudden lane change manoeuvres** Sudden lane change manoeuvres to get into the reserved lane (right turn or left turn lane) can be an issue. There is a road sign that shows the lanes layout with the directions allowed, but it is around 300 m before the intersection and there is no indication of the distance to it. A sudden lane change manoeuvre can be due to the distraction of the driver who realizes too late the need to change lanes or to the traffic on the adjacent lane that force the driver to wait to change the lane. The same situation also occurs for drivers who leave the service area and want to change lanes (yellow in the picture). This can lead to abrupt braking by drivers approaching the junction or risky lane change manoeuvres causing a rear-end or lateral collision.	Rear-end/ lateral collision with vehicle	It is recommended to install a steel gantry for signs closer to the intersection that shows the lanes layout with the directions allowed in order to start moving to the correct lane.	100%	0.70	0.30	0.21

Figure 19 Screenshot of the table filled in with problems identified for the current situation

Once the risk of each problem has been calculated, they are summed, in order to obtain the total road traffic crash risk for the current situation.

The next step is the risk assessment of the automated scenarios. In order to do this, a second part of the table (in green in the Figure 20) is filled in concerning future scenarios in which conventional and automated vehicles coexist. Assumption is made that the road infrastructure configuration remain unchanged.

The expected behaviour of automated vehicles interacting with conventional vehicles is described. This depends on the driving logic used by automated vehicles. The penetration rate of automated vehicles with different driving logics composes a scenario. As the vehicle type changes, it may be necessary to propose different recommendations than those proposed for the current situation (recommendations proposed for conventional vehicles are not necessarily valid also for automated vehicles). The recommendations are also reported in the table. According to the hypothetical behaviour of automated vehicles, a likelihood and severity related to a specific problem can be assessed, and the risk value for automated vehicles can be calculated.

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Case	Conditions	No.	Location	Problem	Crash type	CVs					Avs (Cautious/Normal/All-knowing)							Total risk
						Recommendation	%	F	S	R	Expected behaviour		Recommendation	%	F	S	R	
											Acting AVs	Re-acting AVs						
A	Current	A.1	N270 (both directions)	**Dangerous sudden lane change manoeuvres** Sudden lane change manoeuvres to get into the reserved lane (right turn or left turn lane) can be an issue. There is a road sign that shows the lanes layout with the directions allowed, but it is around 300 m before the intersection and there is no indication of the distance to it. A sudden lane change manoeuvre can be due to the distraction of the driver who realizes too late the need to change lanes or to the traffic on the adjacent lane that force the driver to wait to change the lane. The same situation also occurs for drivers who leave the service area and want to change lanes (yellow in the picture). This can lead to abrupt braking by drivers approaching the junction or risky lane change manoeuvres causing a rear-end or lateral collision.	Rear-end/ lateral collision with vehicle	It is recommended to install a steel gantry for signs closer to the intersection that shows the lanes layout with the directions allowed in order to start moving to the correct lane.	100%	0.70	0.30	0.21				0%	0.00	0.00	0.00	0.21
											Cautious AVs never make sudden lane changes	The problem still exists from CVs that could hit AVs	Improve the width of lane markings from the point where the turn lane starts. A wider line gives to the AV more time to react to unpredicted behaviour of the other cars. Furthermore a narrower lane approaching the intersection will induce drivers to reduce their speed and limit the transversal movement of the car (improve the eventual change lane detection). Some rumblestrips or similar noisy surface on the lane delimitation markings can help driver to keep central trajectory.	50%	0.40	0.30	0.12	0.06

Figure 20 Screenshot of the table filled in with problems identified for the current situation and automated scenarios

At the end, the total risk score for the scenario is obtained (as the sum of risk scores of single road safety problems) and it is possible to compare it with that of the current situation, determining a risk variation. This is done for all the scenarios of the use case (Table 15).

Table 15 Example of a final summary

Scenario	CV	AV	Risk score Current scenario	Risk score Future scenario	% risk change
1	75%	25%	1.81	1.79	-1%
2	75%	25%	1.81	1.72	-5%
3	50%	50%	1.81	1.39	-23%
4	50%	50%	1.81	1.30	-28%
5	25%	75%	1.81	0.92	-49%
6	25%	75%	1.81	0.85	-53%

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4.3 Conclusion for the safety inspection-based assessment methodology

The safety inspection-based assessment methodology developed within the CoEXist project is a new approach for the road safety assessment of automated driving scenarios.

The assumptions and hypotheses made, which are the basis of the whole process, were necessary to achieve the best compromise between the aim of obtaining numerical risk values and the purely theoretical knowledge of the automated vehicles' behaviour.

At the end, the methodology allows to answer the question "Could automated vehicles improve road safety?" by providing results for the different scenarios comparable to each other and with the output of the road safety inspection of the current situation. This provides an estimate of the risk variation due to a reduction of drivers and an increase of automated vehicles.

The added advantage of the site visit, on which the methodology is based, is that it is possible to learn more about the environment, providing evidences of the perception of the site from the user's point of view. Since the scenarios to be assessed are related to situations of coexistence of conventional and automated vehicles, the knowledge acquired from inspections allows to provide customized assessments to each use case.

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Appendix A - Extraction of performance metrics

1 Inputs

The main input to the script that extracts the different metrics from a microscopic simulation model in Vissim is the vehicle and pedestrian records that are possible to extract from Vissim. In order to get both files from Vissim, select the **Evaluation** menu > click on **Configuration** > select the **Direct Output** tab. The window shown is labelled "***Evaluation Configuration***", in the column ***"write to file"*** click the check box for the files that are of interest, (**Vehicle and Pedestrian records**). In the column "***From-Time"*** insert your warm up time for the model. This causes the vehicle and pedestrian record to ignore data that is produced during the warmup time.

IMPORTANT: If Pedestrians are represented as slow vehicles in your model, only the vehicle record is needed.

Both of the files are text files although they have their own extensions .fzp and .pp respectively. The content of both the files are specified in Vissim and in order to get the desired output from the script the attributes of interest are shown in table 1 and 2.

To specify the attributes that are needed there is a button labelled ***"More…"*** in the ***"Evaluation Configuration"*** window, for both vehicle and pedestrian record. Click the button that corresponds to the file of interest, a window corresponding to vehicle or pedestrian record shows up. The resolution of the output file is recommended to be set to equal the number of timesteps in which the model is simulated. In the bottom left there's a button labelled ***"Attributes",*** click here to be able to select the attributes needed. For more information regarding the vehicle and pedestrian records see the Vissim Manual on page 1031.

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Table 16 - Mandatory attributes in Vehicle records

Attribute	Description
Simulation second	Timestep t of simulation i
Number	Vehicle Id
Vehicle type	Travel Mode
Time in network(total)	Total time spent in network in time step t
Delay time	Total experienced delay in time step t
Speed	Speed of each entity in time step t
Safety distance(net)	The safety distance of each time step t
Distance travelled(total)	Total distance travelled in timestep t
Length	Vehicle length

Table 17 - mandatory attributes pedestrian records

Attribute	Description
Simulation second	Timestep t of simulation i
Number	Pedestrian Id
Distance travelled(total)	Total distance travelled in time step t
Time in network(total)	Total time spent in network in time step t
Time Delays	The total experienced delay in time step t

If additional analysis is desired supplementary attributes ought to be accepted, however it is not required in the traffic performance and space efficency assessment tool.

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It is crucial that the numbering of transport user class[9] follows a predefined set of values, in any other case the script will fail to recognize the transport user class and simply give an error message, see table 3 for the predefined transport user classes. Note that in Vissim the transport user class is named Vehicle Type in the Vehicle records and Pedestrian Type in the Pedestrian records.

In the case of pedestrians there are two common practices of modelling these in Vissim one is by utilising Viswalk that comes with Vissim and the other is to model them as slow vehicles. There are several technical and model-wise differences between the two methods. However, the relevant difference for the purpose of extracting data and computing the relevant metrics lies in that pedestrians modelled as modified vehicles will show up in the vehicle records whereas Viswalk pedestrians will show up in the pedestrian records. If pedestrians are modelled as slow vehicles it is important that they get assigned to the corresonding transport user class number. If modelled via Viswalk this is of no concern.

Table 18 - Mandatory vehicle type numbers to use

Transport user class	VehType/PedType number
Car	100
AVCar (Cautious)	1001
AVCar (Normal)	1002
AVCar (All-knowing)	1003
AVCar(Customised)	1010
AVCar(Customised)	1011
AVCar(Customised)	1012
Truck	200
Truck (Cautious)	1004
Truck (Normal)	1005
Truck (All Knowing)	1006
AVTruck(Customised)	1013

[9] 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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AVTruck(Customised)	1014
AVTruck(Customised)	1015
Bus	300
Bus (Customised)	1007
Bus (Customised)	1008
Bus (Customised)	1009
Minibus	500
Minibus(Customised)	1016
Minibus(Customised)	1017
Minibus(Customised)	1018
Bike (man)	610
Bike (woman)	620
Pedestrian (man)	510
Pedestrian (woman)	520

Most of the numbers presented in table 3 are the default values for the different vehicle/pedestrian types, however it is not expected to be so for every model, and it is therefore recommended to take an extra look at the implemented vehicle/pedestrian type numbers for your specific Vissim model. Some of the vehicle types in the table are labelled “customised”. These vehicle type numbers will be classified as automated vehicle, automated trucks, etc in the script.

1.1 Storing of vehicle and pedestrian records

In CoEXist an experimental design is created for each use case. The experimental design presents the different penetration rates, AV-mixes, demand configuration, etc. for each experiment. The experimental design is used as a base for the calculations in the Assessment tool, and also as a base of how to structure the experiments in the scenario management feature in Vissim. By using the scenario management feature in Vissim, Vissim will create a folder structure with a unique folder for each experiment (In Vissim called scenarios). It is important that the vehicle and pedestrian records are saved in the corresponding experiment folder since the script utilises this structure.

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Before creating different experiments make sure to make a copy of your network and store it somewhere safe. When placing your network under scenario management Vissim creates a new folder structure in the same location of the network file. Under the folder named ***"Scenarios"*** you'll find numerous folders called $S00001, S00002, S00003$ ... $S0000N$, these are the folders mentioned in the previous paragraph that are unique for each experiment and it is here that we want to save the vehicle and pedestrian records for every experiment. For clarity, all the vehicle (.fzp) and pedestrian (.pp) files that corresponds to experiment 1 should be placed in the folder called S00001, all the files corresponding to experiment 2 in S00002, and so on. In any other case the script will not be able to find the data and will give an error.

The vehicle and pedestrian records tend to become very large very fast. Out of concern for the space on any given hard drive the recommendation is to use a low vehicle and/or pedestrian record resolution of 1 Hz, so that $1\ second = 1Hz$. Higher frequencies are of no problem for the software, however, be sure to have enough space on the hard drive since the simulations will stop when the hard drive is full.

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2 Outputs

The output of the **Main.py** script is an excel file of a table mimicking the input sheet of the assessment tool, for each metric group. One for traffic performance metrics and one for the space efficiency metrics. In the case where only one network file is used the outputted tables can be directly copied to the input sheet in the assessment tool. However, if several network files are used, e.g. one network file per measure, there will be some manual work that has to be done, since every outputted file will correspond to a network with a specific measure. One way is to simply copy row by row in the output table and paste it in the corresponding row in the input sheet in the assessment tool. Another way would be to reorganize the experimental design so that the table is sorted by measure. This way the outputted data can still be copied and pasted into the input sheet, per measure.

The reorganizing of the experimental design in the assessment tool will not have any effect on the calculations performed in the tool itself. However, it is important that the experiment follow the structure of the experimental design in the assessment tool.

Figure 21 and Figure 22 illustrates a reorganized experimental design table and how the different experiments in Vissim can relate to the table. Figure 21 depicts the case where only one network file is used, as mentioned, when choosing this approach there's no need for the table to be sorted by measure. Figure 22 shows the case when several files are used.

Experimental Design

Penetration rate conf.	Av-class configuration	Demand Configuration	Non-Av behavior	Measure
Today (No AV)(0-0-0)	Today (No AV)	1	Normal	no
Today (No AV)(0-0-0)	Today (No AV)	2	Normal	no
Introductory (20-20-0)	Introductory (80-20-0)	1	Normal	no
Introductory (20-20-0)	Introductory (80-20-0)	2	Normal	no
Established (50-50-0)	Established(10-80-10)	1	Normal	no
Established (50-50-0)	Established(10-80-10)	2	Normal	no
Prevalent (70-70-0)	Prevalent(0-20-80)	1	Normal	no
Prevalent (70-70-0)	Prevalent(0-20-80)	2	Normal	no
Introductory (20-20-0)	Introductory (80-20-0)	1	Normal	1
Introductory (20-20-0)	Introductory (80-20-0)	2	Normal	1
Established (50-50-0)	Established(10-80-10)	1	Normal	1
Established (50-50-0)	Established(10-80-10)	2	Normal	1
Prevalent (70-70-0)	Prevalent(0-20-80)	1	Normal	1
Prevalent (70-70-0)	Prevalent(0-20-80)	2	Normal	1

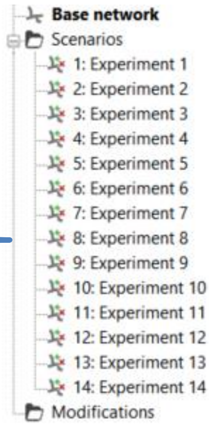
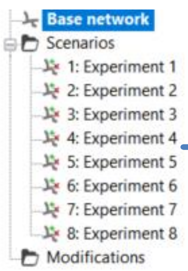


Figure 21 Relation between experimental design and Vissim experiments 1



Experimental Design

Penetration rate conf.	Av-class configuration	Demand Configuration	Non-Av behavior	Measure
Today (No AV)(0-0-0)	Today (No AV)	1	Normal	no
Today (No AV)(0-0-0)	Today (No AV)	2	Normal	no
Introductory (20-20-0)	Introductory (80-20-0)	1	Normal	no
Introductory (20-20-0)	Introductory (80-20-0)	2	Normal	no
Established (50-50-0)	Established(10-80-10)	1	Normal	no
Established (50-50-0)	Established(10-80-10)	2	Normal	no
Prevalent (70-70-0)	Prevalent(0-20-80)	1	Normal	no
Prevalent (70-70-0)	Prevalent(0-20-80)	2	Normal	no
Introductory (20-20-0)	Introductory (80-20-0)	1	Normal	1
Introductory (20-20-0)	Introductory (80-20-0)	2	Normal	1
Established (50-50-0)	Established(10-80-10)	1	Normal	1
Established (50-50-0)	Established(10-80-10)	2	Normal	1
Prevalent (70-70-0)	Prevalent(0-20-80)	1	Normal	1
Prevalent (70-70-0)	Prevalent(0-20-80)	2	Normal	1

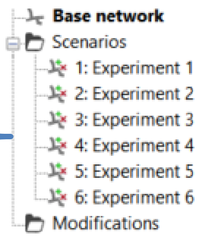


Figure 22 Relation between experimental design and Vissim experiments 2

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3 The scripts

The scripts are implemented in python 2.7.3 utilizing functions in the libraries pandas, numpy, glob, os, sys and copy. To run the program, four *.py files are needed namely **Main.py**, **LoadData.py**, **Metrics.py**,and **Extract_tot_space_time.py,** all provided within the scope of the CoEXist project.

It is also important to acquire the needed libraries for python as the scripts will not work without them. An easy way to do this is by downloading Anaconda Navigator, which includes most of the libraries that are needed. To be safe, make sure to download version 2.7 of python. Since the scripts are written in 2.7.3 there may be some conflicts occurring with newer versions of python. In addition PTV also provides the user with a version of python that is designated for running scripts within the program. This version is also needed in order to be able to run the script **Extract_tot_space_time.py.**

In the case that any library is missing after installing anaconda go to the windows command prompt and type: **pip install *"the missing library"*** i.e: **pip install glob** or **pip install os, etc.**

3.1 Script descriptions

Figure 23 describes the structure used in the code. The two top layers represents the three *.py files and the layers under both LoadData.py and Metrics.py illustrates the functions that are used in each of the files. In addition a script named ***Extract_tot_space_time*** is also provided in order to get the available space time in the network for computing the space time utilisation. This script is not used together with the ones depicted in Figure 23.

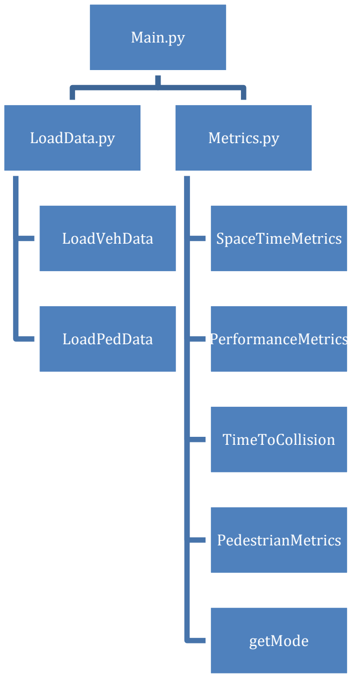

Figure 23 - script structure

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3.2 Extract_tot_space_time

One of the metrics that are explored within the CoEXist project is the space time utilisation. In order to compute this metric the total available space time is needed, which can be extracted from the model by using the provided script ***Extract_tot_space_time.py.*** This script has to be executed from within Vissim before simulations are started which will result in an outputted .csv file named ***"AvailableSpaceTime"***, this file must be placed in the same folder as the ***Main.py*** in order to be able to calculate the space time utilisation.

3.3 Main.py

Main.py is the top layer in the code structure. Here the user must specify the number of experiments that are to be analysed, and the occupancy factor for each transport user class. I.e if the occupancy factor is estimated to be 1.5 person per car, then 1.5 should be inputted behind ***"CarOccup"***, and similarly for ***"TruckOccup", "MinibusOccup",*** and ***"BusOccup"***. This is also the only user defined input to the script. In addition, variables and lists that are needed to store the metric values computed later in the code are also defined here.

In order to extract the data, the code will first browse through the scenario folder storing the path to each experiment, which allows for the creation of the main loop of the program which is a loop over the number of experiments. A second loop is implemented to loop over the number of simulation replications (based on different random seeds), and it is within this loop where functions in both **LoadData.py** and **Metrics.py** are called to perform calculations for each simulation replication. Once these are performed for every simulation replication for one experiment then mean and standard deviation of each metric is calculated and stored in a table mimicking the input table in the Assessment Tool. When data for each experiment has been processed there will be two files (potentially more in a later stage of the project), in the same location as the script and the network file named ***"TrafficPerformanceMetrics.xlsx"*** and ***"SpaceEfficencyMetrics.xlsx".***

3.3.1 LoadData.py

LoadData.py contains two functions that are called upon in main.py named, namely LoadVehData and LoadPedData. The two functions read and pre-process the data stored by the model in the vehicle and pedestrian records and prepare it for further computations. Some of the operations made here are e.g. aggregating data for the different driving logics vehicle type numbers to one transport user class. Effectively making them a single class, e.g. *"AVCar",* instead of three different, e.g. "AVCar (Cautious)", "AVCar (Normal)", "AVCar (All-knowing)". This function also removes datapoints for vehicles and pedestrians with only one occurrence. Once the reading and pre-processing of the data is done a Pandas Dataframe of the processed data is created making it possible to use both pandas and numpy with the data for further computation.

3.3.2 Metrics.py

Metrics.py contains five functions that are called upon in main.py named SpaceEfficiencyMetrics, TrafficPerformanceMetrics, TimeToCollision, PedestrianMetrics, and getModes. The four first functions computes the metrics mentioned in chapter A.1 for each transport user class. All metrics are computed

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for the time being. However, the metric PHT is at the time being simply the VHT multiplied by the Occupancy factor given by the user, representing the number of persons in each vehicle and the TTC is not generated as an output as it is still under discussion on how this metric is going to be used in the analysis.

3.4 Running the scripts

To get the tot available space time the user should open the provided space time extraction script and specify the warmup time used for the network. When this is done it is recommended to only run this script once from within Vissim. I.e in the first experiment. Go to the tab **Scripts** and select **Event-Based Scripts.** A list window will open where the option to add scripts will be available. Add a new event-based script. Under the RunType column select ***Before simulation starts.*** Under scope select ***Simulation run***. Browse for the script in the ScriptFile column and add the name **ExtractTotSpaceTime** in the FuncName column.

Before running **Main.py**, the experiments created in Vissim should be simulated and the vehicle and/or pedestrian records should be available in the corresponding folders, as mentioned in section A.1.1.

For the script to be able to find the data and run properly all four files, **Main.py, LoadData.py, Metrics.py,** and **AvailableSpaceTime.csv** should be stored in the same folder where the network file with the several experiments is stored. This is the same location as where the ***"Scenario"*** folder is created by Vissim, assuming that experiments have been created.

To run the script start anaconda and launch spyder. Open the file **Main.py** via spyder and insert the necessary user input which is the number of experiments and the occupancy factor in each experiment. When this is done hit f5 and wait. For step by step instructions on how to run the script see chapter A.4.

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4 Step by Step Instructions

As a description of the script, the needed input and the given output is of importance it is also important that the intended user is able to run the script. Therefore, a step by step manual on what to do in order to run the script and get the output of interest is provided below:

Step 1	*Create a backup of your network file.*
Step 2	*Make sure that the model is saving the vehicle and/or the pedestrian records file/files with the mandatory attributes described in Table 16 and Table 17.*
Step 3	*Place your network under scenario management in Vissim.*
Step 4	*Create the number of experiments according to your experiment in your experimental design.*
Step 5	*Ensure that the vehicle and/or pedestrian records are saved in the correct folders.*
Step 6	*Place the four .py files in the same folder as your network file/files*
Step 7	*Execute* ***Extract_tot_space_time.py*** *in the first* experiment
Step 8	*Run the simulations (with adequate number of replications with different random seeds)*
Step 9	*Open anaconda and launch spyder, or any python IDE*
Step 10	*Open the file Main.py, state the number of experiments on line 24*
Step 11	*State the occupancy factors for your vehicle modes*
Step 12	*Press f5 and wait*

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Appendix B – Types of accident

Extract from Deliverable 5.5 of the SafetyNet Project (Reed and Morris, 2008)

Accident Classification System (GDV)

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.

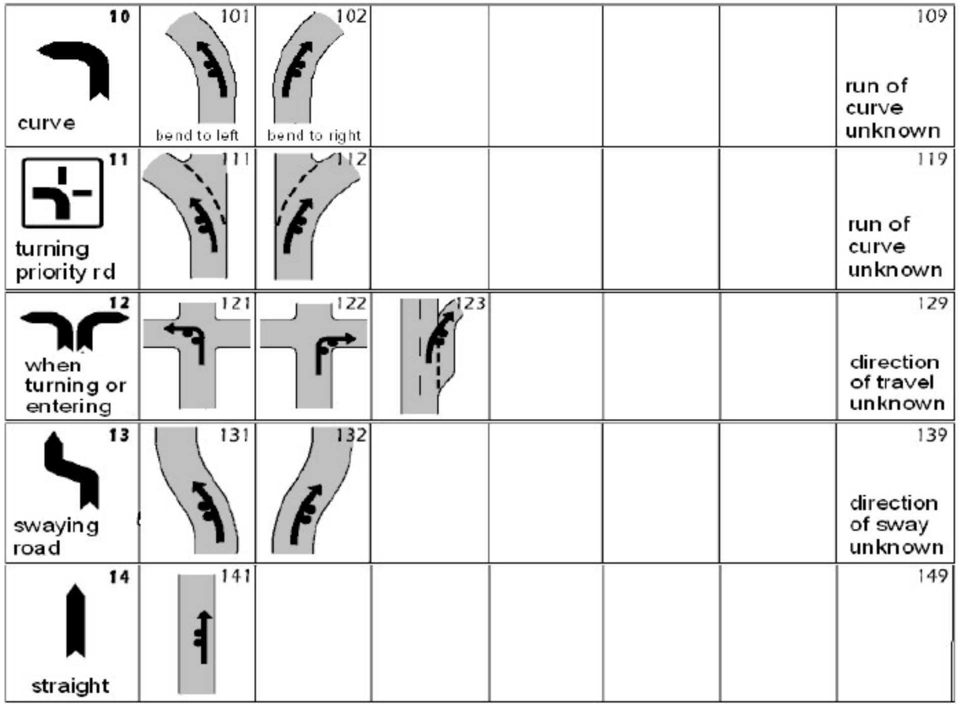
Type 10
In a curve

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	15 incline decline	151	152	153				159 run of the road unknown
Type 16 …traffic island	16 traffic island	161	162	163				169 run of the road unknown
Type 17 … road narrowing	17 road narrowing	171	172	173				179 run of the road unknown
Type 18 … uneven road	18 bumpy road	181	182	183				189 run of the road unknown

Type 19
… other driving accidents

Other driving accidents 199

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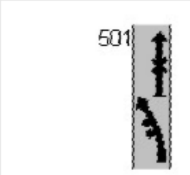
Accident Classification System (GDV)

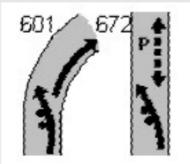
Type 1 : Special cases

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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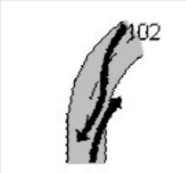
Accident Classification System (GDV)



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.

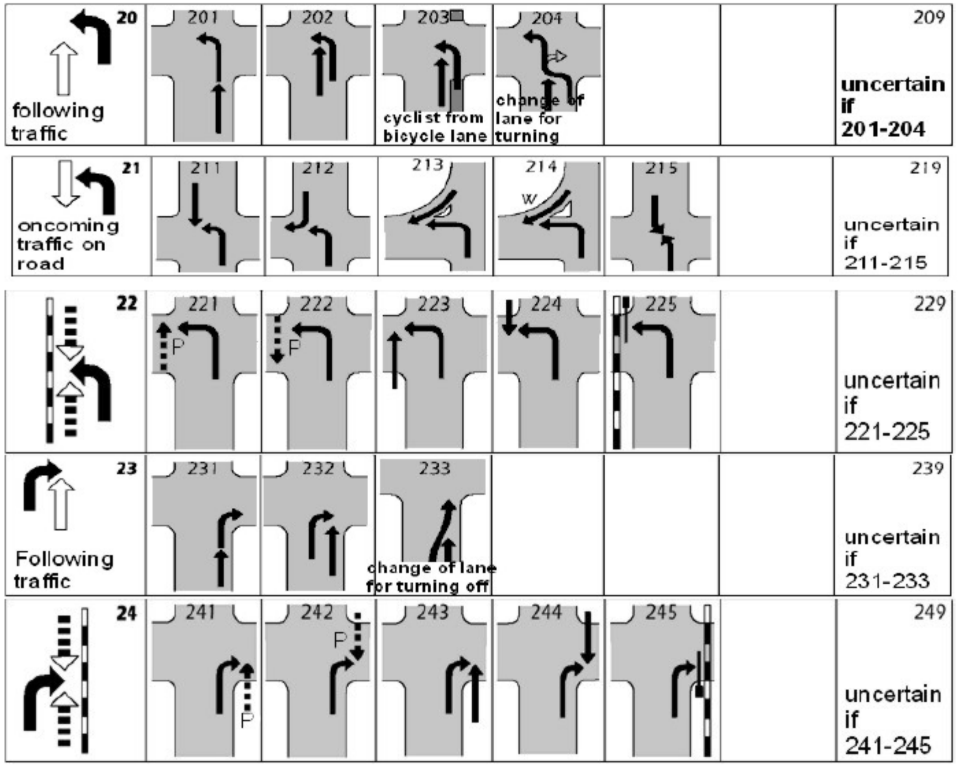
Type 20
Conflict between a vehicle turning off to the left and following traffic

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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Accident Classification System (GDV)

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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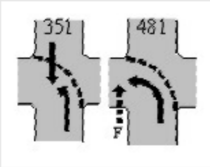
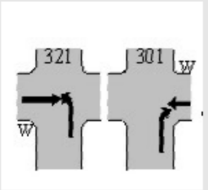
Type 2 : Special cases

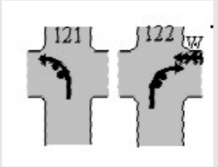
Note:
A road user following a turning priority road is not turning off. Also a conflict between a road user turning off the priority road and a waiting non priority vehicle behaving accordingly is a type 2 accident (turning off accident).



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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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.

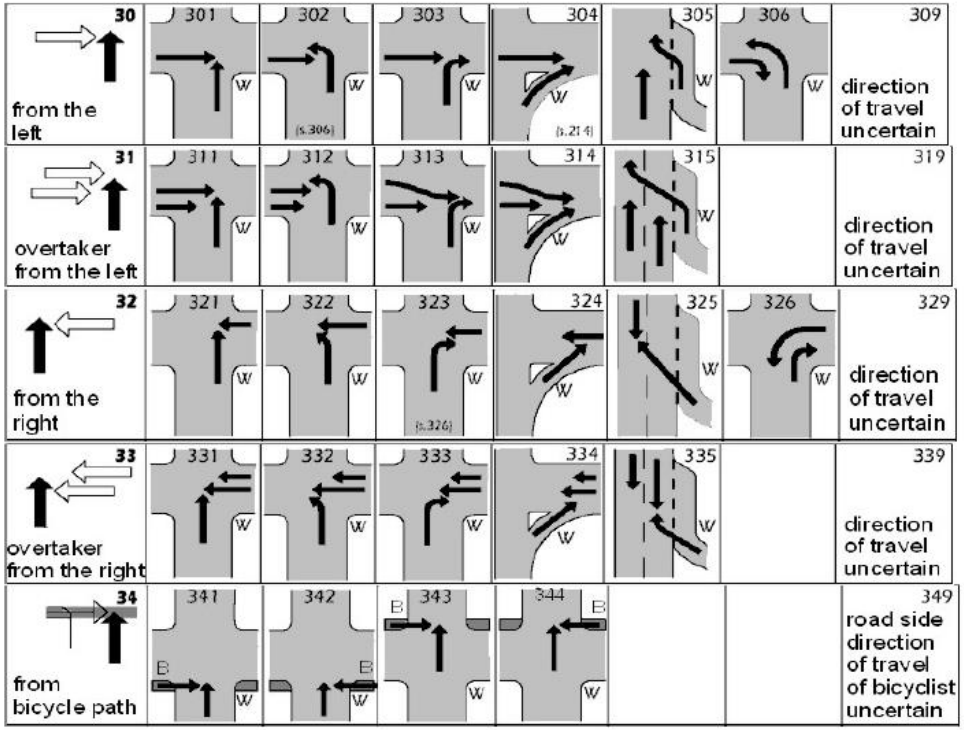
Type 30
Conflict between a non priority vehicle and a priority vehicle coming from the left, which is not overtaking.

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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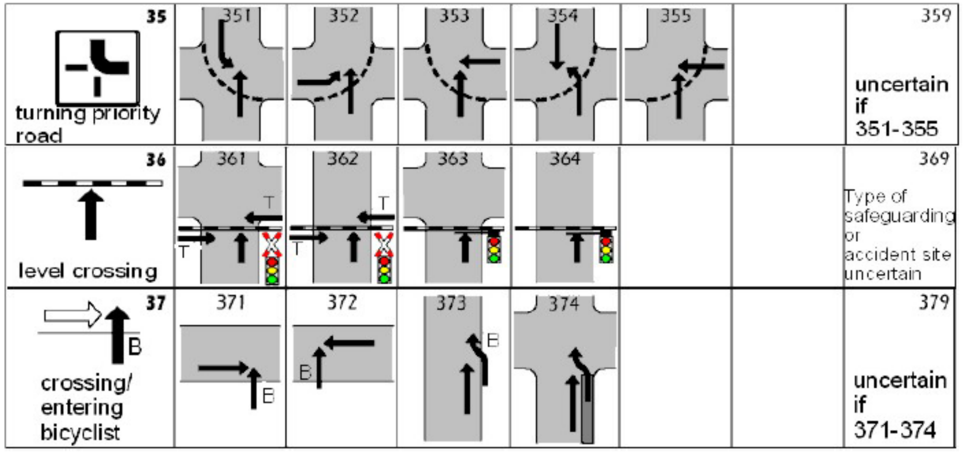
Accident Classification System (GDV)

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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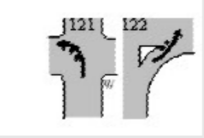
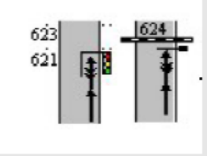
Type 3 : Special cases

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

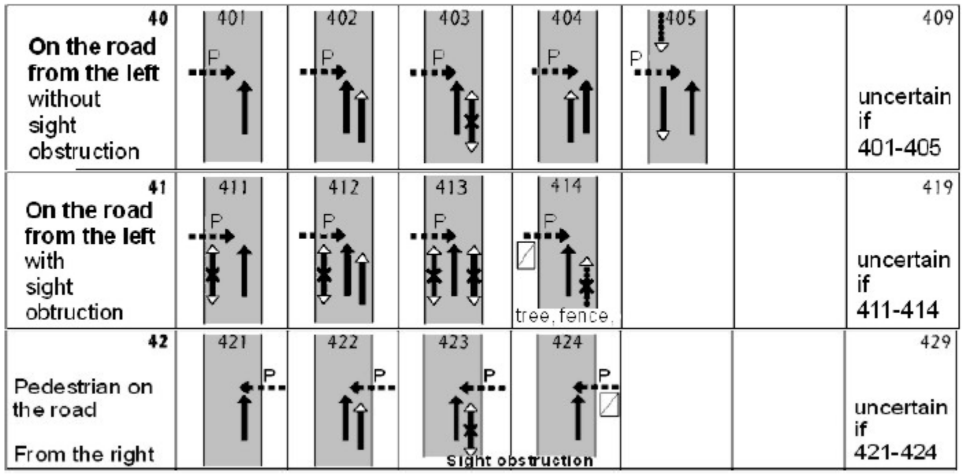
Definition: A pedestrian accident has occurred due to a conflict between a pedestrian crossing the road and a vehicle unless the vehicle was turning off. This is independent of whether the accident occurred at a place without special pedestrian crossing facilities or at a zebra crossing or similar.

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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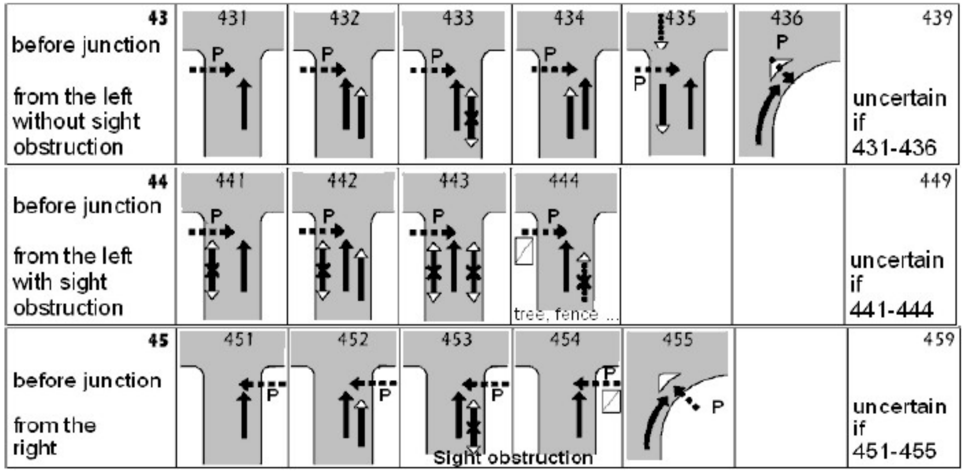
Accident Classification System (GDV)

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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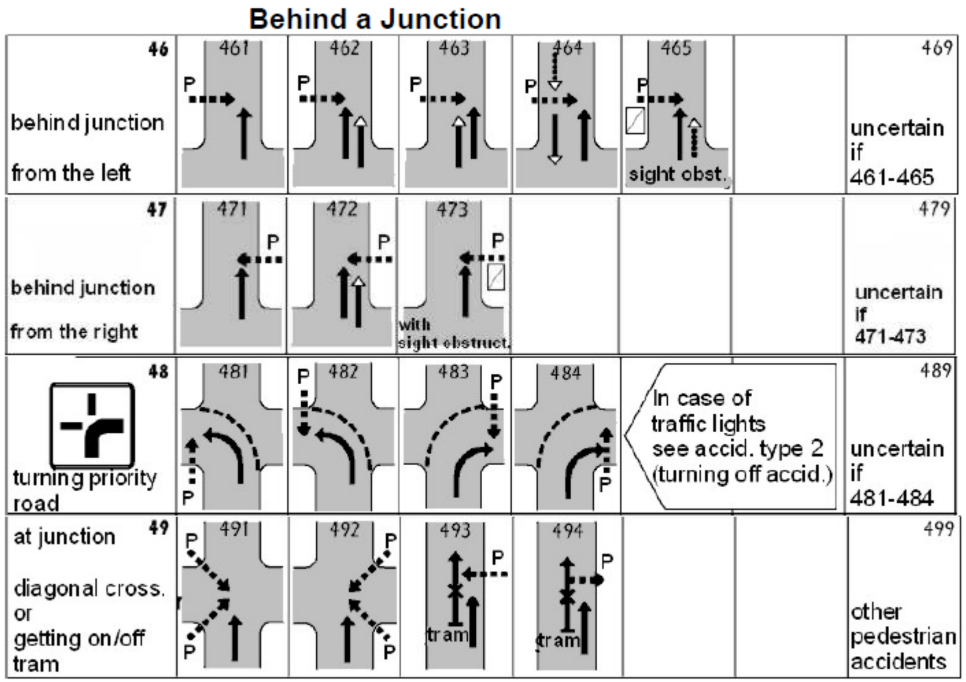
Accident Classification System (GDV)

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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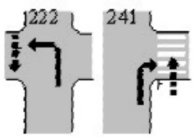
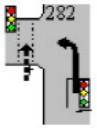
Type 4 : Special cases

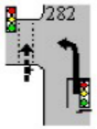
Note:
An accident is also a type 4 accident (pedestrian accident) if the conflict causing pedestrian was not hit. This includes accidents, where the conflict was caused by pedestrians that were e.g. playing, getting in or out of a car, but were not walking in lateral direction.



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.

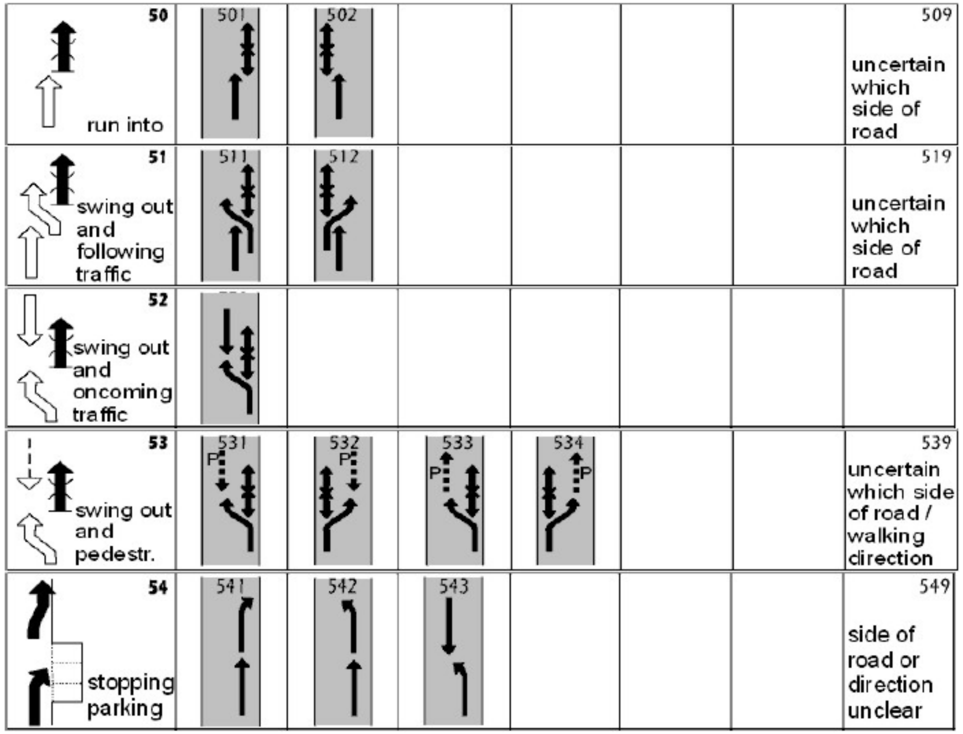
Type 50
Conflict between a vehicle and a parking vehicle in front.

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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Accident Classification System (GDV)

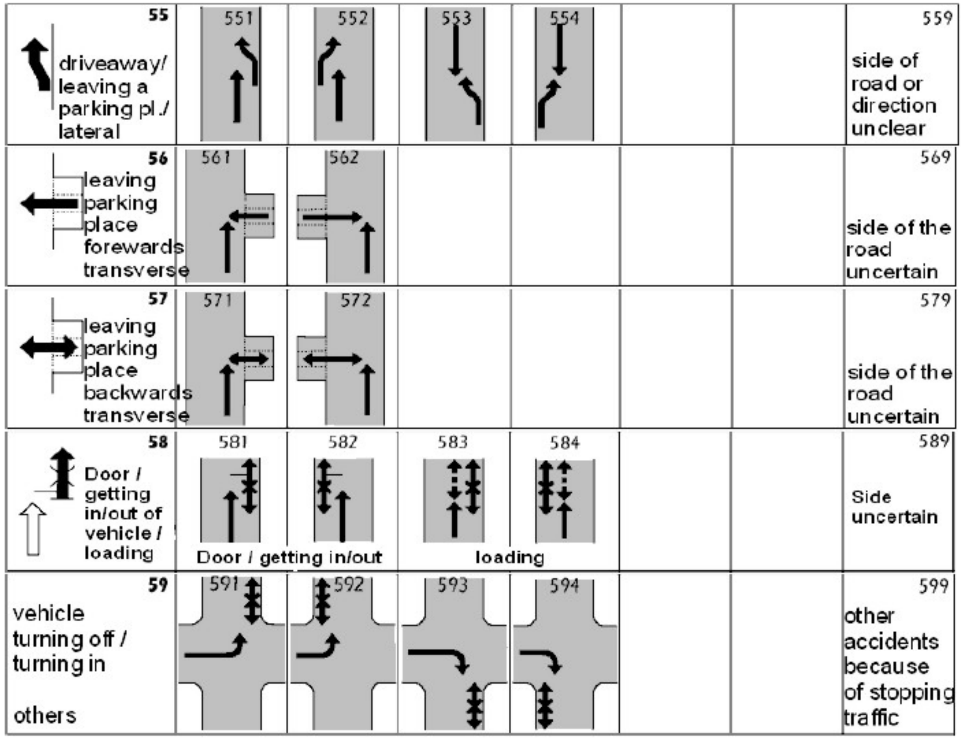
Type 55
Conflict between a vehicle driving away or leaving a lateral parking space and a vehicle of the moving traffic.

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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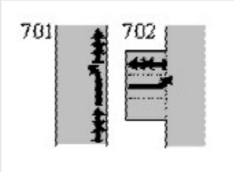
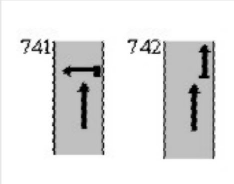
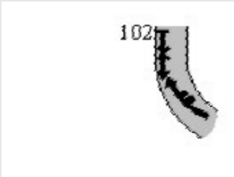
Type 5 : Special cases



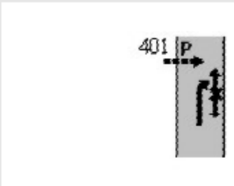
If the accident occurred with a vehicle manoeuvring to enter or leave a parking space and a standing vehicle, the accident is a type 7 accident (Other accident).



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.

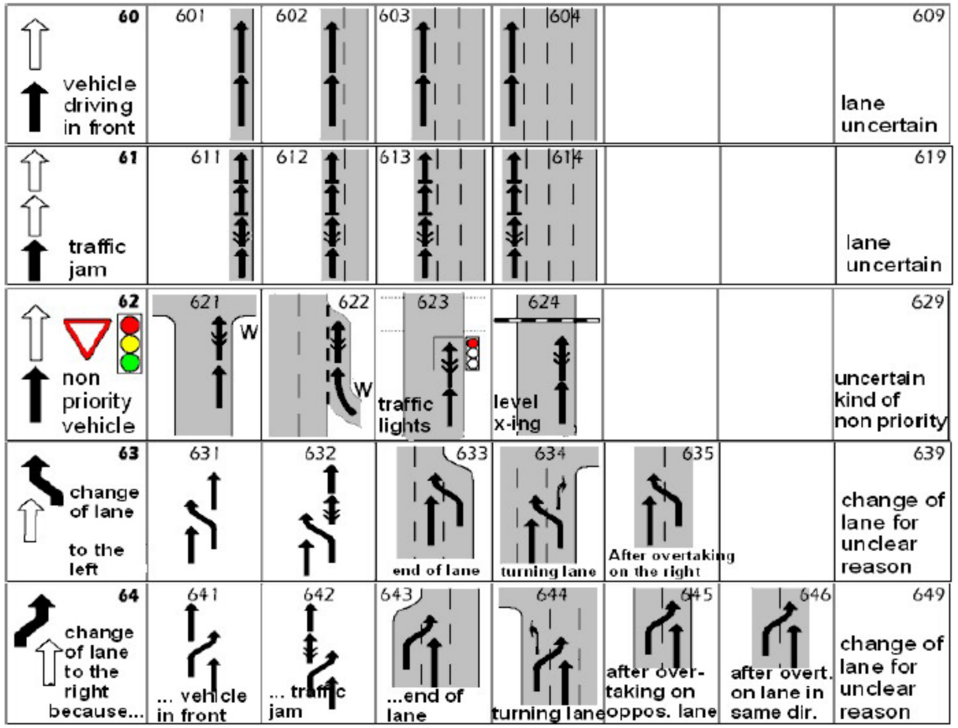
Type 60
Conflict between a vehicle and another vehicle driving in front on the same lane.

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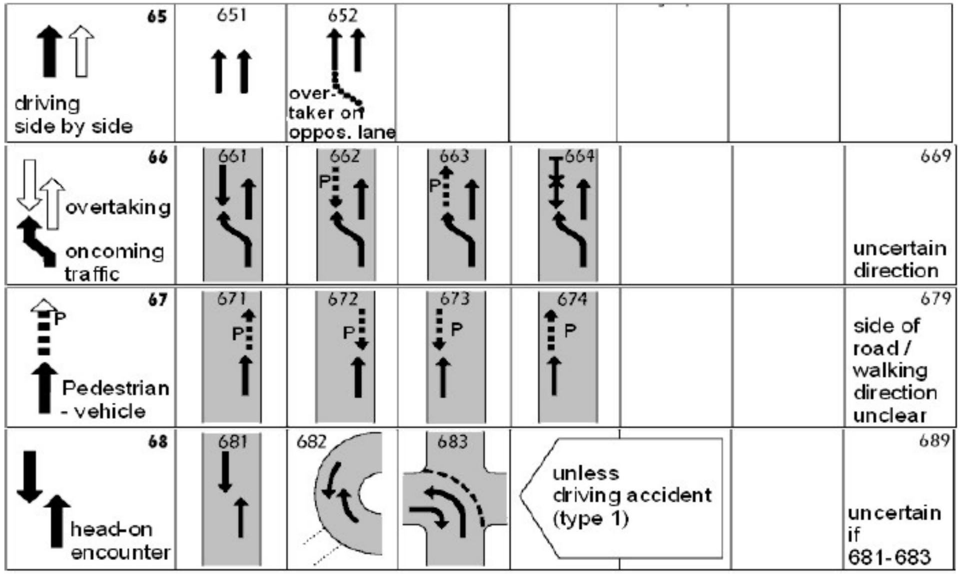
Type 65
Conflict between two vehicles, side by side, going in the same direction.

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

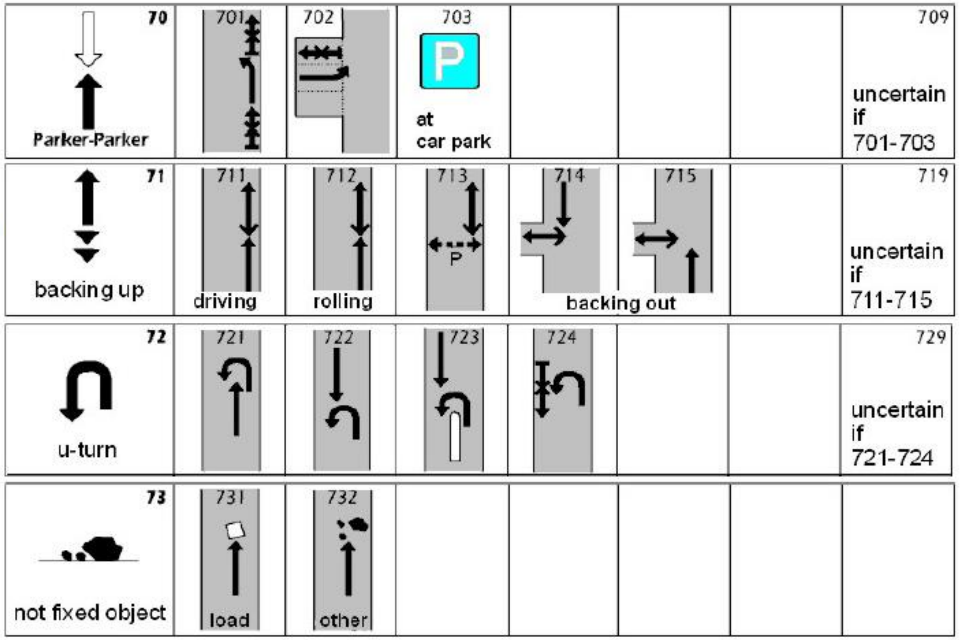
Definition: Other accidents are accidents that cannot be assigned to the accident types 1-6. Examples: Turning around, backing up, accidents between two parking vehicles, objects or animals on the road, sudden vehicle defects.

Type 70
Accident with two parking vehicles.

Type 71
Accident while backing up or rolling back. Unless manoeuvring to park

Type 72
Accident due to a u-turn.

Type 73
Accident due to a not fixed object.



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Accident Classification System (GDV)

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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