D4.3 Technical report on the application of the tools for assessing traffic impacts of automated vehicles

Version: 1.0
Date: 2020-04-29
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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201

Document Control Page

Title	Baseline microscopic and macroscopic models
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Editor	Johan Olstam, Fredrik Johansson, Chengxi Liu, Iman Periera
Brief Description	Descriptions of the results of the impact assessment for the eight use cases in CoEXist
Reviewers	Daniel Franco and Wolfgang Backhaus
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Type (Deliverable/Milestone)	Deliverable
Format	Document with supplementary files for experimental design sheets and assessment tool files including results for each use case
Creation date	2020-01-27
Version number	1.0
Version date	2020-04-29
Last modified by	Johan Olstam
Rights	
Audience	☐ Internal ☒ Public ☐ Restricted, access granted to: EU Commission
Action requested	☐ To be revised by Partners involved in the preparation of the Deliverable ☐ For approval of the WP Manager ☐ For approval of the Internal Reviewer (if required) ☒ For approval of the Project Co-ordinator
Deadline for approval	

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Version	Date	Modified by	Comments
0.1	2020-01-22	Johan Olstam	Document creation and outline
0.2	2020-02-01	Johan Olstam	Draft versions of chapter 1 and 2 and added draft chapters for use case 1,2, and 7
0.3	2020-02-20	Johan Olstam	Added input for use case 5,6,7 and 8
0.4	2020-02-27	Fredrik Johansson & Johan Olstam	Added comments after first review of use case chapters
0.41	2020-03-02	Fredrik Johansson	Updated case 7 and 8 after input from Jörg
0.5	2020-03-12	Fredrik Johansson, Iman Pereira and Johan Olstam	Updates on use case chapters and added safety assessment for use case 3 and 4. Revisions based on review comments from Charlotte Fléchon and inputs from Ammar Anvar
0.6	2020-03-17	Johan Olstam and Iman Pereira	Complete draft of the report
0.7	2020-04-17	Paola Tiberi, Andrea Paliotto, Antonino Tripodi, Edoardo Mazzia, Adriano Alessandrini	Added safety inspection-based results
0.8	2020-04-20	Johan Olstam	Complete draft of the report
0.9-0.92	2020-04-27	Paola Tiberi, Andreas Paliotto and Johan Olstam	Revision of the safety inspection-based assessment sections
0.93	2020-04-28	Adriano Allessandrini & Charlotte Fléchon	Update on the introduction wrt the two safety assessment approaches
1.0	2020-04-29	Johan Olstam	Final version for submission

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CoEXist

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1 Introduction

The many uncertainties related to the introduction of automated vehicles imply a need to for a structured way of assessing impacts for different future development with respect to penetration rates of automated vehicles and mixes of different types of automated vehicles but also for different travel demand levels and behavioural changes of road users. In order to provide a summarized picture of potential impacts for different stages of coexistence between automated vehicles and other road users an assessment approach was developed (see D3.3 (Pereira et al., 2020) for details). To simplify the assessment and to create a standard way of presenting the results taking uncertainties into account the approach was implemented in one spreadsheet-based tool for assessment of traffic performance and space efficiency and one tool for qualitative safety assessment.

1.1 Aim

The aim of this report is to present the results from applying the tools for assessing traffic impacts of automated vehicles to the simulation outputs of the eight use cases within CoEXist. The aim of the traffic performance and space efficiency tool is to concisely present an assessment of the traffic performance impact of the introduction of automated vehicles, based on the output from models, including the uncertainties considered. The aim of the qualitative safety assessment tool is to provide rough estimates on how automated driving functions might affect safety for use case relevant accident types. Both of these tools are tested and demonstrated through the applications presented here.

1.2 Report structure

This report is one of several reports describing the evaluation of the traffic impact of automated vehicles for the eight CoEXist use cases. There are in total seven deliverables related to the evaluation of the use cases:

- D1.3 Use case specifications (Olstam and Johansson, 2018a)
- D1.4 Scenario specifications for eight use cases (Olstam and Johansson, 2018b)
- D3.1: Completed experimental design templates for eight use cases and AV-ready alternative design (Olstam, 2018)
- D4.1 Baseline microscopic and macroscopic models (Liu and Olstam, 2018)
- D4.2 Technical report on the application of AV-ready modelling tools (incl. input and output data) (Olstam et al., 2020b)
- D4.3 Technical report on the application of the tool for assessing traffic impacts of automated vehicles
- D3.4 AV-ready hybrid road infrastructure design recommendations
- D4.7 Guidelines: How to become an AV-ready road authority?

These reports include documentation at different stages of the specification and evaluation of the use cases. D1.3 and D1.4 presents the use cases and the scenarios at the planning stage. D3.1 describes the more formalised experimental designs based on the measures and uncertain factors described in D1.3 and D1.4. Deliverable D4.1 describes the development of the traffic models for the current situation without

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automated vehicles, while D4.2 describes the inclusions of the automated vehicles in the traffic model applications for the use cases and the simulation results. D4.2 will constitute a final report for the traffic modelling and include updated and revised descriptions of the steps documented in the four earlier deliverables, hence D1.3, D1.4, D3.1, D4.1 and can be seen as draft versions of different parts of D4.2 as illustrated in Figure 1. Deliverable D4.3 is a complement to D4.2 with presentation of the results using the tool for assessing traffic impacts of automated vehicles. Deliverable D3.4 will include conclusions on current road designs and tested measures in the eight use cases focusing on the results and not on all the technical details with respect to the traffic modelling. The last deliverable in the bullet list (D4.7) will include summaries of the evaluation of the different use cases from D3.4 and discuss possible implications for the road authorities.

The present report starts with a short description of the assessment approach and the tools developed to structure the assessment and the presentation of the results (section 2). Detailed descriptions of the application of the assessment tools to each use case are presented in section 3 to 10. Conclusions and lessons learnt are presented in section 11.

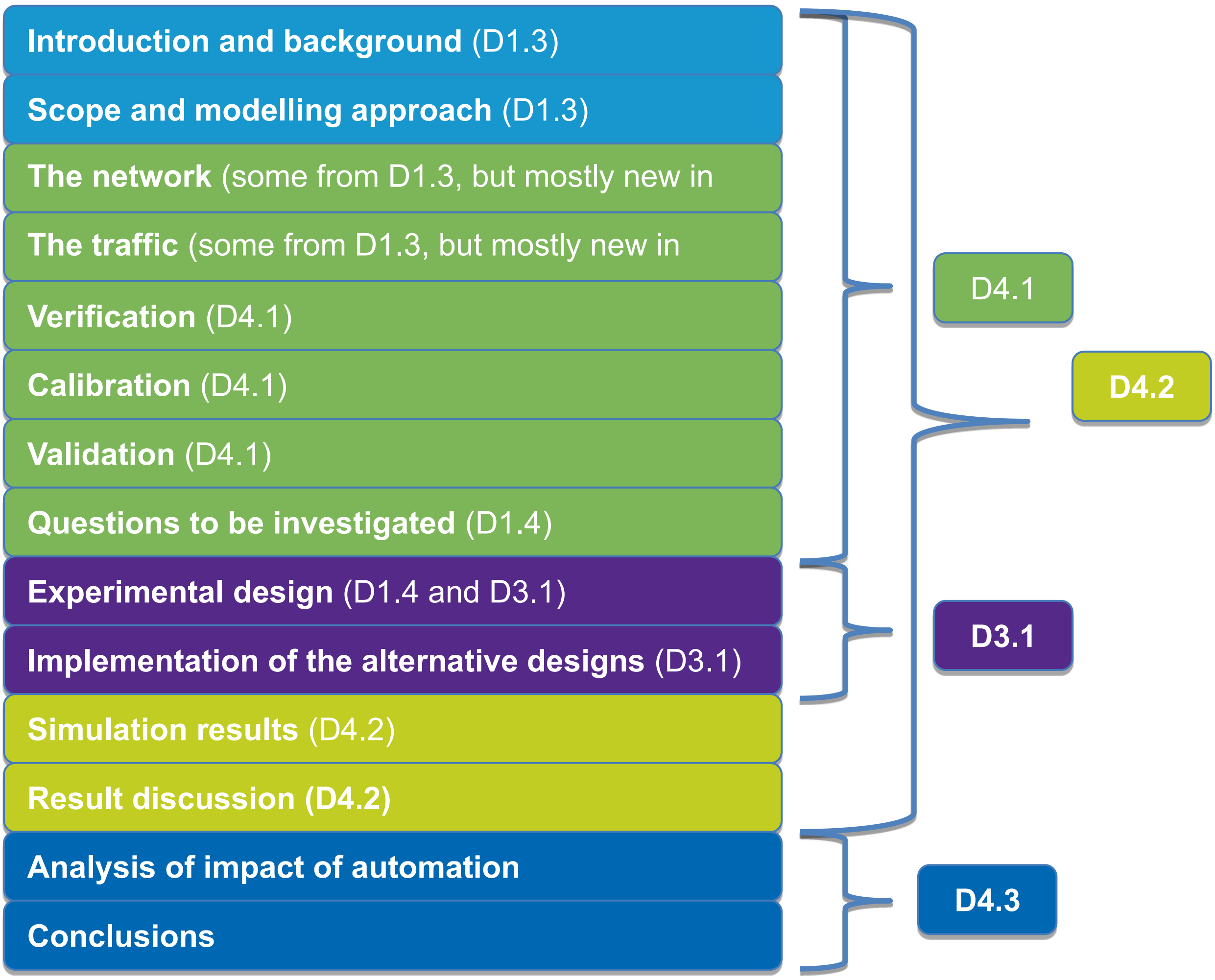

Figure 1 Structure of deliverables related to the description of the traffic modelling, results and interpretation for the use cases.

2 The CoEXist assessment approach

The CoEXist assessment approach consists of two parts:

- One assessment approach and a set of tools for assessment of traffic performance and space efficiency
- Two different assessment approaches for estimation of safety effects

The assessment approach for traffic performance and space efficiency (detailed described in D3.3 (Pereira et al., 2020) and in Olstam et al. (2020a)) use the outputs from the automation-ready transport modelling tools (described in D2.11 (Sukennik, 2020) and D2.8 (Sonnleitner and Friedrich, 2020)) as input. The traffic models are applied to a set of consistent experiments with respect to penetration rates and different mixes of AV classes. Initially planned experimental designs are described in deliverable D3.1 (Olstam, 2018) and final experimental designs are described in D4.2 (Olstam et al., 2020b). Relevant performance metrics, presented in deliverable D3.2 (Olstam et al., 2019), are calculated from the model outputs and used to assess the traffic impact of automation with respect to traffic performance and space efficiency for different infrastructure designs. The calculation of these metrics is automated by the tool presented in D3.3.

Two safety assessment methods and tools are introduced to assess potential safety effects of the introduction of different automated vehicles. The two approaches are described in detail in detailed in D3.3 (Pereira et al., 2020).

The first, a qualitative safety assessment tool, is based upon a thorough review of the advanced driver assist systems (ADAS) functions which will be the building blocks of the lower automation level according to SAE. Using a European accident classification database which describes accidents according to the manoeuvres, the tool gives an indication whether each automation function could have a positive or negative impact to improve safety and applies the results in the different microscopic use-cases of the CoEXist project.

The second, a quantitative method based on the consolidated safety inspection techniques, uses the results of the safety inspection performed on site, which assesses the infrastructural weaknesses of the site safety wise and lists a number of potential interventions to improve it, to consider the effect that the most advanced (SAE level 4 and 5) automated vehicles can have on it. It uses the driving logics defined by the CoEXist project and quantifies the risks related to sites and assesses by comparison whether any problem highlighted for manual driver can be made better or worse by automation and whether new problems could arise. The final output is a comparison of two risk levels in the state of the art and in the design scenario to assess how the designed scenario compares to the state of the art in terms of safety. It also applies to microscopic use-cases.

The two approaches are different and supplementary. First main difference is that the qualitative approach applies to all ADAS functions and not only to fully automated vehicles; the second is that the first is an approach easy to transfer to any site. The second gives a more detailed analyses but requires the presence on site of a road safety expert to make the initial safety inspection and then applies to the higher automation levels and according to the different driving logics as defined by the CoEXist project.

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2.1 Overview of the approach used for assessing traffic performance and space efficiency impacts

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.

- 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.

For each use case 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, in CoEXist specified as the relative improvement in the performance metrics for each case with AVs and compare it to the baseline without any AVs.

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. An example of how the variation in impact on traffic performance metrics for different stages of coexistence is presented and visualized in the assessment approach is given in Figure 2. The example shows relative improvement in average travel time and average delay; hence a positive value implies a decrease in travel time and delay. The orange bars represent the relative improvements that can be accepted; in the example no declines can be accepted for pedestrians while some decline can be expected for minibuses and cars. When interpreting these figures it is important to remember that the “error-bars” do not represent confidence intervals but the minimum and maximum relative improvement among all experiments belonging to the same stage of coexistence. For example, if 10 different combinations of penetration rates, AV mixes and traffic demands are considered for the Introductory stage, the median and the minimum and maximum relative improvement in average travel time for conventional cars are shown as a bar with a lower and upper “error” bar.

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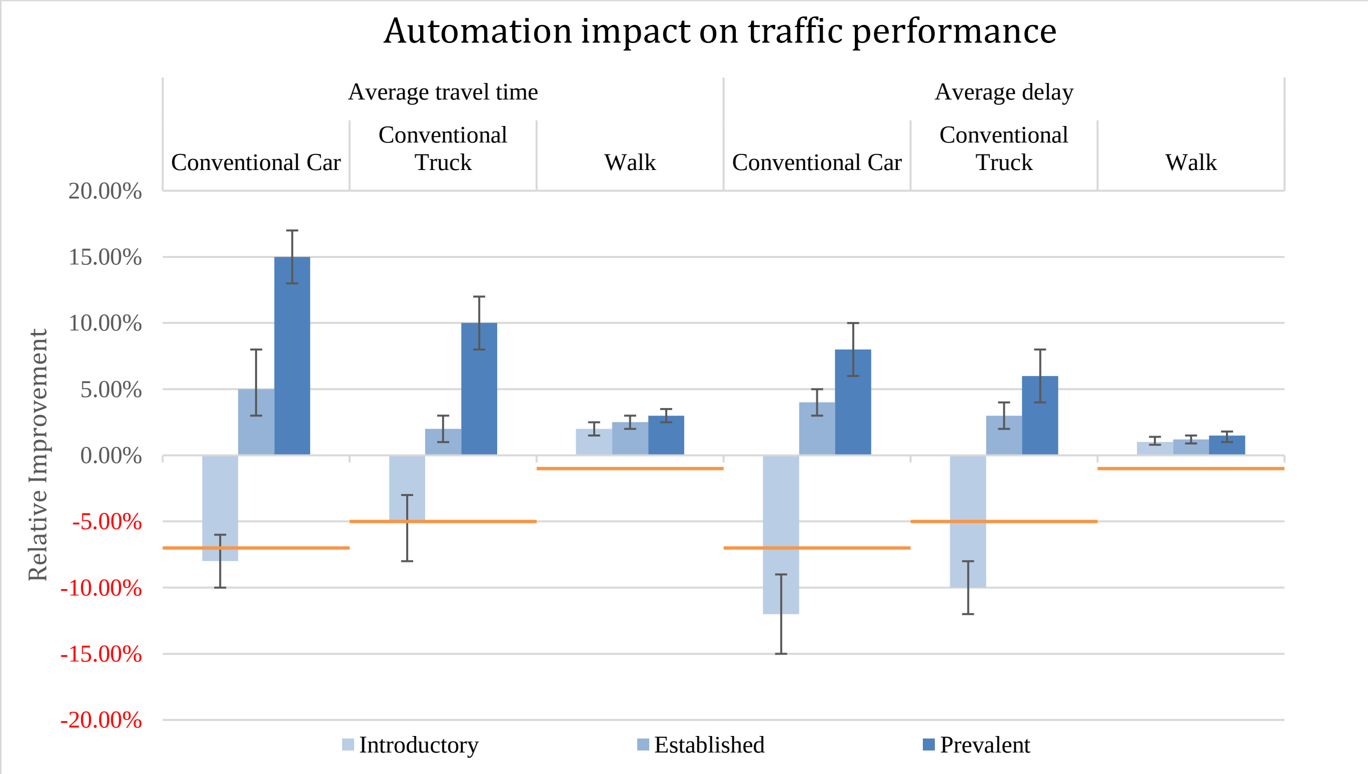

Figure 2 Example of visualization of the traffic impact of automation in terms of median, min and max relative improvement for all experiments belonging to the same stage of coexistence. The orange bars represent acceptable thresholds.

2.2 Overview of the approaches used for assessment of traffic safety

2.2.1 Overview of the qualitative traffic safety assessment approach

The approach of the safety assessment is depicted in Figure 3. A complete description of the approach is given in D3.3. The approach relies on evaluating the expected impact of the driving function on accident types in combination with the road environment.

Figure 3 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.

The assessment is conducted 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.

Detailed description of all considered accident types and driving functions are given in D3.3. There are seven accident categories:

1. Driving accident
2. Turning off accident
3. Turning-in / Crossing accident
4. Pedestrian accident
5. Accident with parking vehicles
6. Accident in lateral traffic
7. Other accident type

Each category is divided into 10 sub-categories (except category 7 and 3 which have 9 sub-categories). This gives in total 68 different accident type categories.

The most relevant driving functions for SAE-level 3-5 vehicles (which is the focus in CoEXist) are:

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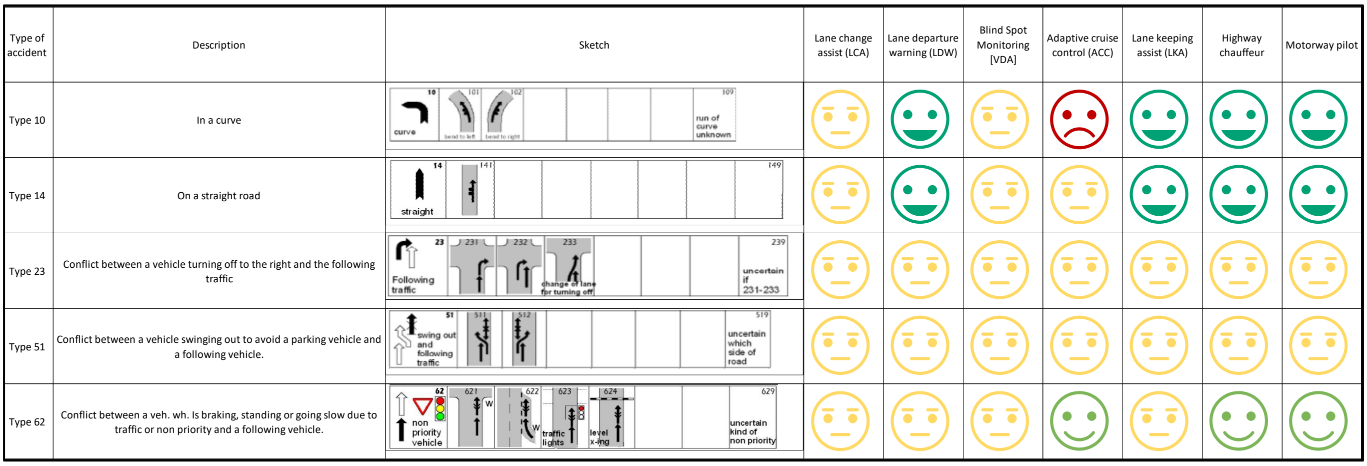
- Level 3
  - Traffic jam chauffeur
  - Highway chauffeur
- Level 4
  - Parking garage pilot
  - Motorway pilot
  - Arterial pilot
  - Urban pilot
- Level 5
  - Fully automated private vehicles

The tool gives an indication if a 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 1:

Table 1 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 tool includes a database that contains the information of the influence of the driving functions on each type of accident for each road environment. In the end the tool gives the results in the form shown in Figure 4.



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 4 Screenshot of the road safety impact assessment tool

2.2.2 Overview of the safety inspection-based assessment approach

The approach for safety inspection-based assessment is depicted in Figure 5. A complete description of the approach is given in D3.3. The approach combines the consolidated knowledge of the usual road safety inspections with a new risk assessment of future scenarios where conventional and automated vehicles coexist.

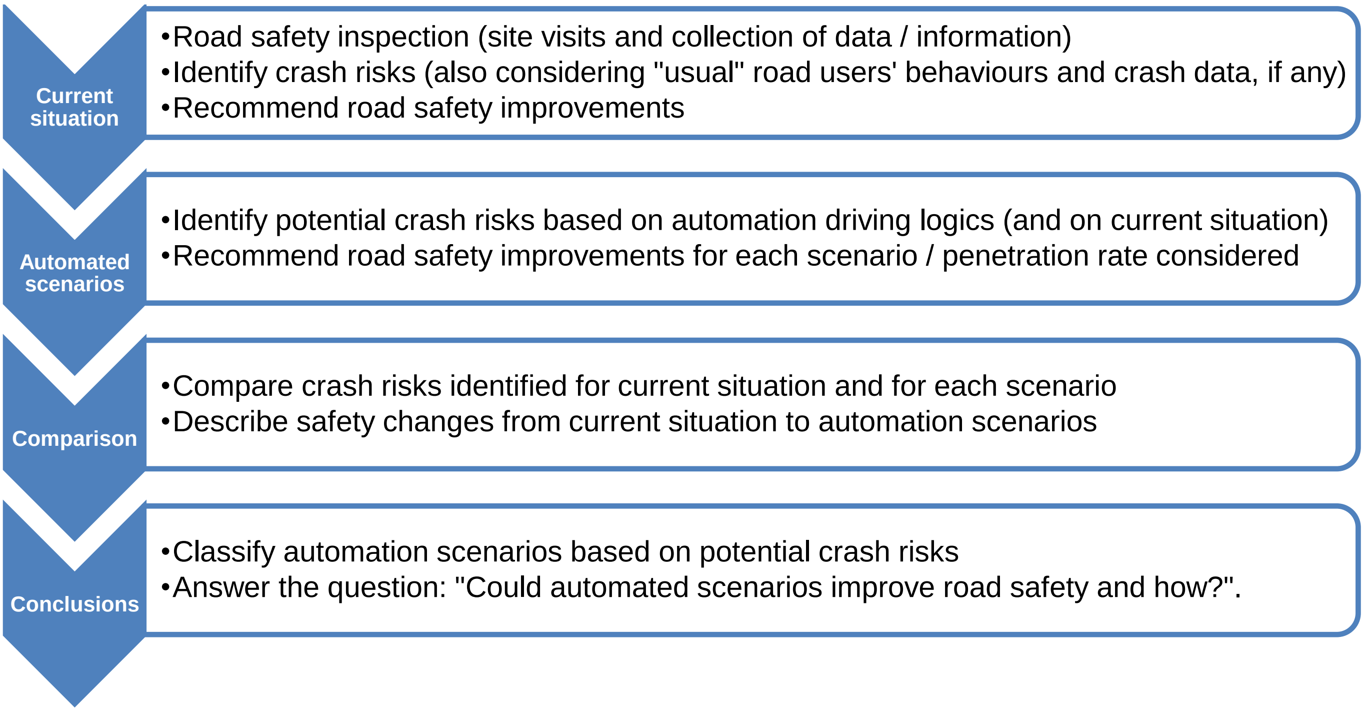


Figure 5 Steps of the safety inspection-based assessment approach

The main steps are:

1. Identification and risk assessment of the problems found in the current situation.
2. Identification and risk assessment of expected problems in automated scenarios.
3. Comparison of the risk scores obtained.

Each scenario is defined with a different combination of conventional and automated vehicles, which differ according to their driving logic, i.e. Rail safe, Cautious, Normal and All-knowing. The driving logics follow different principles that define their behaviour which lead to variations in terms of likelihood of occurrence of crashes.

Using the same criteria for assessing the likelihood of occurrence and severity of a potential crash, this methodology gives an indication of the impact of the introduction of automated vehicles on road safety compared to a baseline corresponding to the current situation with all human driven vehicles.

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The risk value is calculated with the following formulation:

Figure 6 Risk value calculation for each problem

Then the final risk of each scenario is calculated as the sum of the individual risk of each problem (Figure 7).

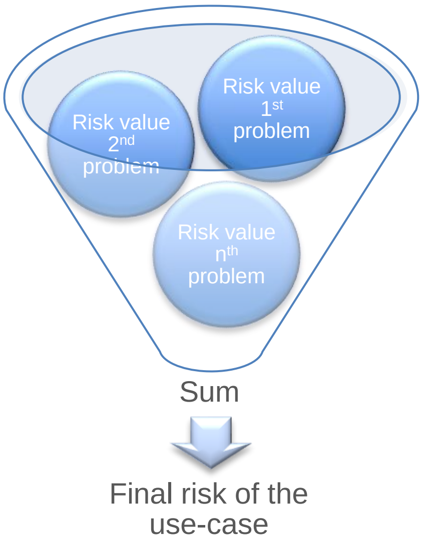

Figure 7 Process for the computation of the final risk of the use-case

An example of a risk assessment table of identified problems for a specific scenario is shown in the Table 2.

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Table 2 Risk assessment table for a scenario. F refer to frequency (likelihood of occurrence), S refer to severity and R is the risk value calculated according to Figure 6.

No.	CONVENTIONAL VEHICLES				ALL-KNOWING AVs				Total
	%	F	S	R	%	F	S	R	R
S.1	25	0.4	0.3	0.12	37.5	0.1	0.3	0.03	**0.05**
S.2	25	0.4	0.3	0.12	37.5	0.1	0.3	0.03	**0.05**
S.3	25	0.4	0.6	0.24	37.5	-	-	-	**0.06**
S.4	25	0.4	0.3	0.12	37.5	0.4	0.3	0.12	**0.12**
A.1	25	0.7	0.3	0.21	37.5	0.4	0.3	0.12	**0.14**
A.2	25	0.4	0.6	0.24	37.5	0.1	0.6	0.06	**0.11**
…	…	…	…	…	…	…	…	…	**…**
TOTAL RISK									**0.85**

Once the total risk value of each scenario has been obtained, it is possible to represent the risk variation in relation to the change in the percentage of automated and conventional vehicles as shown in Figure 8.

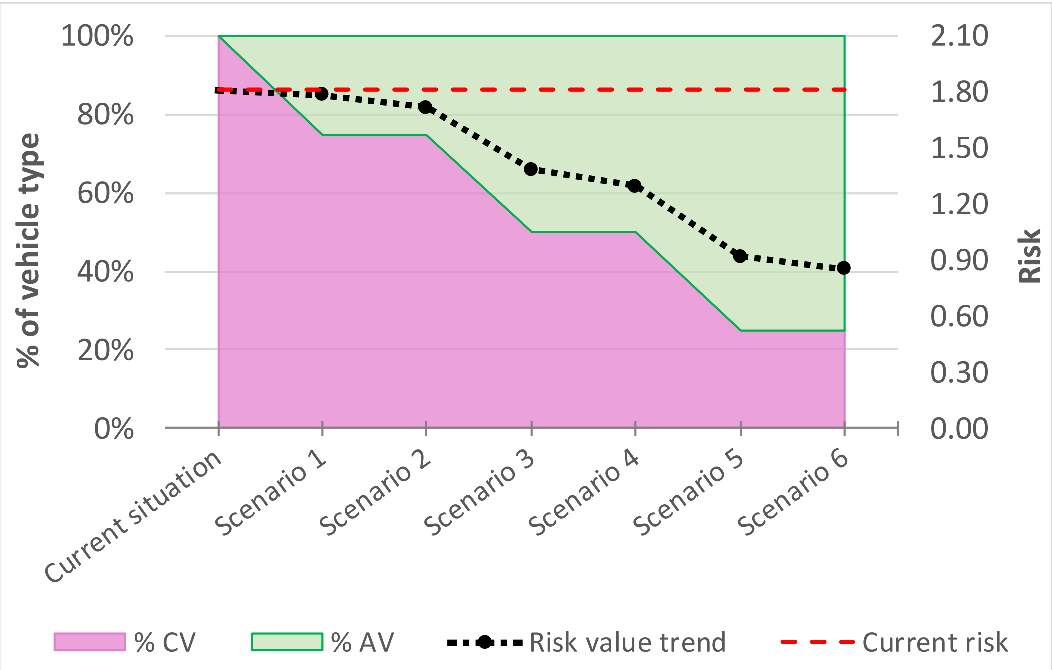

Figure 8 Risk evolution based on AVs scenarios

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3 Traffic impact of automation in use case 1: Shared space

Use case 1 consists of the area with shared space characteristics in connection to Kungstorget in central Gothenburg, see Figure 9. The definition of shared space varies between countries. In general, a shared space is an area without any clear infrastructure separation of travel modes and where pedestrians and vehicles can move freely, but only at walking pace and with caution. Exact rules differ between countries; in Sweden the formal name is 'Gångfartsområde', that is, walking speed area, and all vehicles are limited to walking speed and should give way to pedestrians. Bicycles are included as vehicles in these regulations.

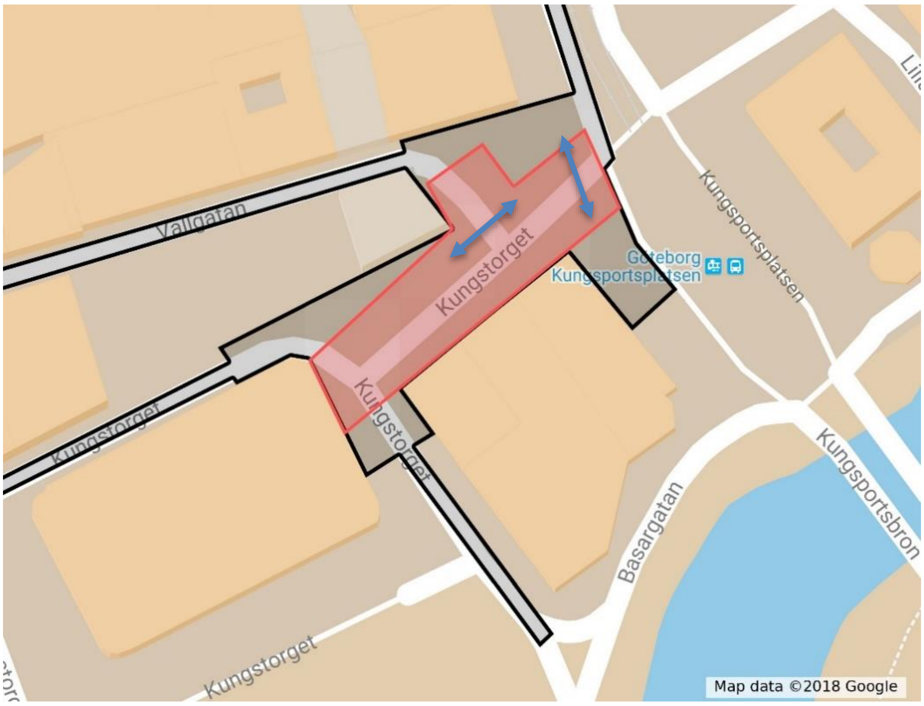

Figure 9 The proposed study site 'Kungstorget' and its surroundings. The blue arrows indicate large pedestrian flows that crosses Vallgatan and Kungstorget. The red marked polygon indicates the area of interest and black marked polygon the area included in the simulation model.

The main focus in use case 1 is to investigate the impact that automated vehicles will have on the level of service for all users utilising the area, and to see how sensitive the predicted impact is with respect to assumptions made on the interaction between active modes and AVs and on the assumptions on the behaviour of the AVs. In addition emphasis is also put on identifying in what stage of coexistence it would be feasible to incorporate AVs without any significant drawbacks to the traffic flow of all users in the area.

3.1 Traffic performance and space efficiency

3.1.1 Parameter settings in the assessment tool

The impact of automation is in this use case analysed in terms of the relative improvement of average travel time, average delay, average travel time per distance, and total travel time. Since the travel time per

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distance showed no additional information, this metric is not depicted in any of the upcoming figures for this use case. The figures presented in upcoming sections also show the minimum and the maximum value from each stage depicting a potential range of the automation impact.

From a city perspective there is potentially an interest in defining thresholds for when the impact of automation on the active modes is considered to be unacceptable. These thresholds would be given by the corresponding city; however, no such information exist for this use case.

In the model of the area there are three transport user classes present, cars, minibuses and pedestrians. The main focuses of the use case are the minibuses providing a last mile service which also constitute 50% of the vehicle demand in the model. The entire fleet of minibuses is replaced by minibus (AV) in the three different stages of coexistence. In contrast to the standard approach in CoEXist, to assess the impact of automation as the relative improvement for the remaining non automated road users. As there are no remaining conventional minibuses at any stage of coexistence for minibuses, the impact is evaluated as the relative improvement when replacing the entire conventional minibus fleet with an automated counterpart. The general CoEXist approach is motivated partly by that the value of time of drivers will be reduced when the car is automated, but this is not the case for the minibuses since it is the value of time of the passengers that is relevant, and that is not expected to be significantly affected by automation. However, the impact of automation on conventional cars is assessed using the standard CoEXist methodology.

In addition to the assessment of the impact of automation, an infrastructural measure is also investigated, measure 1: pedestrian crossings. The purpose of implementing pedestrian crossings in the model is to see what effects channelization of pedestrians, and clear walking areas would have on the impact of automation. In the current design pedestrians cross at any location at Kungstorget. Figure 10 shows where the crossings would be applied limiting the crossing possibilities for pedestrians.

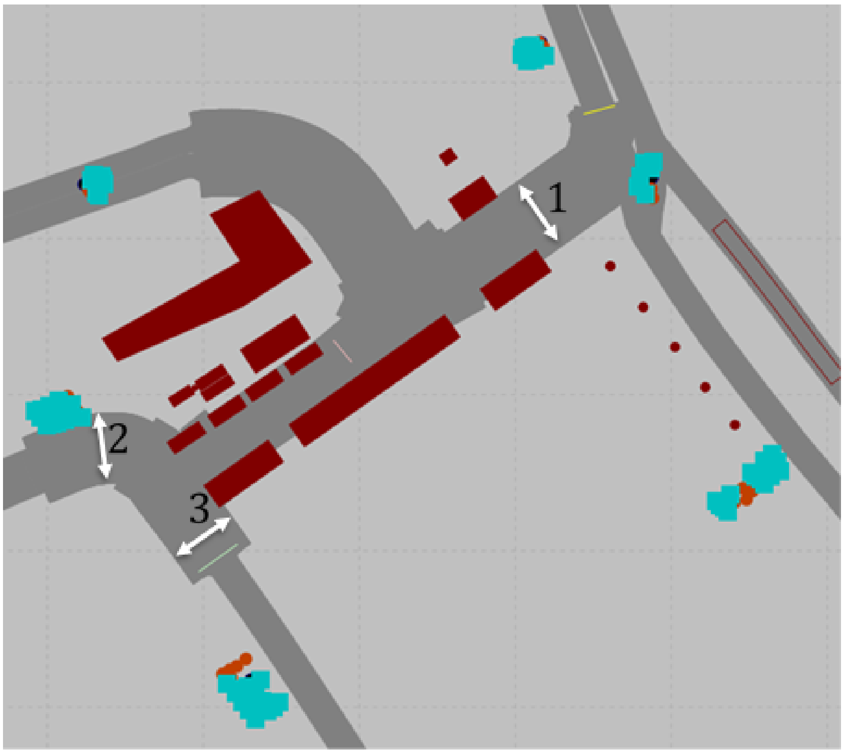

Figure 10 Pedestrian crossing placement

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3.1.2 Results

Figure 11 shows the impact that automation has on each transport user class for each stage of coexistence in terms of the chosen metrics. As expected, the automation impact on pedestrians is very limited due to that the pedestrians are given the right of way, and this is assumed to be valid also in the future, see D4.2 for a more extensive discussion on the modelling of this. The pedestrian performance metric affected most is the average delay which varies from -2.4% in the Introductory stage up to -0.81% in the Prevalent stage. The impact of automation on the other pedestrian performance metrics is insignificant.

One of the metrics that is impacted the most by the introduction of AVs is the average delay. The delay for minibuses shows a relative improvement that ranges from -170% to -110% in the Introductory stage and in some case in the Prevalent stage it reaches 3% less delay in comparison to the theoretical conventional minibus fleet. As seen in Figure 11, even though delay could potentially be positively improved the travel time has a median increase of almost 80% in the Introductory stage eventually reaching a median increase of approximately 40% in the Prevalent stage.

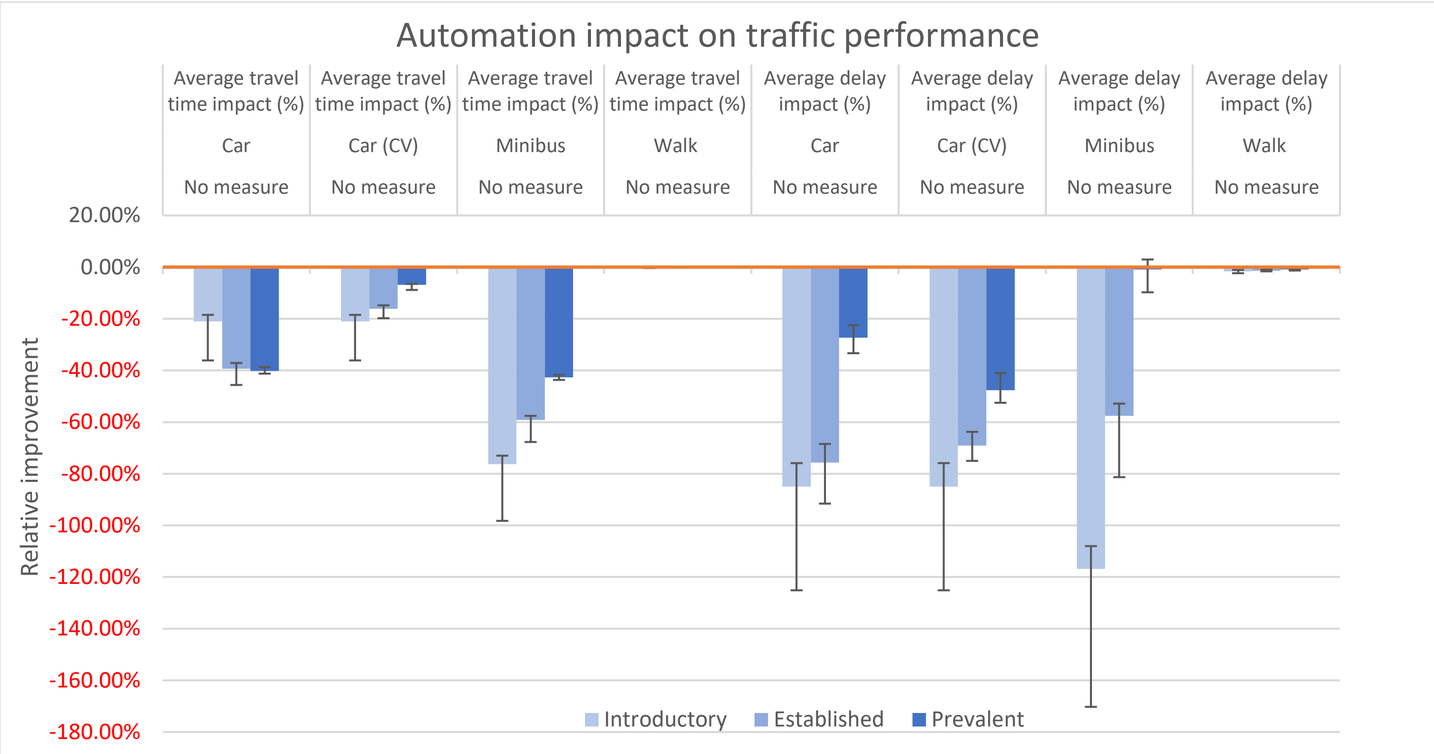

Figure 11 Automation impact on traffic performance in terms of average travel time and delay

In the Introductory stage the fleet of conventional cars is intact from today. By changing the entire minibus fleet from manually driven to Basic AV in the Introductory stage we see negative effect on the average travel time and delay for conventional cars; the relative improvement in travel time is approximately -20% and in delay approximately -80%. In the Established stage a proportion of the cars are substituted for Basic AVs and the minibus fleet changes to Intermediate AVs we see a lesser deterioration of the relative improvements of the travel times and delays, -16% and -69% respectively, finally reaching a level of -6.8%

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and -47% in the Prevalent stage when an even larger fraction of cars are automated and the minibuses become Normal AVs.

One measure to improve the traffic performance is investigated in this use case: introduction of pedestrian crossings to try to channel the pedestrian flows to cross the street at specific places instead of anywhere. The simulations indicate clearly that this will lead to a breakdown of the vehicle traffic since much of the pedestrian flow across Kungstorget is concentrated to one pedestrian crossing, leading to a continuous stream of pedestrians which completely hinders the vehicle traffic. The impact on traffic performance when implementing the measure is not presented in detail since it is immediately evident from the simulation that the system breaks down when implementing the measure.

3.1.3 Discussion

Discussion, No measure

The impact of automation can be interpreted as large and negative, especially for conventional cars and minibuses in the Introductory stage. However, these transport user classes constitute a small proportion of the total person hours spent in the network. Thus, the negative impact is experienced by a minority of the total traffic on Kungstorget. It could also be discussed whether the negative effect on traffic performance could be desirable from a city perspective due to the potential gains in safety, mainly for pedestrians, due to the lower speed of the vehicles.

Although the relative effect on delay is rather high for conventional cars, the additional delay is only from around 8 s per vehicle in the Prevalent stage to around 14 s per vehicle in the Introductory stage. So, if only short sections of the network have shared space characteristics these delays may be acceptable, but if they constitute a large part of the network an automated last mile service may be infeasible, given the assumed capabilities of the AVs.

The relative change in travel time for conventional cars is much less than that of delay, but this is simply an effect of that the delay is much smaller than the travel time (by necessity), and that the travel time increase for conventional cars due to automation is all delay.

The increase in travel time and delay for both AVs and CVs due to automation derives from two assumptions. The first is that AVs are assumed to keep the speed limit for shared spaces, 8 ± 2 km/h. This will directly lead to an increase in travel time for AVs due to their lower desired speed and will also affect CVs since these will be hindered by the slow-moving AVs. The AVs will not by definition be delayed by this, since the increase in travel time is due to a decreased desired speed. The CVs on the other hand will incur a delay equal to the increase in travel time. The second assumption is that AVs in the Introductory stage are assumed to keep a much larger safety margin to pedestrians than manually driven vehicles. This implies that they incur more delay in interactions with pedestrians than CVs, and also hinders any CVs that queue up behind them during such interactions. As the stages progress the AVs are assumed to be able to keep a smaller safety margin to pedestrians, and in the Prevalent stage it is assumed that they keep a margin just slightly larger than that of CVs. This leads to similar delays for minibuses in the Prevalent stage as for conventional minibuses in the baseline.

Since the only difference between the base line and the Introductory stage is the automation of the minibus fleet, the difference in average free flow travel time for the minibuses is around 35 s, given by the difference in desired speed of the automated and conventional minibuses. Similarly, the difference in average delay is

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around 25 seconds. That is, the speed limit compliance of the automated minibuses has a larger impact on the travel time than the more passive interaction with the pedestrians. This means that the delay is a smaller fraction of the travel time for the automated minibuses, so if the extended travel time due to the low free flow speed feels acceptable for passengers, the delay is unlikely enough to render the last mile service infeasible, at least for the later stages of coexistence.

The result that the traffic performance of the pedestrian traffic is unaffected by the automation may be due to specifics of the design of the study site. At the site vehicle traffic is one-directional going from north-east to south-west and the main pedestrian flow crosses the vehicle traffic stream directly where the vehicles turn into the area with shared space characteristics. This leads to that the, often short, queue that forms upstream of the conflict area is located in an area where no pedestrians are moving. If the main pedestrian flow instead had crossed the vehicle path at a more central point of the shared space, or if the vehicle flows would have been bi-directional or just directed in the opposite direction, the queues of vehicles caused by the interaction with the major pedestrian flow could possibly hinder lesser pedestrian flows crossing the street.

Since Kungstorget is a pedestrian heavy area other, possibly more qualitative factors, such as the attitudes towards automation, could be investigated in order to give a more solid understanding of the potential impact of automation at the site. Such factors are not investigated within the CoEXist project.

Discussion, Measure: pedestrian crossings

The simulation results indicate that the vehicle traffic breaks down completely if the proposed measure is implemented; a significant fraction of the input demand does not leave the network during the study period (SDR<1), indicating severe queueing. In addition to this, pedestrian travel time is slightly increased due to less direct routes through the network. Thus, no further analysis of the results from the simulations of the measure is motivated since the measure clearly worsen the situation.

3.2 Qualitative safety assessment

The upcoming sections show visual illustration of the accident types that are identified as relevant for use case 1. A majority of the relevant accident types involves conflicts between vehicle and pedestrians, which is expected on such a high pedestrian volume area. Accident types involving stationary parked vehicles is also selected due to the taxis that are parked at Kungstorget a majority of the time. Although other accident types are identified as possible to occur, the two mentioned are the main focus of the safety assessment.

3.2.1 Accident type 1 – Driving accident

Accident types classified as a type 1 are single-car accidents. As no conflict has occurred with other vehicles in this accident type the source of the accident might for example be due to the road condition, not being able to adapt the speed to current conditions, etc. One important aspect for this accident type is the geometry of the road, as it is of interest to know whether the road is straight, swaying, intersection, etc. For use case 1, two potential types of accidents from this category have been identified. A visual depiction of them is shown in Figure 12 and Figure 13.

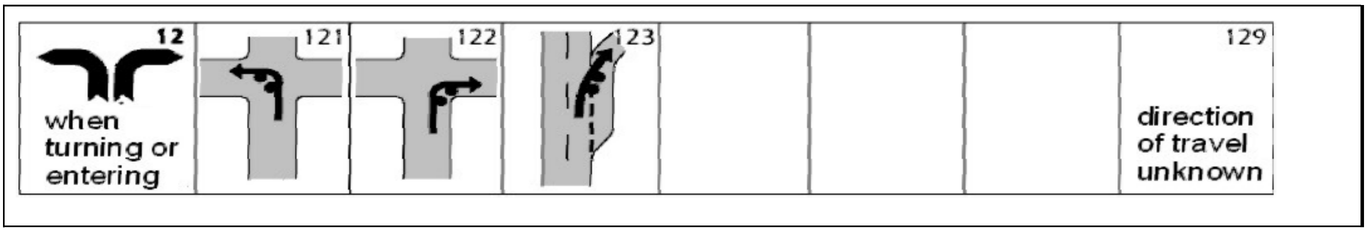

Figure 12 Accident type 12 turning in or off to another road

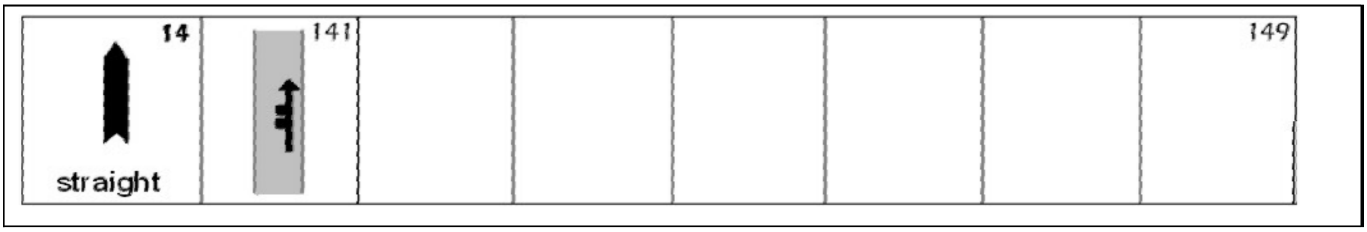

Figure 13 Accident type 14 on a straight road

3.2.2 Accident type 2 – Turning off accident

Accident type 2 focuses mainly on conflicts that may occur when vehicles are turning off a road and interact with road users from the same or opposite direction. The listed accident types are mainly related to vehicle to vehicle interaction but also cyclist and pedestrians are considered. In the vehicle and pedestrian conflict listed for this accident type it is stated that the pedestrian would be crossing on a special path/track meaning a zebra crossing. There are formal zebra crossings at Kungstorget but there exists at least one informal zebra-crossing of type 241 and 242 as illustrated in Figure 14.

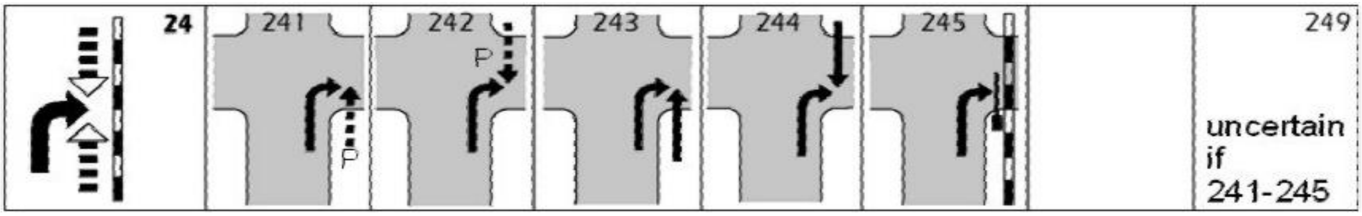

Figure 14 Accident type 24 Conflict between a vehicle turning off to the right and a veh. From a special path/track or a pedestrian moving in to the same or opposite direction.

3.2.3 Accident type 3 – Turning in/crossing accident

Accident type 3 covers conflicts that mainly occurs at intersections between road users with priority and non-priority road users. Even though there are some minor intersection-like areas at Kungstorget the number of vehicle to vehicle interaction is considered to be insignificant and is not include as a potential conflict, especially since vehicle speeds in the area is low (15 km/h or lower). For the reason mentioned accident type 3 was considered irrelevant for use case 1, with exception for accident type 30 (.

3.2.4 Accident type 4 – Pedestrian accident

Accident type 4 includes accidents between pedestrians and vehicles related to when pedestrians are crossing the road in one way or another. That is accidents that could potentially occur on the road and not by a vehicle intruding on a designated pedestrian area, such as sidewalks or strict walking areas. As the

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main transport user class in use case 1 are the pedestrians, most of the accident types presented in this category are identified as relevant for use case 1. A selection of them are presented in Figure 15 to Figure 17.

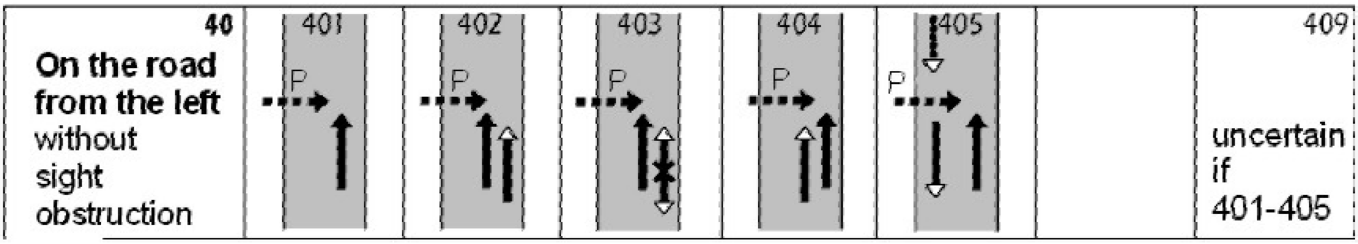

Figure 15 Accident type 40 Conflict between a pedestrian coming from the left and a vehicle. No Junction

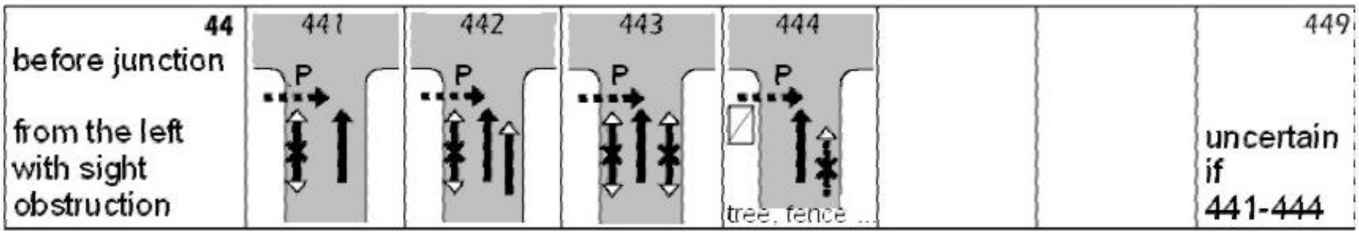

Figure 16 Accident type 44 Conflict between a pedestrian coming from the left and a vehicle which had an obstructed line of sight by parking vehicle, tree, fence. Before a junction

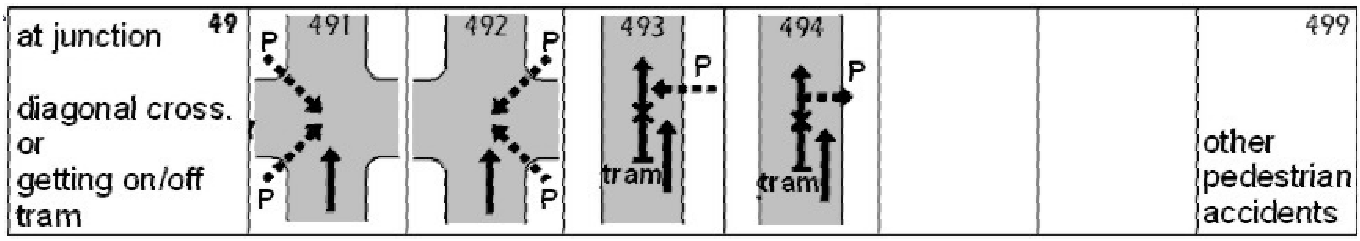

Figure 17 Accident type 49 Conflict between a vehicle and a pedestrian crossing a junction diagonally or getting on/off a tram. As well as other pedestrian accidents. Behind a junction

3.2.5 Accident type 5 – Accident with parking traffic

Accidents which may occur with parked vehicles, or vehicles manoeuvring to park are considered under accident type 5. At Kungstorget there is a road section that functions as a parking area for taxis and is frequently utilised during the day. Their presence at Kungstorget are the justification of selecting potential conflicts from this category. A selection of relevant sub accident types are depicted in Figure 18 to Figure 20.

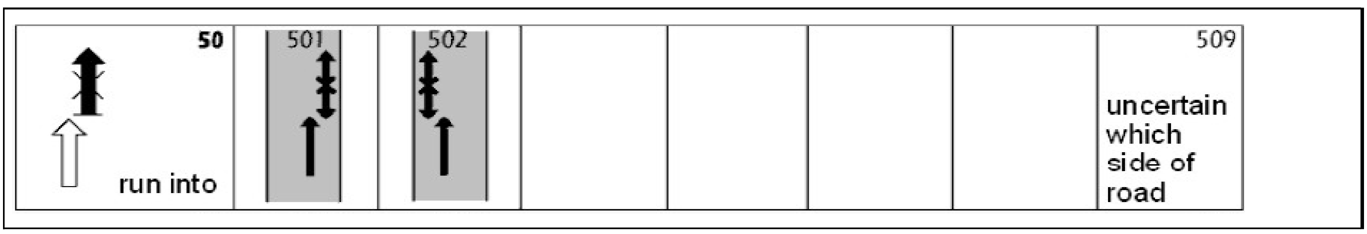

Figure 18 Accident type 50 conflict between a vehicle and a parking vehicle in front.

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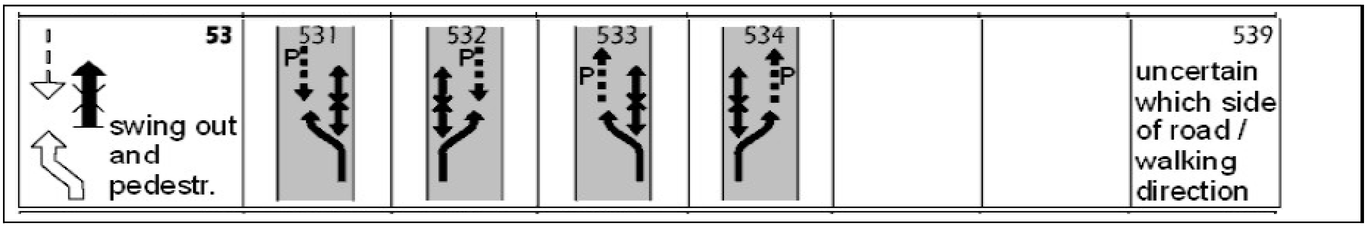

Figure 19 Accident type 53 conflict between a vehicle swinging out to avoid a parking vehicle and a pedestrian.

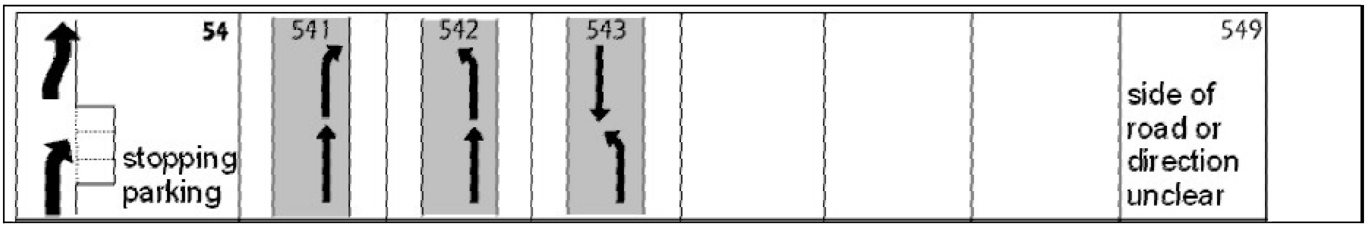

Figure 20 Accident type 54 conflict between a vehicle which is stopping to park or entering a parking space and a vehicle of the moving traffic.

3.2.6 Accident type 6 – Accident with lateral traffic

Accident type 6 would mainly consider lateral conflict in vehicle to vehicle interaction. Although vehicle volume during peak hour is low at Kungstorget, there is a risk of vehicle to vehicle conflicts. In addition, accident type 6 also covers conflicts between vehicle and pedestrian on the same lane, which is most relevant for use case 1. A selection of the selected accident types within this category are illustrated in Figure 21 and Figure 22.

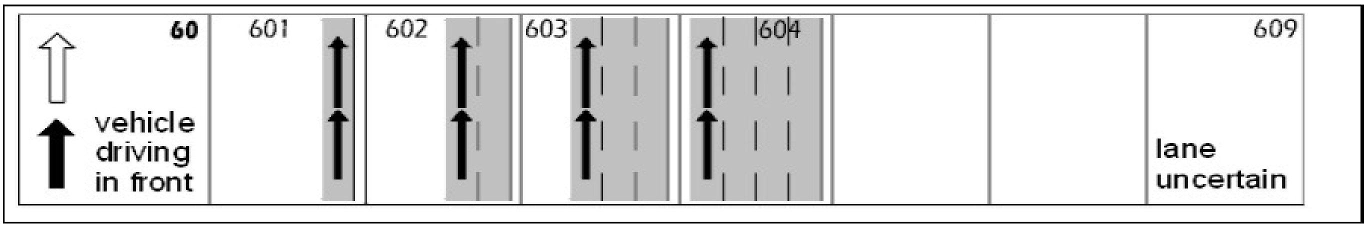

Figure 21 Accident type 60 conflict between a vehicle and another vehicle driving in front on the same lane.

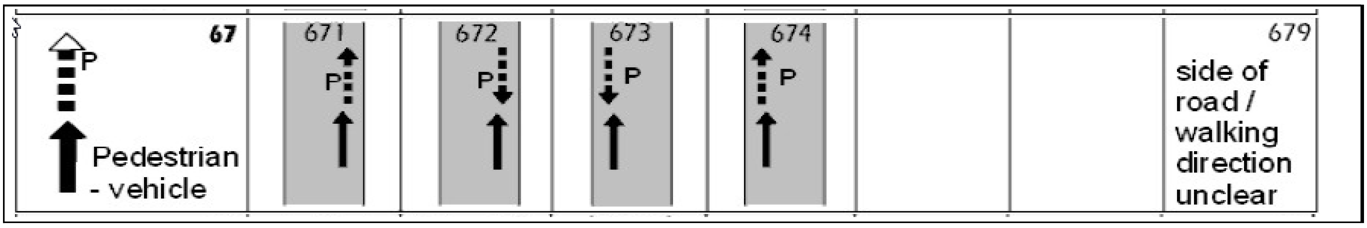

Figure 22 Accident type 67 conflict between vehicle which is not overtaking and a pedestrian on the same lane.

3.2.7 Accident type 7 – Other accident types

Accident type 7 is the last category and covers the more unusual accident types e.g. accidents with animals, or accidents that would occur due to sleepiness, or dizziness, etc. In general accident type 7 covers accident types that cannot be assigned to any of the accident types 1-6. Accident type 7 was

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deemed irrelevant for use case 1 as there's very little traffic during nights, and animal activity is non-existent at the site.

3.2.8 Results

The results from the qualitative assessment tool are presented in Table 3. The table show to what extent and for how many accident types the relevant driving functions might imply negative, none, positive or very positive impact on safety. The interpretation of the pictograms are given in Table 1 in section 2.2.1. For this use case which mainly include a shared space environment 27 of the 68 sub-accident types have been considered to be relevant. The results are shown for the urban pilot and the parking (garage) pilot which are the automated driving functions that are predicted to be the ones required for level 4 automated driving in a shared space.

For the shared space environment in use case 1 the urban pilot is estimated to have largest impact on accident type 4 – pedestrian accidents and type 5 – accident with parking vehicles. For accident type 4 the urban pilot imply positive (and sometimes very positive) safety impact for 9 of 10 sub-accident types. For type 4, accident type 40 and 43 are the only two accident types with pedestrian involvement where safety could potentially be impacted very positively. Both these accident types include conflicts where there's a sight obstruction for the vehicle and as AVs drive in areas where sensors sight is obstructed they might take extra precautionary measures in order to be able to stop suddenly. For accident type 5 the estimated impact is very positive for a majority of the sub-accident types. For the other types of accidents the urban pilot might imply positive impact in some sub-categories but is considered irrelevant for most of the sub-accident types.

As expected, the parking (garage) pilot the is not expected to have much of an impact on the safety for most of the relevant accident types for use case 1. However, for accident type 50 and 70, which are both conflicts involving parking vehicles, there's an indication of improved safety. As for all the other accident types considered in use case 1, there's an expectation of a positive impact on the safety by utilising an urban pilot.

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Table 3 Qualitative safety assessment for use case 1 – shared space. The numbers show in how many sub-accident categories the driving function is estimated to imply negative, none, positive or very positive impacts on safety. Grey marked cells are accident categories that are considered irrelevant for the driving function in the use case.

	Type of accident	Urban Pilot				Parking (Garage) Pilot			
		☹	😐	🙂	😀	☹	😐	🙂	😀
1	Driving accident				2				
2	Turning off accident				2				
3	Turning-in / Crossing accident				2				
4	Pedestrian accident			7	2				
5	Accident with parking vehicles			1	6		4		1
6	Accident in lateral traffic				4				
7	Other accident type				1				1

3.3 Safety inspection-based assessment

This section presents the results of the safety inspection-based assessment considering the crash types and wrong manoeuvres relevant for use case 1. Three scenarios were considered based on automated vehicles penetration rates and mix of AV classes / driving logics. For each scenario, the crash frequency and severity was estimated and the risk calculated (see section 2.2.2 for an overview and Deliverable 3.3 for details on the methodology). Finally, the risk for the various scenarios was compared.

3.3.1 Existing scenario

A Road Safety Inspection (RSI) was carried out to assess the existing road safety conditions on the site for use case 1.

A visit to the site (by a team of experts) was done in January 2020, both in daytime and night-time.

To facilitate the collection of information during the inspection, the following tools were used:

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- Nextbase 612GW camera with integrated GPS
- Application ASIA[1] (installed on a smartphone) to quickly note road safety problems and their location during the inspections

The site was inspected and a report of those matters that may have an adverse effect on road safety was compiled. The inspection did not include any examination or verification of the compliance with any other standard or criteria. All of the issues highlighted in this report are considered by the safety inspection team to require action in order to improve the safety of the area and minimise collision occurrence. Each item identified in the inspection is outlined below, together with recommendations to mitigate the issue in question.

Background information

Description of the site

This shared space is an area in the city centre of Gothenburg, in Sweden. An overview of the area is shown in Figure 23. This square is highly used by pedestrians and cyclists, but also by few vehicles and trucks. Around the square there are several commercial activities leading to high mobility flows during all hours of the day. The vehicle driving speeds are very low, between 8 and 15 km/h.

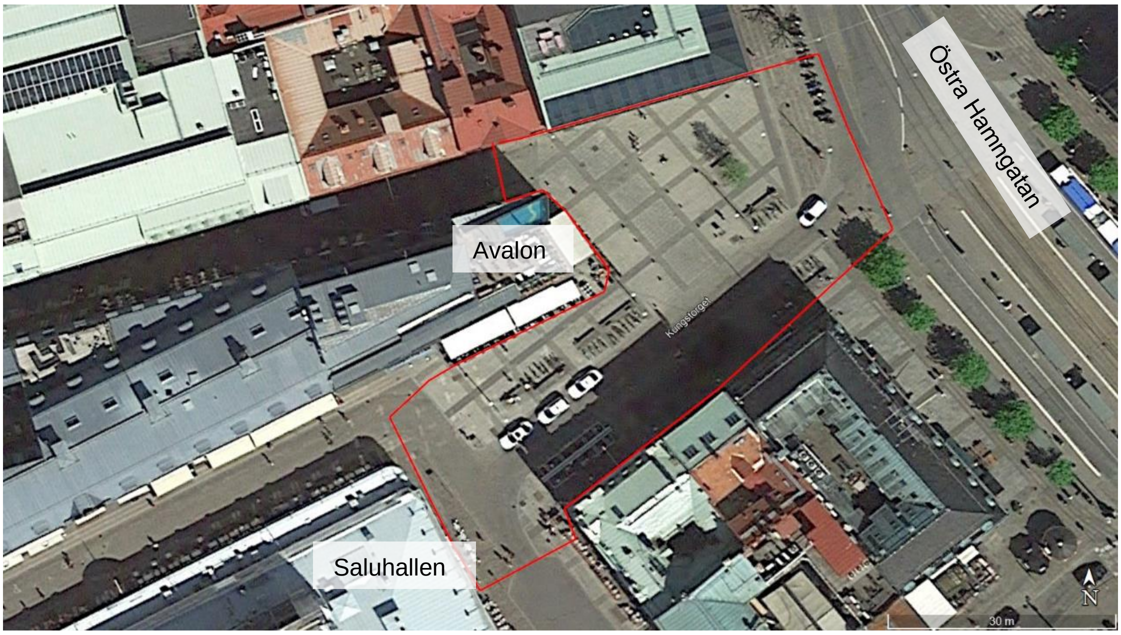

Figure 23 Use Case 1 - Kungsportsplatsen boundaries (source: elaboration on Google Earth)

Road traffic crash analysis

This area does not have a high number of recorded road traffic crashes, probably due to the fact that the speeds are very low and that few vehicles use the shared space. The road traffic crash data recorded over the last five years (2015-2019) showed only three collisions in which motorised vehicles were involved. One collision occurred between two cars, when one of them did not follow the yielding regulations. The other

[1] ASIA (Assistant for road Safety Inspections and Audits) is an application developed by FRED Engineering (www.fredeng.eu) for Android with the aim of maximizing the effectiveness of road safety audits and inspections

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two collisions occurred between a car and a pedestrian. In addition, two falls of cyclists alone have been recorded. In all these cases, there were only minor injuries. Figure 24 shows a map with the location of the recorded road traffic crashes.

Figure 24 Use Case 1 - Location of crashes

Even if the road traffic crash analysis does not show relevant results, it does not mean that the site is risk-free. 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. Thus, it is important to specify that the results of the road traffic crash analysis and the results of the road safety inspections are not directly correlated (EuroRAP, 2020), hence:

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

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

Traffic flow analysis

The latest available data on vehicle traffic flows for the site refer to 2011. The annual average daily traffic (AADT) was equal to 2,300 vehicles in one direction (Figure 25).

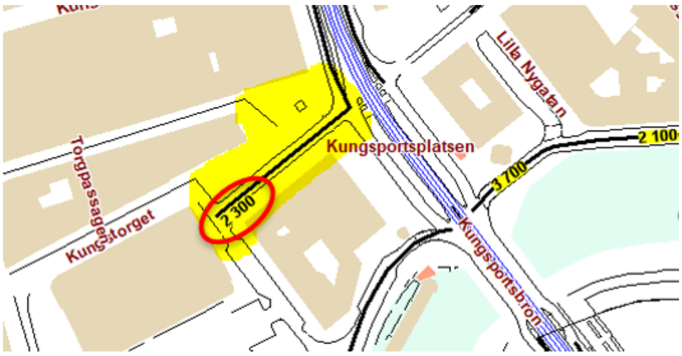

Figure 25 Use Case 1 - Annual average daily traffic (2011) (source: statistik.tkgbg.se)

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These data are quite old, but some hourly measurements were made in 2018 in different cross sections and directions. Table 4 shows the vehicle count over the cross sections. The directions of the observed vehicles are seen in Figure 26, marked by the arrow on each cross section.

Figure 26 Use Case 1 Cross sections and direction of counted vehicles

Table 4 Use Case 1 - Cross sectional vehicle counts

Cross section	Vehicle counts (veh/h)
1	35
2	3
3	38
4	12
5	50

The daily average pedestrian flow measured between Wednesday 14th - Sunday 18th of November 2018 is shown in the map below, referring to values in the red ellipse (Figure 27). From this data it is evident that in this area one of the highest pedestrian flow compared to the whole center of Gothenburg is registered.

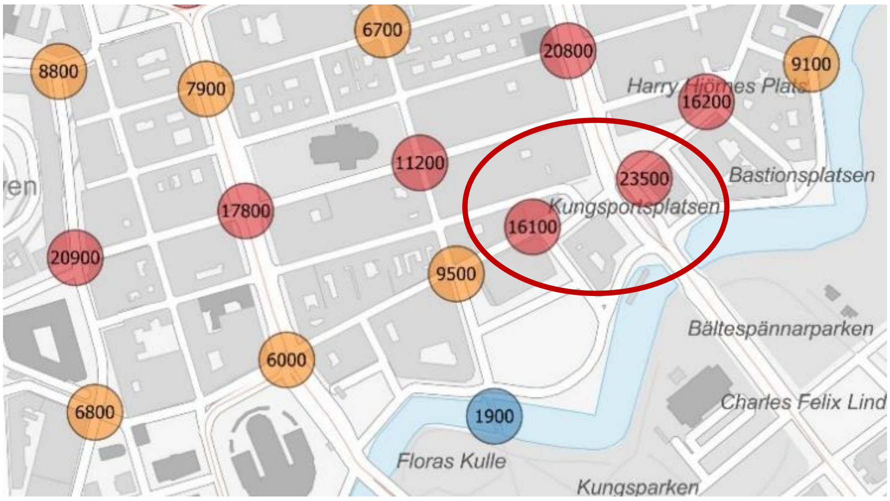

Figure 27 Use Case 1 - Daily average pedestrian flow (measured with wi-fi-data)

The hourly flow of pedestrians through different sections was also measured. For each cross section, the two opposite directions of the pedestrians are seen in Figure 28 and Figure 29. Table 5 and Table 6 show the pedestrian counts over the cross sections and the considered directions. The sections through which the highest flows were recorded are highlighted in red.

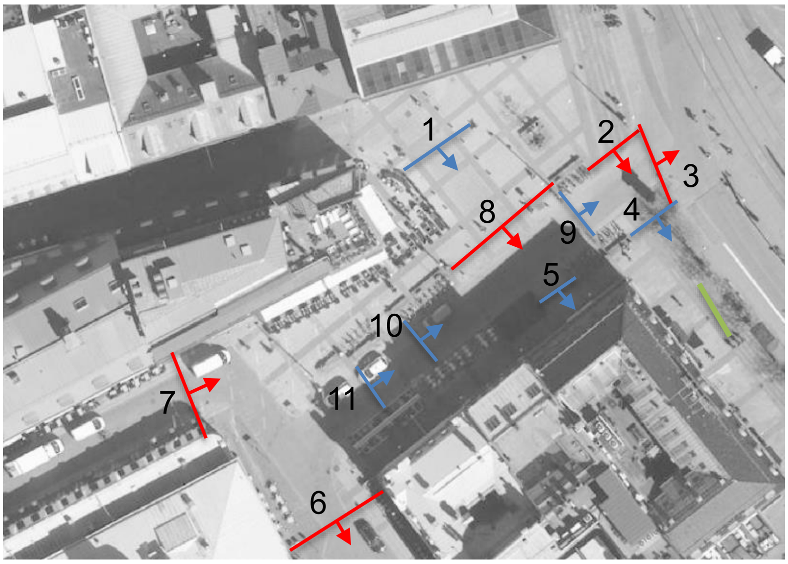

Figure 28 Use Case 1 - Cross sections and direction of counted pedestrians (a)

Table 5 Cross sectional counts of pedestrians

Cross section	Pedestrian counts (ped/h)
1	332
2	614
3	490
4	387
5	194
6	479
7	864
8	423
9	322
10	139
11	141

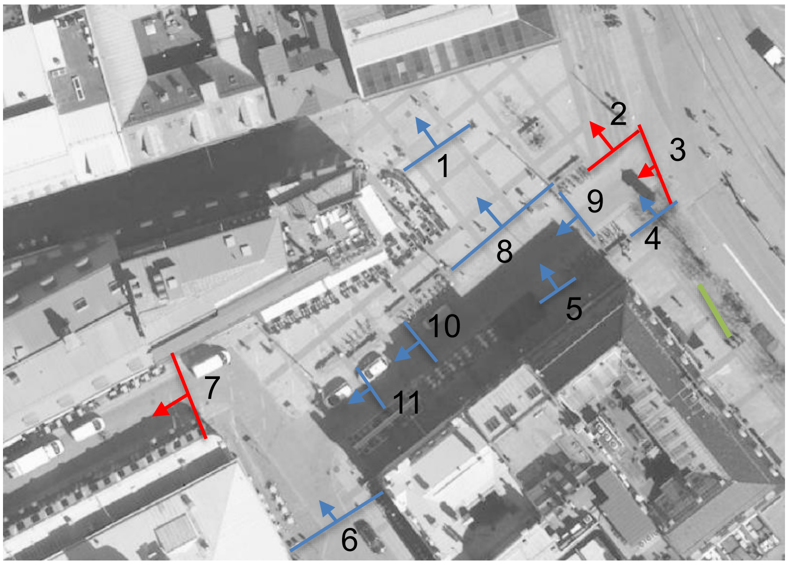

Figure 29 Use Case 1 - Cross sections and direction of counted pedestrian (b)

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Table 6 Use Case 1 - Cross sectional counts of pedestrians

Cross section	Pedestrian counts (ped/h)
1	233
2	542
3	446
4	155
5	158
6	321
7	470
8	243
9	286
10	152
11	187

From the two maps it is clear that the highest flows are recorded in cross sections 2, 3 and 7, in both directions. Although the vehicle flow is significantly lower than the pedestrian one, its higher values are recorded in section 6 and in the perpendicular direction to the flow of section 2 where continuous road crossings take place so the likelihood of pedestrian-vehicle conflicts is the highest.

Road safety assessment

This section presents the results of the inspection.

In particular, it summarises the road safety problems identified, their location, the probable/typical accident (in the form of an icon) that they may cause, the recommendation to eliminate or mitigate them, and finally, their risk value.

All problems are identified with a code composed of a literal part, representing the category of problems and a numerical part, representing the sequential number.

Road signs

In a shared space there is normally minimal signage because pedestrians represent the strong user and vehicles must give them priority and cross carefully without generating danger to them.

However, the absence at some points of road signs for the vehicles could lead them to carry out unauthorized manoeuvres, thus endangering vulnerable users.

Details are shown in the following table.

No.	Location	Problem	Crash type	Recommendation	Risk
S.1	Kungsportsplatsen	**Misleading path of the road** Coming from Vallgatan to the square, the configuration seems to allow drivers to enter the square where in fact vehicles are not authorized. The effect is accentuated at night, in winter, when the streetlights illuminate the square more than the road that turns right. Furthermore, there are no signs indicating that vehicles must turn right and there are no obstacles that block the passage.	 	It is recommended to place physical obstacles to avoid the transit of vehicles on the square. In addition, it is recommended to install a right-hand turn sign.	0.42

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No.	Location	Problem	Crash type	Recommendation	Risk
		Especially during the summer, when there is a very high density of pedestrians and cyclists passing through the square, the mistaken crossing of it by vehicles could lead to a high likelihood of conflicts with vulnerable users who do not expect vehicles on that space. 			
S.2	Östra Hamngatan-Kungsportsplatsen	**Manoeuvre not allowed** On Östra Hamngatan along the edge of the square, there is a parking space for motorcycles that during some hours of the day is empty and although there is the sidewalk slightly raised compared to the road, some vehicles (more likely heavy trucks) turn right going up to the square.	 	It is recommended to place physical obstacles to avoid this manoeuvre.	0.24

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No.	Location	Problem	Crash type	Recommendation	Risk
		There may be pedestrians or cyclists on the square who do not expect a vehicle to arrive from that direction and conflicts may arise.  			
S.3	Kungstorget	**Vehicle path unclear** Coming from Södra Larmgatan and going along Kungstorget, it seems that it is allowed to go straight on the square whose step is very flat. The effect is accentuated at night because the blocks further ahead cannot be seen and during winter when	 	It is recommended to place physical obstacles to avoid the transit of vehicles on the square or to increase the step between the square and the street to make the difference of spaces more visible. In addition, it is recommended to install a right-hand turn sign.	0.42

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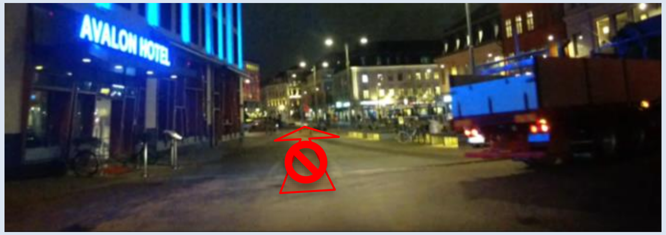
No.	Location	Problem	Crash type	Recommendation	Risk
		there are no tables in the square outside of the restaurant. Furthermore, there are no signs indicating that vehicles must turn right and there are no obstacles on the edge of the square that block the passage. Pedestrians and cyclists passing through the square do not expect the passage of vehicles that may have mistakenly crossed the square. It is likely that crashes involving vulnerable users will occur. 			
S.4	Intersection Vallgatan - Kungstorget	**Signs not clearly visible** At the intersection between Vallgatan and Kungstorget, in front of the hotel, vehicles could not turn left. This is indicated on two small signs that are not clearly visible to a driver who is still on Vallgatan. Only after wrongly turning left, it is possible to see the two signs shown in the picture indicating the forbidden transit for vehicles and motorcycles, but they are partially covered by the bikes or e-scooters that are parked in front of them.	 	It is recommended to install a right-hand turn sign on Vallgatan on the corner of the Avalon hotel and to move the two signs so that they are visible before making the left turn and make them more visible using a higher support structure.	0.21

No.	Location	Problem	Crash type	Recommendation	Risk
		This leads to reversing or U-turning manoeuvres with limited visibility which are very dangerous due to the high presence of vulnerable users who do not expect such manoeuvres and could be involved in a crash. 			

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Roadsides

Roadside obstacle, whether fixed or derived from unappropriated vehicles stops, could lead to risks both for vehicles and pedestrians. Details are shown in the following table.

No.	Location	Problem	Crash type	Recommendation	Risk
RS.1a	Intersection Vallgatan - Kungstorget	**Obstacle on the road** Along Kungstorget, the sign indicating to turn left on Vallgatan for all vehicles except bicycles is placed on the road and seems to be a temporary sign. The base of the sign is an obstacle for vehicles passing through the intersection and may be hit because there is not much space for two vehicles to meet side-by-side. It can also cause vehicles to divert into the opposing lane because of a sudden steering or a sudden brake. The obstacle is also potentially dangerous for bicycles. 	 	It is recommended to replace the temporary sign with a permanent one or in the meantime to place it outside the roadside.	0.03

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No.	Location	Problem	Crash type	Recommendation	Risk
RS.1b	Intersection Vallgatan - Kungstorget	**Obstacle on the road** As RS.1a.		It is recommended to replace the temporary sign with a permanent one or in the meantime to place it outside the roadside.	0.01
RS.2	Kungsportsplatsen	**Blocked roads due to truck operations** The passage of trucks in the area around Kungsportsplatsen for the unloading of goods and for garbage removal is allowed from 5 to 11 a.m. However, around 8:00 a.m., a high concentration of trucks (mostly heavy trucks) often block the roads completely. This leads to reversing or U-turning manoeuvres with limited visibility. The time period from 7:00 to 9:00 is also one of the pedestrian peak hours during weekdays. The high presence of vulnerable road users, who could not expect reversing or U-turning manoeuvres, could be dangerous and lead to crash. 	 	It is recommended to increase police enforcement in order to minimise these situations, trying to not block the transit of vehicles during unloading of goods. In the medium-long term, policies for goods delivery should be revised, for instance by prioritising use of smaller trucks or by revising the time period for good delivery (different from peak hours).	0.07

No.	Location	Problem	Crash type	Recommendation	Risk
					
RS.3	Kungsportsplatsen	**Dangerous manoeuvres due to truck congestion** When trucks block the passage along the road, some dangerous manoeuvres are carried out to avoid them. Many vehicles, also including other trucks, use the sidewalks to cross the obstacle. A person exiting a shop along the sidewalk or a pedestrian that overtake the truck on the road may not be seen by the vehicle and may be run over. 	 	It is recommended to increase police enforcement in order to minimise these situations, trying to not block the transit of vehicles during unloading of goods. Poles on sidewalk preventing the vehicles to drive on it are also recommended.	0.24

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No.	Location	Problem	Crash type	Recommendation	Risk
RS.4a	Kungsportsplatsen	**Entering from Taxi Parking** The manoeuvre should generally not create any problems, however sometimes an inattentive driver can enter the road and cause a minor accident. 		Increase the space between the parking lot and the lane so that approaching vehicles can better understand if a taxi is leaving the parking lot.	0.03
RS.4b	Kungsportsplatsen	**Entering from Taxi Parking** As RS.4a.		Increase the space between the parking lot and the lane so that approaching vehicles can better understand if a taxi is leaving the parking lot.	0.01

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Conflicts with crossing vulnerable road users

As a shared space, one of the main safety problems observed in use case 1 is conflicts with crossing pedestrians and cyclists. Because of the absence of confined space for crossings (i.e. pedestrian zebra crossings), pedestrians (and cyclist) could cross the road spaces in every points of the square. This means that drivers must pay attention continuously to the road margins and being ready to brake.

To face this problem, the administration imposed a very low speed limits of 8 km/h in the square area. The speed limit on the other roads are higher but the actual speed of drivers lies around 15 km/h.

No.	Location	Problem	Crash type	Recommendation	Risk
C.1a	Intersection Vallgatan - Kungstorget	**No confined spaces for pedestrians crossing** Pedestrians and cyclists can cross the road in every point of the square with the risk to cross in front of a vehicle that is not able to react in time.	 	Check that drivers follow the speed limits and, in case not, think about speed reduction-based countermeasures (traffic -calming countermeasures).	0.42
C.1b	Intersection Vallgatan - Kungstorget	**No confined spaces for pedestrians crossing** As C.1a.		Check that drivers follow the speed limits and, in case not, think about speed reduction-based countermeasures (traffic -calming countermeasures).	0.01

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Road Safety Inspection summary

It is important to highlight that the risk value themself obtained from the risk formulation is of minor importance here, and it is the comparison of the final risk scores obtained for the current situation and the scenarios with automated vehicles of the same use case that is of main interest in the assessment.

Ref.	Items resulting from Inspection	Recommendations	Risk value
S.1	Misleading path of the road	Installation of physical obstacles and a right-hand turn sign	0.42
S.2	Manoeuvre not allowed	Installation of physical obstacles	0.24
S.3	Vehicle path unclear	Installation of physical obstacles or increase of the step between square and road and installation of a right-hand turn sign	0.42
S.4	Signs not clearly visible	Increase the visibility of signs and installation of a right-hand turn sign	0.21
RS.1	Obstacle on the road	Removal of sign from the road	0.04
RS.2	Blocked roads due to truck operations	Increase police enforcement and revision of policies for goods delivery	0.07
RS.3	Dangerous manoeuvres due to truck operations	Increase police enforcement and installation of poles on sidewalk	0.24
RS.4	Entering from Taxi Parking	Increase the space between the parking lot and the lane	0.04
C.1	No confined spaces for pedestrian crossing	Check for speed limits compliance and eventually improve traffic calming countermeasures.	0.43
		TOTAL RISK	**2.11**

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3.3.2 Future scenarios

The future scenarios assessed in terms of road safety (and compared with the existing situation) are reported in Table 7. Two scenarios with different penetration rates of Automated Vehicles (with different driving logics: Cautious / Normal / All-knowing) have been considered.

The risk of road traffic crashes has been assessed for all the scenarios according to the methodology described in Deliverable 3.3.

The problems identified for the future scenarios are classified according to three types:

- A = a problem existing in the current scenario for conventional vehicles will still be a problem also for automated vehicles in the future scenario.
- B = a problem existing in the current scenario for conventional vehicles will no more be a problem for automated vehicles in the future scenario.
- C = a problem is not existing in the current scenario for conventional vehicles but will appear in the future scenario due to presence of automated vehicles.

Table 7 Use case 1 – Scenarios assessed

Scenario	CV	AV	AV Class		Driving Logic	AV Class		Driving Logic
1	45%	55%	100%[1]	Intermediate	Cautious	-	-	-
2	9%	91%	40%	Advanced	Cautious	60%[1]	Advanced	Normal

[1] these vehicles are all minibuses

The percentage of automated vehicles and the driving logics considered slightly differ from the ones used in the simulations of use case 1 (Table 8). The Rail-Safe driving logic was not considered in the risk assessment. This decision is based on the definition of the Rail-Safe driving logic leading to the conclusion that such an automated vehicle should not have any interaction within its perception field of view with other users to be able to move. Being a shared space, an area in which the pedestrians are free to move everywhere, there are few situations in which the automated vehicle would not have any interference. Assessing scenarios in which the vehicle has considerable mobility difficulties and moves in a regular way only in a confined space becomes irrelevant in terms of safety.

Table 8 Use case 1 - Driving logics used in the simulation

	Driving Logic: M=Manual, RS=Rail Safe, C=Cautious, N=Normal		
Vehicle type	**Basic AV**	**Intermediate AV**	**Advanced AV**
Car	M	RS	C
Minibus	RS	C	N

Table 9 describes the road safety issues that could arise due to the presence of automated vehicles (both considering those caused by acting and re-acting behaviours of AVs).

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Table 9 Use case 1 – Scenario 1 and 2 – Road safety issues related with Automated Vehicles

No.	PROBLEM		Crash type	CAUTIOUS AV		NORMAL AV	
	Type	Description		Acting behaviour	Re-acting behaviour	Acting behaviour	Re-acting behaviour
S.1	B	**Misleading path of the road**		The AV will preventively know which is the right path.	-	The AV will preventively know which is the right path.	-
S.2	B	**Manoeuvre not allowed**		The AV will preventively know which is the right path.	-	The AV will preventively know which is the right path.	-
S.3	B	**Vehicle path unclear**		The AV will preventively know which is the right path.	-	The AV will preventively know which is the right path.	-
S.4	B	**Signs not clearly visible**		The AV will preventively know which is the right path.	The AV is able to perceive and react on time even to any incorrect manoeuvres of the drivers.	The AV will preventively know which is the right path.	The AV is able to perceive and react on time even to any incorrect manoeuvres of the drivers.
RS.1a	A	**Obstacle on the road**		The AV will detect the obstacle in time to prevent any hazardous manoeuvres.	The AV will detect the vehicle coming from the opposite direction faster.	The AV will detect the obstacle in time to prevent any hazardous manoeuvres.	The AV will detect the vehicle coming from the opposite direction faster.
RS.1b	B	**Obstacle on the road**		The AV will detect the obstacle in time to prevent any hazardous manoeuvres. Slow speed and sudden braking will increase the chance of rear-end collisions.	The AV will maintain the adequate distance avoiding any rear-end collision	The AV will detect the obstacle in time to prevent any hazardous manoeuvres.	The AV will maintain the adequate distance avoiding any rear-end collision

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No.	PROBLEM		Crash type	CAUTIOUS AV		NORMAL AV	
	Type	Description		Acting behaviour	Re-acting behaviour	Acting behaviour	Re-acting behaviour
RS.2	B	**Blocked roads due to truck operations**		The AV won't make any forbidden manoeuvre.	The AV won't make any forbidden manoeuvre.	The AV won't make any forbidden manoeuvre.	The AV won't make any forbidden manoeuvre.
RS.3	B	**Dangerous manoeuvres due to truck operations**		The AV won't make any forbidden manoeuvre.	The AV won't make any forbidden manoeuvre.	The AV won't make any forbidden manoeuvre.	The AV won't make any forbidden manoeuvre.
RS.4a	A	**Entering from Taxi Parking**		The AV will detect the taxi faster	The AV will detect the vehicle coming from the opposite direction faster.	The AV will detect the taxi faster	The AV will detect the vehicle coming from the opposite direction faster.
RS.4b	C	**Entering from Taxi Parking**		The AV will detect the taxi faster. Slow speed and sudden braking will increase the chance of rear-end collisions.	The AV will maintain the adequate distance avoiding any rear-end collision	The AV will detect the taxi faster	The AV will maintain the adequate distance avoiding any rear-end collision
C.1a	A	**No confined spaces for pedestrian crossing**		The AV has better chance to detect the obstacle in time	-	The AV has better chance to detect the obstacle in time	-
C.1b	C	**No confined spaces for pedestrian crossing**		The AV has better chance to detect the obstacle in time. Slow speed and sudden braking will increase	The AV will maintain the adequate distance avoiding any rear-end collision	The AV has better chance to detect the obstacle in time	The AV will maintain the adequate distance avoiding any rear-end collision

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No.	PROBLEM		Crash type	CAUTIOUS AV		NORMAL AV	
	Type	Description		Acting behaviour	Re-acting behaviour	Acting behaviour	Re-acting behaviour
				the chance of rear-end collisions.			

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Scenario 1

This scenario represent the Established stage and it is composed by about half of automated vehicles (55%) that are all minibuses of intermediate AV Class with a Cautious driving logic. Table 10 provides the risk values estimated for each road safety issue.

Table 10 Use case 1 – Scenario 1 – Risk scores related with Automated Vehicles

No.	CONVENTIONAL VEHICLES				CAUTIOUS AVs				Total
	%	F	S	R	%	F	S	R	R
S.1	45	0.7	0.6	0.42	55	-	-	-	**0.19**
S.2	45	0.4	0.6	0.24	55	-	-	-	**0.11**
S.3	45	0.7	0.6	0.42	55	-	-	-	**0.19**
S.4	45	0.7	0.3	0.21	55	-	-	-	**0.09**
RS.1a	45	0.1	0.3	0.03	55	0.1	0.3	0.03	**0.03**
RS.1b	45	0.1	0.1	0.01	55	-	-	-	**0.00**
RS.2	45	0.7	0.1	0.07	55	-	-	-	**0.03**
RS.3	45	0.4	0.6	0.24	55	-	-	-	**0.11**
RS.4a	45	0.1	0.3	0.03	55	0.1	0.3	0.03	**0.03**
RS.4b	45	0.4	0.1	0.04	55	0.1	0.1	0.01	**0.02**
C.1a	45	0.7	0.6	0.42	55	0.4	0.6	0.24	**0.32**
C.1b	45	0.4	0.1	0.04	55	0.1	0.1	0.01	**0.02**
TOTAL RISK									**1.15**

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Scenario 2

This scenario represent the Prevalent stage and it is mainly composed by automated vehicles (91%), 40% of these AV are cars and trucks and the remaining 60% are minibuses of advanced class. Thus, the minibuses have a Normal driving logic while cars and trucks have a Cautious driving logic. Table 11 provides the risk values estimated for each road safety issue.

Table 11 Use case 1 – Scenario 2 – Risk scores related with Automated Vehicles

No.	CONVENTIONAL VEHICLES				CAUTIOUS AVs				NORMAL AVs				Total
	%	F	S	R	%	F	S	R	%	F	S	R	R
S.1	9	0.7	0.6	0.42	36	-	-	-	55	-	-	-	**0.04**
S.2	9	1	0.6	0.6	36	-	-	-	55	-	-	-	**0.05**
S.3	9	0.7	0.6	0.42	36	-	-	-	55	-	-	-	**0.04**
S.4	9	0.7	0.3	0.21	36	-	-	-	55	-	-	-	**0.02**
RS.1a	9	0.1	0.3	0.03	36	0.1	0.3	0.03	55	0.1	0.3	0.03	**0.03**
RS.1b	9	0.1	0.1	0.01	36	-	-	-	55	-	-	-	**0.00**
RS.2	9	0.7	0.1	0.07	36	-	-	-	55	-	-	-	**0.01**
RS.3	9	0.4	0.6	0.24	36	-	-	-	55	-	-	-	**0.02**
RS.4a	9	0.1	0.3	0.03	36	0.1	0.3	0.03	55	0.1	0.3	0.03	**0.03**
RS.4b	9	0.1	0.1	0.01	36	0.1	0.1	0.01	55	0.1	0.1	0.01	**0.01**
C.1a	9	0.7	0.6	0.42	36	0.4	0.6	0.24	55	0.4	0.6	0.24	**0.26**
C.1b	9	0.1	0.1	0.01	36	0.1	0.1	0.01	55	0.1	0.1	0.01	**0.01**
TOTAL RISK													**0.51**

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For each problem identified in the scenarios with different penetration rates of automated vehicles, recommendations are provided in Table 12.

Table 12 Use Case 1 - Recommendations related to each problem

No.	Type	Description	Crash Type	Recommendation
S.1	B	Misleading path of the road		-
S.2	B	Manoeuvre not allowed		-
S.3	B	Vehicle path unclear		-
S.4	B	Signs not clearly visible		Increase the visibility of signs and installation of a right-hand turn sign
RS.1a	A	Obstacle on the road		Removal of sign from the road
RS.1b	B	Obstacle on the road		Removal of sign from the road
RS.2	B	Blocked roads due to truck operations		-
RS.3	B	Dangerous manoeuvres due to truck operations		-
RS.4a	A	Entering from Taxi Parking		Increase the space between the parking lot and the lane
RS.4b	C	Entering from Taxi Parking		Increase the space between the parking lot and the lane
C.1a	A	No confined spaces for pedestrian crossing		Increasing the space between the lane and the no traffic area making it clear, also by means of coloured surface. The space division must be clear also to pedestrians.
C.1b	C	No confined spaces for pedestrian crossing		Increasing the space between the lane and the no traffic area making it clear, also by means of coloured surface. The space division must be clear also to pedestrians..

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3.3.3 Comparisons and road safety conclusions

Table 13 shows the risk scores calculated for the current scenario (without AVs) and for the two scenarios with AVs, as well as the percentage change from current to future scenarios. The same information is also graphically shown in Figure 30.

All the AV scenarios indicate a potential reduction of road traffic crash risk, but the risk is not eliminated. The higher benefits are obtained by increasing the presence of automated vehicles in the mixed environment as shown by scenario 1 (55% of AV) and scenario 2 (91% of AV). This was expectable, due to the fact that AVs are expected to make less (or no) “driving errors”, compared to human drivers. Most of the risk is due to “re-acting” situations, where the automated vehicle could have a crash due to a traffic condition caused by a conventional vehicle. However, also in this case, AVs should react better than the human driver as a consequence of the improved reaction time and the improved capacities of reading the situation.

In the first scenario, the frequency of rear-end collisions is increased due the Cautious driving logic that, because of a very slow speed, could bring the following car to don’t respect the safety distance. Furthermore, Cautious AV will probably make many sudden braking which increase the possibilities of such a crash. In the second scenario the risk of rear-end collision is the same as in the current scenario without AVs because there are a higher number of Normal AVs than Cautious AVs and it can be assumed that in the Prevalent stage, drivers know how an AV behaves. In this use case there are few differences between the risk caused by different driving logics.

Table 13 Use case 1 – Scenarios assessed

Scenario	CV	AV	Risk score Current scenario	Risk score Future scenario	% risk change
1	45%	55%	2.11	1.15	-45%
2	9%	91%	2.11	0.51	-76%

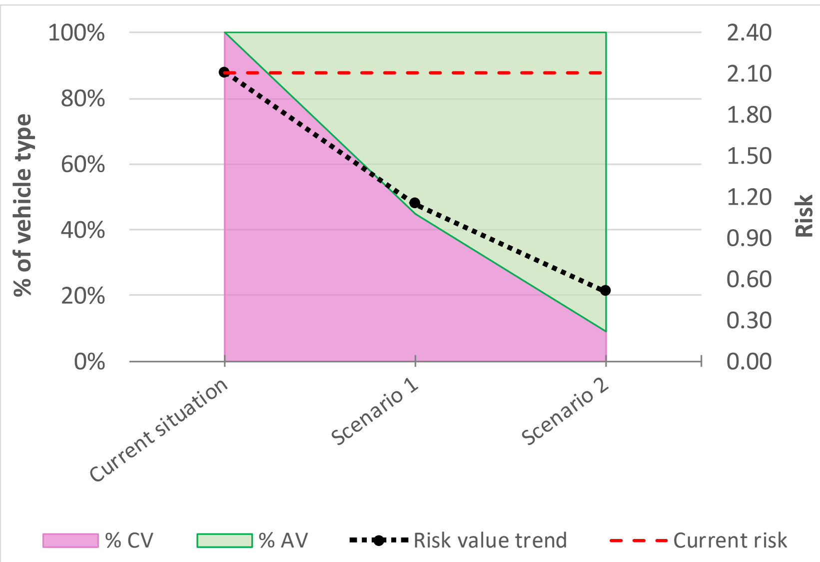

Figure 30 Use case 1 - Risk evolution based on AVs scenarios

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3.4 Conclusions

The simulation results indicate that the introduction of a last mile service in the form of automated minibuses impacts the traffic performance of the conventional vehicles negatively. Furthermore, the results indicate that the automated last mile service will suffer significant delays at the shared space due to interactions with pedestrians, at least until the automation technology reaches a point when their capabilities are similar to that of a human driver, which in this case is assumed to happen in the Prevalent stage. However, the delays of the vehicle traffic due to the interactions with pedestrians never becomes so large that long queues are formed, due to the small volumes of vehicle traffic, and the results of the evaluation of the proposed measure indicates that the traffic performance will not improve from structuring the pedestrian flows using pedestrian crossings. Also, for the later stages of coexistence the delay of the minibuses is small enough for the service to be considered feasible from a traffic performance point of view.

The impact of automation on the performance of the pedestrian traffic seems to be negligible. However, this may to some extent be due to the modelling approach used since the approach did not allow vehicles to be significantly more aggressive or pedestrians significantly more passive, which meant that the uncertainty in the road user behaviour could not be investigated fully.

Any evaluation of the impact of automation should consider more than just the impact on traffic performance given by the simulations, and this is especially true for such a complex scenario as considered in this use case, but from a purely traffic performance point of view the evaluated automated last mile service may have problems if implemented during the Introductory stage before the automation technology is sufficiently advanced, but should be feasible at later stages.

The qualitative safety assessment indicates that the two automation driving functions considered relevant for use case 1 might have a positive safety impact to have a positive impact on the safety in 24 of the 68 different accident types. As the parking pilot might have a positive impact when parking vehicles in the area it will most likely have no impact at all on vehicles who are simply driving through Kungstorget. This driving function is probably most relevant for taxis and freight transport that goes in and out from Kungstorget during designated hours (note that taxis and freight delivery trucks were not included in the simulation model since they were not appearing during the study time period). The urban pilot is expected to compensate for the lacking abilities of the parking pilot in situations when not parking a vehicle. This is most evident for situations where only vehicles are involved in a potential conflict as AVs have an aspect of predictability to them which is not always the case for humans.

As there is little knowledge on how AVs are going to interact in areas such as shared spaces it is difficult to analyse the potential impact that AVs will have from a safety perspective. However, assuming that the AVs present in a shared space area are equipped with an urban and parking pilot. The results show that there in general is a chance of a positive impact on the safety both for pedestrians and vehicles. The safety inspection-based assessment indicates a potential reduction of road traffic crash risk, but that automated vehicles will not eliminate it. The decreased risk comes to a large extent from that AVs make less (or no) “driving errors”. However, there might be a risk of increased frequency of rear-end collisions due to the Cautious driving logic that, because of a very slow speed, could bring the following car to don’t respect the safety distance.

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4 Traffic impact of automation in use case 2: Accessibility during long-term construction works

Use case 2 aims to investigate traffic performance effects of automated vehicles in the Gothenburg region during long term construction periods. The yellow circle in Figure 31 represents the city centre of Gothenburg while the blue circle represents the metropolitan area that are the main area included in the traffic model. Among all construction projects, there is one major road (marked in red) that is of special interest since it serves as an important linkage for traffic flow into the city. The green lines illustrate examples of roads where capacity will be reduced due to long-term construction works. Motorways carry large volumes during the peak hour. The main motorways are the E6 motorway passing by Gothenburg in the north-south direction as well as the motorway E20 that enters Gothenburg from the east.

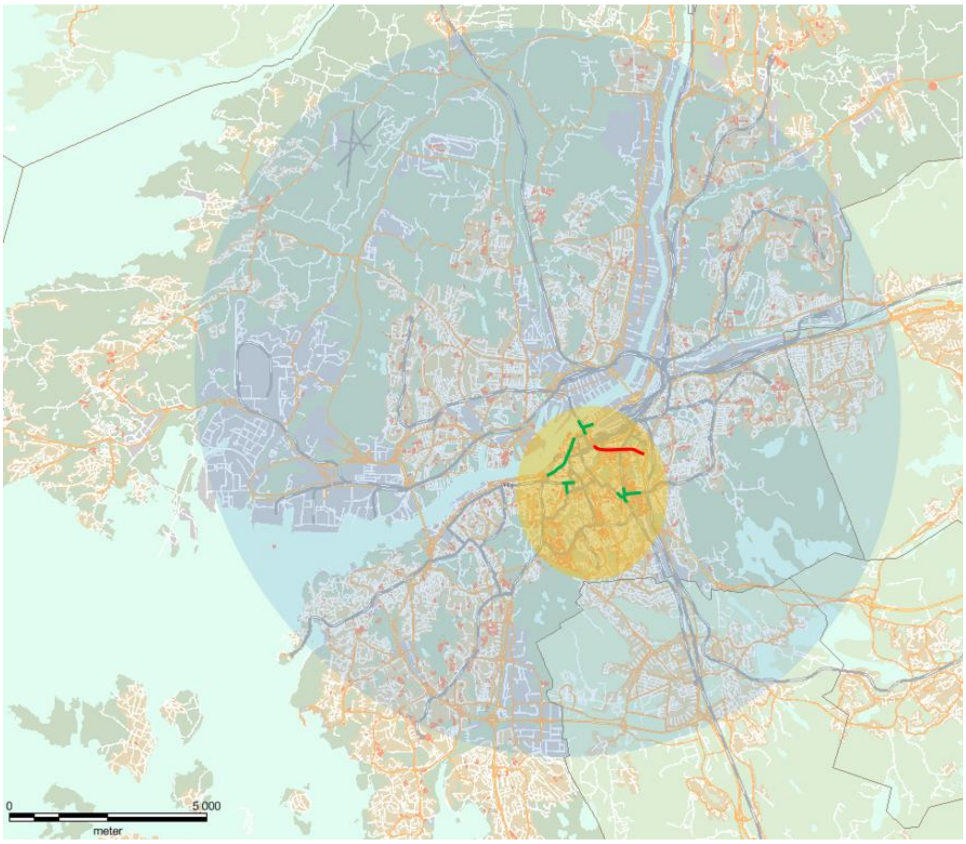

Figure 31 Map of the city of Gothenburg. The yellow circle represents the inner city and the coloured roads show roads that are affected by construction projects. Source: City of Gothenburg.

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4.1 Traffic performance

4.1.1 Parameter settings in the assessment tool

Following the work described in CoEXist deliverable D 3.3 (Olstam, et al., 2019b), the results presented is analysed by using the assessment tool designed for macro use cases. The following traffic performance metrics can be selected in the tool:

- Average travel time (s/transport user class)
- Average individual travel time per distance unit (s/km/transport user class)
- Average delay (s/transport user class)
- Vehicle Hours Travelled (h/transport user class)
- Person Hours Travelled (h/person/transport user class)
- Vehicle Distance Travelled (total km/transport user class)
- Person Distance Travelled (total km/person/transport user class)

All the metrics are considered for use case 2 except Person Hours Travelled (h/person/transport user class) and Person Distance Travelled (total km/person/transport user class). In this use case it is not possible to distinguish "Vehicle" and "Person" given that demand is only presented as a fixed matrix in the unit of vehicles. Only cars & trucks are considered relevant travel mode in this use case since other modes are not represented in the model.

The relative improvements of the selected traffic performance metrics at each stage are presented in the next section. The user or the decision maker can select a threshold for a given traffic performance metric at a given stage so that value above the threshold can be considered as automation ready. In this report, the thresholds are all set to 0% to avoid any potential misunderstanding.

4.1.2 Results and discussions

Impact on traffic performance, No measure

Figure 32 presents the result from the assessment tool. The assessment tool summarizes the relative improvements in each individual scenario and presents the impacts for each of Introductory, Established and Prevalent stages. Since a stage consists of several scenarios, the mean value is presented, and the variation is then presented by a range denoting the maximum and minimum values of all scenarios within the given stage. The relative improvements of all vehicles (AVs and CVs) and CVs are presented for average travel time, average travel time/km, average delay. Vehicle hour travelled and vehicle distance travelled for all vehicles are presented too.

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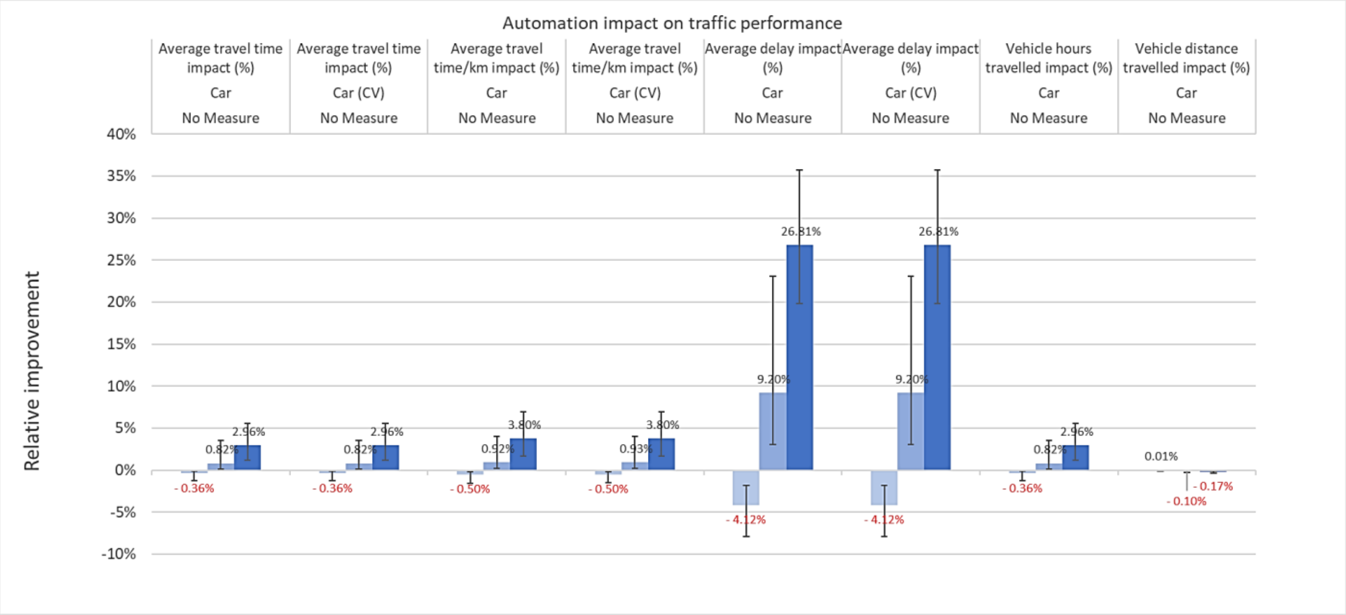

Figure 32 The impact of AVs on traffic performance metrics in different stages. Note, “no” in the figure denotes this is the results without any measures.

Figure 32 shows that the improvements of traffic performance metrics in the Introductory stage are negative while those in the Established and Prevalent stage are positive. The overall trend meets our expectation. The variations of traffic performance metrics in the Establish stage are substantially larger compared to those in the other two stages, which indicates strong uncertainties. The establish stage consists of AV penetration rates ranging from 30% to 70% and a variation of AV mixtures, and therefore exhibits the large variation. There is almost an identical relative improvement between CVs and AVs in all stages. This is due to the foundation of macroscopic models where traffic flow is modelled but not the individual vehicles. In this use case, the free flow speed of AVs and CVs are set the same. Therefore, speed and travel time of AVs and CVs are always the same on a given link/turn. This can be interpreted as only the average speed and travel time of all vehicles on the link/turn level are estimated in a macroscopic model. This results in almost the same route choice of AVs and CVs for a given OD pair. It is also important to note that the relative improvements of average travel time and total vehicle hours travelled are identical, since the total demand is fixed.

Impact on traffic performance, Measure 1: Two-way AV-only tunnel tube

During the construction period, the construction and maintenance of tunnels will require that one of the tunnel tubes needs to be closed for traffic. If only allowing AVs in the open tunnel tube, it could be possible to allow bidirectional traffic and add extra lanes by making the lanes narrower, therefore increases the capacity of AVs. Measure 1 refers to a redesign from a one-way three lane tunnel tube into a two-way AV-only tunnel tube for the Göta tunnel.

Figure 33 presents the application of the assessment tool for this measure. The relative improvements in the scenarios with and without measure 1 compared to the baseline are presented. Total vehicle hours travelled is not presented since it shows identical trend as the average travel time. Total vehicle distance travelled is also not presented since the improvement is too small.

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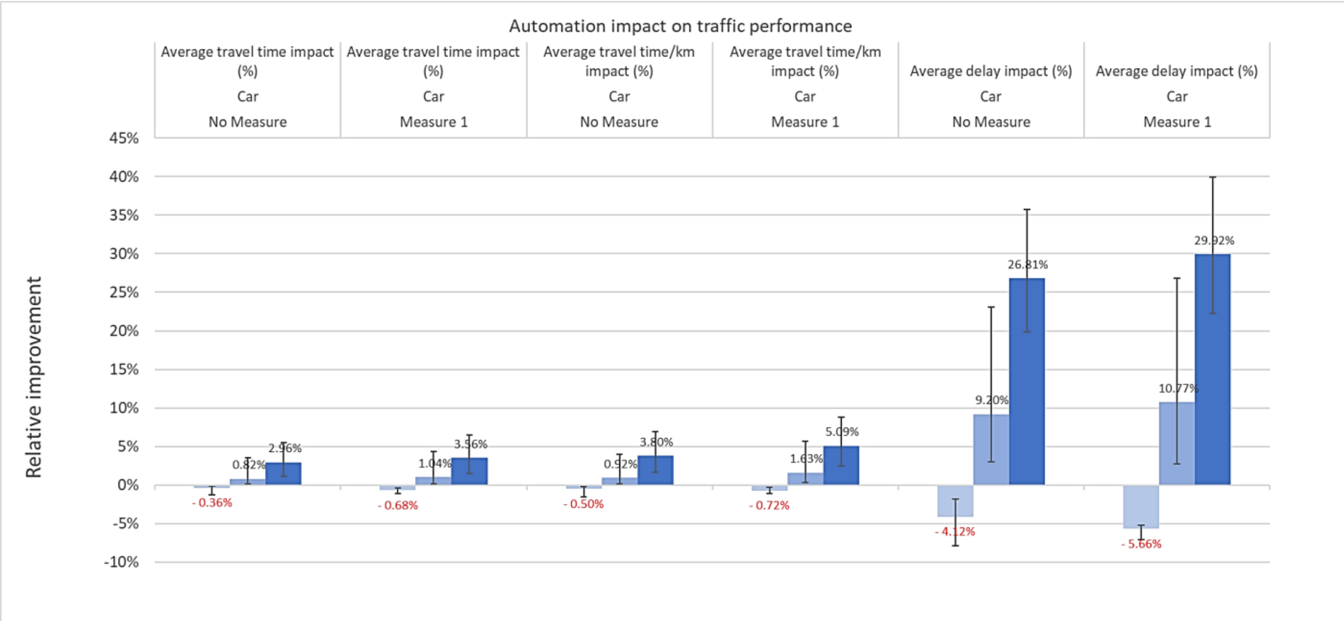
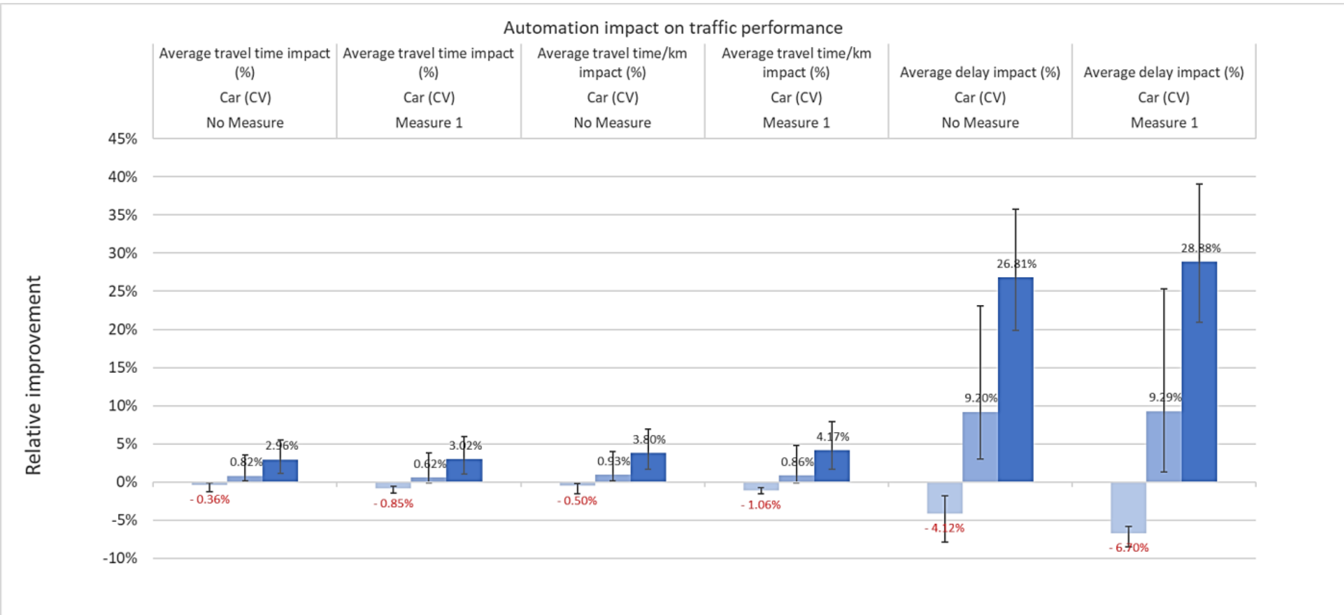


(a) All vehicles (CVs + AVs)



(b) Only CVs

Figure 33 Comparison of relative improvements with and without measure 1.

In general, this measure corresponds to a decrease in relative improvements in the Introductory stage and an increase in relative improvements in the Established and Prevalent stage. The magnitude is larger when all vehicles are considered compared to only CVs. Interestingly, the variation (the range bar) of the Introductory stage is smaller with measure 1 compared to without but in the Established and Prevalent stages, the variation is larger. This suggests that although measure 1 can be considered as a useful measure in the Established and Prevalent stages, its effectiveness is largely subject to the specific combination of AV penetration rate and AV type mixtures. Whilst in the Introductory stage, the

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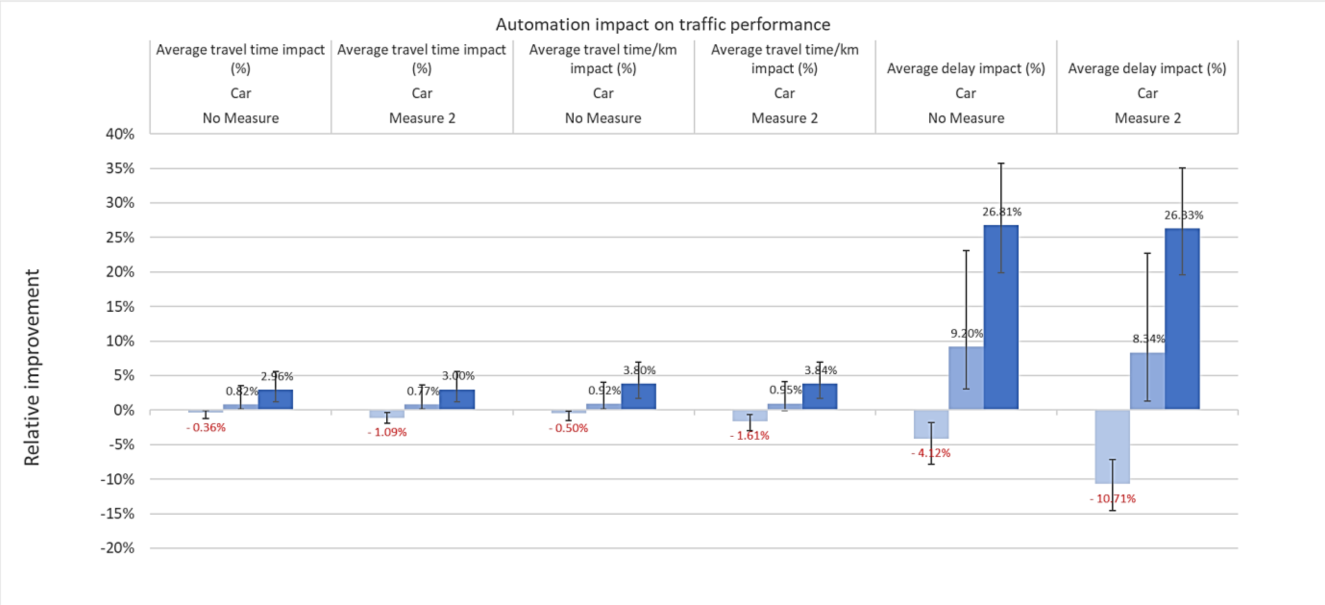
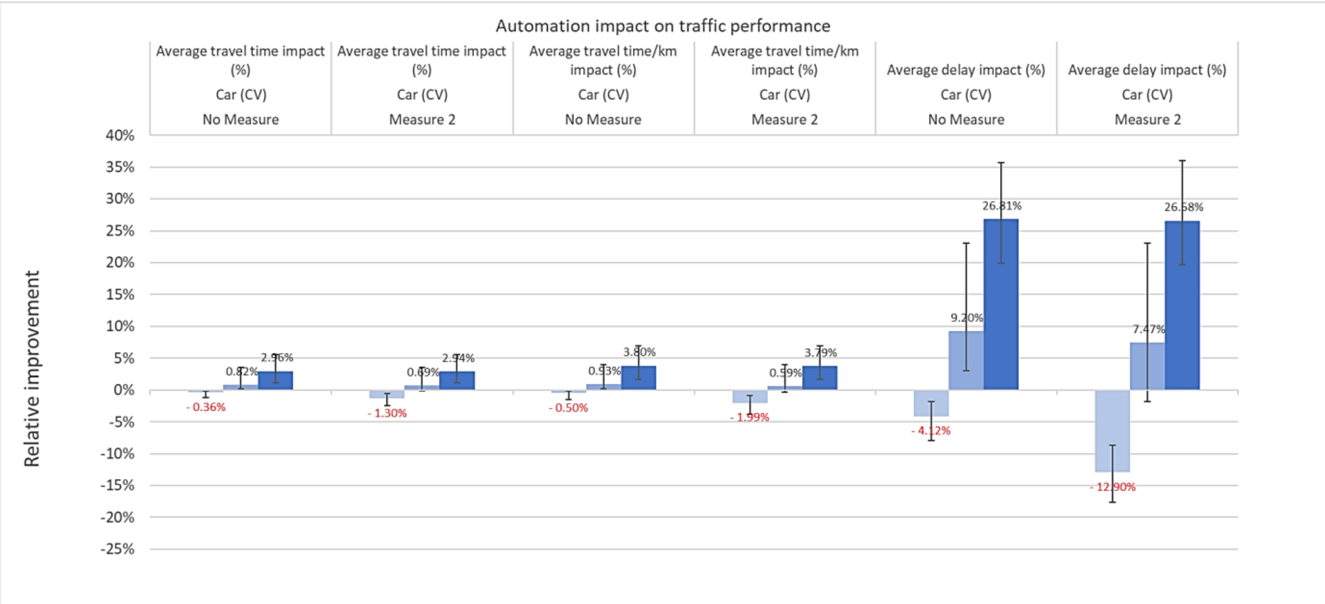
negative effect of measure 1 is mostly certain and less subject to the specific combination of AV penetration rate and AV mixtures.

Impact on traffic performance, Measure 2: Reserved bus and AV lane on the motorway network

Introducing dedicated bus lanes is one type of measure that prioritizes public transport. However, this will most probably imply an increase in congestion for the car traffic. Allowing AVs to use dedicated bus lanes can be considered as a way to prioritize AVs but also a way to efficiently utilize the resources and still give priority for public transport. Measure 2 refers to reserving a lane on major motorway networks for buses and AVs. Figure 34 presents the application of the assessment tool for measure 2.



(a) All vehicles (CVs + AVs)



(b) Only CVs

Figure 34 Comparison of relative improvements with and without measure 2.

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Figure 34 shows that this measure greatly worsens the traffic performance metrics in the Introductory stage. The magnitude is also more substantial for CVs compared to all vehicles (AVs + CVs). When it comes to the Established and Prevalent stages, no positive effect is found as well. In the Established stage, measure 2 can even lead to an increase in travel time and delay compared to the baseline (negative value of relative improvement) in the scenarios where AV penetration rate is 30%. To summarize, there is no positive effect of measure 2 being found in any of the stages.

4.2 Qualitative safety assessment

The Gothenburg travel demand model is a macroscopic model which does not provide data or sufficient information for assessing impacts of CAV on safety. However, it is still possible to analyse effects on vehicle kilometres. An increase in kilometers driven imply more accidents if the accident probability per vehicle kilometers stay the same. That's is true for conventional vehicles and that's probably also true for AVs. However, for use case 2, on the one hand the vehicle kilometers change only marginal since the demand for car trips is not affected (since the model do not include mode choice). On the other hand, the modelling results do show that the vehicle kilometers on different road types (Motorway, Arterial and Urban street) vary when AVs are introduced. There is a clear trend that total vehicle kilometers on motorway decrease in the Introductory stage and increase in the Established and Prevalent stages, while total vehicle kilometers on urban street exhibit an opposite trend. This indicates potentially an increased safety risks on motorway in the Established and Prevalent stages due to higher volumes. However, no clear trend on arterial is observed. Although travel time and delay is shorter on arterial in Established and Prevalent stages, this does not necessarily lead to an increase in traffic volumes due to the network topology as many arterial roads serve as alternatives to motorway and therefore traffic volumes on these arterial roads decrease in the Established and Prevalent stages.

It is also possible to analyze the effects on velocity. Higher velocities imply higher severity of an accident due to higher kinetic energy at higher speeds. This is true for CVs and is expected to be true also for AVs. The travel speed decrease in the Introductory stage but as the AVs become more advanced the travel speed increase compared to the baseline. It is important to note that the macroscopic modelling do not capture the effect of full speed compliance of AVs compared to CVs since the AVs and CVs use the same travel time function and the same free flow speed / free flow travel time. Thus, safety gains on roads with lower flows due to higher speed compliance are not visible in the macroscopic use cases.

4.3 Conclusions

In this use case, the impact of AVs on traffic performance is examined by using a macroscopic transport model. This particular use case focuses on the traffic performance in the city of Gothenburg during the construction period. Two research questions are studied:

- How does the introduction of AVs (at different penetration rates and different types of AV) affect route choice, travel time saving and delay under the intensive construction period?
- At what penetration rates and which combinations of AV types can the following measures improve traffic performance? 1. Adding special dedicated AV lanes at a bottleneck link: Göta Tunnel. 2. Reserving a dedicated "Bus + AV" lane on the major motorways.

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The impact of AVs is modelled by representing traffic flows of AVs as its equivalent traffic flows of CVs through passenger car unit. Results are presented as the relative improvements of predefined traffic performance metrics. The results can be summarized as:

- The introduction of AVs indicates a worsened traffic performance metrics when it comes to the Introductory stage and then an improvement when it comes to the Established stage and Prevalent stage. The magnitude of the improvements depends on the congestion level in the current network.
- Large variation in traffic performance measures observed in the Established stage due to a wide range of penetration rates and AV configurations tested in that stage.
- Measure 1: Two-way AV-only tunnel tube - can be considered as a measure that improves the traffic performance metrics when AV penetration rate reaches 30% and Intermediate AVs start to become the majority. CVs are also benefited from measure 1 although measure 1 only increases the capacity of AVs.
- No major improvement in traffic performance is observed in all of the scenarios tested for measure 2 (reserved bus and AV lane on the motorway network), and therefore it is difficult to justify its effectiveness.

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5 Traffic impact of automation in use case 3: Signalised intersection including pedestrians and cyclists and use

Use case 3 consists of a signalised intersection with pedestrians and cyclists, see Figure 35. The intersection is located on an important arterial that runs through the city of Helmond from east to west and vice versa. The intersection is located on the west side of the city and it is one of the first at-grade intersections in the eastbound direction where pedestrians and cyclists are allowed to cross the road. The conflicts between vehicles and vulnerable road users are controlled by traffic signals and since pedestrians have their own green phase there are no secondary conflicts between vehicles and vulnerable road users.

Figure 35 Intersection Europaweg - Hortsedijk

5.1 Traffic performance and space efficiency

5.1.1 Parameter settings in the assessment tool

The impact of automation on traffic performance is for this use case analysed in terms of the relative improvement of average travel time and average delay. In addition, investigations of the automation impact on the space efficiency metrics: space claim, space time footprint, and space time utilisation are also conducted. Results on average travel time per distance unit is not presented as it gives no additional information in this use case. The figures presented in upcoming sections also show the minimum and the maximum value from each stage depicting a potential range of the automation impact.

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It is possible for a city to define a threshold for when the impact of automation on the active modes is considered to be unacceptable. However, the city of Helmond has no such thresholds defined and have a larger interest in seeing the potential effects with respect to traffic performance and space efficiency for when AVs are introduced and deployed in areas where other technological measures, such as the adaptive traffic signal in Helmond, already are in place. The threshold is therefore set to 0% in the assessment tool.

The traffic simulation model of the use case includes four transport user classes: cars, trucks, cyclists and pedestrians. The automation impact on traffic performance and space efficiency metrics are assessed using the methodology developed in CoEXist.

As the main arterial going through the city of Helmond is a heavily used road segment, the traffic signal policy is to prioritize vehicles with the aim of avoiding cues. However, by prioritizing the vehicles, naturally, pedestrians and cyclists get to wait longer before being allowed to cross. In an attempt to keep the travel time and delays of vehicles at similar levels as of today, while improving the traffic performance of pedestrians and cyclist, there was initially intentions of investigating a measure where V2I and I2V communication would allow for only prioritizing AVs, or CVs at the intersection. However, due to limitations in the compatibility of the utilised traffic light simulator and Vissim this was not possibly and therefore no measure is assessed for use case 3.

5.1.2 Results and discussions

The signalized intersection in Helmond is controlled by an adaptive traffic signal. The implementation of the traffic signal controller in the simulation model is done utilising a third-party software which works in conjunction with the Vissim protocol. Since there's little knowledge within CoEXist of the exact implementation of the traffic signal, results may be difficult to interpret as there might by underlying effects which aren't intuitive or known to partners within the CoEXist project.

Results and discussion, No measure

The effect of introducing automated cars on the signalized intersection in Helmond leads to an increase of the average travel time of conventional cars (see Figure 36). The effects seem to be largest in the Established stage where the average travel time reaches a relative improvement of -2.5%. Both the Introductory stage and the Prevalent stage shows a relative improvement off approximately -1.9%. A similar pattern is shown for conventional trucks where the most noticeable decrease of relative improvement is seen in the Established stage reaching a level of -2.88%. Both the Introductory and Prevalent stages show a decreased relative improvement of approximately -2.5%. This could be explained by the speed reducing effect that AVs will have on CVs due to that AVs fully comply with the speed limits, which imply a speed reducing effects on CVs as well. The results in Figure 36 also show that the entire car fleet (car (CV)+car (AV)) and truck fleet (truck (CV)+truck (AV)) will have longer travel times which is expected due to the full speed limit compliance of AVs.

The traffic performance of bikes and pedestrians, with respect to travel time, will initially decrease in the Introductory stage. This is expected, as the saturation flow of AVs is also expected to decrease in the early stages of coexistence. This is mainly due to the assumed capabilities of AVs (Cautious AVs requiring large time gaps which imply lower saturation flows). However, as the technology of AVs gets more advanced throughout the stages the saturation flow will increase. Since capacity as signalised intersections is governed by share of green time and saturation flow, an increased saturation flow

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decreases the need for green share to keep the same capacity. Hence an increased saturation flow may eventually lead to a redistribution of green time by the adaptive traffic light control resulting in a relative improvement of ~1.2% for bikes and ~1.7% for pedestrians. This is achieved without changes to the priority settings of the adaptive traffic signal controls as it in this case still prioritizes vehicles on the main arterial.

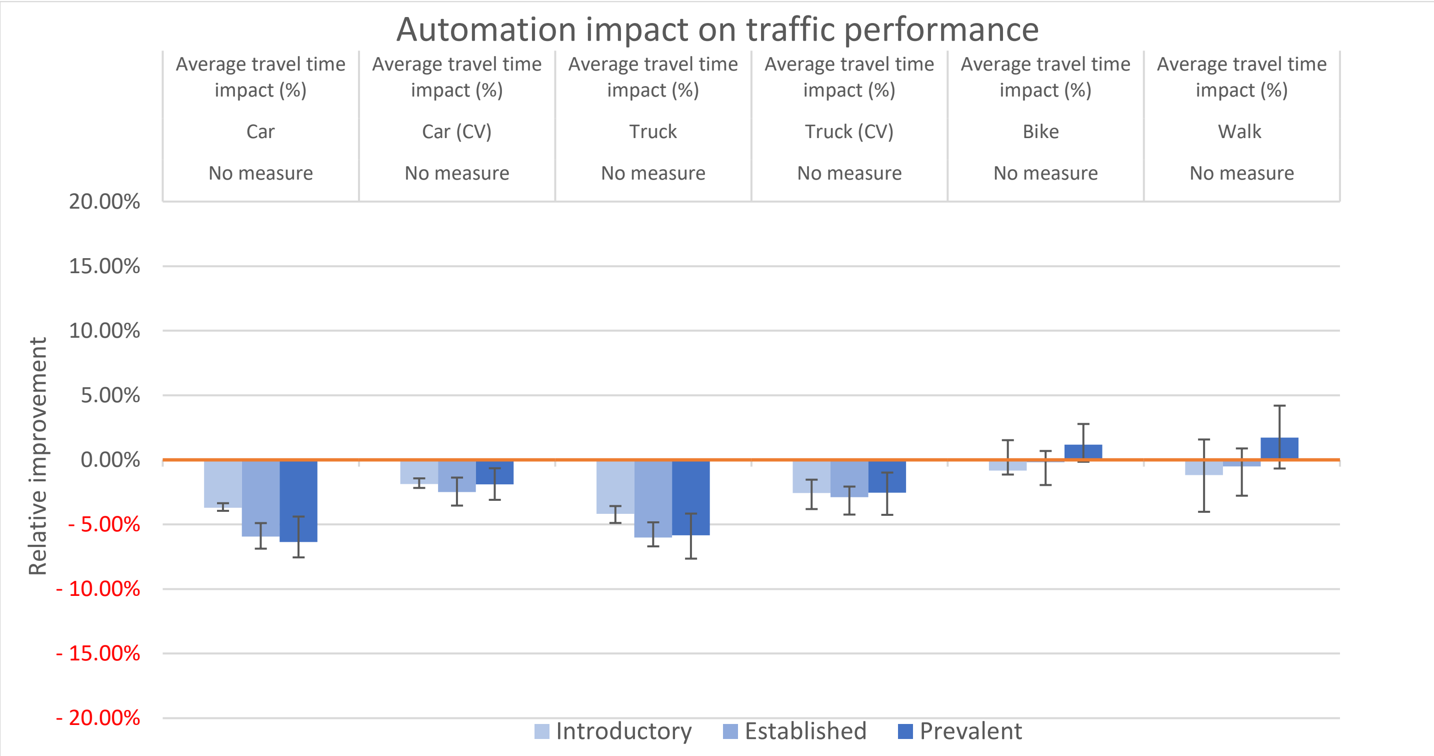

Figure 36 Automation impact on traffic performance in terms of relative improvement in average travel time

Figure 37 shows that the delay of conventional cars follows the same pattern as travel time (which is expected). The relative improvement of delay is -7.5% in the Introductory stage, -9.7% in the Established stage and -6% in the Prevalent stage. As indicated by the impacts on average travel time conventional vehicles will be delayed due to the AVs which comply with the speed limit. What is somewhat remarkable is that conventional trucks deviates from the pattern observed as there is a continues decrease of the delay over the stages. The reason for this has not been found within the project.

The delay of the entire car fleet (car (CV) + car (AV)) shows that the delay will improve over the stages starting at -5% in the Introductory stage and reaching a positive relative improvement of 3.68% in the Prevalent stage. Similarly the truck fleet (truck (CV) + truck (AV)) shows the same trend starting at -5.7% in the Introductory stage reaching a positive relative improvement of 4.6% in the Prevalent stage, this is due to a combination of more advanced driving logics and higher penetration rates of advanced AVs, which enhances the performance of the adaptive traffic signal.

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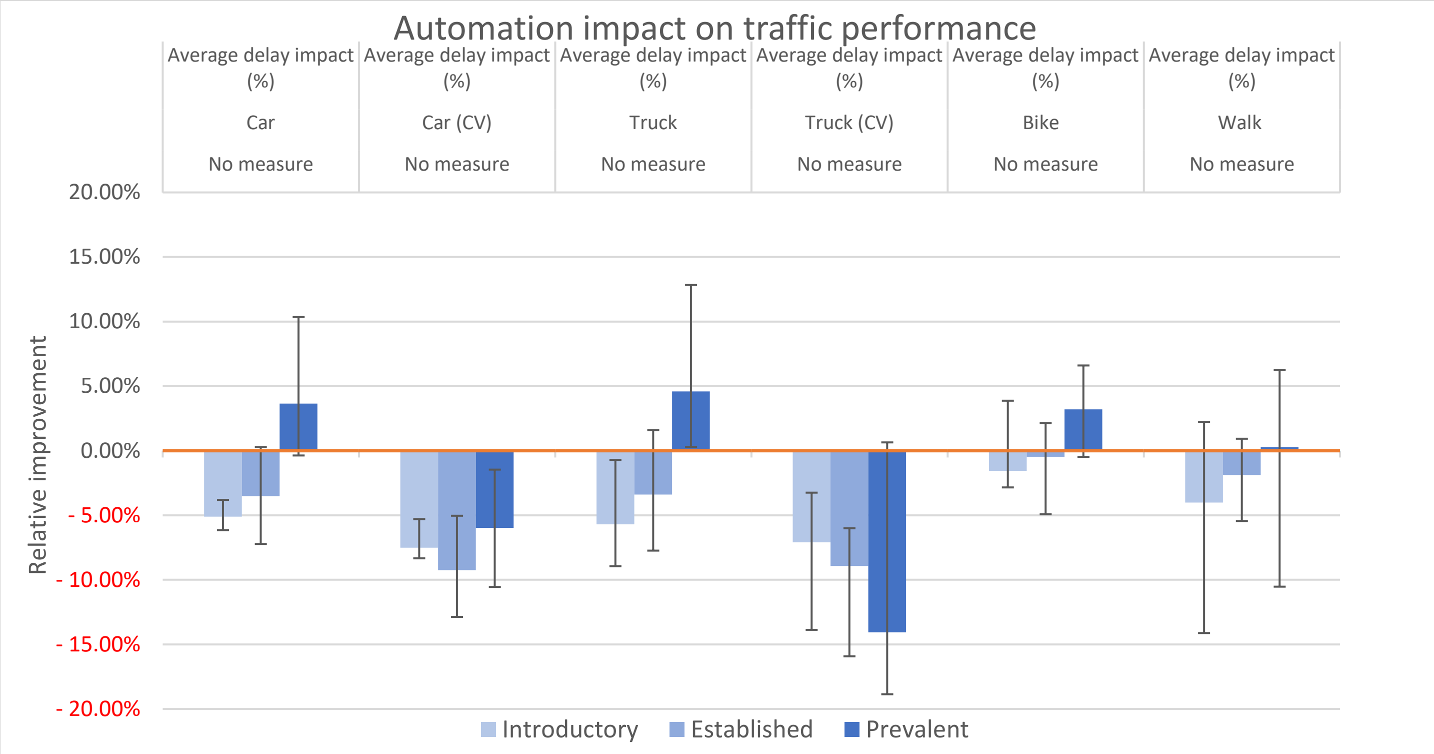

Figure 37 Automation impact on traffic performance in terms of relative improvement in delay

Figure 38 shows the impact of automation on pedestrians and bicycles. There are small negative impacts for both pedestrians and bicyclists in the Introductory stage and the Established stage. This is most likely due to the decreased saturation flow for vehicles which causes a redistribution of green time from pedestrians and bikes to vehicles. At the Prevalent stage the automation impact on traffic performance becomes positive in terms of travel times and delay for both pedestrians and cyclists. This effect is a result of the adaptive traffic signal that will redistribute the green time from vehicles to pedestrians and bicyclists due to the increase in saturation flow due to the advanced AVs.

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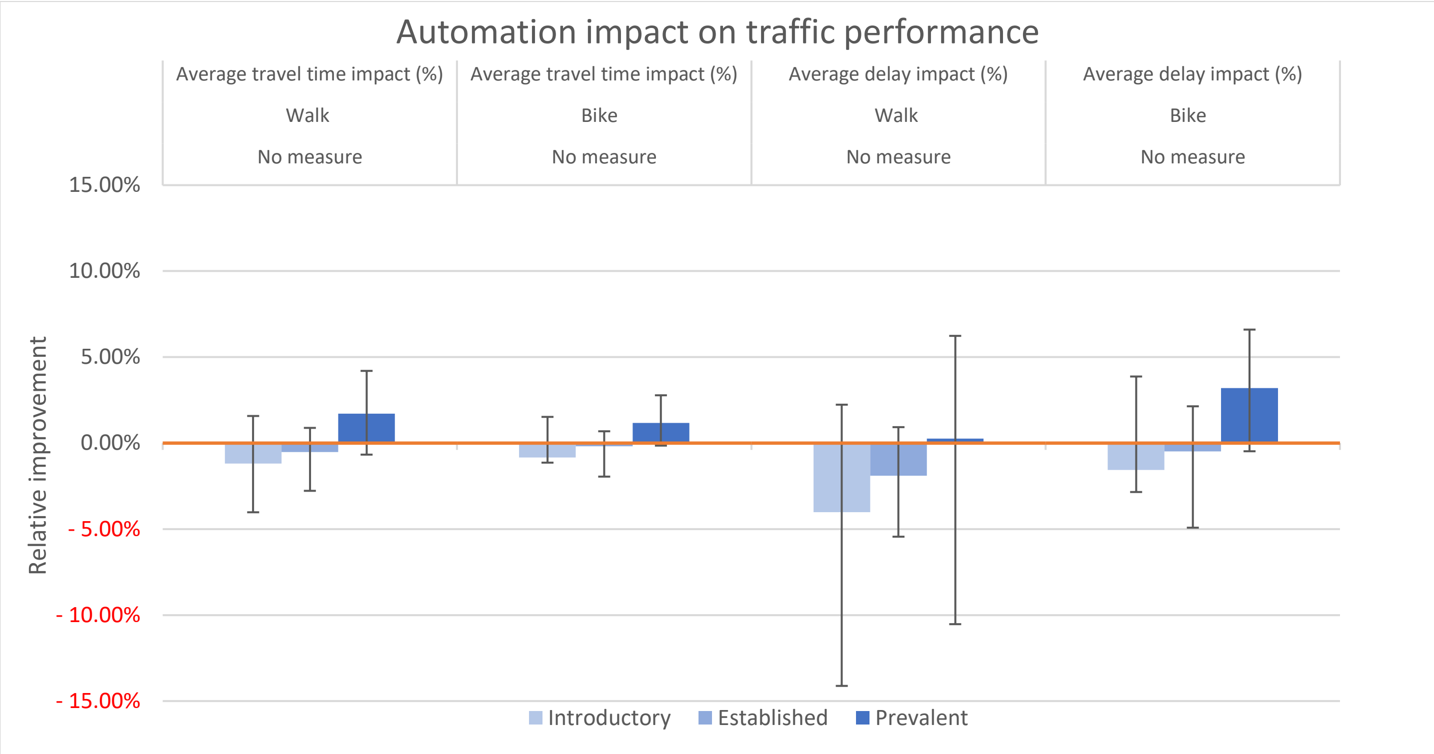

Figure 38 Automation impact on traffic performance in terms of relative improvement in travel time and delay

Figure 39 show the average space claim and the average space time footprint. Looking at the space claim of the transport user classes car (car (CV) + car (AV)) and truck (truck (CV) + truck (AV)), there's a clear indication that the space claim of AVs in the earlier stages of coexistence are larger than the space claim of conventional vehicles today. This is to a large extent due to the larger gaps required by AVs in the earlier stages of coexistence where for example the Cautious driving logic is assumed to keep distances large enough to be able to stop safely in the case that the preceding vehicle would come to an instant stop (brick wall stop distance). However, as we reach the Prevalent stage the space claim is reduced significantly as we start to see an average space claim in similar levels to the one of today for both car and truck. While the space claim for the AVs increase there is a decrease of the space claim for car (CV) and truck (CV). This is probably an effect of that the speed of CVs decrease due the slower AVs (full speed compliance), which imply a lower required safety gap in meters, thus a lower average space claim.

The space claim only gives an indication of the space that is claimed by each vehicle it is important to take the time that a vehicle spends in the network into consideration. Therefore, Figure 39 also show the space time footprint. Interestingly the introduction of AVs seems to imply only a small positive impact on the space time footprint of conventional cars. It also shows that the gains in space claim are higher than the losses in travel time causing an increase in average space time footprint, although it is small. As for conventional trucks the relative improvement of the average space time footprint stays at the same levels as today in the Introductory stages, to drop slightly, -1%, in the Established stage, and then, show an increased relative improvement in the Prevalent stage. The automation impact on the space time footprint of conventional trucks shows that even though an increased travel time is expected for conventional trucks, the required average space of those trucks is lower to such a degree that we see an improvement in the average space time footprint of that transport user class. Furthermore, Figure 39

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shows that all cars and trucks, CVs and AVs, imply a higher space time footprint than cars and trucks today. Indicating that AVs will in general need more space-time for moving the travel demand from origin to destination in the network.

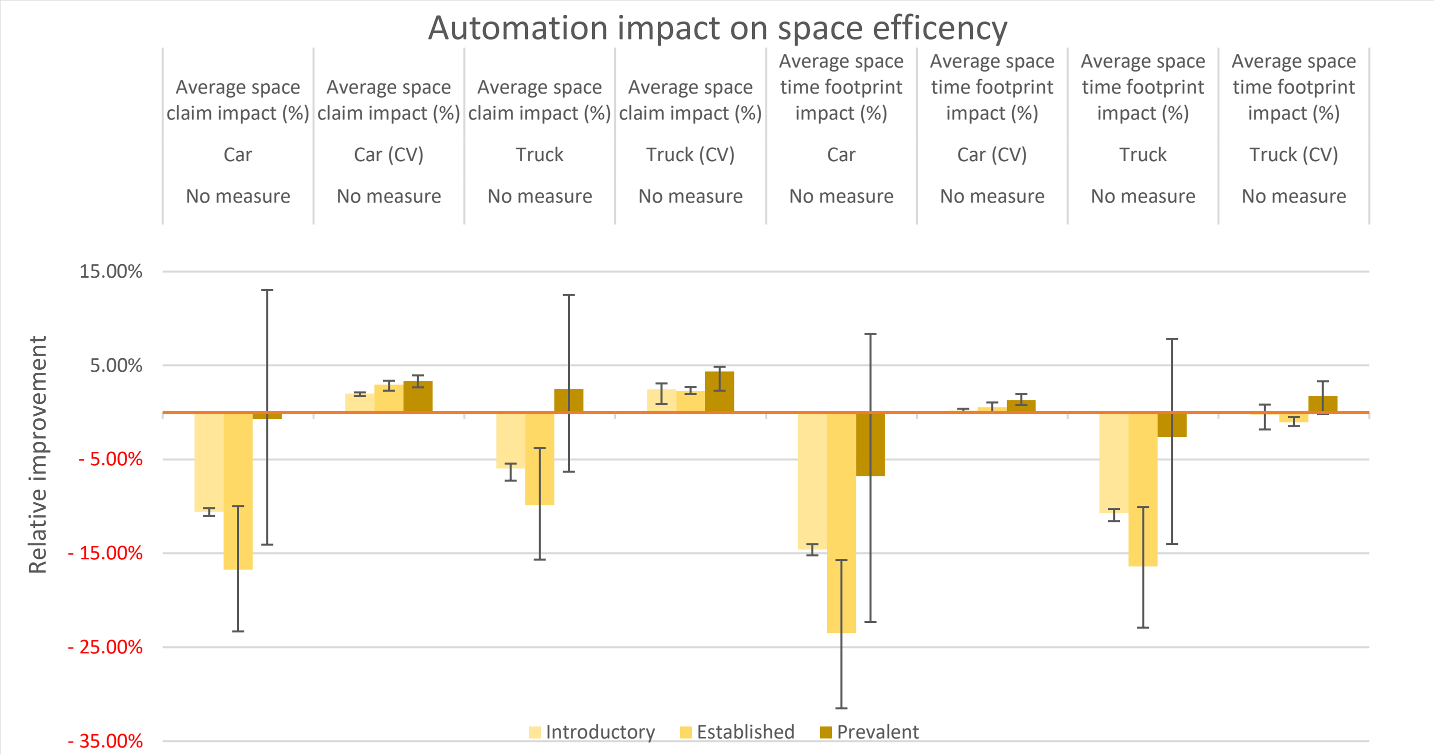

Figure 39 Space efficiency in terms of average space claim and average space time footprint

Figure 40 shows the relative improvement of the space time utilisation of all vehicles, and for car and truck separately. The space time utilisation is a kind of degree of saturation showing the ratio between the total space-time required for all vehicles to reach their destination and the total available space-time (which depend on the length of network and the duration of the study period). The figure shows that even though there is an underlying assumption that technology is going to advance and make AVs less cautious and more efficient in utilising the given space there is potentially still some negative impacts to be expected even in the Prevalent stage. However, the uncertainty range depicted by the error bars, shows that in some of the experiments conducted there will be a better utilisation of the available space time in the signalized intersection. The space time utilisation might be correlated with cross-sectional metrics as degree of saturation or volume-to-capacity (Engelfeldt and Persson, 2019). Since the adaptive signal controller tries to redistribute green time to keep a satisfactory degree of saturation for all vehicle types and approaches, the negative effects on space time utilisation also for the Prevalent stage might depend on that the traffic performance in terms of delay for vehicles can be kept at a similar level as today at a lower degree of saturation due to an increased saturation flow.

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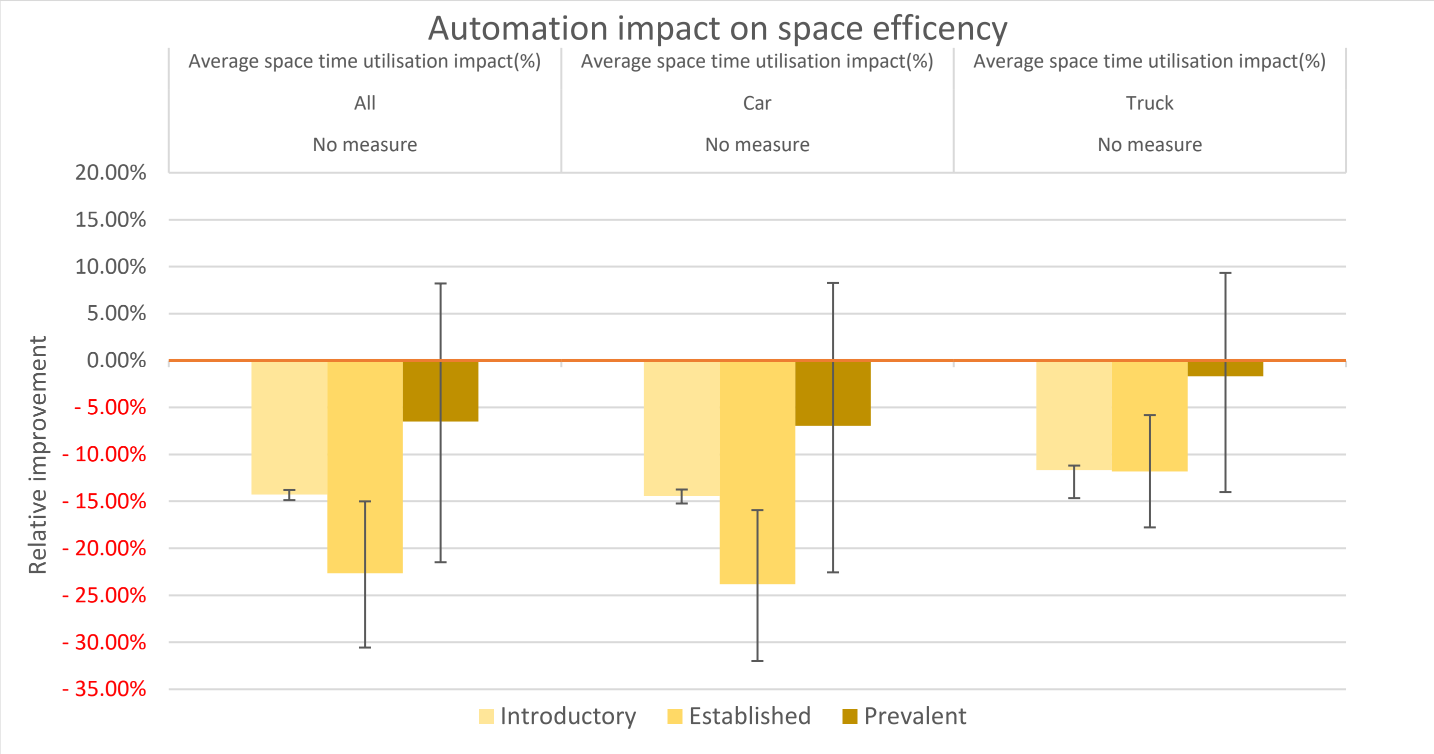

Figure 40 Space efficiency in terms of space time utilisation

Discussion, potential measure

An intended measure to implement in use case 3 was to allow for communication between the traffic signal controller and AVs. As this was not possible due to technical limitations in the signal control simulator no such results can be presented. However similar studies have been conducted in another H2020 European Project named Maven where impact assessment simulations were done with SUMO (opensource microscopic model). The results as stated in the publishable summary (Přibyl, 2019) are:

The impact assessment simulations of the integrated green wave system with speed and lane advice showed that stopping at main corridors was completely eliminated. The total network capacity was increased by 34%, average queue length decreased by 74% and CO2 emissions reduced by 11%. Looking at the integrated MAVEN system based on negotiation-driven adaptive traffic light control, a large reduction of 52% delay time for all traffic participants in the network was observed. The average queue length reduced by 46% and CO2 emissions by 12%. An interesting finding was that lane advice excelled in reducing queue length and delay but performed sub optimally in terms of stops and CO2 emissions. Deeper analysis pointed out that the traffic control algorithm has to be recalibrated for denser platoons to have a good synergy with this service. Lastly, the system based on actuated traffic control also showed good performance, but with 5% CO2 reduction this was slightly less than for green waves and adaptive control.

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5.2 Qualitative safety assessment

The upcoming sections show visual illustration of the identified relevant accident types for use case 3. A majority of the relevant accident types involves conflicts between vehicles. Secondary conflicts between vehicles and pedestrians and bikes may only happen in cases with red-light driving or jaywalking since turning vehicles and crossing pedestrians are separated in the signal control.

5.2.1 Accident type 1 – Driving accident

Accident types classified as type 1 are single-car accidents. As no conflict has occurred with other vehicles in this accident type the source of the accident might for example be due to the road condition, not being able to adapt the speed to current conditions, etc. For use case 3, driving accidents are probably mainly related to turning (Figure 12) or traffic islands (Figure 13).

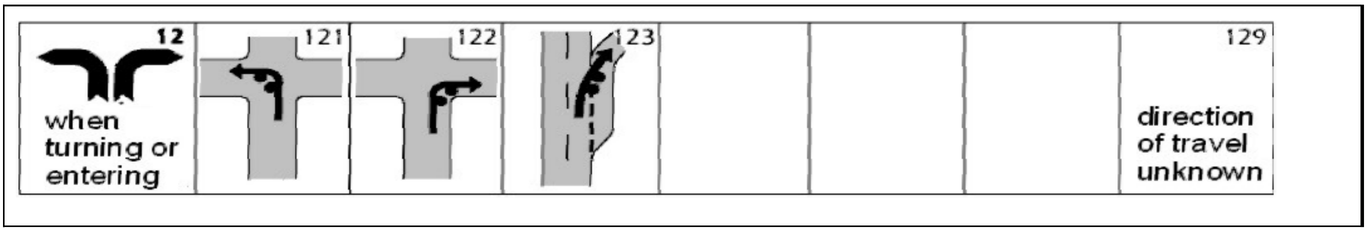

Figure 41 Accident type 12 turning in or off to another road

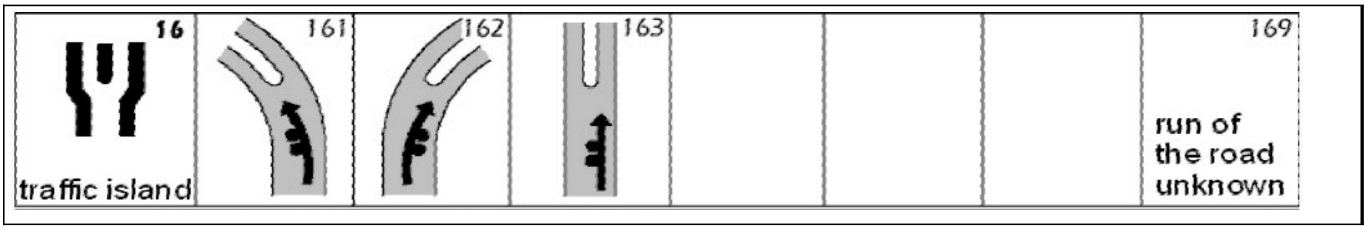

Figure 42 Accident type 16 driving accident on a traffic island

5.2.2 Accident type 2 – Turning off accident

Accident type 2 focuses mainly on conflicts that may occur when vehicles are turning off a road and interact with road users from the same or opposite direction. The listed accident types are mainly related to vehicle to vehicle interaction but also cyclist and pedestrians are considered. For the signalised intersection in use case 3 the most relevant types of accident are related to rear-end collisions (as in Figure 43). Secondary conflicts between turning vehicles and other vehicles, pedestrians or bicyclists may only appear if cases of red light driving or jaywalking, but consequences of such accident may be more severe due to higher speeds.

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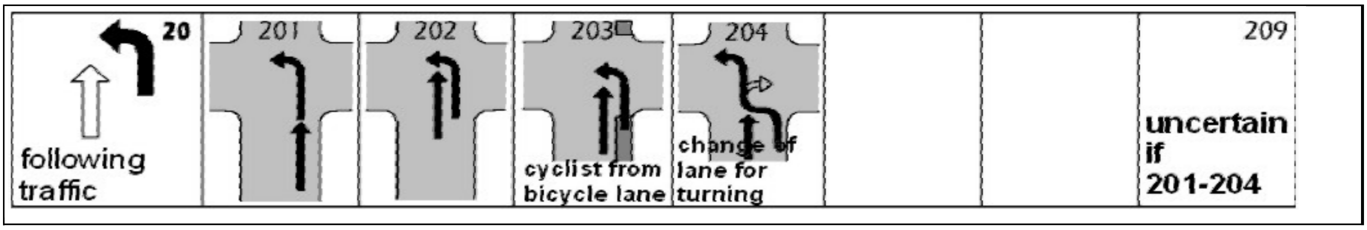

Figure 43 Accident type 20 conflict between a vehicle turning off to the left and following traffic

5.2.3 Accident type 3 – Turning in/crossing accident

Accident type 3 is mainly related to red light driving accidents since the use case consist of a signalised intersection and the accidents are related to collisions between a vehicle with priority and a vehicle without priority at intersections (as in Figure 44).

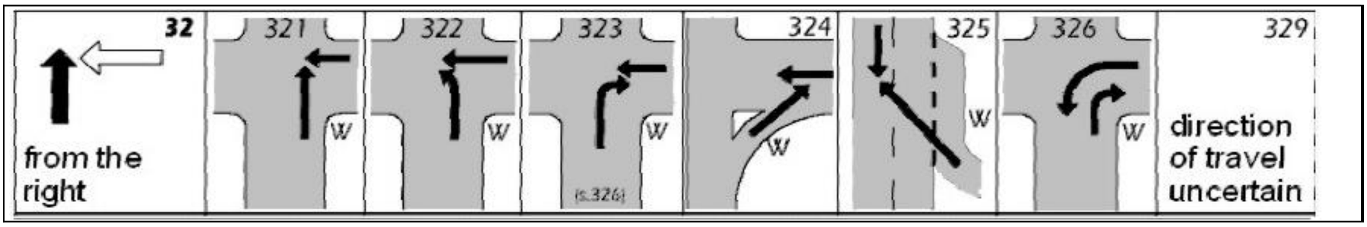

Figure 44 Accident type 32 conflict between a non priority vehicle and a priority vehicle coming from the right, which is not overtaking.

5.2.4 Accident type 4 – Pedestrian accident

Accident type 4 includes accidents between pedestrians and vehicles related to when pedestrians are crossing the road in one way or another. That is accidents that could potentially occur on the road and not by a vehicle intruding on a designated pedestrian area, such as sidewalks or strict walking areas. Since the intersection in use case 3 is signalised and secondary conflicts between turning vehicles and pedestrians are time separated such accident (as in Figure 45 and Figure 46) can only occur in cases with red light driving or if pedestrians are jay-walking.

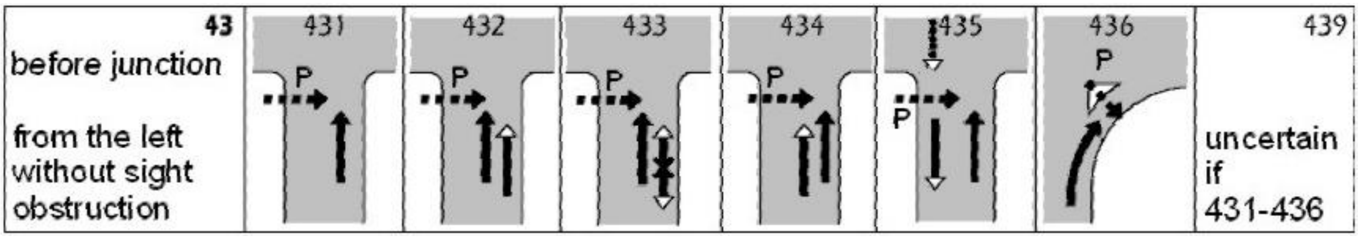

Figure 45 Accident type 43 conflict between a pedestrian coming from the left and a vehicle. Before a junction

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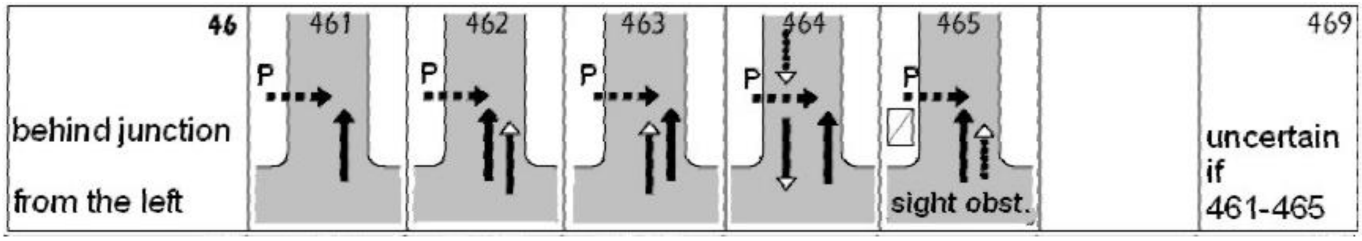

Figure 46 Accident type 46 conflict between a pedestrian coming from the left and a vehicle. Behind a junction

5.2.5 Accident type 5 – Accident with parking traffic

Use case 3 do not include any parked vehicles and this accident type is not relevant for this use case.

5.2.6 Accident type 6 – Accident with lateral traffic

Accident type 6 would mainly consider lateral conflict in vehicle to vehicle interaction. This could for example be rear-end collisions (as in Figure 46).

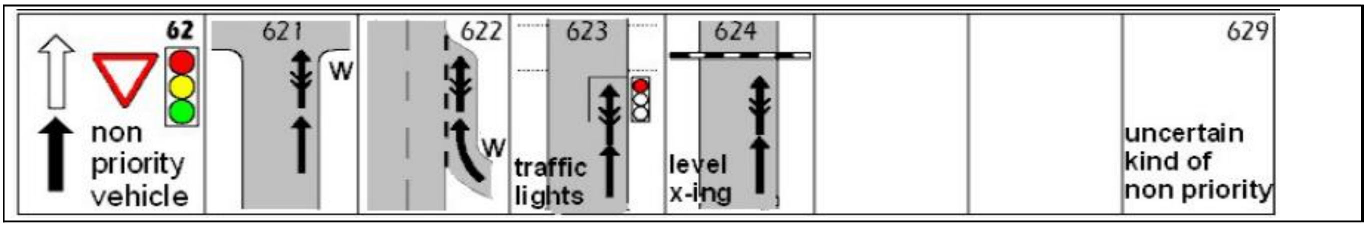

Figure 47 Accident type 62 conflict between a vehicle which is braking, standing or going slow due to traffic or non priority and a following vehicle.

5.2.7 Accident type 7 – Other accident types

Accident type 7 is the last category and covers the more unusual accident types e.g. accidents with animals, or accidents that would occur due to sleepiness, or dizziness, etc. In general accident type 7 covers accident types that cannot be assigned to any of the accident types 1-6. The only accident type in this category that might appear in use case 3 are related to u-turns (as in Figure 48). U-turns are not allowed but occur sometimes.

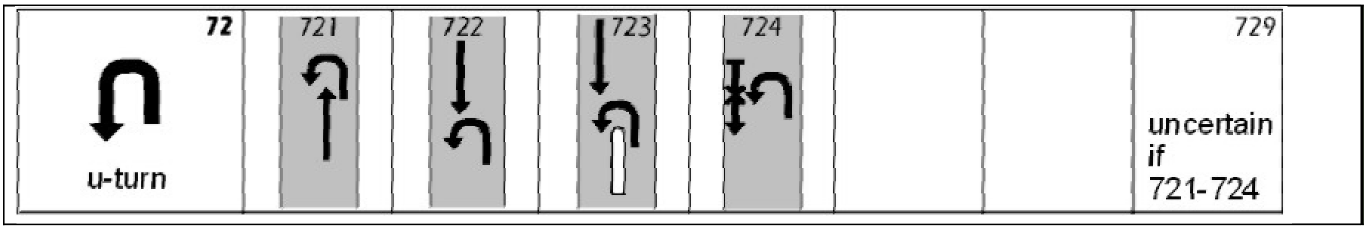

Figure 48 Accident type 72 accident due to a u-turn.

5.2.8 Results

A summary of the qualitative safety assessment for use case 3 is shown in Table 14. The interpretation of the pictograms are given in Table 1 in section 2.2.1. The only driving function considered is the arterial

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pilot since the use case mainly consists of a signalised intersection located along a multi-lane arterial and bicycle and pedestrian traffic are clearly separated from the vehicle traffic and vehicles, bicycles and pedestrians interact at intersections. For the accident types considered to be relevant for this use case the main very positive impact is expected for driving accidents (type 1) and accident in lateral traffic (type 6). There are also positive effects for pedestrian accidents (type 4) but these effects would only occur if red light driving or jaywalking exists and occur in such a way that such conflicts appear. In total 23 of the 68 accident types are considered relevant for this use case and the arterial pilot is expected to give positive or very positive impact in 15 of the 68 sub-accident types.

Table 14 Qualitative safety assessment for use case 3 – Signalised intersection with pedestrians and bicycles. The numbers show in how many sub-accident categories the driving function is estimated to imply negative, none, positive or very positive impacts on safety. Grey marked cells are accident categories that are considered irrelevant for the driving function in the use case.

	Type of accident	Arterial Pilot			
1	Driving accident				3
2	Turning off accident			3	1
3	Turning-in / Crossing accident		1	4	
4	Pedestrian accident				4
5	Accident with parking vehicles				
6	Accident in lateral traffic				6
7	Other accident type				1

5.3 Safety inspection-based assessment

This section presents the results of the safety inspection-based assessment considering the crash types and wrong manoeuvres relevant for use case 3. Six scenarios were considered based on automated vehicles penetration rates and mix of AV classes / driving logics. For each scenario, the crash frequency

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and severity was estimated and the risk calculated (see section 2.2.2 for an overview and Deliverable 3.3 for details on the methodology). Finally, the risk for the various scenarios was compared.

5.3.1 Existing scenario

A Road Safety Inspection (RSI) was carried out to assess the existing road safety conditions on the site for use case 3. The intersection assessed is located between the road N 270 and Hotsedijk near the city centre of Helmond, Netherlands.

A visit to the site (by a team of experts) was done in January 2020. It was cloudy and foggy during the site visit, with temperatures around 5°C.

To facilitate the collection of information during the inspection, the following tools were used:

- Nextbase 612GW camera with integrated GPS
- Application ASIA[2] (installed on a smartphone) to quickly note road safety problems and their location during inspections

The site was inspected and a report of those matters that may have an adverse effect on road safety was compiled. The inspection did not include any examination or verification of the compliance with any other standard or criteria.

At this intersection no crashes occurred in the last five years.

All of the issues highlighted in this report are considered by the safety inspection team to require action in order to improve the safety of the area and minimise collision occurrence. Each item identified in the inspection is outlined below, together with recommendations to mitigate the issue in question. Each item identified in the inspection is outlined below, together with recommendations to mitigate the issue in question.

Background information

Description of the intersection

The scope of this inspection covers the intersection between N 270 and Hotsedijk. This intersection is near the city centre of Helmond, in Netherlands (Figure 49). It is a signalised intersection with several separate phases that do not foresee any conflict point between the manoeuvres, including separate traffic light phases for pedestrians and cyclists. There are houses and commercial activities around the intersection.

[2] **ASIA** (Assistant for road Safety Inspections and Audits) is an application developed by FRED Engineering (www.fredeng.eu) for Android with the aim of maximizing the effectiveness of road safety audits and inspections

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Figure 49 Location of intersection in Helmond (source: elaboration on Google Earth)

Road traffic crash analysis

Even if the road traffic crash analysis does not show relevant results, it does not mean that the site is risk-free. 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. Thus, it is important to specify that the results of the road traffic crash analysis and the results of the road safety inspections are not directly correlated (EuroRAP, 2020), hence:

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

A crash is a rare event that occurs due to one or more interacting factors, but the risk of a crash due to road-related problems is always present. Therefore, the number of crashes that occurred on a section is a consequence not only of road characteristics, but also of traffic levels, road user behaviour and the characteristics of the vehicle fleet.

Traffic flow analysis

The available traffic flow data refer to the main road N270. Measurements were made in 2015 for both directions, not exactly at the intersection assessed, but two km earlier coming from Eindhoven. In both directions, two peak times were recorded: in the morning between 7:00 and 9:00 and in the evening between 17:00 and 18:00 (Figure 50 and Figure 51).

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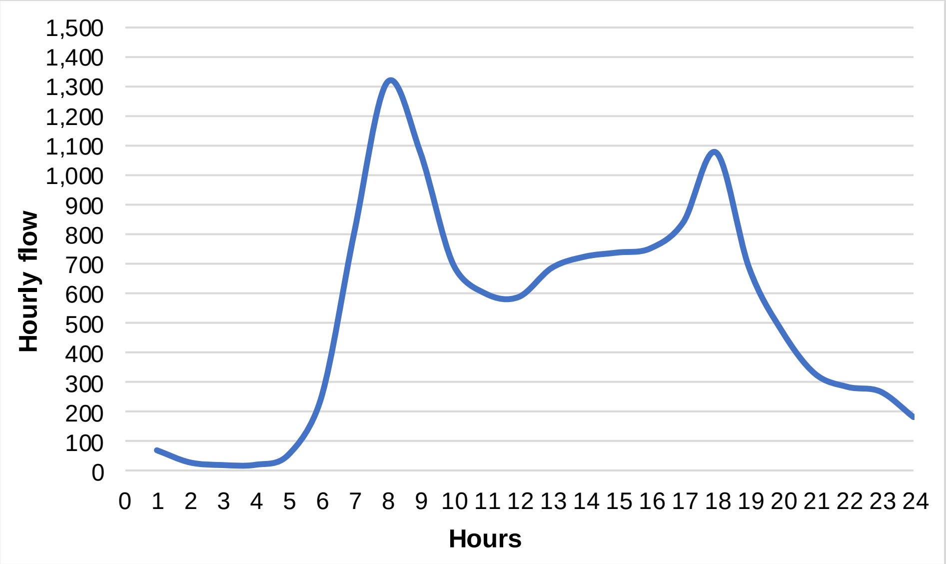

Figure 50 Hourly flow, direction Helmond-Eindhoven

From Helmond to Eindhoven the highest traffic flow is in the morning (between 7:00 and 8:00) with about 1,300 vehicles per hour, probably due to several commuters working in Eindhoven (Figure 50). But there is also a lower peak around 18:00., when the workday ends and some people come back to Eindhoven.

In fact, in the opposite direction (Eindhoven - Helmond) the inverse situation occurs: the highest traffic flow is around 18:00 due to commuters returning to Helmond after the workday and the lower peak is in the morning, around 8:00 (Figure 51).

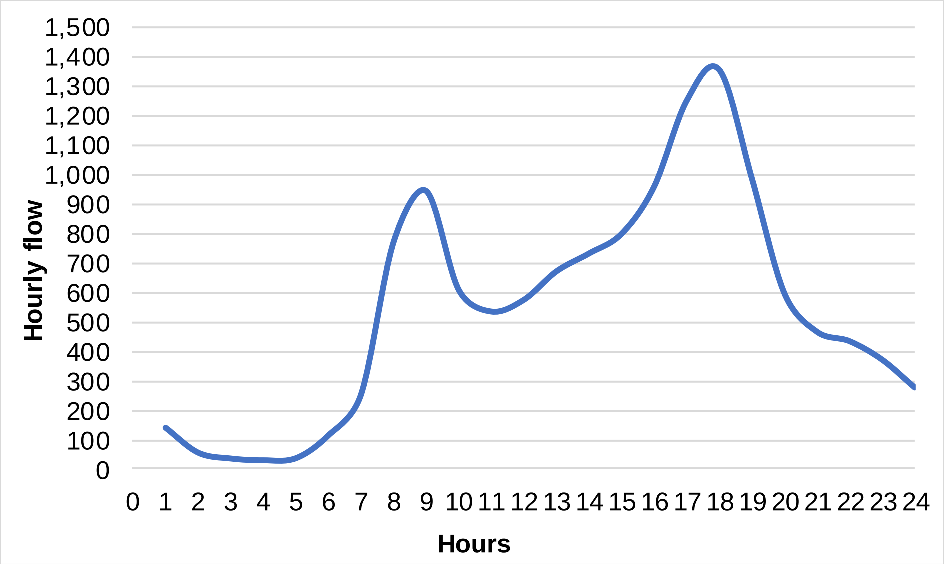

Figure 51 Hourly flow, direction Eindhoven-Helmond

The traffic light phases of the intersection ensure that that no queues occur along the different lanes.

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Road safety assessment

This section presents the results of the inspection.

In particular, it summarises the road safety problems identified, their location, the probable/typical accident (in the form of an icon) that they may cause, the recommendation to eliminate or mitigate them, and finally, a priority level or their possible implementation. In particular, the priority level is given according to a risk assessment.

All problems are identified with a code composed of a literal part, representing the category of problems and a numerical part, representing the sequential number.

Road signs

Along the roadside at the intersection there are access points that cause conflicts between vehicles and vulnerable users.

Details are shown in the following table.

No.	Location	Problem	Crash type	Recommendation	Risk
S.1	Hotsedijk (north direction)	**Accesses near the intersection** Near the intersection there are some private and commercial accesses that generate many conflicts between drivers entering and exiting these accesses and the flow of vehicles coming from or going to the intersection.		It is recommended to increase the signage warning of the presence of accesses.	0.12

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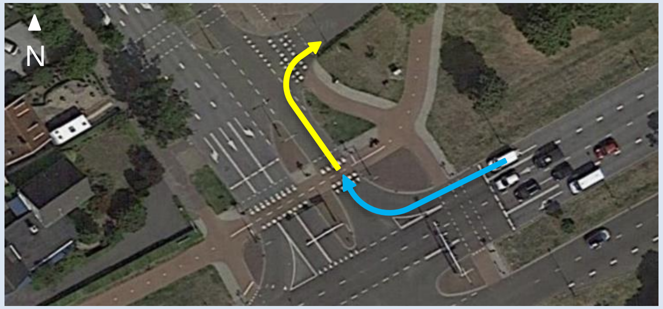
		There is the risk of rear-end collisions between vehicles turning right from the N 270 towards Hotsedijk (in light blue in the picture) and those who slow down to enter the side access (yellow arrow). 			
S.2	Hotsedijk (north direction)	**Lateral access near the intersection** Near the intersection there are some private and commercial accesses that generate many conflicts between drivers entering and exiting these accesses and the flow of vehicles coming from or going to the intersection. This also generates dangerous manoeuvres such as the one in red in the picture below: leaving the access and turning left towards the intersection, it is possible to choose the lane for the right turn towards the N 270 in the west direction. To carry out this manoeuvre, it is necessary to cross all the lanes of Hotsedijk with the risk of lateral crashes.		It is recommended to prohibit left-hand turns from the Hotsedijk towards the lateral access and to improve the signage warning of the presence of possible vehicles coming from the left.	0.12

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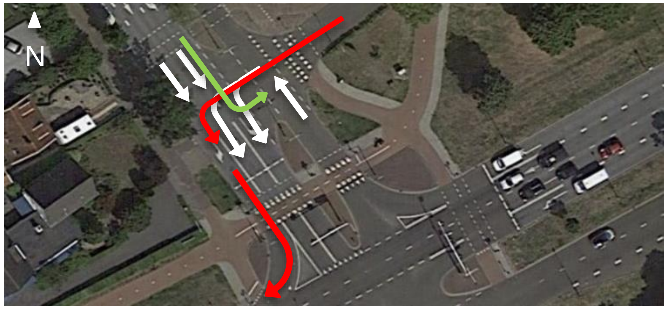
		The same risk occurs for vehicles making the manoeuvre in green to enter the access.  			
S.3	Hotsedijk (north direction)	**Lateral access** Near the intersection there are some private and commercial accesses that generate many conflicts between drivers entering and exiting these accesses and the flow of vehicles coming from or going to the intersection. There is the risk that a vehicle, that is performing the manoeuvre represented by the red arrow, brakes suddenly in the middle of the road due to an oncoming vehicle in orthogonal direction. A driver (yellow arrow), trying to avoid the vehicle, could have a collision with pedestrian/cyclist on the right side.	 	It is recommended to place some coloured and raised strips between the road and the priority markings on the access of the minor road. The raised strips will induce drivers to stay behind them and to pay attention when crossing them. 	0.24

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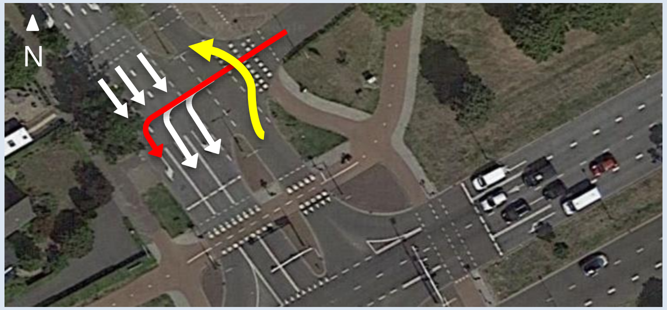
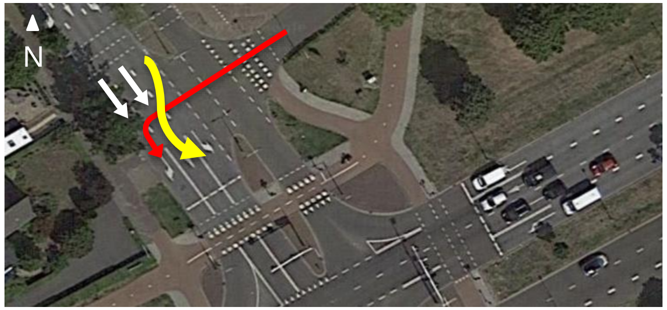
					
S.4	Hotsedijk (north direction)	**Lateral access near the intersection** A vehicle leaving the lateral access and turning left towards the intersection (red arrow) could brake suddenly in the middle of the lanes due to an oncoming vehicle in the orthogonal direction and a driver, trying to overtake it, could have a lateral collision with another vehicle (yellow arrow). 		It is recommended to Extend the width of lane markings from the point where the turn lane starts and to place some rumble strips or similar noisy surface on the lane delimitation markings that can help driver not to cross them. 	0.12

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Alignment

The intersection is well organized, with differentiated accumulation lanes for each direction.

The main problems that could occur are those arising from lane change that could produce conflict points with the flows already present on the other lanes.

In addition, often sudden manoeuvres occur due to the user's lack of attention.

Details are shown in the following table.

No.	Location	Problem	Crash type	Recommendation	Risk
A.1	N 270 (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).	 	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.  It is also recommended to Extend the width of lane markings from the point where the turn lane starts and to place some rumble strips or similar noisy	0.21

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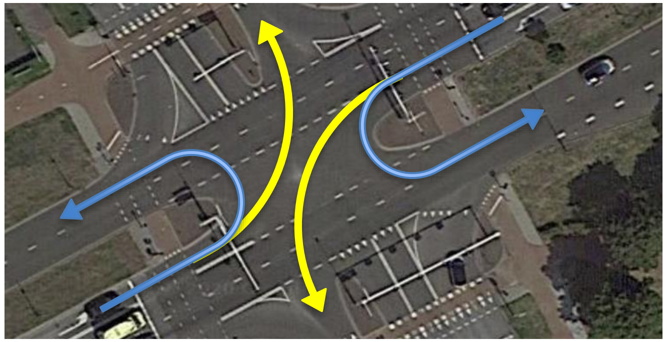
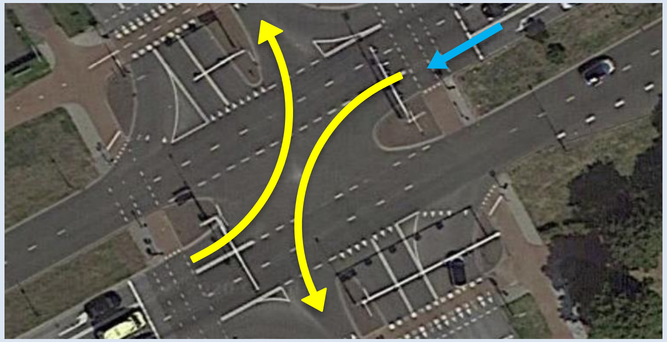
		This can lead to abrupt braking by drivers approaching the junction or risky lane change manoeuvres causing a rear-end or lateral collision. 		surface on the lane delimitation markings that can help driver not to cross them. 	
A.2	N 270 (both directions)	**U-turn manoeuvres** Some drivers have been found U-turning on the N 270. However, it is not clear whether these manoeuvres are allowed and whether the traffic light phases take this possibility into account because there are no signs to avoid them. This, however, leads to potential conflicts with vehicles having to make simultaneous left-hand turns. If a vehicle that is turning left overtakes one that is making a U-turn, it could invade the space of the vehicle that is turning from the opposite direction (yellow manoeuvres in the picture).		It is recommended to create a raised wide turn lane marking. This can help also drivers to follow the right trajectory. 	0.24

		This manoeuvre could cause head-on crashes, especially if the vehicle involved are trucks that take up a lot of space. 		Alternatively, it is recommended to install signs that prohibit U-turn manoeuvres on both directions. 	
A.3	N 270 (both directions)	**Turn left manoeuvre** A vehicle, during left turning manoeuvre, could brake suddenly due to an oncoming vehicle in the opposite direction that may have invaded its lane. This could lead to rear-end collision. 		It is recommended to create a raised wide turn lane marking. This can help also drivers to follow the right trajectory.  Alternatively, it is recommended to separate the traffic light phase to reduce the conflicts.	0.12

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Vulnerable users

Many cyclists and pedestrians cross this intersection, who, since they are vulnerable users, should interact safely with each other with the vehicles. Details are shown in the following table.

No.	Location	Problem	Crash type	Recommendation	Risk
VU.1	Sidewalk/cycle lane-lateral access	**Conflicts between cyclists, pedestrians and vehicles** The lateral accesses generate conflict points not only with vehicles on the driveway, but also with the cycle lane and sidewalk, with particular reference to the access located north-east of the intersection. A vehicle entering the road from the lateral access has the view obstructed by several obstacles on the side flowerbed and could cross the cycle lane and the sidewalk without seeing cyclists or pedestrians arriving and running over them. 	 	It is recommended to remove all obstacles that reduce the visibility and to raise the pedestrian and bicycle paths at the crossing of the lateral access.	0.24

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VU.2	Pedestrian crossings	**Short duration of the green light phase for pedestrians** The green phase of pedestrians has a very short duration (only 8 seconds for 13 m of pedestrian crossing). Elderly people or mobility impaired people may not be able to cross the whole carriageway in time. Even if a pedestrian crosses the road at a normal walking speed, there is the risk of still being on the road when the red light comes on.		It is recommended to extend the duration of the green light phase for pedestrians to at least 13 seconds (considering a walking speed of 1 m/s) to allow them to reach the opposite sidewalk before the red light comes on.	0.40

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Road Safety Inspection summary

It is important to highlight that the risk value themself obtained from the risk formulation is of minor importance here, and it is the comparison of the final risk scores obtained for the current situation and the scenarios with automated vehicles of the same use case that is of main interest in the assessment.

Ref.	Items resulting from Inspection	Recommendations	Risk value
S.1	Accesses near the intersection	Improvement of the signage	0.12
S.2	Lateral access near the intersection	Improvement of the signage	0.12
S.3	Lateral access	Improvement of the signage	0.24
S.4	Lateral access near the intersection	Improvement of the signage	0.12
A.1	Dangerous sudden lane change manoeuvres	Improvement of the signage	0.21
A.2	U-turn manoeuvres	Improvement of the signage or installation of signs that prohibit U-turn manoeuvres	0.24
A.3	Turn left manoeuvre	Improvement of the signage or phase-shifting traffic lights	0.12
V.1	Conflict points between cyclists, pedestrians and vehicles	Removal of the obstacles	0.24
V.2	Short duration of the green light phase for pedestrians	Extending the duration of the green light phase for pedestrians	0.40
TOTAL RISK			1.81

5.3.2 Future scenarios

The future scenarios assessed in terms of road safety (and compared with the existing situation) are reported in Table 15. Six scenarios with different penetration rates of Automated Vehicles (with different driving logics: Cautious / Normal / All-knowing) were assessed.

The risk of road traffic crashes has been assessed for all the scenarios according to the methodology described in Deliverable 3.3.

The problems identified for the future scenarios are classified according to three types:

- A = a problem existing in the current scenario for conventional vehicles will still be a problem also for automated vehicles in the future scenario.
- B = a problem existing in the current scenario for conventional vehicles will no more be a problem for automated vehicles in the future scenario.
- C = a problem is not existing in the current scenario for conventional vehicles but will appear in the future scenario due to presence of automated vehicles.

Table 15 Use case 3 – Scenarios assessed

Scenario	CV	AV	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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Scenario 1

This scenario is composed by a majority of conventional vehicles (75% of the total) and by a mix of Cautious (20%) and Normal (5%) automated vehicles. Table 16 describes the road safety issues that could arise due to the presence of automated vehicles (both considering those caused by acting and re-acting behaviours of AVs). These issues will be the same for all scenarios, what will change is the driving logic of automated vehicles and their behaviour related to each problem.
Table 17 provides the risk values estimated for each road safety issue.

Table 16 Use case 3 – Scenario 1 – Road safety issues related with Automated Vehicles (Cautious and Normal)

No.	PROBLEM			CAUTIOUS AV		NORMAL AV	
	Type	Description	Crash type	Acting behaviour	Re-acting behaviour	Acting behaviour	Re-acting behaviour
S.1	A	**Accesses near the intersection**		Cautious AVs could have abrupt braking, so that rear-end still is a possibility	Rear-end by a Cautious AV is likely not possible	Normal AVs could have abrupt braking, so that rear-end still is a possibility (less frequent than Cautious AVs)	Rear-end by a Normal AV is likely not possible
S.2	A	**Lateral access near the intersection**		Cautious AVs could brake suddenly in the middle of the road due to the presence of vehicles in the orthogonal direction, so that lateral collisions could happen	Lateral collision by a Cautious AV is likely not possible	Normal AVs could brake suddenly in the middle of the road due to the presence of vehicles in the orthogonal direction, so that lateral collisions could happen (less frequent than Cautious AVs)	Lateral collision by a Normal AV is likely not possible
S.3	B	**Lateral access**	 	Dangerous manoeuvres by a Cautious AV is likely not possible	Not applicable	Dangerous manoeuvres by a Normal AV is likely not possible	Not applicable

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No.	PROBLEM			CAUTIOUS AV		NORMAL AV	
	Type	Description	Crash type	Acting behaviour	Re-acting behaviour	Acting behaviour	Re-acting behaviour
S.4	A	**Lateral access near the intersection**		Dangerous manoeuvres by a Cautious AV is likely not possible	The problem still exists due to that CVs that could hit AVs	Dangerous manoeuvres by a Normal AV is likely not possible	The problem still exists from CVs that could hit AVs
A.1	A	**Dangerous sudden lane change manoeuvres**	 	Cautious AVs never make sudden lane changes	The problem still exists due to that CVs that could hit AVs	Normal AVs never make sudden lane changes	The problem still exists due to that CVs that could hit AVs
A.2	A	**U-turn manoeuvres**		Cautious AVs never make dangerous manoeuvres	The problem still exists due to that CVs that could hit AVs	Normal AVs never make dangerous manoeuvres	The problem still exists due to that CVs that could hit AVs
A.3	A	**Turn left manoeuvre**		Cautious AVs could have abrupt braking, so that rear-end is a possibility	Rear-end by a Cautious AV is likely not possible	Normal AVs could have abrupt braking, so that rear-end is a possibility (less frequent than Cautious AVs)	Rear-end by a Normal AV is likely not possible
AR.1	C	**Turn left manoeuvre**		Cautious AVs never make dangerous overtaking manoeuvres	The problem still exists due to that CVs that could hit AVs	Normal AVs never make dangerous overtaking manoeuvres	The problem still exists due to that CVs that could hit AVs
VU.1	B	**Conflicts between cyclists, pedestrians and vehicles**	 	Cautious AVs never hit pedestrian/cyclist	Not applicable	Normal AVs never hit pedestrians/cyclists	Not applicable

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No.	PROBLEM			CAUTIOUS AV		NORMAL AV	
	Type	Description	Crash type	Acting behaviour	Re-acting behaviour	Acting behaviour	Re-acting behaviour
VU.2	B	**Short duration of the green light phase for pedestrians**		Cautious AVs never hit pedestrian	Not applicable	Normal AVs never hit pedestrians	Not applicable

Table 17 Use case 3 – Scenario 1 – Risk scores related with Automated Vehicles

No.	CONVENTIONAL VEHICLES				CAUTIOUS AVs				NORMAL AVs				Total
	%	F	S	R	%	F	S	R	%	F	S	R	R
S.1	75	0.4	0.3	0.12	20	0.7	0.3	0.21	5	0.4	0.3	0.12	**0.14**
S.2	75	0.4	0.3	0.12	20	0.7	0.3	0.21	5	0.4	0.3	0.12	**0.14**
S.3	75	0.4	0.6	0.24	20	-	-	-	5	-	-	-	**0.18**
S.4	75	0.4	0.3	0.12	20	0.1	0.3	0.03	5	0.1	0.3	0.03	**0.10**
A.1	75	0.7	0.3	0.21	20	0.4	0.3	0.12	5	0.4	0.3	0.12	**0.19**
A.2	75	0.4	0.6	0.24	20	0.1	0.6	0.06	5	0.1	0.6	0.06	**0.20**
A.3	75	0.4	0.3	0.12	20	0.7	0.3	0.21	5	0.4	0.3	0.12	**0.14**
AR.1	75	0.4	0.6	0.24	20	0.4	0.6	0.24	5	0.1	0.6	0.06	**0.23**
VU.1	75	0.4	0.6	0.24	20	-	-	-	5	-	-	-	**0.18**
VU.2	75	0.4	1.0	0.40	20	-	-	-	5	-	-	-	**0.30**
TOTAL RISK													**1.79**

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Scenario 2

This scenario is composed by a majority of conventional vehicles (75% of the total) and by a mix of Cautious (5%) and Normal (20%) automated vehicles. Table 16 describes the road safety issues that could arise due to the presence of automated vehicles (both considering those caused by acting and re-acting behaviours of AVs). Compared to scenario 1, only the penetration rates of AVs changes. Since this scenario still includes Cautious and Normal AVs, the road safety issues identified for scenario 1 are still valid. The risk values change due to differences in the conventional and automated vehicles penetration rates between the scenarios. Table 18 provides the risk values estimated for each road safety issue.

Table 18 Use case 3 – Scenario 2 – Risk scores related with Automated Vehicles

No.	CONVENTIONAL VEHICLES				CAUTIOUS AVs				NORMAL AVs				Total
	%	F	S	R	%	F	S	R	%	F	S	R	R
S.1	75	0.4	0.3	0.12	5	0.7	0.3	0.21	20	0.4	0.3	0.12	**0.12**
S.2	75	0.4	0.3	0.12	5	0.7	0.3	0.21	20	0.4	0.3	0.12	**0.12**
S.3	75	0.4	0.6	0.24	5	-	-	-	20	-	-	-	**0.18**
S.4	75	0.4	0.3	0.12	5	0.1	0.3	0.03	20	0.1	0.3	0.03	**0.10**
A.1	75	0.7	0.3	0.21	5	0.4	0.3	0.12	20	0.4	0.3	0.12	**0.19**
A.2	75	0.4	0.6	0.24	5	0.1	0.6	0.06	20	0.1	0.6	0.06	**0.20**
A.3	75	0.4	0.3	0.12	5	0.7	0.3	0.21	20	0.4	0.3	0.12	**0.12**
AR.1	75	0.4	0.6	0.24	5	0.4	0.6	0.24	20	0.1	0.6	0.06	**0.20**
VU.1	75	0.4	0.6	0.24	5	-	-	-	20	-	-	-	**0.18**
VU.2	75	0.4	1.0	0.40	5	-	-	-	20	-	-	-	**0.30**
TOTAL RISK													**1.72**

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Scenario 3

This scenario is composed by equal share of conventional vehicles and automated vehicles. In this case, 20% of the AVs (10% of all vehicle) use a Cautious driving logic, while 80% of the AVs (40% of all vehicles) use a Normal driving logic. Table 16 describes the road safety issues that could arise due to the presence of automated vehicles (both considering those caused by acting and re-acting behaviours of AVs). Compared to scenario 1, only the penetration rates of AVs changes. Since this scenario still includes Cautious and Normal AVs, the road safety issues identified for scenario 1 are still valid. The risk values change due to differences in the conventional and automated vehicles penetration rates between the scenarios. Table 19 provides the risk values estimated for each road safety issue.

Table 19 Use case 3 – Scenario 3 – Risk scores related with Automated Vehicles

No.	CONVENTIONAL VEHICLES				CAUTIOUS AVs				NORMAL AVs				Total
	%	F	S	R	%	F	S	R	%	F	S	R	R
S.1	50	0.4	0.3	0.12	10	0.7	0.3	0.21	40	0.4	0.3	0.12	**0.13**
S.2	50	0.4	0.3	0.12	10	0.7	0.3	0.21	40	0.4	0.3	0.12	**0.13**
S.3	50	0.4	0.6	0.24	10	-	-	-	40	-	-	-	**0.12**
S.4	50	0.4	0.3	0.12	10	0.1	0.3	0.03	40	0.1	0.3	0.03	**0.08**
A.1	50	0.7	0.3	0.21	10	0.4	0.3	0.12	40	0.4	0.3	0.12	**0.17**
A.2	50	0.4	0.6	0.24	10	0.1	0.6	0.06	40	0.1	0.6	0.06	**0.15**
A.3	50	0.4	0.3	0.12	10	0.7	0.3	0.21	40	0.4	0.3	0.12	**0.13**
AR.1	50	0.4	0.6	0.24	10	0.4	0.6	0.24	40	0.1	0.6	0.06	**0.17**
VU.1	50	0.4	0.6	0.24	10	-	-	-	40	-	-	-	**0.12**
VU.2	50	0.4	1.0	0.40	10	-	-	-	40	-	-	-	**0.20**
TOTAL RISK													**1.39**

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Scenario 4

This scenario is composed by half conventional vehicles and half automated vehicles. In this case, 25% of AVs use a Normal driving logic, whose behaviours are already described in the Table 16, while 25% of AVs use an All-knowing driving logic, whose behaviours are reported in the Table 20 that describes the road safety issues that could arise due to the presence of this type of automated vehicles (both considering those caused by acting and re-acting behaviours of AVs). Compared to previous scenarios, only risks related to the All-knowing driving logic change. Table 21 provides the risk values estimated for each road safety issue.

Table 20 Use case 3 – Scenario 4 – Road safety issues related with Automated Vehicles (All-knowing)

No.	PROBLEM			ALL-KNOWING AV	
	Type	Description	Crash type	Acting behaviour	Re-acting behaviour
S.1	A	**Accesses near the intersection**		All-knowing AVs could have abrupt braking, so that rear-end still is a possibility (less than Normal AVs)	Rear-end by an All-knowing AV is likely not possible
S.2	A	**Lateral access near the intersection**		All-knowing AVs could predict the arrival of other vehicles in the orthogonal direction, so its movement is more fluent, without too much sudden braking. However, lateral collisions could happen (less than other AVs)	Lateral collision by an All-knowing AV is likely not possible
S.3	B	**Lateral access**	 	Dangerous manoeuvres by an All-knowing AV is likely not possible	Not applicable
S.4	A	**Lateral access near the intersection**		All-knowing AV could suddenly change lane and hit another vehicle	The problem still exists also due to that CVs that could hit AVs
A.1	A	**Dangerous sudden lane change manoeuvres**	 	All-knowing AV could suddenly change lane and hit another vehicle	The problem still exists also due to that CVs that could hit AVs

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No.	PROBLEM			ALL-KNOWING AV	
	Type	Description	Crash type	Acting behaviour	Re-acting behaviour
A.2	A	**U-turn manoeuvres**		All-knowing AVs never make dangerous overtaking manoeuvres	The problem still exists due to that CVs that could hit AVs
A.3	A	**Turn left manoeuvre**		All-knowing AVs could have abrupt braking, so that rear-end is a possibility (less than Normal AVs)	Rear-end by an All-knowing AV is likely not possible
AR.1	C	**Turn left manoeuvre**		All-knowing AVs never make dangerous overtaking manoeuvres	The problem still exists due to that CVs that could hit AVs
VU.1	B	**Conflicts between cyclists, pedestrians and vehicles**	 	All-knowing AVs never hit pedestrian/cyclist	Not applicable
VU.2	B	**Short duration of the green light phase for pedestrians**		All-knowing AVs never hit pedestrian/cyclist	Not applicable

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Table 21 Use case 3 – Scenario 4 – Risk scores related with Automated Vehicles

No.	CONVENTIONAL VEHICLES				NORMAL AVs				ALL-KNOWING AVs				Total
	%	F	S	R	%	F	S	R	%	F	S	R	R
S.1	50	0.4	0.3	0.12	25	0.4	0.3	0.12	25	0.1	0.3	0.03	**0.10**
S.2	50	0.4	0.3	0.12	25	0.4	0.3	0.12	25	0.1	0.3	0.03	**0.10**
S.3	50	0.4	0.6	0.24	25	-	-	-	25	-	-	-	**0.12**
S.4	50	0.4	0.3	0.12	25	0.1	0.3	0.03	25	0.4	0.3	0.12	**0.10**
A.1	50	0.7	0.3	0.21	25	0.4	0.3	0.12	25	0.4	0.3	0.12	**0.17**
A.2	50	0.4	0.6	0.24	25	0.1	0.6	0.06	25	0.1	0.6	0.06	**0.15**
A.3	50	0.4	0.3	0.12	25	0.4	0.3	0.12	25	0.1	0.3	0.03	**0.10**
AR.1	50	0.4	0.6	0.24	25	0.1	0.6	0.06	25	0.1	0.6	0.06	**0.15**
VU.1	50	0.4	0.6	0.24	25	-	-	-	25	-	-	-	**0.12**
VU.2	50	0.4	1.0	0.40	25	-	-	-	25	-	-	-	**0.20**
TOTAL RISK													**1.30**

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Scenario 5

This scenario is composed by a majority of automated vehicles (75% of the total), composed by a mix of Normal (37.5% of all vehicles) and All-knowing (37.5% of all vehicles) driving logics. Table 20 describes the road safety issues that could arise due to the presence of automated vehicles (both considering those caused by acting and re-acting behaviours of AVs). Compared to scenario 4, only the penetration rates and the mix of AVs changes. Since this scenario still includes Normal and All-knowing AVs, the road safety issues identified for scenario 4 are still valid. The risk values change due to differences in the conventional and automated vehicles penetration rates between the scenarios. Table 22 provides the risk values estimated for each road safety issue.

Table 22 Use case 3 – Scenario 5 – Risk scores related with Automated Vehicles

No.	CONVENTIONAL VEHICLES				NORMAL AVs				ALL-KNOWING AVs				Total
	%	F	S	R	%	F	S	R	%	F	S	R	R
S.1	25	0.4	0.3	0.12	37.5	0.4	0.3	0.12	37.5	0.1	0.3	0.03	**0.09**
S.2	25	0.4	0.3	0.12	37.5	0.4	0.3	0.12	37.5	0.1	0.3	0.03	**0.09**
S.3	25	0.4	0.6	0.24	37.5	-	-	-	37.5	-	-	-	**0.06**
S.4	25	0.4	0.3	0.12	37.5	0.1	0.3	0.03	37.5	0.4	0.3	0.12	**0.09**
A.1	25	0.7	0.3	0.21	37.5	0.4	0.3	0.12	37.5	0.4	0.3	0.12	**0.14**
A.2	25	0.4	0.6	0.24	37.5	0.1	0.6	0.06	37.5	0.1	0.6	0.06	**0.11**
A.3	25	0.4	0.3	0.12	37.5	0.4	0.3	0.12	37.5	0.1	0.3	0.03	**0.09**
AR.1	25	0.4	0.6	0.24	37.5	0.1	0.6	0.06	37.5	0.1	0.6	0.06	**0.11**
VU.1	25	0.4	0.6	0.24	37.5	-	-	-	37.5	-	-	-	**0.06**
VU.2	25	0.4	1.0	0.40	37.5	-	-	-	37.5	-	-	-	**0.10**
TOTAL RISK													**0.92**

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Scenario 6

This scenario is composed by a majority of All-knowing automated vehicles (75% of the total). Table 20 describes the road safety issues that could arise due to the presence of automated vehicles (both considering those caused by acting and re-acting behaviours of AVs).Table 23 provides the risk values estimated for each road safety issue.

Table 23 Use case 3 – Scenario 6 – Risk scores related with Automated Vehicles

No.	CONVENTIONAL VEHICLES				ALL-KNOWING AVs				Total
	%	F	S	R	%	F	S	R	R
S.1	25	0.4	0.3	0.12	37.5	0.1	0.3	0.03	**0.05**
S.2	25	0.4	0.3	0.12	37.5	0.1	0.3	0.03	**0.05**
S.3	25	0.4	0.6	0.24	37.5	-	-	-	**0.06**
S.4	25	0.4	0.3	0.12	37.5	0.4	0.3	0.12	**0.12**
A.1	25	0.7	0.3	0.21	37.5	0.4	0.3	0.12	**0.14**
A.2	25	0.4	0.6	0.24	37.5	0.1	0.6	0.06	**0.11**
A.3	25	0.4	0.3	0.12	37.5	0.1	0.3	0.03	**0.05**
AR.1	25	0.4	0.6	0.24	37.5	0.1	0.6	0.06	**0.11**
VU.1	25	0.4	0.6	0.24	37.5	-	-	-	**0.06**
VU.2	25	0.4	1.0	0.40	37.5	-	-	-	**0.10**
TOTAL RISK									**0.85**

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Recommendations

For each problem identified in the scenarios with different mixes of conventional and automated vehicles, recommendations are provided in the Table 24.

Table 24 Use Case 3 - Recommendations related to each problem

No.	PROBLEM			Recommendation
	Type	Description	Crash type	
S.1	A	**Accesses near the intersection**		Increase the signage warning of the presence of accesses.
S.2	A	**Lateral access near the intersection**		Place some coloured and raised strips between the main road and the waiting area at the traffic divider. The strips will create a “space” that help the AV to better understand if the crossing vehicle is far enough and have to stop/yield or is already crossing. The raised bar will induce drivers to stay behind it.
S.3	B	**Lateral access**	 	Not applicable
S.4	A	**Lateral access near the intersection**		Extend the width of lane markings from the point where the turn lane starts. A wider line gives more time to the AV 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 rumble strips or similar noisy surface on the lane delimitation markings can help driver to keep central trajectory.
A.1	A	**Dangerous sudden lane change manoeuvres**	 	Extend the width of lane markings from the point where the turn lane starts. A wider line gives more time to the AV 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 rumble strips or similar noisy surface on the lane delimitation markings can help driver to keep central trajectory.

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A.2	A	**U-turn manoeuvres**		It is recommended to give more time to the AVs to react and understand what happens by create a raised and wider turn lane marking. This can help also drivers to follow the right trajectory. Alternatively, it is recommended to separate the traffic light phase for the U-turn to reduce the conflicts.
A.3	A	**Turn left manoeuvre**		It is recommended to give more time to the AVs to react and understand what happens by creating a raised and wider turn lane marking. This can help also drivers to follow the right trajectory. Alternatively, it is recommended to separate the traffic light phase to reduce the conflicts.
AR.1	C	**Turn left manoeuvre**		It is recommended to give more time to the AVs to react and understand what happens by creating a raised and wider turn lane marking. This can help also drivers to follow the right trajectory. Alternatively, it is recommended to separate the traffic light phase to reduce the conflicts.
VU.1	B	**Conflicts between cyclists, pedestrians and vehicles**	 	Not applicable
VU.2	B	**Short duration of the green light phase for pedestrians**		Not applicable

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5.3.3 Comparisons and road safety conclusions

Table 25 shows the risk scores calculated for the current scenario (without AVs) and for the six scenarios with AVs, as well as the percentage change from current to future scenarios. The same information is also graphically shown in Figure 52.

Table 25 Use case 3 – Scenarios assessed

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%

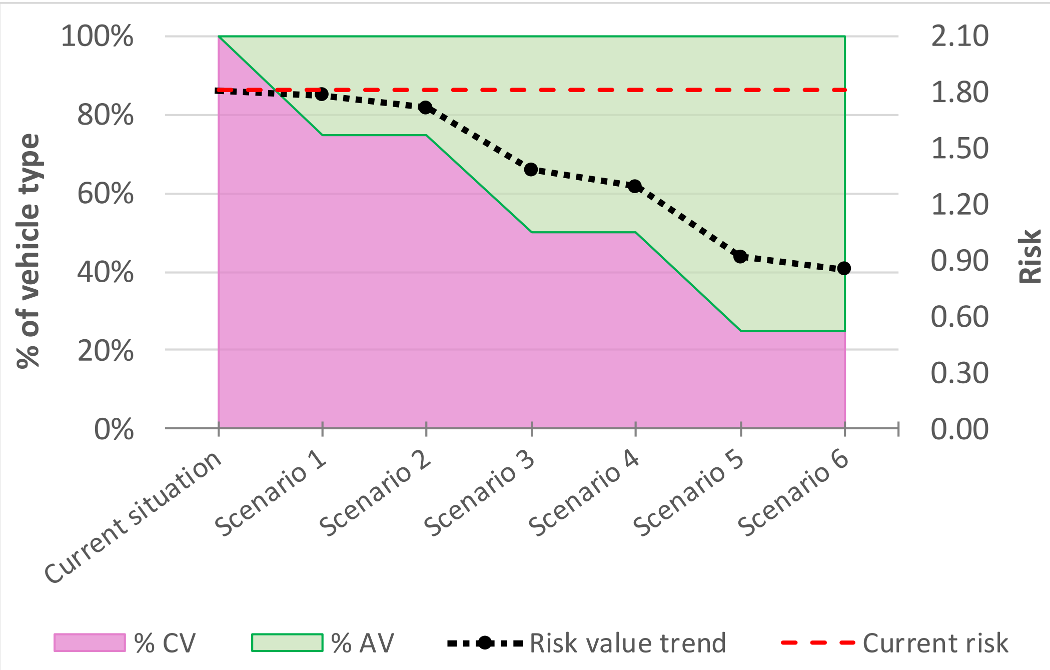

Figure 52 Use case 3 - Risk evolution based on AVs scenarios

All the AV scenarios indicate a potential reduction of road traffic crash risk, but that the risk is not eliminated. The higher benefits are obtained by increasing the presence of automated vehicles in the mixed environment. For instance, scenarios 1 and 2 (where 25% of AVs are present) is estimated to reduce the risk to a maximum of 5%., compared to the current situation (with no AVs). On the contrary, the other scenarios (with 50% or 75% of AVs) lead to higher risk reductions (from minimum 23% to maximum 53% less compared to current situation).

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This was expectable, due to the fact that AVs are expected to make less (or no) “driving errors”, compared to human drivers. Most of the risk is due to “re-acting” situations, where the automated vehicle could have a crash due to a traffic condition caused by a conventional vehicle.

The first three scenarios are defined as a mix of Cautious and Normal automated vehicles that tend to adopt a more “conservative” behaviour. However, driving around the intersection, they can “get in the way” of conventional vehicles. In particular, Cautious vehicles move in an unfriendly way from a human driver perspective due to many potential conflicts that arise at an intersection, making frequent sudden brakes.

Scenarios 5 and 6, where 75% of AVs are present, lead to similar risks. Scenario 5 is a mix of Normal and All-knowing AVs, while in scenario 6 there are only All-knowing AVs.

This is due to the fact that, despite the more aggressive behaviour of All-knowing vehicles, they do not have much freedom of movement at the intersection and they are also able to predict or avoid dangerous behaviour of other vehicles.

5.4 Conclusions

Simulations for this the use case shows that once automated cars and trucks are introduced and allowed in a signalized intersection such as the one in Helmond, the traffic performance in terms of travel times and delays will get worse for conventional cars and trucks. Automated vehicles will fully comply with speed limit regulations and thereby experience increase in travel times compared to the baseline without automated vehicles. Furthermore, the Basic and intermediate AVs require larger gaps between vehicles which decrease saturation flow which increase travel time and delay for all vehicles and also pedestrians and bikes due to that the adaptive signal controller redistribute green times to counteract the decreased saturation flow. However, as technology progresses and the capabilities of AVs becomes more advanced, keeping smaller distances to other vehicles, the delays decrease for AVs in the Prevalent stage. Furthermore, at the Prevalent stage with more advanced AVs the saturation flow increase, which decrease the green time need for vehicles. This imply that the adaptive signal controller redistributes green time from vehicles to pedestrians and bikes. Resulting in lower travel times and delays for both pedestrians and bikes, but only in the Prevalent stage.

From a space efficiency perspective, the simulations show that the introduction of automated vehicles imply an increased space claim and space-time footprint compared to the baseline without any automated vehicles. Although the space time footprint of conventional vehicles will decrease marginally over the three stages and an improvement for trucks can be seen in the Prevalent stage, the results indicate that due to the AVs requiring larger gaps between vehicles and complying with speed limit regulations there will be a higher usage of the available space time in the study area. There are potential space efficiency gains to harvest from advanced AVs, however this requires a high penetration rate and advanced and potentially more advanced technologies such as communication between infrastructure and AVs.

Different automated driving functions can help reducing the risk and consequences of accidents. The qualitative safety assessment show that positive or very positive effects might be expected for 15 of the 68 different accident types. For the accident types considered to be relevant for this use case the main very positive impact is expected for driving accidents (type 1) and accident in lateral traffic (type 6).

There are also positive effects for pedestrian accidents (type 4) but these effects would only occur if red light driving or jaywalking exists and occur in such a way that such conflicts appear. The safety inspection-based assessment also indicates a potential reduction of road traffic crash risk and that the benefits increase with increased penetration rate of automated vehicles in the mixed environment. A large part of the risk reduction is due to that AVs are expected to make less (or no) “driving errors”, compared to human drivers. Most of the remaining risk is due to “re-acting” situations, where the automated vehicle could be involved in a crash due to a traffic condition caused by a conventional vehicle. The more conservative driving logics (e.g. Cautious) may lead to more frequent sudden brakes which might cause problems from a human driver perspective. Design recommendations from a safety perspective focus to a large extent on to find ways to give more time to the AVs to react and understand what happens, e.g. by wider, raised or rumbled lane markings or coloured and raised strips at waiting areas in the intersection.

6 Traffic impact of automation in use case 4: Transition from interurban highway to arterial

Use case 4 focuses on the evaluation of the impact of automated vehicles on the transition road section from the interurban highway between Eindhoven and Helmond to the arterial that enters Helmond. The speed variation among AVs is expected to be lower than for conventional vehicles which could provide a more reliable travel time and less delays for the total traffic.

The road environment studied in this use case, A270/N270/Europaweg, is the main connection between Eindhoven and Helmond and is used by about 35,000 vehicles daily. The road has different speed limits and several signalized intersections, as depicted in Figure 53. The transport user classes operating on this road stretch are conventional cars and trucks, but also pedestrians and bicycles can be observed crossing at the intersections.

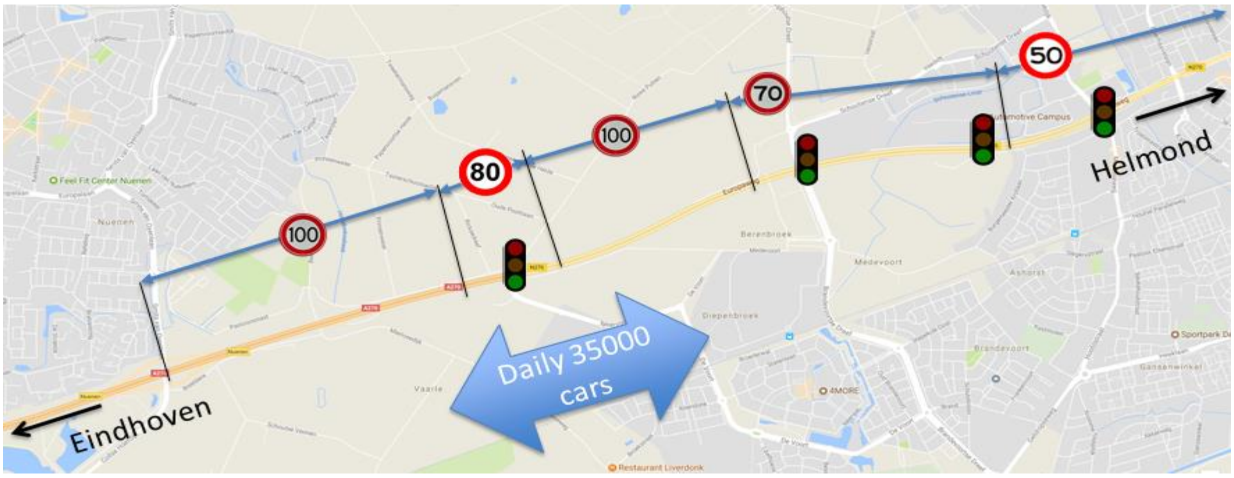

Figure 53 The use case 4 track with several traffic lights and speed limits

6.1 Traffic performance and space efficiency

6.1.1 Parameter settings in the assessment tool

By using the traffic performance and space efficiency assessment tool for microscopic models, the simulation results from use case 4 have been analysed in accordance with the approach described in D3.3. All present conventional transport user classes are considered in the assessment. In addition, car and truck, which is car (CV) + car (AV) and truck (CV) + truck (AV), are also included to see how the car and truck fleet as a whole is impacted by the introduction of automated vehicles.

Both performance and space efficiency metrices are used in the assessment of the traffic impact of automation, and since the city of Helmond has no thresholds defined regarding the relative improvement of these metrics the threshold in the tool is set to 0. The different metrics used in the automation impact assessment are:

- Average travel time

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- Average delay
- Average space claim
- Average space time footprint
- Space time utilisation

To further investigate the potential impact of automated vehicles two measures are implemented and assessed as well. Measure 1 – platooning, consist of adding functionality to the AVs, allowing them to form platoons when possible on any lane and section of the main road. The platooning feature is limited to platooning between the same transport user classes operating under the same driving logic.

Measure 2 – platooning on the rightmost lane, also involves the feature of allowing AVs to form platoons but limiting them spatially to the rightmost lane, leaving conventional traffic and non-platooning AVs to utilise the left lane.

6.1.2 Results and discussions

Impact on traffic performance, No measure

Figure 54 depicts the relative improvement of the average travel time and delay over the three stages of coexistence, with no measure applied. Looking at the conventional transport user classes, both car (CV) and truck (CV), there is a negative impact, although small, in terms of average travel time. This negative impact, which is less than -5% in the Introductory stage, decreases over the stages of coexistence to a point where CVs, in the Prevalent stage, can expect to experience similar travel times as today. The same trend can be observed for delays, where the introduction of automated vehicles has a negative impact, starting at approximately -10% in the Introductory stage, but eventually reaching levels similar to today in the Prevalent stage. Delays of conventional cars and trucks seem to follow the trend of travel time with negative impact in the earlier stages of coexistence and improvements as the capabilities of the AVs increases, as shown in Figure 54.

What is somewhat unexpected is the slight increase of delay and travel time that is experienced in the Established stage by conventional trucks. The reason for this might be that some experiments in the Introductory and Established stage utilises the same AV mix. The AV mix referred to is: (20% Basic AVs, and 80% Normal AVs), and when only increasing the penetration rate from 25% to 50% conventional trucks are affected even more negatively due to the increase of AVs operating under a simpler driving logic.

Looking at the impact of automation when taking the entire car and truck fleet into consideration shows, as expected, that there might be an increase in travel time when introducing automated vehicles as well as an increase in delay. However, when the Prevalent stage is reached the travel time would still be larger than in the baseline but at the same time there is a significant improvement of the delay, ~10% for cars and ~7% for trucks. Observations in other use cases in CoEXist shows that this is most likely is an effect of the full speed limit compliance of the AVs, as CVs tend to drive faster than the speed limit lowering their travel time but also making them more likely to experience delay and the delay they experience is larger due to a larger difference between the actual travel time and the desired one (according to the desired speed).

It is interesting that the travel time and delay for CVs gets better when the penetration rate of AVs increase. One possible explanation is that AVs stay more in the rightmost lane since the AVs will

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conduct fewer overtakings since they will catch up with fewer slower vehicles than the conventional vehicles. Hence, there might be a spontaneous lane separation between CVs and AVs, similar as sometimes can be observed between cars and trucks.

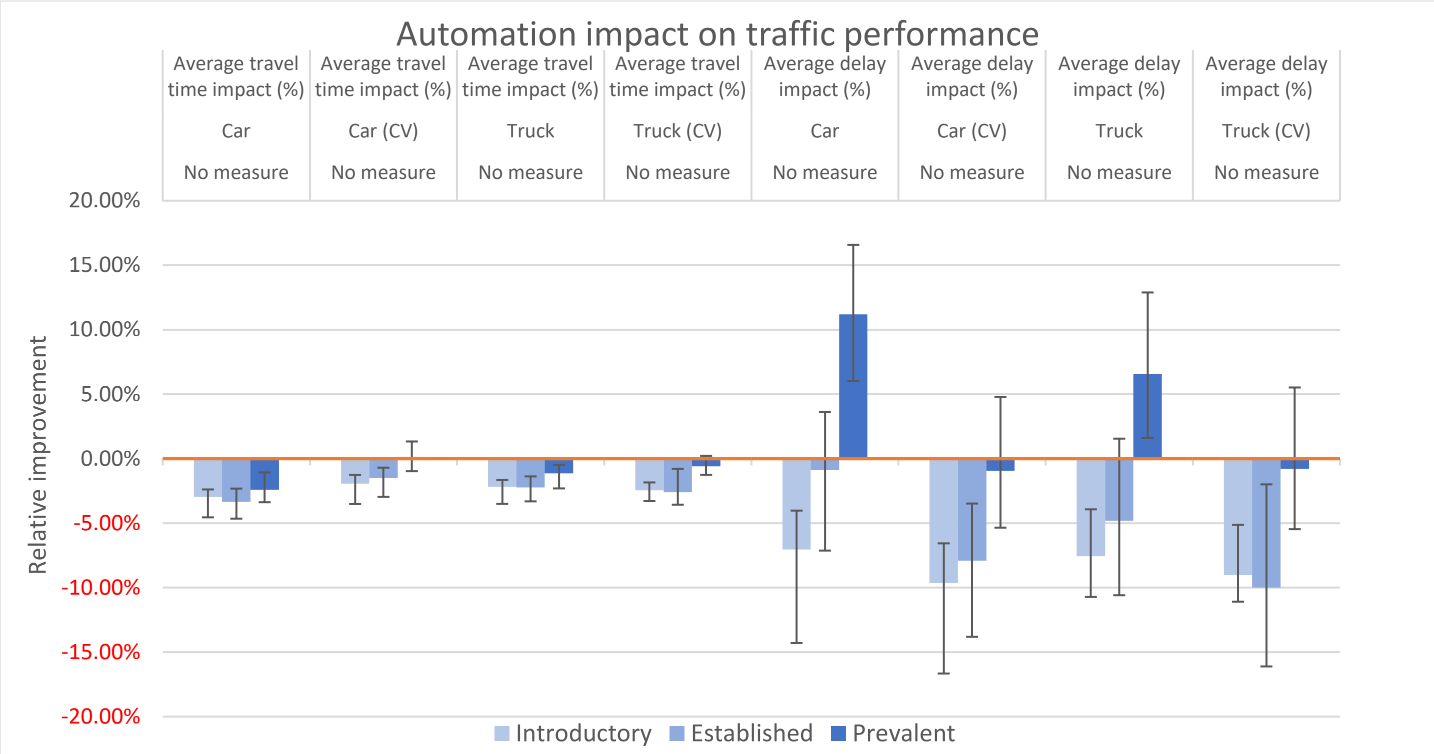

Figure 54 Automation impact in terms of average travel time and delay, no measure

Impact on traffic performance, Measure: platooning

Figure 55 and Figure 56 show the traffic performance impact of automation for use case 4 with measure 1 and 2, respectively. By introducing the possibility for AVs to form platoons, the negative effects seen from an introduction of AVs are somewhat mitigated. In contrast to the case where no measure is applied there is a trend forming where both travel time and delays continuosly improve over the three stages of coexistence for all transport user classes. In addition the difference in the impact of automation between the two measures are minor.

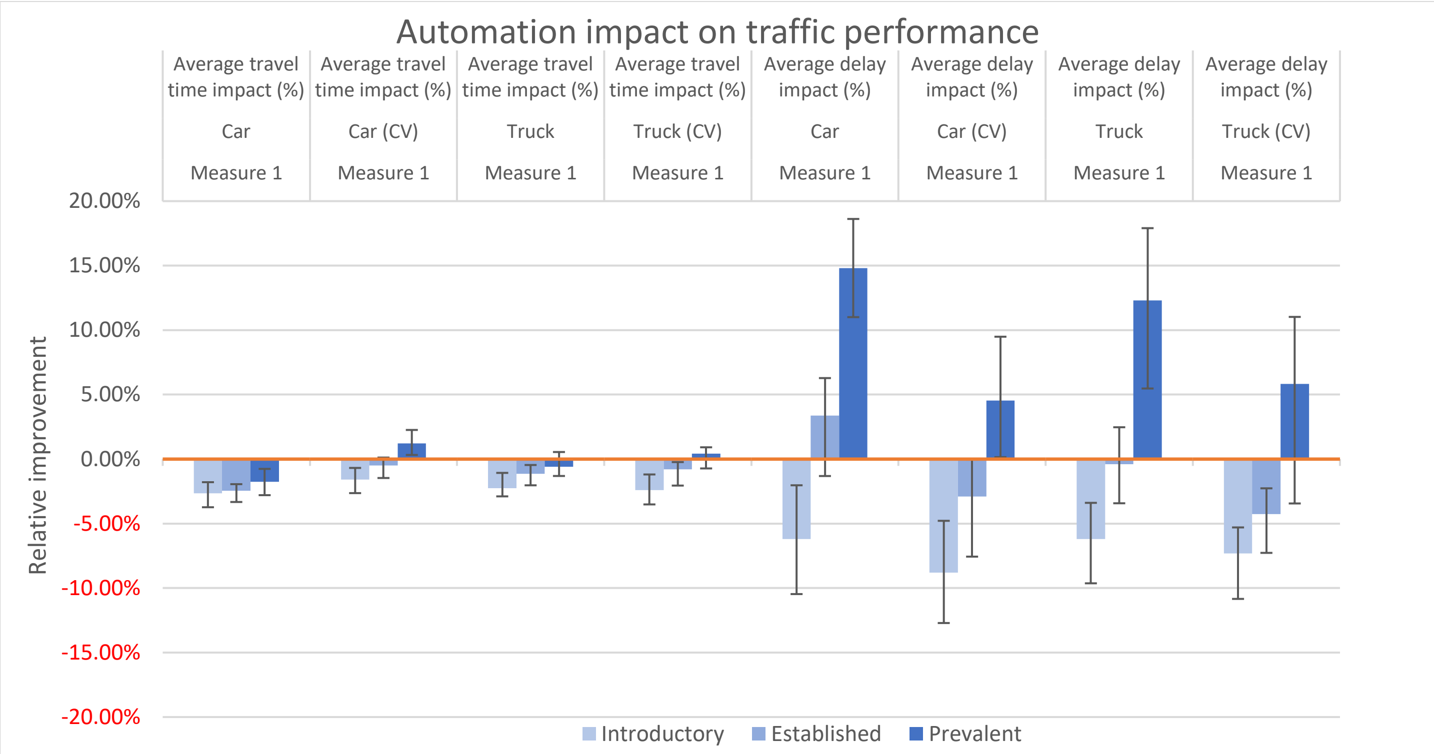

Figure 55 Automation impact in terms of average travel time and average delay, measure 1 – platooning

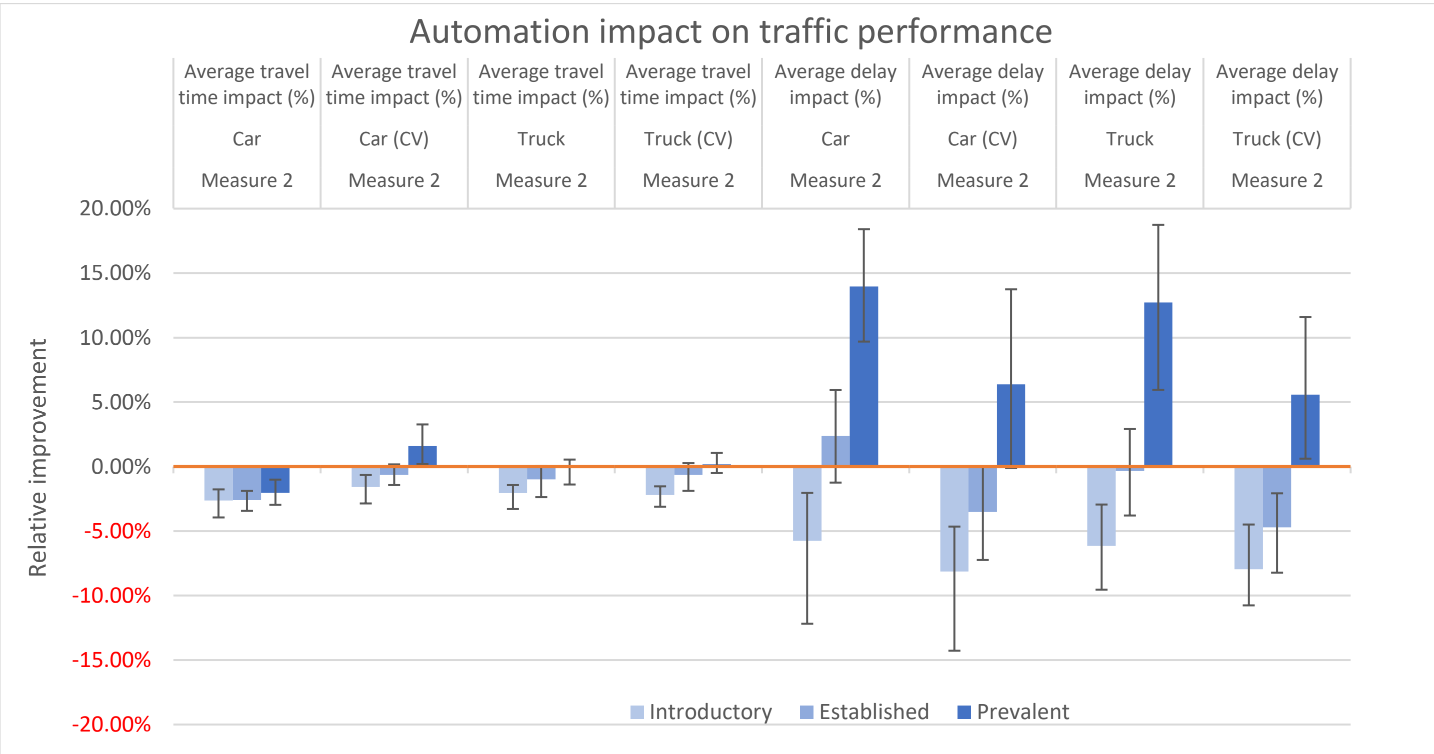

Figure 56 Automation impact in terms of average travel time and average delay, measure 2 - platooning in right lane

Figure 57 shows the automation impact in terms of travel time and delay for pedestrians and bicycles. In the case where no measure is implemented there is a small impact over the three stages of coexistence.

However, when allowing AVs to form platoons we can see that a small gain in terms of travel time and delay is achieved already in the Established stage, and increases significantly in the Prevalent stage, see Figure 57 (travel time) and Figure 58 (delay). Once the Prevalent stage is reached the simulations show that both pedestrians and bicyclists can experience an improvement of approximately 6-8% with respect to travel times and approximately 10-12% with respect to delays. The positive traffic performance effects for active modes are to a large part due to that the adaptive traffic signal distributes more green time to active modes when the traffic efficiency for motorized traffic increases and lowering the green need for the motorized vehicles. The results indicate that the introduction of AVs could have beneficial effects on the traffic performance of pedestrians and cyclist potentially allowing new traffic light strategies to be adopted.

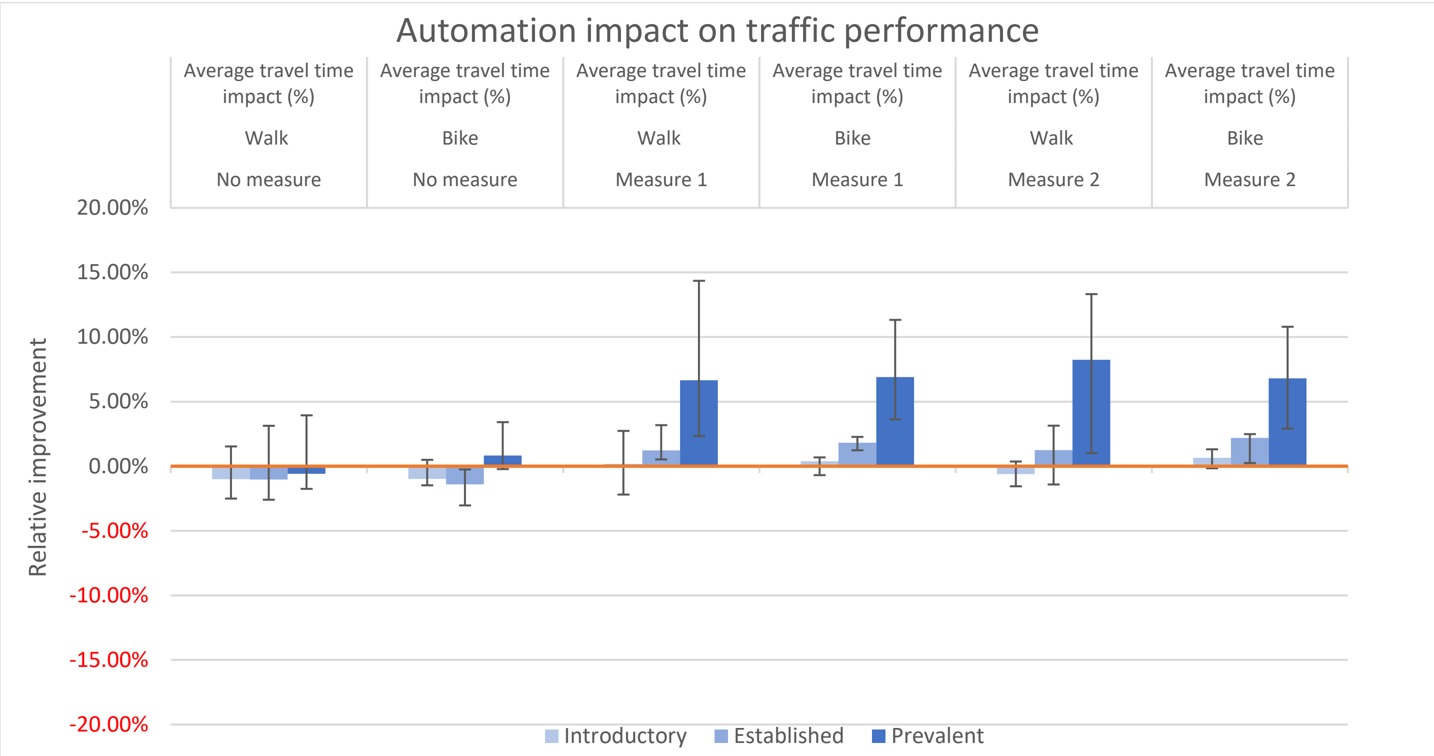

Figure 57 Automation impact in terms of average travel time, all measures

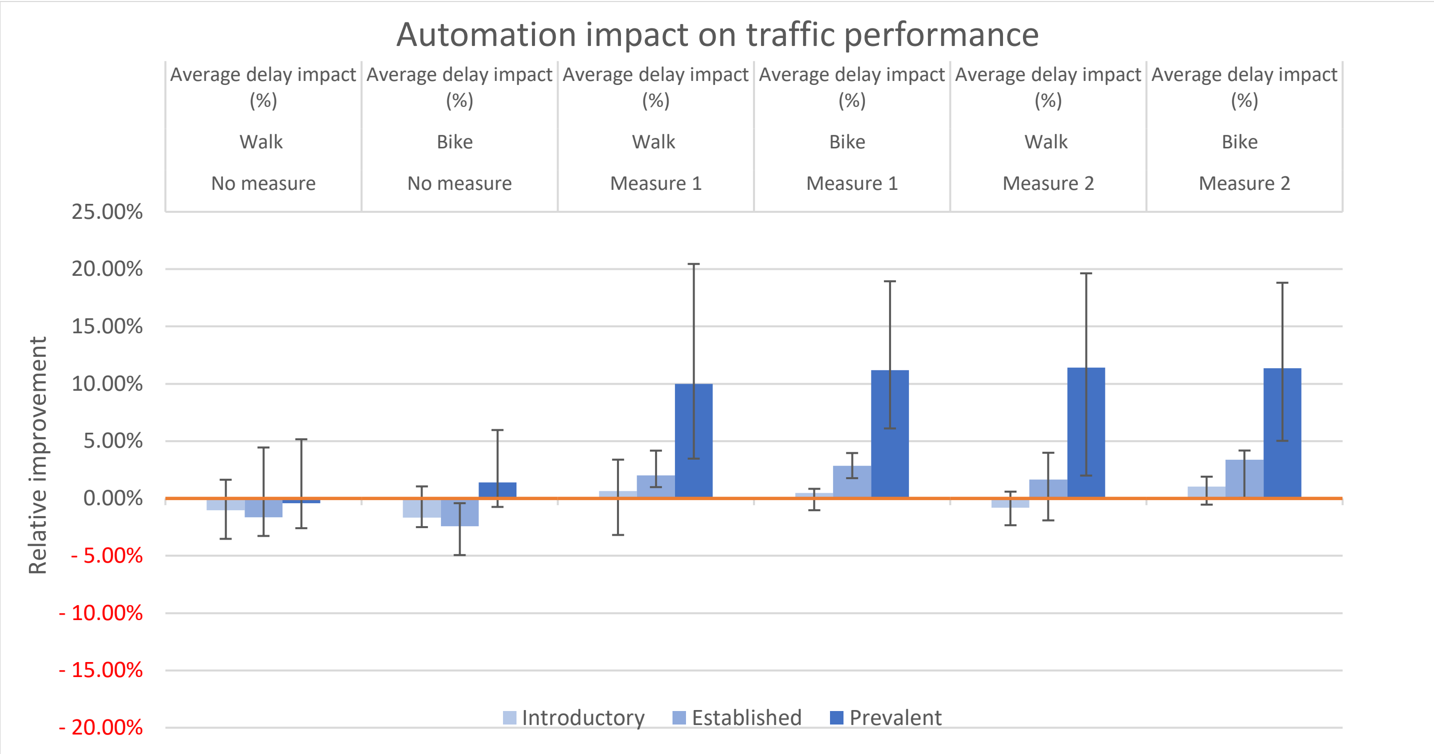

Figure 58 Automation impact in terms of average delay, all measures

Impact on space efficiency

Since the measures implemented in use case 4 ought to have a direct impact on the different space efficiency metrics defined within coexist these are depicted together with the baseline where no measure has been applied, as seen in Figure 59. The results show that automation will initially, in the Introductory an Established stage, have a negative impact on the entire car fleet. Largely due to the large gaps that are required by AVs operating under a Cautious driving logic. Reaching the Prevalent stage where technology is assumed to be significantly improved the impact is positive with less space claimed by the car fleet. Adding the possibility of platooning shows a clear improvement compared to the case with automated vehicles without platooning. Measure 1 with platooning in any lane of the highway shows to be most efficient with respect to space claim.

Figure 60 depicts the average space claim of trucks and trucks (CV) over the different stages of coexistence and for the different measures. The space claim of trucks follows the same trend as cars due to the same reasons. However, the observed improvement is lower for trucks than for cars.

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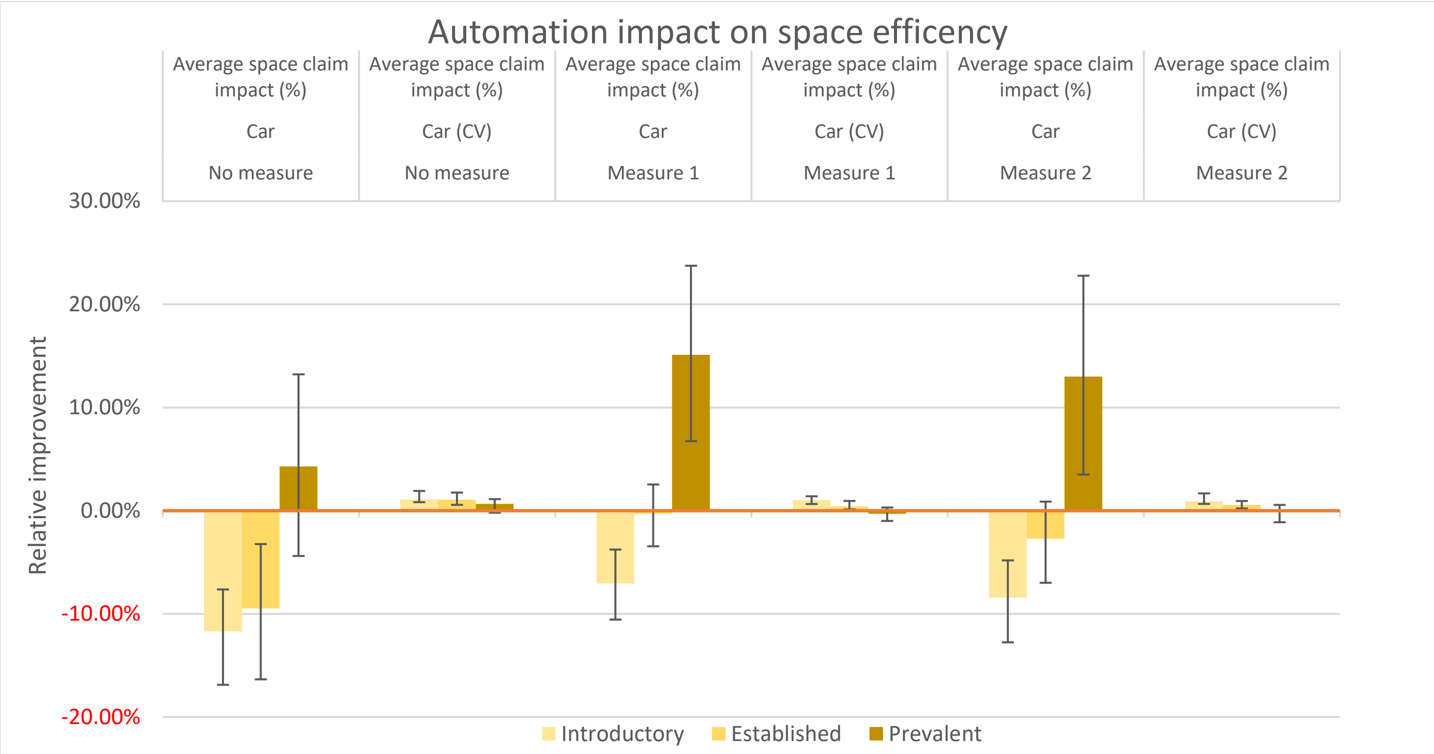

Figure 59 Space claim of car and car (CV)

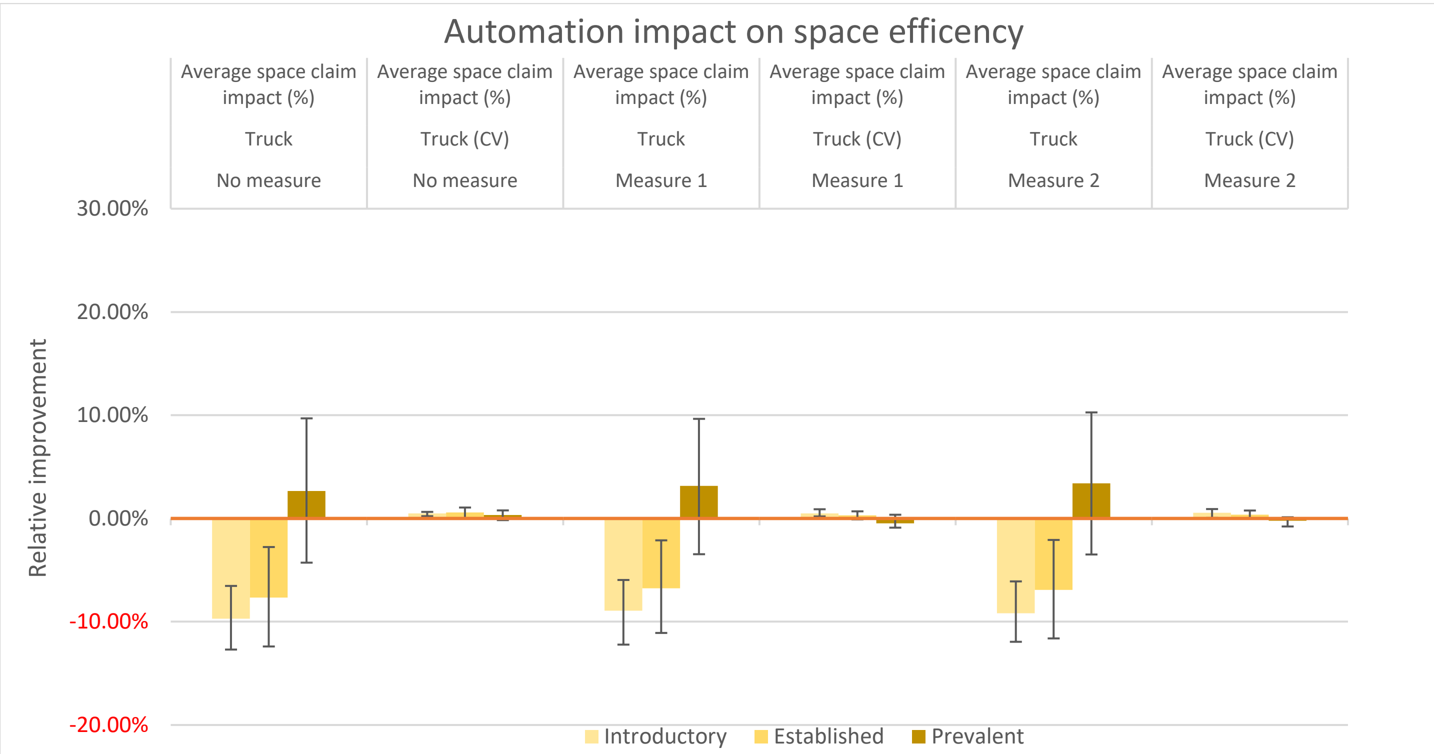

Figure 60 Space claim of truck and truck (CV)

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As the average space claim could in some cases be misleading since it does not include the time dimension, also the space time footprint is presented. The average space time footprint accounts for the time spent in the network of each vehicle as well. Figure 61 and Figure 62 shows the average space time footprint over the different stages and measures. The results follow the same trend as the average space claim confirming the initial indication of that the platooning measures imply a better utilization of the space-time capacity.

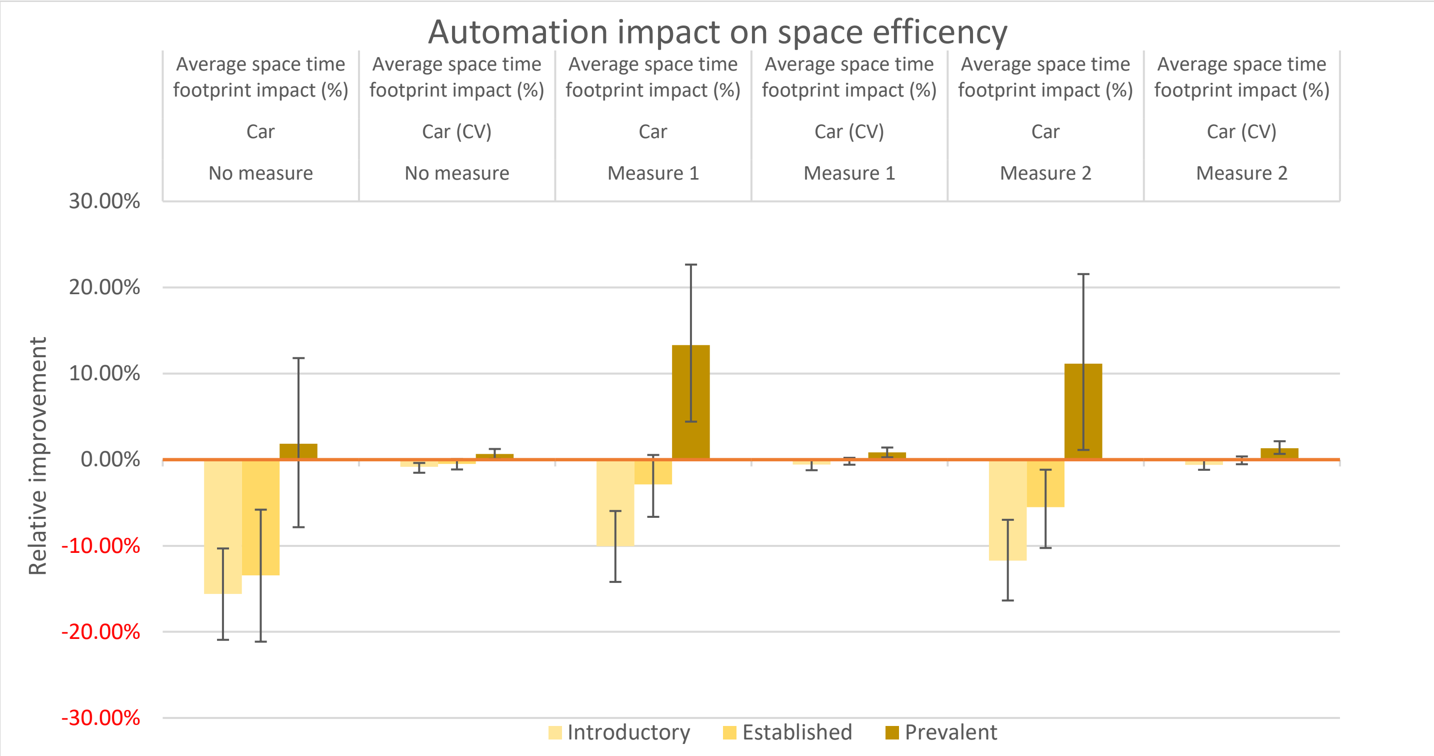

Figure 61 Average space time footprint of car and car(cv)

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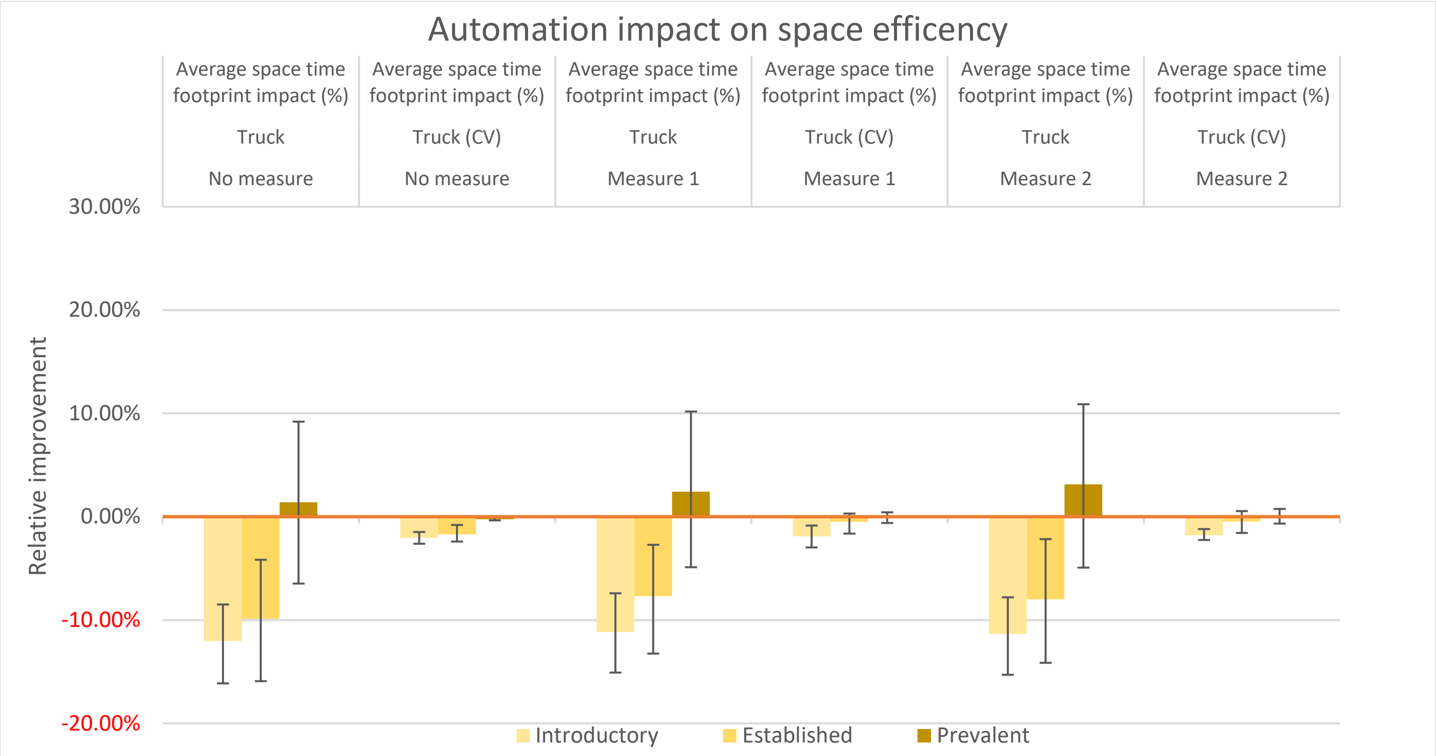

Figure 62 Space time footprint of trucks and trucks (CV)

The last space efficiency metric assessed considered for use case 4 is the space time utilisation, showing that in total vehicles, both AVs and CVs utilize a smaller proportion of the availabe space time when reaching the Prevalent stage of coexistence. This is expected given the results of the average space claim and average space time footprint.

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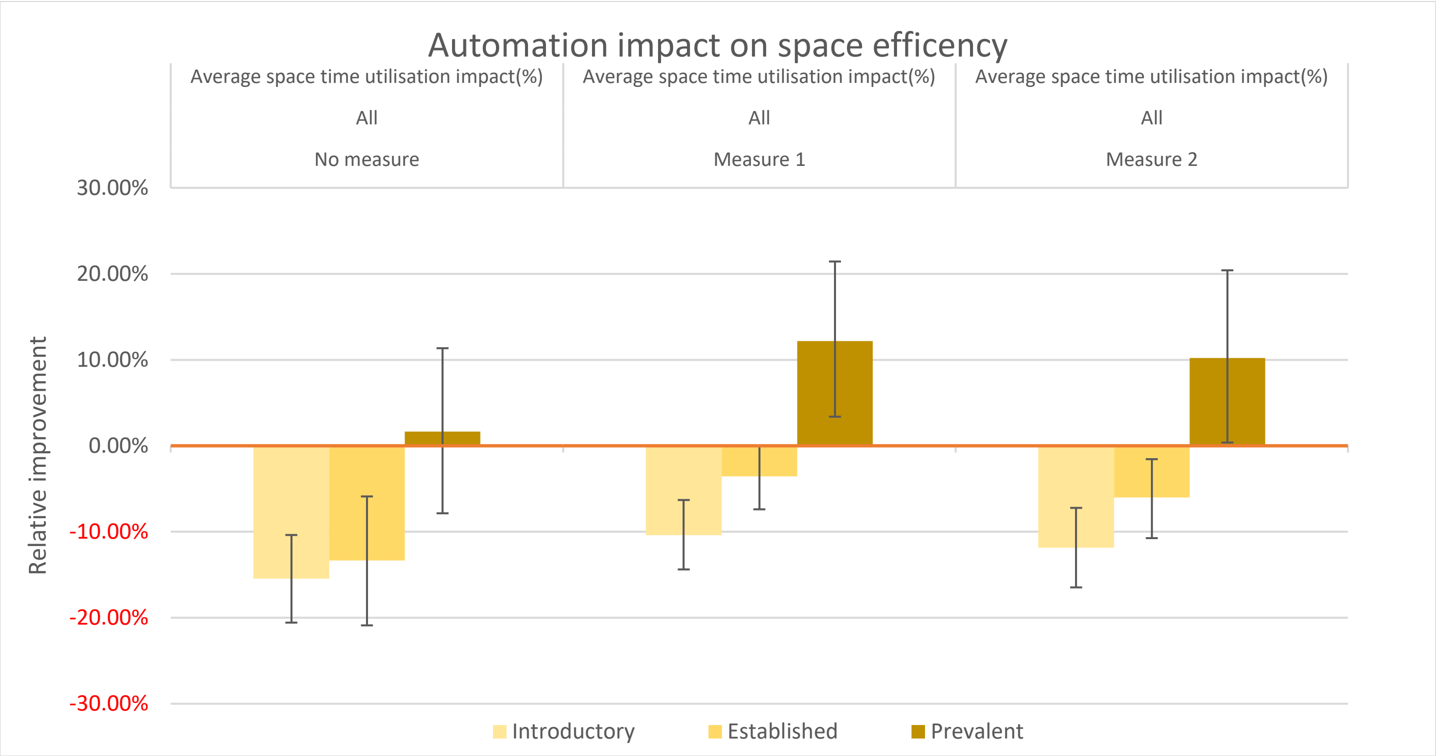

Figure 63 Space time utilisation for use case 4

6.2 Qualitative safety assessment

The upcoming sections show visual illustration of the identified relevant accident types for use case 4. Since use case 4 include the signalised intersection in use case 3, the focus on the presented accident types are on the motorway to arterial transition and the majority of the relevant accident types therefore mainly involves conflicts between vehicles.

6.2.1 Accident type 1 – Driving accident

Accident types classified as a type 1 are single-car accidents. As no conflict has occurred with other vehicles in this accident type the source of the accident might for example be due to the road condition, not being able to adapt the speed to current conditions, etc. For use case 4, driving accidents are probably mainly related to straight roads (Figure 64) or turning (Figure 65).

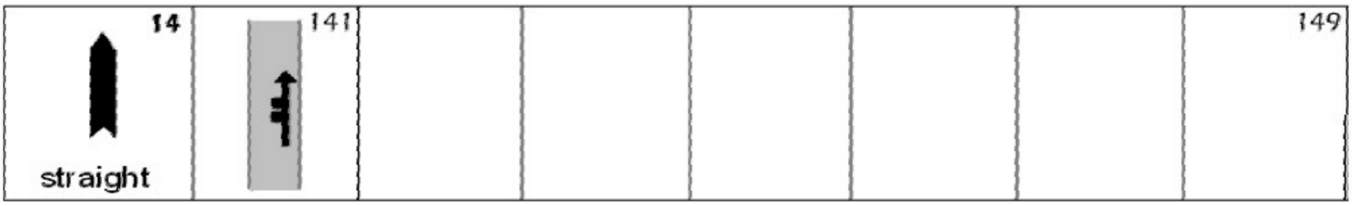

Figure 64 Accident type 14 on a straight road

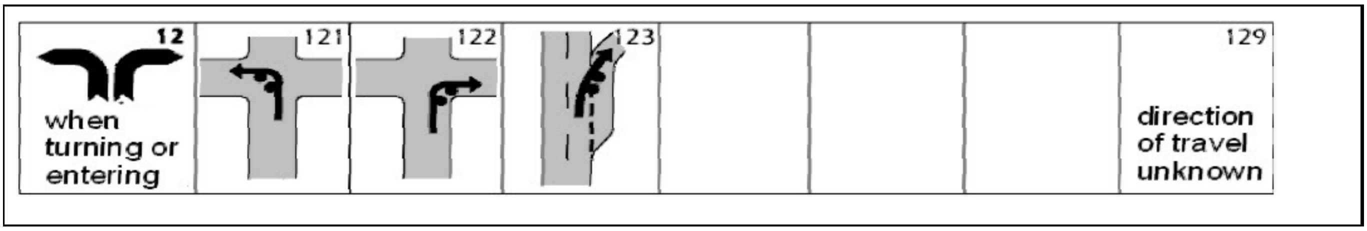

Figure 65 Accident type 12 turning in or off to another road.

6.2.2 Accident type 2 – Turning off accident

Accident type 2 focuses mainly on conflicts that may occur when vehicles are turning off a road and interact with road users from the same or opposite direction. The listed accident types are mainly related to vehicle to vehicle interaction but also cyclist and pedestrians are considered. For use case 4 this accident types are mainly related to the intersections along the arterial part, e.g. rear-end collisions (as in Figure 66).

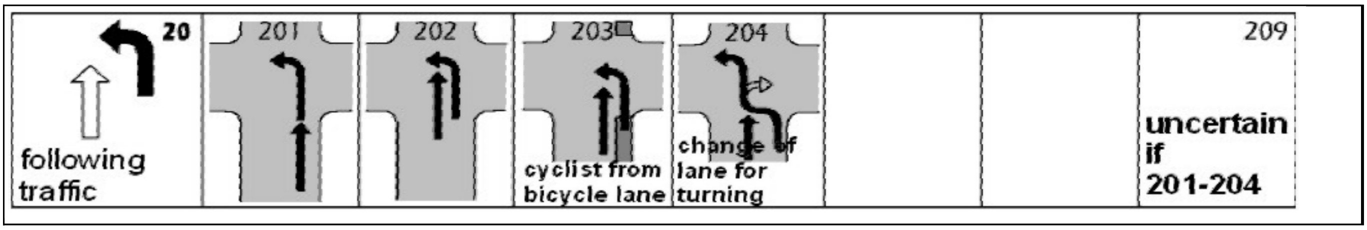

Figure 66 Accident type 20 conflict between a vehicle turning off to the left and following traffic

6.2.3 Accident type 3 – Turning in/crossing accident

Accident type 3 is mainly related to red light driving accidents at the signalised intersections along the arterial part of the use case. This could for example be accidents related to collisions between a vehicle with priority and a vehicle without priority at intersections (as in Figure 67).

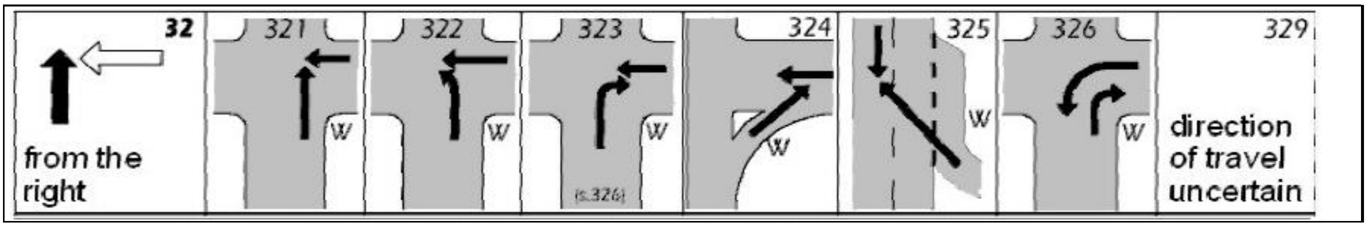

Figure 67 Accident type 32 conflict between a non priority vehicle and a priority vehicle coming from the right, which is not overtaking.

6.2.4 Accident type 4 – Pedestrian accident

Accident type 4 includes accidents between pedestrians and vehicles related to when pedestrians are crossing the road in one way or another. Since pedestrians are separated from vehicle traffic in this use case, interaction only occur at the intersections. Since the intersections in use case 4 are signalised and secondary conflicts between turning vehicles and pedestrians are time separated such accidents (as in Figure 68 and Figure 69) can only occur in cases with red light driving or if pedestrians are jay-walking.

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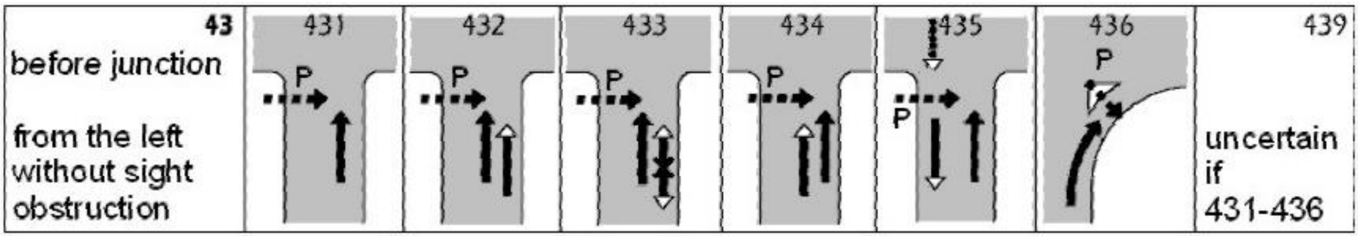

Figure 68 Accident type 43 conflict between a pedestrian coming from the left and a vehicle. Before a junction

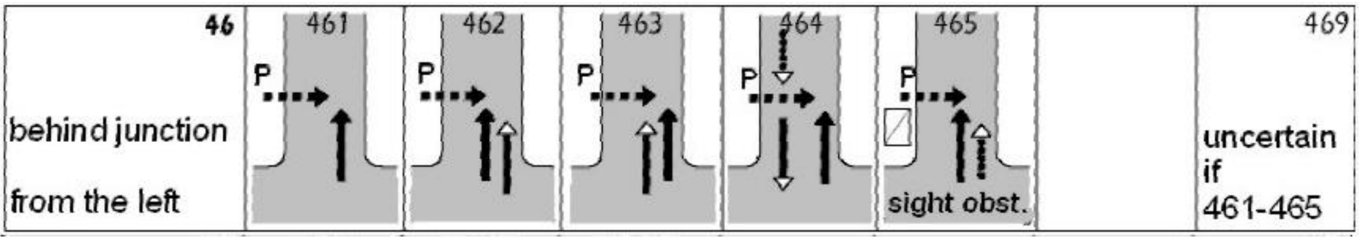

Figure 69 Accident type 46 conflict between a pedestrian coming from the left and a vehicle. Behind a junction

6.2.5 Accident type 5 – Accident with parking traffic

Use case 4 do not include any parked vehicles and this accident type is not relevant for this use case.

6.2.6 Accident type 6 – Accident with lateral traffic

Accident type 6 mainly consider lateral conflict in vehicle to vehicle interaction. This could for example lane changing related accidents (as in Figure 70) or rear-end collisions (as in Figure 71).

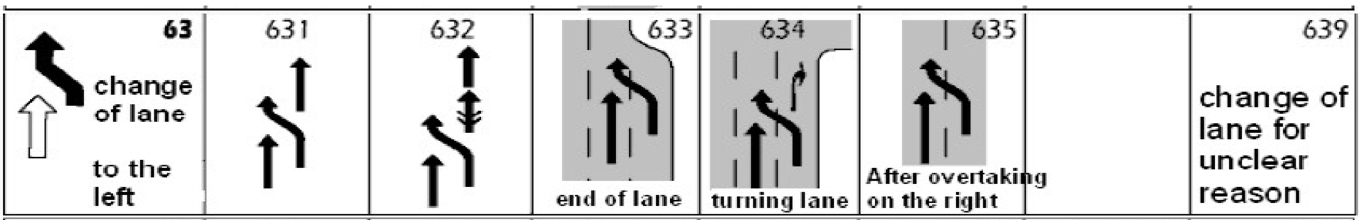

Figure 70 Accident type 60 conflict between a vehicle which is changing lanes to the left and a following vehicle on the lane alongside.

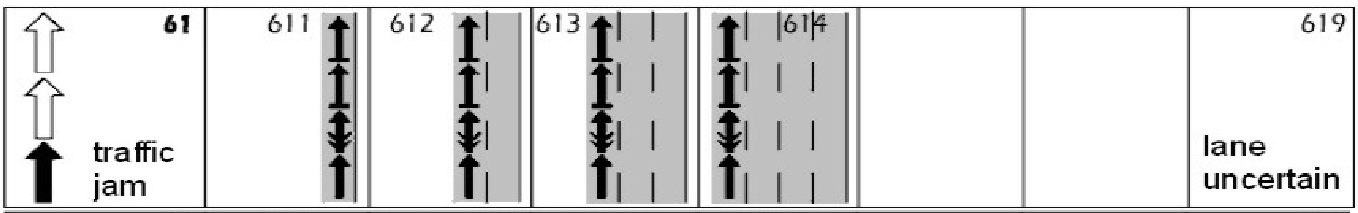

Figure 71 Accident type 61 conflict between a vehicle which is braking, standing or going slow due to a traffic jam and a following vehicle.

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6.2.7 Accident type 7 – Other accident types

Accident type 7 is the last category and covers the more unusual accident types e.g. accidents with animals, or accidents that would occur due to sleepiness, or dizziness, etc. In general accident type 7 covers accident types that cannot be assigned to any of the accident types 1-6. The only accident types in this category that might appear in use case 4 are related to sudden vehicle damage (as in Figure 72) or u-turns (as in Figure 73). U-turns are not allowed but occur sometimes at the intersections in use case 4.

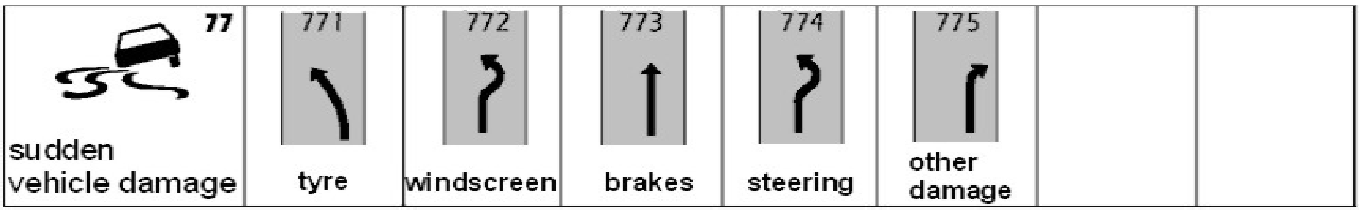

Figure 72 Accident type 72 accident due to a sudden technical defect on the vehicle.

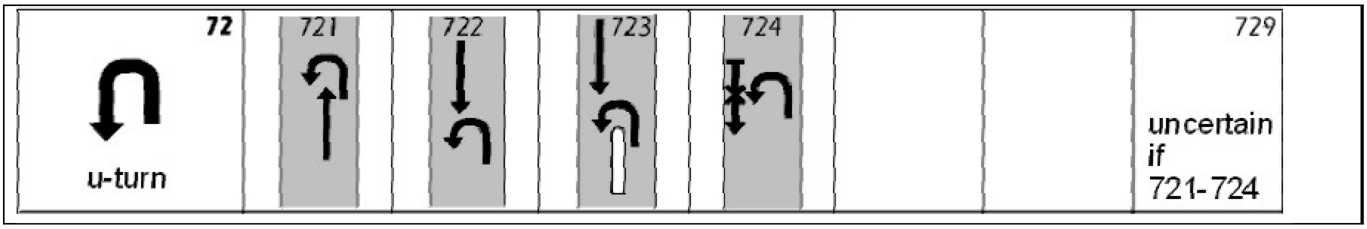

Figure 73 Accident type 72 Accident due to a u-turn.

6.2.8 Results

A summary of the qualitative safety assessment for use case 4 is shown in Table 26. The interpretation of the pictograms are given in Table 1 in section 2.2.1. The driving functions considered is the motorway and arterial pilot since the use case consists of a motorway that changes into a signalised arterial with intersection. Bicycle and pedestrian traffic are clearly separated from the vehicle traffic and vehicles, bicycles and pedestrians only interact at intersections.

For the accident types considered to be relevant for this use case the main very positive impact is expected for driving accidents (type 1) and accident in lateral traffic (type 6). There are also positive effects for pedestrian accidents (type 4) but these effects would only occur if red light driving or jaywalking exists and occur in such a way that such conflicts appear. In total 10 of the 68 accident types are considered relevant for the motorway part of this use case and the motorway pilot is expected to give positive or very positive impact in 10 of the 68 sub-accident types. In total 23 of the 68 accident types are considered relevant for the arterial part of this use case and the arterial pilot is expected to give positive or very positive impact in 15 of the 68 sub-accident types.

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Table 26 Qualitative safety assessment for use case 4 – Transition from interurban highway to arterial

	Type of accident	Motorway Pilot				Arterial Pilot			
									
1	Driving accident			1	1				3
2	Turning off accident							3	1
3	Turning-in / Crossing accident						1	4	
4	Pedestrian accident								4
5	Accident with parking vehicles								
6	Accident in lateral traffic			2	5				6
7	Other accident type			1					1

6.3 Safety inspection-based assessment

This section presents the results of the safety inspection-based assessment considering the crash types and wrong manoeuvres relevant for use case 4. Six scenarios were considered based on automated vehicles penetration rates and mix of AV classes / driving logics. For each scenario, the crash frequency and severity was estimated and the risk calculated (see section 2.2.2 for an overview and Deliverable 3.3 for details on the methodology). Finally, the risk for the various scenarios was compared.

6.3.1 Existing scenario

A Road Safety Inspection (RSI) was carried out to assess the existing road safety conditions on the site for use case 4. The road section assessed is around 6 km of road N 270 in Helmond, Netherlands.

A visit to the site (by a team of experts) was done in January 2020. It was cloudy and foggy during the site visit, with temperatures around 5°C.

To facilitate the collection of information during the inspection, the following tools were used:

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- Nextbase 612GW camera with integrated GPS
- Application ASIA[3] (installed on a smartphone) to quickly note road safety problems and their location during inspections

The site was inspected and a report of those matters that may have an adverse effect on road safety was compiled. The inspection did not include any examination or verification of the compliance with any other standard or criteria.

All of the issues highlighted in this report are considered by the safety inspection team to require action in order to improve the safety of the area and minimise collision occurrence. Each item identified in the inspection is outlined below, together with recommendations to mitigate the issue in question. Each item identified in the inspection is outlined below, together with recommendations to mitigate the issue in question.

Background information

Description of the section

The scope of this inspection covers the road section of N270 about 6 km long (from km 7.8 to km 13.3). This road links Eindhoven to Helmond, in Netherlands (Figure 74).

The road section is composed by two separate carriageways, each one with two lanes, with the exception of intersections where there are left and right turn pockets lanes. The first part, from East to West, is in an urban context for about 2 km (from km 13.3 to km 11.4), while the remaining part is located in a suburban area (from km 11.4 to km 7.8). The road is mostly flat.

[3] ASIA (Assistant for road Safety Inspections and Audits) is an application developed by FRED Engineering (www.fredeng.eu) for Android with the aim of maximizing the effectiveness of road safety audits and inspections

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Figure 74 Location of road section between Eindhoven and Helmond (source: elaboration on Google Earth)

There are several speed limits along the whole section (Figure 75):

- 50 km/h from km 12.6 to km 13.3 (i.e. inside the urban area).
- 70 km/h from km 11.4 to km 12.6 (mainly due to the presence of two intersections).
- 100 km/h from km 9.0 to km 11.4.
- 80 km/h from 9.0 to km 9.2 (near to an intersection).
- 100 km/h from km 9.2 to km 7.8.

Figure 75 Speed limits along the road section of use case 4

Road traffic crash analysis

Along the road section inside Helmond municipality there have been six crashes in the last six years (January 2014-January 2020) without injuries (Figure 76). The available data do not provide more details on the type of crash, the vehicles involved and the date and time of these crashes.

Figure 76 Location of crashes (source: Helmond municipality)

Even if the road traffic crash analysis does not show relevant results, it does not mean that the site is risk-free. 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. Thus, it is important to specify that the results of the road traffic crash analysis and the results of the road safety inspections are not directly correlated (EuroRAP, 2020), hence:

Collision level ⇎ Risk level from road safety

A crash is a rare event that occurs due to one or more interacting factors, but the risk of a crash due to road-related problems is always present. Therefore, the number of crashes that occurred on a section is a consequence not only of road characteristics, but also of traffic levels, road user behaviour and the characteristics of the vehicle fleet.

Traffic flow analysis

The available traffic flow data are measurements made in 2015 for both directions on the N270 and they show that we have two peak times: in the morning between 7:00 and 9:00 and in the evening between 17:00 and 18:00 (Figure 77 and Figure 78).

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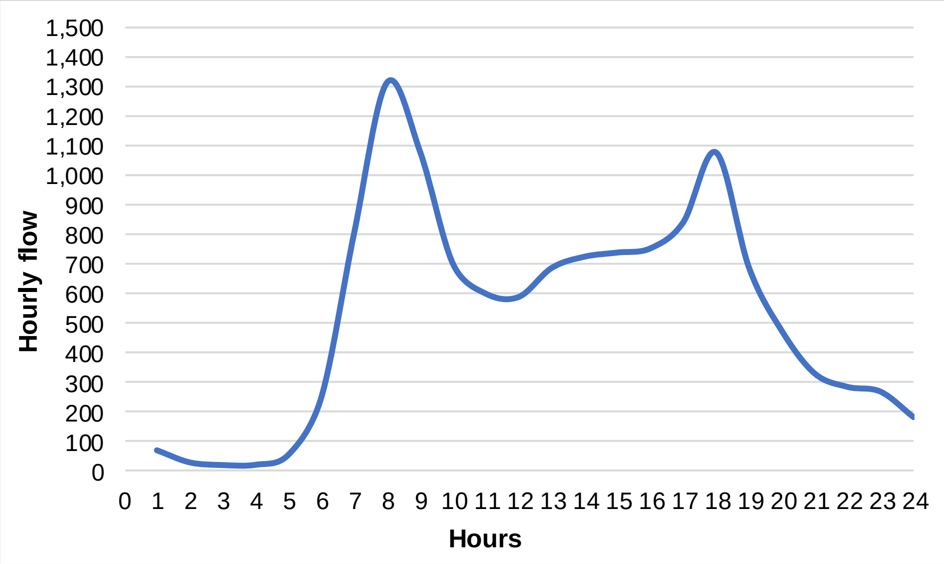

Figure 77 - Hourly flow, direction Helmond-Eindhoven

From Helmond to Eindhoven the highest traffic flow is in the morning (between 7:00 and 8:00) with about 1,300 vehicles per hour, probably due to several commuters working in Eindhoven (Figure 77). But there is also a lower peak around 18:00, when the workday ends and some people come back to Eindhoven.

In fact, in the opposite direction (Eindhoven - Helmond) the inverse situation occurs: the highest traffic flow is around 18:00 due to commuters returning to Helmond after the workday and the lower peak is in the morning, around 8:00 (Figure 78).

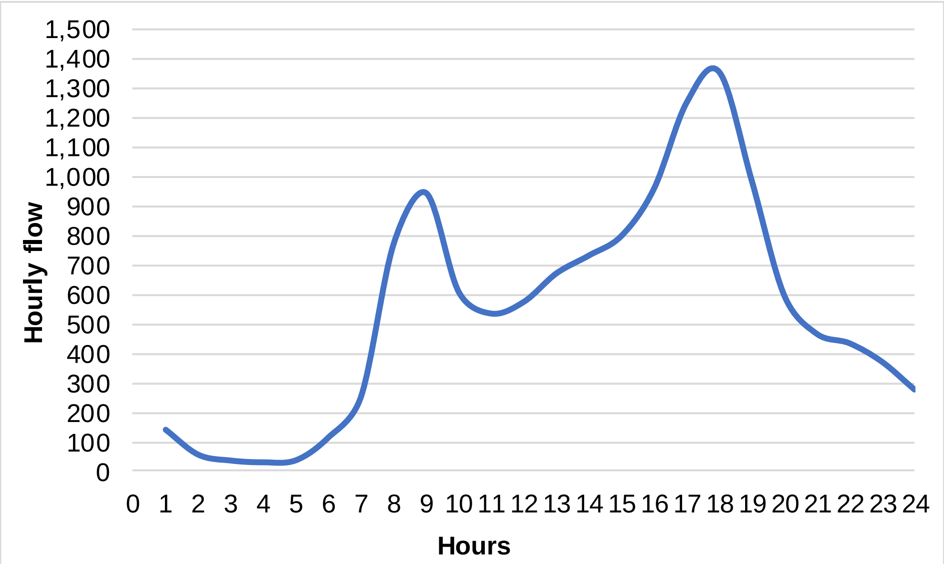

Figure 78 - Hourly flow, direction Eindhoven-Helmond

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Road safety assessment

This section presents the results of the inspection. In particular, it summarises the road safety problems identified, their location, the probable/typical accident (in the form of an icon) that they may cause, the recommendation to eliminate or mitigate them, and finally, a priority level or their possible implementation. In particular, the priority level is given according to a risk assessment.

All problems are identified with a code composed of a literal part, representing the category of problems and a numerical part, representing the sequential number.

Roadside

The main problems found along the roadside are the presence of obstacles very close to the edge of the road and deep ditches. In addition, other problems related to road maintenance have been identified.

Details are shown in the following table.

No.	Location	Problem	Crash type	Recommendation	Risk
RS.1	From km 11.4 to km 13.3 (both directions)	**Streetlamps along the roadside in urban area** In the urban section, the streetlamps and some sign poles are located about 0.50 m from the roadway edges and there are no safety barriers. This situation becomes more dangerous when the speed limit is 70 km/h. In case of run off and collision with a pole at this speed, there is a risk of serious injuries to drivers.  		It is recommended to replace these poles with breakable poles.	0.42

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No.	Location	Problem	Crash type	Recommendation	Risk
RS.2	From km 7.8 to km 11.4 (both directions)	**Poles along the roadside in rural area** In the suburban section, where the speed limit is 100 km/h, there are some poles with speed cameras along the emergency lane edge. The emergency lane should provide a safe space in case of emergency/vehicle failure, but the presence of side obstacles so close to the edge could make the lane less safe. 		It is recommended to install safety barriers (minimum class H2, UNI EN1317) along the edge of the emergency lane. Alternatively, it is recommended to replace these poles with breakable poles.	0.24
RS.3	From km 11.7 to km 12.4 (both directions)	**Ditch along the traffic island** In the central part of the traffic island there is a deep ditch not protected by any safety barrier. In the event of a run-off of a vehicle, it could fall into the ditch with no chance of escaping.		It is recommended to install safety barriers (minimum class H2, UNI EN1317) along the edge of the traffic island.	0.21

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No.	Location	Problem	Crash type	Recommendation	Risk
					
RS.4	From km 7.8 to km 8.6 (both directions)	**Ditch on the right side** For a section of about 800 m there is a ditch on the right side of the N270. In the eastbound carriageway, along this stretch, there is an auxiliary lane between the junction and the parking area. In the event of a run-off of a vehicle, it could fall into the ditch with no chance of escaping. 		It is recommended to install safety barriers (minimum class H2, UNI EN1317) along the roadside.	0.21

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No.	Location	Problem	Crash type	Recommendation	Risk
RS.5	km 9.7 (direction Helmond)	**Dirty emergency lane** In many stretches, the emergency lane is dirty and muddy. This could make the road surface slippery, not allowing to stop safely if necessary. 		It is recommended to clean up the road surface of the emergency lane. If it is a frequent problem, it is recommended to increase the frequency of cleaning.	0.12
RS.6	km 9.7 (direction Eindhoven)	**Vertical sign covered by trees** Along the roadside there are trees that in some cases cover the signs. In this way it is difficult to read the sign and could lead to hesitation or even worse, to a lack of perception of the message. 		It is recommended to trim the vegetation regularly.	0.04

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No.	Location	Problem	Crash type	Recommendation	Risk
RS.7	km 9.2 (both directions)	**Open space on the median without “no-parking” signs** The traffic island is about 14 m wide and is covered with vegetation for most of the road length. At km 9.2 there is a paved section of about 80 m where there is only the central safety barrier dividing the two carriageways. Users may use this space improperly for parking as there is no sign to prohibit it. Vehicles in the overtaking lane do not expect vehicles entering from the median so they may carry out sudden lane change manoeuvres to avoid them with the risk of side collisions with vehicles in the right-hand lane. 		It is recommended to add “no-parking” signs and to install retroreflective road studs along the median line. 	0.12

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Road signs and markings

Some signs are missing and in certain cases the maintenance of them and road markings is not optimal. Details are shown in the following table.

No.	Location	Problem	Crash type	Recommendation	Risk
S.1	General	**Road markings not clearly visible** There are some sections where the road markings are not clearly visible. In particular, in some places the edge line is completely absent, the line dividing the two lanes is not so visible and, at the end of the emergency lane, the road markings are almost completely deleted. Poor visibility of the road markings could lead to loss of track or incorrect driving in the lane.  		It is recommended to ensure that the road markings are always in good conditions so that they are visible.	0.12
S.2	km 9.8 (direction Eindhoven)	**Speed limit too high near intersection** At the regulated intersection with Neervoortsedreef, the speed limit is 80 km/h. This speed seems to be very high for an intersection of this type and could cause abrupt braking and rear-end		It is recommended to reduce the speed limit up to 60 km/h by installing decreasing speed limits: 100 km/h, 80 km/h and 60 km/h.	0.12

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No.	Location	Problem	Crash type	Recommendation	Risk
		collisions by drivers who see the light turn red at the last moment or sudden acceleration in the case of the green phase. 		Alternatively, it is recommended to provide a high-friction pavement before the intersection to reduce braking distances.	
S.3	km 12.0, before Automotive Campus intersection (direction Helmond)	**Warning sign missing** Proceeding in the direction of Helmond, on the section where the speed limit is 70 km/h, there is a signalised intersection for the Automotive Campus. Before this intersection there is no sign warning of its presence. A driver may not be aware of the presence of an intersection and therefore not behave properly, which could lead to sudden braking and rear-end collisions.		It is recommended to install a warning sign for signalised intersection 300 m before the intersection, as it is for the other signalised intersections along the road. 	0.12

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No.	Location	Problem	Crash type	Recommendation	Risk
					
S.4	General	**Margin delineators not very visible** The margin delineators are darkened and sometimes damaged. Generally, during the night, in the absence of artificial lighting, they are very helpful for drivers to have a good perception of the track. If they are not efficient, there may be track losses and run-off. 		It is recommended to ensure good maintenance of the delineators.	0.12

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No.	Location	Problem	Crash type	Recommendation	Risk
S.5	Junction ramp (km 7.8)	**Road signs turned in the opposite direction** On the junction ramp, there are signs turned in the opposite direction. This may confuse the drivers and lead to incorrect behaviours. 		It is recommended to check whether these signals should be removed or turned in the correct direction.	0.01

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Junction

The problems identified at the junction refer to obstacles which could be dangerous for vehicles making entry and exit manoeuvres along the deceleration and acceleration lanes. Details are shown in the following table.

No.	Location	Problem	Crash type	Recommendation	Risk
J.1	km 7.8 (direction Eindhoven)	**Divergent nose unprotected at junction** At the junction, the point where the lane separates from the ramp is unprotected and there are dangerous obstacles, such as the camera pole and sign support. Junctions are intrinsically very dangerous points where serious crashes, such as collision with obstacles within the verge area immediately downstream of the diverge nose, could happen. In this case, the risk is accentuated by dirty and muddy emergency lane (see Problem RS.5). 		It is recommended to remove all obstacles at the back of divergent nose, such that the physical nose is free from all hazards to minimise the risk to errant vehicles. Otherwise, if it is not possible to remove the obstacles, it is recommended to install a Crash Cushion System (minimum class 80, UNI EN 1317-3) protecting drivers and vehicles by absorbing the impact energy and also redirecting the vehicle away from the hazard. 	0.42

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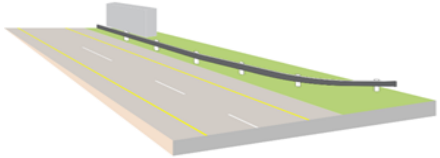
No.	Location	Problem	Crash type	Recommendation	Risk
J.2	Junction ramp (km 7.8)	**Dangerous barrier terminal** Barrier terminals are critical points for road safety. This type is not among the most dangerous, but it is still an unsafe configuration. In fact, in the event of a collision, the vehicle may lift off the ground because the barrier becomes a sort of ramp. 		It is recommended to bend the barrier terminal to the outside as far away from the roadside as possible or to install a barrier terminal that absorb impact energy.  	0.24

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Road Safety Inspection summary

It is impor	Items resulting from Inspection	Recommendations	Risk value
RS.1	Streetlamps along the roadside in urban area	It is recommended to replace these poles with breakable poles	0.42
RS.2	Poles along the roadside in rural area	It is recommended to install safety barriers (minimum class H2, UNI EN1317) along the edge of the emergency lane. Alternatively, it is recommended to replace these poles with breakable poles.	0.24
RS.3	Ditch along the traffic island	Installation of safety barriers along the edge of the traffic island.	0.21
RS.4	Ditch on the right side	Installation of safety barriers along the roadside.	0.21
RS.5	Dirty emergency lane	Cleaning of the road surface of the emergency lane.	0.12
RS.6	Vertical sign covered by trees	Proper maintenance of the vegetation.	0.04
RS.7	Open space on the median without “no-parking” signs	Installation of adequate signage.	0.12
S.1	Road markings not clearly visible	Proper maintenance of the road markings.	0.12
S.2	Speed limit too high near intersection	Speed limit reduction.	0.12
S.3	Warning sign missing	Installation of warning sign for signalised intersection.	0.12
S.4	Margin delineators not very visible	Proper maintenance of the delineators.	0.04

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It is impor	Items resulting from Inspection	Recommendations	Risk value
S.5	Road signs turned in the opposite direction	Checking the purpose of the signs.	0.01
J.1	Divergent nose unprotected at junction	Removal of obstacles or installation of crush cushion system.	0.42
J.2	Dangerous barrier terminal	Bending the barrier terminal to the outside or installing a barrier terminal.	0.24
TOTAL RISK			**2.51**

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6.3.2 Future scenarios

The future scenarios assessed in terms of road safety (and compared with the existing situation) are presented in Table 27. Six scenarios with varying penetration rates and mixes of Automated Vehicles (with different driving logics: Cautious / Normal / All-knowing) were assessed.

The risk of road traffic crashes was assessed for all the scenarios according to the methodology described in Deliverable 3.3. The problems identified for the future scenarios are classified according to three types:

- A = a problem existing in the current scenario for conventional vehicles will still be a problem also for automated vehicles in the future scenario.
- B = a problem existing in the current scenario for conventional vehicles will no more be a problem for automated vehicles in the future scenario.
- C = a problem is not existing in the current scenario for conventional vehicles but will appear in the future scenario due to presence of automated vehicles.

Table 27 Use case 4 – Scenarios assessed for use case 4

Scenario	CV	AV	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	0%	-	-

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Scenario 1

This scenario is composed by a majority of conventional vehicles (75% of the total) and by a mix of Cautious (20% of all vehicles) and Normal (5% of all vehicles) automated vehicles. Table 28 describes the road safety issues that could arise due to the presence of automated vehicles (both considering those caused by acting and re-acting behaviours of AVs). Table 29 presents the estimated risk values estimated for each road safety issue.

Table 28 Use case 4 – Scenario 1 – Road safety issues related with Automated Vehicles (Cautious and Normal)

No.	PROBLEM			CAUTIOUS AV		NORMAL AV	
	Type	Description	Crash type	Acting behaviour	Re-acting behaviour	Acting behaviour	Re-acting behaviour
RS.1	A	**Streetlamps along the roadside in urban area**		In case of obstacle too close to the driving lane, a Cautious AV would reduce the speed to reduce the possibility of run off.	Any vehicle could be hit by another and pushed out of the road, and in turn collide with fixed obstacle too close to the lane	A Normal AV should be able to avoid run off.	Any vehicle could be hit by another and pushed out of the road, and in turn collide with fixed obstacle too close to the lane
RS.2	A	**Poles along the roadside in rural area**		A Cautious AV should be able to avoid run off	Any vehicle could be hit by another vehicle and pushed out of the road, and in turn collide with a fixed obstacle too close to the lane	A Normal AV should be able to avoid run off	Any vehicle could be hit be another and pushed out of the road, and in turn collide with fixed obstacle too close to the lane
RS.3	A	**Ditch along the traffic island**		A Cautious AV should be able to avoid run off	Any vehicle could be hit be another and pushed out of the road, and in turn collide with fixed obstacle too close to the lane	A Normal AV should be able to avoid run off	Any vehicle could be hit be another and pushed out of the road, and in turn collide with fixed obstacle too close to the lane
RS.4	A	**Ditch on the right side**		A Cautious AV should be able to avoid run off	Any vehicle could be hit by another vehicle and pushed out of the road, and in turn	A Normal AV should be able to avoid run off	Any vehicle could be hit by another vehicle and pushed out of the road, and in turn

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No.	PROBLEM			CAUTIOUS AV		NORMAL AV	
	Type	Description	Crash type	Acting behaviour	Re-acting behaviour	Acting behaviour	Re-acting behaviour
					collide with fixed obstacle too close to the lane		collide with fixed obstacle too close to the lane
RS.5	B	**Dirty emergency lane**		A Cautious AV should be able to always stop safely	Not applicable	A Normal AV should be able to always stop safely	Not applicable
RS.6	B	**Vertical sign covered by trees**		No issues with sign readability.	Not applicable	No issues with sign readability.	Not applicable
RS.7	A	**Open space on the median without "no-parking" signs**		AVs should be able to use the space correctly.	The problem still exists from CVs that could hit AVs	Normal AVs could make sudden lane changes, even if it's quite rare	The problem still exists from CVs that could hit AVs
S.1	B	**Road markings not clearly visible**		Cautious AVs never lose track or use incorrect lanes	Not applicable	Cautious AVs never lose track or use incorrect lanes	Not applicable
S.2	A	**Speed limit too high near intersection**		Cautious AVs could have abrupt braking, so that rear end still is a possibility.	Rear end by a Cautious AV is likely not possible	Normal AVs could have abrupt braking, so that rear end still is a possibility.	Rear end by a Cautious AV is likely not possible
S.3	A	**Warning sign missing**		Cautious AVs should know the presence of an intersection. Sudden braking is unlikely.	Rear end by a Cautious AV is likely not possible	Normal AVs should know the presence of an intersection. Sudden braking is unlikely.	Rear end by a Normal AV could still be possible (even if with less chances than conventional vehicles)

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No.	PROBLEM		Crash type	CAUTIOUS AV		NORMAL AV	
	Type	**Description**		**Acting behaviour**	**Re-acting behaviour**	**Acting behaviour**	**Re-acting behaviour**
S.4	B	**Margin delineators not very visible**		Cautious AVs should not have perception issues	Not applicable	Normal AVs should not have perception issues	Not applicable
S.5	A	**Road signs turned in the opposite direction**		Cautious AVs should not have perception issues	Incorrect behaviours from conventional vehicles drivers could lead to collision with AVs	Normal AVs should not have perception issues	Incorrect behaviours from conventional vehicles drivers could lead to collision with AVs
J.1	A	**Divergent nose unprotected at junction**		Cautious AVs should not go out of the road	Any vehicle could be hit by another vehicle and pushed out of the road, and in turn collide with fixed obstacle	Normal AVs should not go out of the road	Any vehicle could be hit by another vehicle and pushed out of the road, and in turn collide with fixed obstacle
J.2	A	**Dangerous barrier terminal**		Cautious AVs should not go out of the road	Any vehicle could be hit by another vehicle and pushed out of the road, and in turn collide with fixed obstacle	Normal AVs should not go out of the road	Any vehicle could be hit by another vehicle and pushed out of the road, and in turn collide with fixed obstacle
AR.1	C	**AVs could slow and stop for any potential danger thus happening to be often rear-ended**		Cautious AVs could often slow down and stop, causing rear end collisions	Not applicable	Normal AVs could often slow down and stop, causing rear end collisions	Not applicable

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Table 29 Use case 4 – Scenario 1 – Risk scores related with Automated Vehicles

No.	CONVENTIONAL VEHICLES				CAUTIOUS AVs				NORMAL AVs				Total
	%	F	S	R	%	F	S	R	%	F	S	R	R
RS.1	75	0.7	0.6	0.42	20	0.4	0.6	0.24	5	0.4	0.6	0.24	**0.38**
RS.2	75	0.4	0.6	0.24	20	0.1	0.6	0.06	5	0.1	0.6	0.06	**0.20**
RS.3	75	0.7	0.3	0.21	20	0.4	0.3	0.12	5	0.4	0.3	0.12	**0.19**
RS.4	75	0.7	0.3	0.21	20	0.4	0.3	0.12	5	0.4	0.3	0.12	**0.19**
RS.5	75	0.4	0.3	0.12	20	-	-	-	5	-	-	-	**0.09**
RS.6	75	0.4	0.1	0.04	20	-	-	-	5	-	-	-	**0.03**
RS.7	75	0.4	0.3	0.12	20	0.4	0.3	0.12	5	0.4	0.3	0.12	**0.12**
S.1	75	0.4	0.3	0.12	20	-	-	-	5	-	-	-	**0.09**
S.2	75	0.4	0.3	0.12	20	0.4	0.3	0.12	5	0.4	0.3	0.12	**0.12**
S.3	75	0.4	0.3	0.12	20	-	-	-	5	0.4	0.3	0.12	**0.10**
S.4	75	0.4	0.3	0.12	20	-	-	-	5	-	-	-	**0.09**
S.5	75	0.1	0.1	0.01	20	0.1	0.1	0.01	5	0.1	0.1	0.01	**0.01**
J.1	75	0.7	0.6	0.42	20	0.4	0.6	0.24	5	0.4	0.6	0.24	**0.38**
J.2	75	0.4	0.6	0.24	20	0.4	0.6	0.24	5	0.4	0.6	0.24	**0.24**
AR.1	75	0.4	0.3	0.12	20	0.4	0.3	0.12	5	0.4	0.3	0.12	**0.12**
TOTAL RISK													**2.33**

Scenario 2

This scenario is composed by a majority of conventional vehicles (75% of the total) and by a mix of Cautious (5% of the total) and Normal (20% of the total) automated vehicles. Table 28 describes the road safety issues that could arise due to the presence of automated vehicles (both considering those caused by acting and re-acting behaviours of AVs). Compared to scenario 1, only the penetration rates of AVs differs. Since this scenario still includes Cautious and Normal AVs, the road safety issues identified for scenario 1 are still valid.

The risk values also do not change, except for the road safety issue "S.3" having a slightly higher total risk (0.11) compared to scenario 1. The total risk for this scenario is equal to 2.34 (compared to 2.33 of scenario 1).

Scenario 3

This scenario is composed by equal share of conventional vehicles and automated vehicles. In this case, 20% of AVs (10% of all vehicles) use a Cautious driving logic, while 80% of AVs (40% of all vehicles) use a Normal driving logic. Table 28 describes the road safety issues that could arise due to the presence of automated vehicles (both considering those caused by acting and re-acting behaviours of AVs). Compared to scenario 1, only the penetration rates of AVs changes. Since this scenario still includes Cautious and Normal AVs, the road safety issues identified for scenario 1 are valid.

The risk values change due to differences in the conventional and automated vehicles penetration rates. Table 30 provides the risk values estimated for each road safety issue.

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Table 30 Use case 4 – Scenario 3 – Risk scores related with Automated Vehicles

No.	CONVENTIONAL VEHICLES				CAUTIOUS AVs				NORMAL AVs				Total
	%	F	S	R	%	F	S	R	%	F	S	R	R
RS.1	50	0.7	0.6	0.42	10	0.4	0.6	0.24	40	0.4	0.6	0.24	**0.33**
RS.2	50	0.4	0.6	0.24	10	0.1	0.6	0.06	40	0.1	0.6	0.06	**0.15**
RS.3	50	0.7	0.3	0.21	10	0.4	0.3	0.12	40	0.4	0.3	0.12	**0.17**
RS.4	50	0.7	0.3	0.21	10	0.4	0.3	0.12	40	0.4	0.3	0.12	**0.17**
RS.5	50	0.4	0.3	0.12	10	-	-	-	40	-	-	-	**0.06**
RS.6	50	0.4	0.1	0.04	10	-	-	-	40	-	-	-	**0.02**
RS.7	50	0.4	0.3	0.12	10	0.4	0.3	0.12	40	0.4	0.3	0.12	**0.12**
S.1	50	0.4	0.3	0.12	10	-	-	-	40	-	-	-	**0.06**
S.2	50	0.4	0.3	0.12	10	0.4	0.3	0.12	40	0.4	0.3	0.12	**0.12**
S.3	50	0.4	0.3	0.12	10	-	-	-	40	0.4	0.3	0.12	**0.11**
S.4	50	0.4	0.3	0.12	10	-	-	-	40	-	-	-	**0.06**
S.5	50	0.1	0.1	0.01	10	0.1	0.1	0.01	40	0.1	0.1	0.01	**0.01**
J.1	50	0.7	0.6	0.42	10	0.4	0.6	0.24	40	0.4	0.6	0.24	**0.33**
J.2	50	0.4	0.6	0.24	10	0.4	0.6	0.24	40	0.4	0.6	0.24	**0.24**
AR.1	50	0.4	0.3	0.12	10	0.4	0.3	0.12	40	0.4	0.3	0.12	**0.12**
TOTAL RISK													**2.06**

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Scenario 4

This scenario is composed by equal share of conventional vehicles and automated vehicles. In this case, 50% of AVs (25 of all vehicles) use a Normal driving logic, whose behaviours are already described in the Table 28, while 50% of AVs (25% of all vehicles) use an All-knowing driving logic, whose behaviours are reported in the Table 31 that describes the road safety issues that could arise due to the presence of automated vehicles (both considering those caused by acting and re-acting behaviours of AVs). Compared to previous scenarios, only risks related with All-knowing AVs change.

Table 32 provides the risk values estimated for each road safety issue.

Table 31 Use case 4 – Scenario 4 – Road safety issues related with Automated Vehicles (All-knowing)

No.	PROBLEM			ALL-KNOWING AV	
	Type	Description	Crash type	Acting behaviour	Re-acting behaviour
RS.1	A	**Streetlamps along the roadside in urban area**		An All-knowing AV should be able to avoid run off	Any vehicle could be hit by another vehicle and pushed out of the road, and in turn collide with fixed obstacle too close to the lane
RS.2	A	**Poles along the roadside in rural area**		An All-knowing AV should be able to avoid run off	Any vehicle could be hit by another vehicle and pushed out of the road, and in turn collide with fixed obstacle too close to the lane
RS.3	A	**Ditch along the traffic island**		An All-knowing AV should be able to avoid run off	Any vehicle could be hit by another vehicle and pushed out of the road, and in turn collide with fixed obstacle too close to the lane
RS.4	A	**Ditch on the right side**		An All-knowing AV should be able to avoid run off	Any vehicle could be hit by another vehicle and pushed out of the road, and in turn collide with fixed obstacle too close to the lane

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No.	PROBLEM			ALL-KNOWING AV	
	Type	Description	Crash type	Acting behaviour	Re-acting behaviour
RS.5	B	**Dirty emergency lane**		An All-knowing AV should be able to always stop safely	Not applicable
RS.6	B	**Vertical sign covered by trees**		No issues with signs readying.	Not applicable
RS.7	A	**Open space on the median without “no-parking” signs**		All-knowing AVs could make sudden lane changes, similarly to MVs	The problem still exists from conventional vehicles that could hit AVs
S.1	B	**Road markings not clearly visible**		All-knowing AVs never lose track or use incorrect lanes	Not applicable
S.2	A	**Speed limit too high near intersection**		All-knowing AVs could have abrupt braking, so that rear end still is a possibility.	Rear end by a Cautious AV is likely not possible
S.3	A	**Warning sign missing**		All-knowing AVs should know the presence of intersection. However, sudden brakes cannot be excluded.	Rear end by an All-knowing AV still could be possible (even if with less chances than conventional vehicles)
S.4	B	**Margin delineators not very visible**		All-knowing AVs should not have perception issues	Not applicable
S.5	A	**Road signs turned in the opposite direction**		All-knowing AVs should not have perception issues	Incorrect behaviours from conventional vehicles drivers could lead to collision with AVs
J.1	A	**Divergent nose unprotected at junction**		All-knowing AVs should not go out of the road	Any vehicle could be hit by another vehicle and pushed out of the road, and in turn collide with fixed obstacle

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No.	PROBLEM			ALL-KNOWING AV	
	Type	Description	Crash type	Acting behaviour	Re-acting behaviour
J.2	A	**Dangerous barrier terminal**		All-knowing AVs should not go out of the road	Any vehicle could be hit by another vehicle and pushed out of the road, and in turn collide with fixed obstacle
AR.1	C	**AVs could slow and stop for any potential danger thus happening to be often rear-ended**		All-knowing AVs could often slow and stop, causing rear end collisions	Not applicable
AR.2	C	**All-knowing AVs could make aggressive manoeuvres, not necessarily expected by conventional drivers (not used with new behaviours)**		All-knowing AVs could make sudden manoeuvres (e.g. lane changing)	Conventional vehicles could hit AVs like any other vehicle

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Table 32 Use case 4 – Scenario 4 – Risk scores related with Automated Vehicles

No.	CONVENTIONAL VEHICLES				NORMAL AVs				ALL-KNOWING AVs				Total
	%	F	S	R	%	F	S	R	%	F	S	R	R
RS.1	50	0.7	0.6	0.42	25	0.4	0.6	0.24	25	0.4	0.6	0.24	**0.33**
RS.2	50	0.4	0.6	0.24	25	0.1	0.6	0.06	25	0.1	0.6	0.06	**0.15**
RS.3	50	0.7	0.3	0.21	25	0.4	0.3	0.12	25	0.4	0.3	0.12	**0.17**
RS.4	50	0.7	0.3	0.21	25	0.4	0.3	0.12	25	0.4	0.3	0.12	**0.17**
RS.5	50	0.4	0.3	0.12	25	-	-	-	25	-	-	-	**0.06**
RS.6	50	0.4	0.1	0.04	25	-	-	-	25	-	-	-	**0.02**
RS.7	50	0.4	0.3	0.12	25	0.4	0.3	0.12	25	0.4	0.3	0.12	**0.12**
S.1	50	0.4	0.3	0.12	25	-	-	-	25	-	-	-	**0.06**
S.2	50	0.4	0.3	0.12	25	0.4	0.3	0.12	25	0.4	0.3	0.12	**0.12**
S.3	50	0.4	0.3	0.12	25	0.4	0.3	0.12	25	0.4	0.3	0.12	**0.10**
S.4	50	0.4	0.3	0.12	25	-	-	-	25	-	-	-	**0.06**
S.5	50	0.1	0.1	0.01	25	0.1	0.1	0.01	25	0.1	0.1	0.01	**0.01**
J.1	50	0.7	0.6	0.42	25	0.4	0.6	0.24	25	0.4	0.6	0.24	**0.33**
J.2	50	0.4	0.6	0.24	25	0.4	0.6	0.24	25	0.4	0.6	0.24	**0.24**
AR.1	50	0.4	0.3	0.12	25	0.4	0.3	0.12	25	0.4	0.3	0.12	**0.12**
AR.2	50	0.7	0.3	0.21	25	0.7	0.3	0.21	25	0.7	0.3	0.21	**0.21**
TOTAL RISK													**2.28**

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Scenario 5

This scenario is composed by a majority of automated vehicles (75% of the total), composed by a mix of Normal (37.5% of the total) and All-knowing (37.5% of the total) driving logics.

Table 31 describes the road safety issues that could arise due to the presence of automated vehicles (both considering those caused by acting and re-acting behaviours of AVs).

Compared to scenario 4, only the penetration rates of AVs changes. Since this scenario still includes Normal and All-knowing AVs, the road safety issues identified for scenario 4 are still valid. The risk values change due to differences in the conventional and automated vehicles penetration rates. Table 33 provides the risk values estimated for each road safety issue.

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Table 33 - Use case 4 – Scenario 5 – Risk scores related with Automated Vehicles

No.	CONVENTIONAL VEHICLES				NORMAL AVs				ALL-KNOWING AVs				Total
	%	F	S	R	%	F	S	R	%	F	S	R	R
RS.1	25	0.7	0.6	0.42	37.5	0.4	0.6	0.24	37.5	0.4	0.6	0.24	**0.29**
RS.2	25	0.4	0.6	0.24	37.5	0.1	0.6	0.06	37.5	0.1	0.6	0.06	**0.11**
RS.3	25	0.7	0.3	0.21	37.5	0.4	0.3	0.12	37.5	0.4	0.3	0.12	**0.14**
RS.4	25	0.7	0.3	0.21	37.5	0.4	0.3	0.12	37.5	0.4	0.3	0.12	**0.14**
RS.5	25	0.4	0.3	0.12	37.5	-	-	-	37.5	-	-	-	**0.03**
RS.6	25	0.4	0.1	0.04	37.5	-	-	-	37.5	-	-	-	**0.01**
RS.7	25	0.4	0.3	0.12	37.5	0.4	0.3	0.12	37.5	0.4	0.3	0.12	**0.12**
S.1	25	0.4	0.3	0.12	37.5	-	-	-	37.5	-	-	-	**0.03**
S.2	25	0.4	0.3	0.12	37.5	0.4	0.3	0.12	37.5	0.4	0.3	0.12	**0.12**
S.3	25	0.4	0.3	0.12	37.5	0.4	0.3	0.12	37.5	0.4	0.3	0.12	**0.12**
S.4	25	0.4	0.3	0.12	37.5	-	-	-	37.5	-	-	-	**0.03**
S.5	25	0.1	0.1	0.01	37.5	0.1	0.1	0.01	37.5	0.1	0.1	0.01	**0.01**
J.1	25	0.7	0.6	0.42	37.5	0.4	0.6	0.24	37.5	0.4	0.6	0.24	**0.29**
J.2	25	0.4	0.6	0.24	37.5	0.4	0.6	0.24	37.5	0.4	0.6	0.24	**0.24**
AR.1	25	0.4	0.3	0.12	37.5	0.4	0.3	0.12	37.5	0.4	0.3	0.12	**0.12**
AR.2	25	0.7	0.3	0.21	37.5	0.7	0.3	0.21	37.5	0.7	0.3	0.21	**0.21**
TOTAL RISK													**2.00**

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Scenario 6

This scenario is composed by a majority of All-knowing automated vehicles (75% of the total). Table 31 describes the road safety issues that could arise due to the presence of automated vehicles (both considering those caused by acting and re-acting behaviours of AVs). Table 34 provides the risk values estimated for each road safety issue.

Table 34 – Use case 4 – Scenario 6 – Risk scores related with Automated Vehicles

No.	CONVENTIONAL VEHICLES				ALL-KNOWING AVs				Total
	%	F	S	R	%	F	S	R	R
RS.1	25	0.7	0.6	0.42	75	0.4	0.6	0.24	**0.29**
RS.2	25	0.4	0.6	0.24	75	0.1	0.6	0.06	**0.11**
RS.3	25	0.7	0.3	0.21	75	0.4	0.3	0.12	**0.14**
RS.4	25	0.7	0.3	0.21	75	0.4	0.3	0.12	**0.14**
RS.5	25	0.4	0.3	0.12	75	-	-	-	**0.03**
RS.6	25	0.4	0.1	0.04	75	-	-	-	**0.01**
RS.7	25	0.4	0.3	0.12	75	0.4	0.3	0.12	**0.12**
S.1	25	0.4	0.3	0.12	75	-	-	-	**0.03**
S.2	25	0.4	0.3	0.12	75	0.4	0.3	0.12	**0.12**
S.3	25	0.4	0.3	0.12	75	0.4	0.3	0.12	**0.12**
S.4	25	0.4	0.3	0.12	75	-	-	-	**0.03**
S.5	25	0.1	0.1	0.01	75	0.1	0.1	0.01	**0.01**
J.1	25	0.7	0.6	0.42	75	0.4	0.6	0.24	**0.29**
J.2	25	0.4	0.6	0.24	75	0.4	0.6	0.24	**0.24**

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No.	CONVENTIONAL VEHICLES				ALL-KNOWING AVs				Total
	%	F	S	R	%	F	S	R	R
AR.1	25	0.4	0.3	0.12	75	0.4	0.3	0.12	**0.12**
AR.2	25	0.7	0.3	0.21	75	0.7	0.3	0.21	**0.21**
TOTAL RISK									**2.00**

Recommendations

For each problem identified in the scenarios with different mixes of conventional and automated vehicles, recommendations are provided in Table 35.

Table 35 Recommendations related to each problem in automated scenarios for use case 4

No.	PROBLEM			Recommendation
	Type	Description	Crash type	
RS.1	A	**Streetlamps along the roadside in urban area**		Replace streetlamps with breakable poles.
RS.2	A	**Poles along the roadside in rural area**		Install safety barriers along the edge of the emergency lane or replace the poles with breakable poles.
RS.3	A	**Ditch along the traffic island**		Install safety barriers along the edge of the emergency lane.
RS.4	A	**Ditch on the right side**		Install safety barriers along the edge of the emergency lane.
RS.5	B	**Dirty emergency lane**		Not applicable
RS.6	B	**Vertical sign covered by trees**		Not applicable
RS.7	A	**Open space on the median without "no-parking" signs**		Add "no-parking" signs and install retroreflective road studs along the median line.
S.1	B	**Road markings not clearly visible**		Not applicable

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S.2	A	**Speed limit too high near intersection**		Reduce the speed limit down to 60 km/h by installing decreasing speed limits: 100 km/h, 80 km/h and 60 km/h.
S.3	A	**Warning sign missing**		Not applicable
S.4	B	**Margin delineators not very visible**		Not applicable
S.5	A	**Road signs turned in the opposite direction**		Check whether these signals should be removed or turned in the correct direction
J.1	A	**Divergent nose unprotected at junction**		Remove all obstacles at the back of divergent nose or install a Crash Cushion System.
J.2	A	**Dangerous barrier terminal**		Bend the barrier terminal to the outside as far away from the roadside as possible or install a barrier terminal that absorb impact energy.
AR.1	C	**AVs could slow and stop for any potential danger thus happening to be often rear-ended**		Install signals informing about the danger
AR.2	C	**All-knowing AVs could make aggressive manoeuvres, not necessarily expected by conventional drivers (not used with new behaviours)**		Install signals informing about the danger due to presence of AVs.

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6.3.3 Comparisons and road safety conclusions

Table 36 shows the risk scores calculated for the current scenario (without AVs) and for the six scenarios with AVs, as well as the percentage change from current to future scenarios. The same information is also graphically shown in Figure 79.

Table 36 Use case 4 – Scenarios assessed

Scenario	CV	AV	Risk score Current scenario	Risk score Future scenario	% risk change
1	75%	25%	2.51	2.33	-7%
2	75%	25%	2.51	2.34	-7%
3	50%	50%	2.51	2.06	-18%
4	50%	50%	2.51	2.28	-9%
5	25%	75%	2.51	2.00	-20%
6	25%	75%	2.51	2.00	-20%

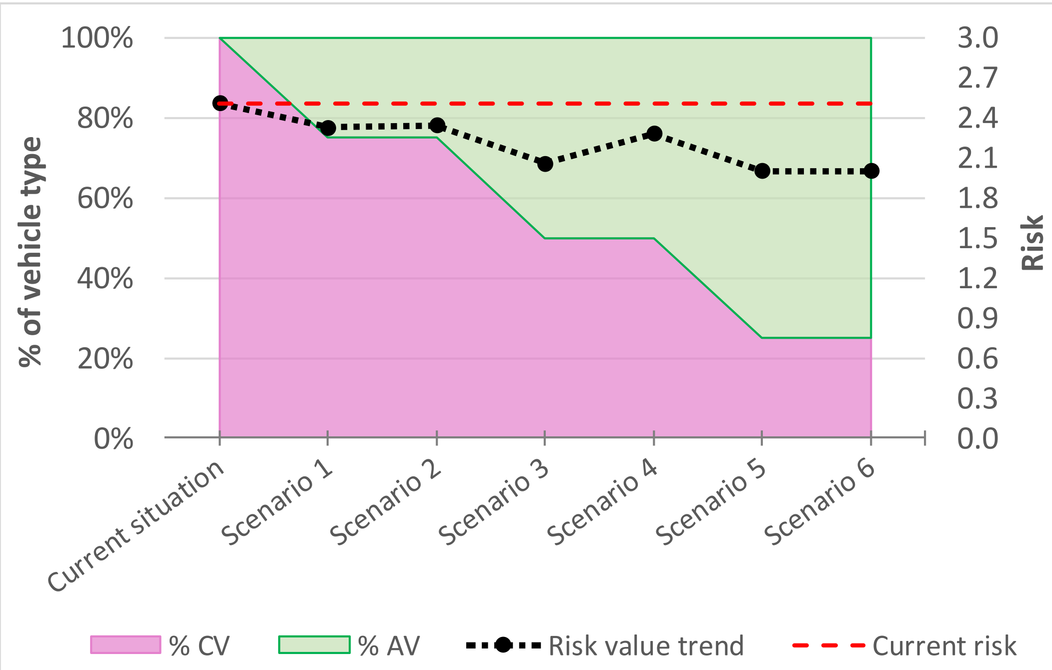

Figure 79 Use case 4 - Risk evolution based on AVs scenarios

All the AV scenarios indicate a potential reduction of road traffic crash risk, but not a total elimination. The higher benefits are obtained by increasing the presence of automated vehicles in the mixed environment. For instance, scenarios 1 and 2 (where 25% of AVs are present) reduce the risk of around 7%, compared to the current situation (with no AVs). On the contrary, the other scenarios (with 50% or 75% of AVs) lead to higher risk reductions (from minimum 9% to maximum 20% less compared to current situation), except for the scenario 4.

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The overall risk decrease was expectable, due to the fact that AVs are expected to make less (or no) “driving errors”, compared to human drivers. Most of the risk is due to “re-acting” situations, where the automated vehicle could have a crash due to a traffic condition caused by a conventional vehicle.

In addition to this, the introduction of quite aggressive vehicles (All-knowing) could significantly increase the risk. In scenario 4, for instance, the presence of All-knowing AVs should cause a high risk due to aggressive manoeuvres like sudden lane changing.

It is important to note that also the driving logic used by AVs has a quite strong influence on road traffic crash risk. While Cautious and Normal AVs tend to adopt a more “conservative” behaviour, the All-knowing AVs are more aggressive and thus riskier.

This is clear when looking at scenarios 3 and 4. These two scenarios both have 50% of AVs. However, the first is a mix of Cautious and Normal AVs, while the second is a mix of Normal and All-knowing AVs. The presence of All-knowing is deemed to increase both the frequency and the severity of eventual crashes, leading to higher risks.

Scenarios 5 and 6, where 75% of the AVs are present, lead to similar risks. Scenario 5 is a mix of Normal and All-knowing AVs, while in scenario 6 there are only All-knowing AVs. In this case, the high presence of “more aggressive vehicles” introduces new road safety issues the crash risk but strongly reduces others.

6.4 Conclusions

Simulations of the motorway and main arterial leading into Helmond shows that the traffic performance of conventional vehicles in terms of travel times and delay is, in general, marginally impacted negatively by the introduction of AVs in the Introductory and Established stages of coexistence. A similar level of traffic performance as today is achieved first when reaching the Prevalent stage with substantially high penetration rates and more advanced driving logics. From a pedestrian and bicycle perspective similar results as for motorized vehicles are expected, i.e. increased travel times and delays, except for bikes in the Prevalent stage. The effects for pedestrians and bicycles are also marginal and one important aspect to take into account when allowing AVs into the traffic system is to underline the importance of the automation ready threshold. How much of a decline is a city prepared to accept considering other benefits that may be associated with the introduction of AVs. However, these types of questions are not addressed within traffic impact assessment approach in CoEXist, but they are still important to discuss as they ought to arise during the process of the introduction of AVs.

The investigated measure “platooning” is actually not a measure that a city can take but has to do with the developments of the automated cars or availability of advanced functions in the vehicles. The city can only decide to allow or deny platooning. Implementing these more advanced functions of automated vehicles, shows to have a contribution in a positive direction regarding the effects on traffic performance of conventional cars and trucks. A more substantial gain from these measures are seen when looking at the traffic performance of pedestrians and bicyclists where gains around 5% are achieved in the Prevalent stage.

An interesting aspect of the platooning measures from a city perspective is that in the future it could be possible to restrict where automated cars are allowed but also where automated functions such as

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platooning is allowed. Therefore, in this use case one of the measures was to only allow platooning in the rightmost lane to investigate if it would make a difference. It is striking that there is no large difference in the effect between platooning allowed in both lanes or only in one lane. The positive effects of the platooning measure could also be of use in the introduction stage in terms that cities might consider not to implement or allow automated cars everywhere but to gradually implement it on lanes or roads as it mitigates the negative effects associated with the early stages of coexistence.

From a space efficiency perspective, the impact on conventional vehicles are marginal, especially with respect to the space time footprint. However, this metrics might be more relevant to apply for the entire car and truck fleet. Simulations show that an introduction of automated vehicles will initially imply a larger space time footprint and positive impacts are expected first in the Prevalent stage. Nevertheless, assuming that AVs can create platoons mitigates the negative effects seen in the Introductory stage and the Established stage. In addition, platooning imply that substantial positive impacts can be achieved in the Established stage both in terms of space time footprint and the space time utilisation, indicating that the space-time capacity is more efficiently utilised.

The qualitative safety assessment indicate that positive or very positive effects might be expected in 10 of the 68 sub-accident types for the highway part of the use case and in 15 of the 68 sub-accident types of the arterial part. The safety inspection-based assessment also indicates a potential reduction of road traffic crash risk and that the benefits increase with increased penetration rate of automated vehicles in the mixed environment. A large part of the risk reduction is due to that AVs are expected to make less (or no) “driving errors”, compared to human drivers. Most of the remaining risk is due to “re-acting” situations, where the automated vehicle could be involved in a crash due to a traffic condition caused by a conventional vehicle. The risk reduction increase with increasing penetration rate of AVs but the change is not that large due to the correlation of more advanced AVs at scenarios with higher penetration rates. This is due to that the All-knowing driving logic is deemed to increase both the frequency and the severity of eventual crashes compared to the more conservative driving logics as Cautious and Normal. The recommendations from the safety inspection-based approach consist to a large degree of measures that also improve safety for the current situation with conventional vehicles, e.g. installation of safety barriers and barrier terminals, replace street lamps by breakable poles, removing obstacles, reducing speed limits, etc.

7 Traffic impact of automation in use case 5: Waiting and drop-off areas for passengers

Milton Keynes is a relatively new, green field city, with a road network laid out in a grid pattern as shown in Figure 80. Whilst the city is untypical of UK inner city areas, it is reasonably representative of suburbia.

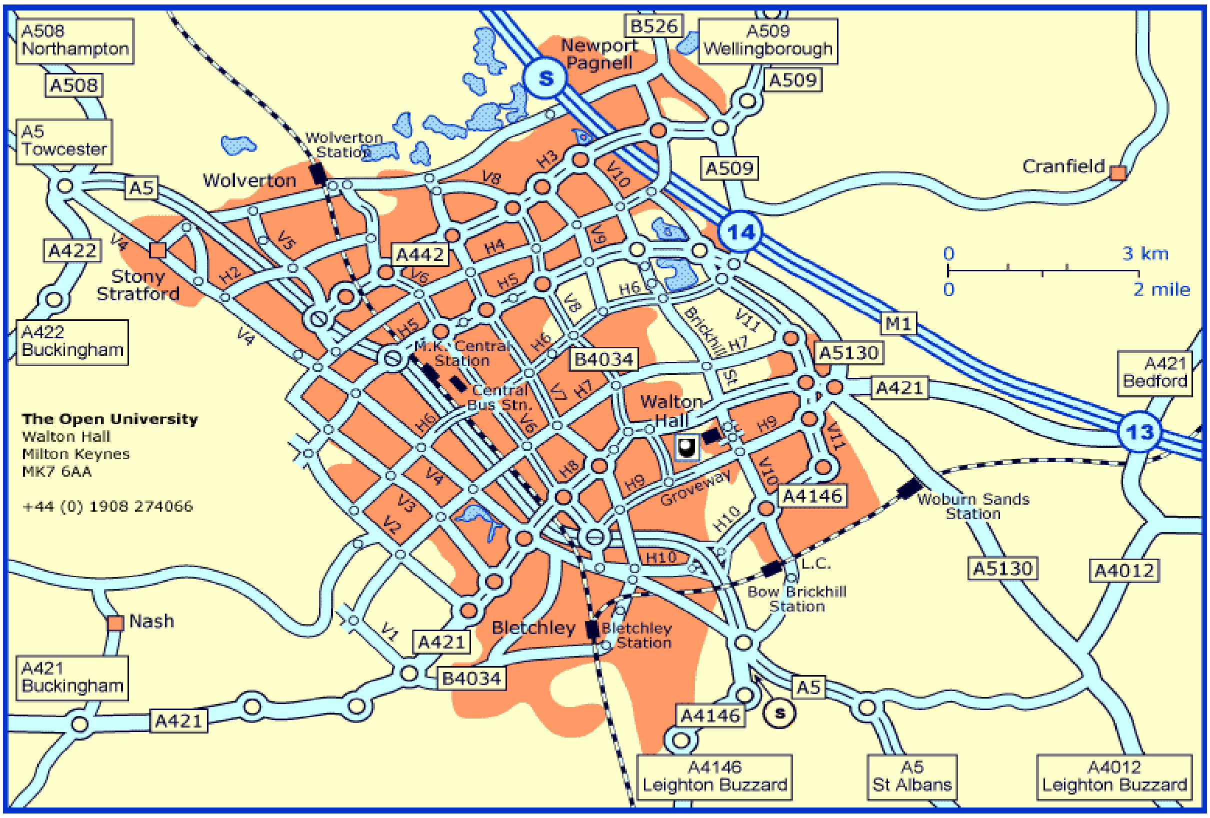

Figure 80 Milton Keynes road network

The focus of this use case was to evaluate the impact on existing and future infrastructure by creating waiting and drop-off areas for CAVs. Many road authorities are looking for ways to decrease motorized traffic in the city centre in order to enhance air quality and reallocate car parking space to other purposes. Restricting vehicle access to the city centre is assumed to require facilities for CAVs to drop off and collect users. The last mile will then be undertaken by connection to other modes such as walk, cycle, or a dedicated CAV last mile service, and maybe a higher capacity shuttle service. How the vehicles behave at the waiting and drop-off zones is critical with regards to dwell time, approach speeds, and reliability of pick-up/human interface, as well as for traffic performance at the roads and junctions at the edge of the city centre. The exact road network that was modelled is displayed below in Figure 81. For modelling the area to assess the impact of CAVs on the Milton Keynes centre area there were two parts to the use case. The base scenario was the current situation of traffic with conventional vehicles in Milton Keynes without the introduction of CAVs. Another element of the base scenario was that in this

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part the city centre road network was also modelled which was cordoned off and not modelled after the measures were implemented.

Figure 81 Exact base microsimulation model built within Vissim

7.1 Traffic performance and space efficiency

The work for the use case analysed how the city of Milton Keynes could be best prepared to tackle the coming of automated vehicles in the near future. The city in anticipation of AVs becoming a part of road-faring vehicles has implemented three measures within the city model to see the impacts. These measures were implemented on top of a large microscopic model. The main theme of the investigation is to assess the effects of restricting access of private cars to the city centre and instead provide some waiting and drop-off areas at the perimeter of the city centre.

The main metrics that were important for the study have been the average travel time improvement, and average delay improvement relative the baseline without automated vehicles. These two metrics were key to understanding congestion that might occur within the city as a result of AVs becoming a part of the mix of cars in the near future. It is also believed that these two metrics combined are what would affect travellers the most. Travellers feel strongly about sitting in traffic jams or their total journey times being increased. The main mode that was modelled for the purpose of this use case was cars, as the

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network modelled area outlined doesn't contain many bikes or pedestrian journeys being more arterial rather than urban in nature it was statistically insignificant to add these modes.

7.1.1 Parameter settings in the assessment tool

The relative improvement in average travel time/delay for cars shows results for a mix of car (CV) and car (AV). The result for car (CV) just shows the results of conventional vehicles within the mix. Car is the only mode visualised within the assessment tool as that is the only mode that has a significant difference to the overall flows.

The assessment tool was used to visualise the results of all scenarios that were simulated. The tool was set to generate a default baseline within the traffic performance input data tab. This was with today's traffic composition without AV's and the corresponding two demand levels of (1.0X and 1.2X, where X denotes the current traffic demand level). This default baseline was used as the baseline to compare for every scenario. The results show the two demand levels averaged out.

The baseline model was used as a reference as of how the traffic is today. To notice the differences, it is important to note that the measures had no city centre area like the baseline. The cars within the baseline have origins and destinations of vehicles going towards the city centre whilst with the measures implemented the cars are stopped at the perimeter of the city. Therefore, it is not a like-for-like comparison. However, to visualise the current traffic situation the baseline is necessary. To analyse the effect of the measures it is deemed much more suitable to compare measures referenced to each other.

7.1.2 Results and discussions

Impact on traffic performance, No measure

Figure 82 presents the average travel time over two demand configurations for each stage of coexistence. The results confirm the envisaged hypothesis that as software programmed within the CAVs starts to become more confident in its ability in later stages there is a reduction in the average travel time. This graph can be thought of as what will happen in the city if no measures are introduced and the CAVs are allowed during all stages of coexistence.

The figure shows that initially as CAVs are introduced if there are no measures introduced comparative to today, during the Introductory stage, with Cautious CAVs it will make the city traffic worse and the average travel times would increase. This is shown by the dip in travel time improvement. However as less Cautious CAV's (the Normal driving logic) start to enter the mix this will then be the same as today's traffic situation within the city. Finally, in the Prevalent stage with more confident types of CAVs the travel times would become better by a proportion of approximately 5%.

As for the average delay it is observed in Figure 82 that there is sharp increase in delay times when CAVs first come into the mix during the coexistence period. However, it is noticed that later during the coexistence period CAVs have the ability to improve city traffic even without any measures just due to better control and sensory equipment which would make them more confident.

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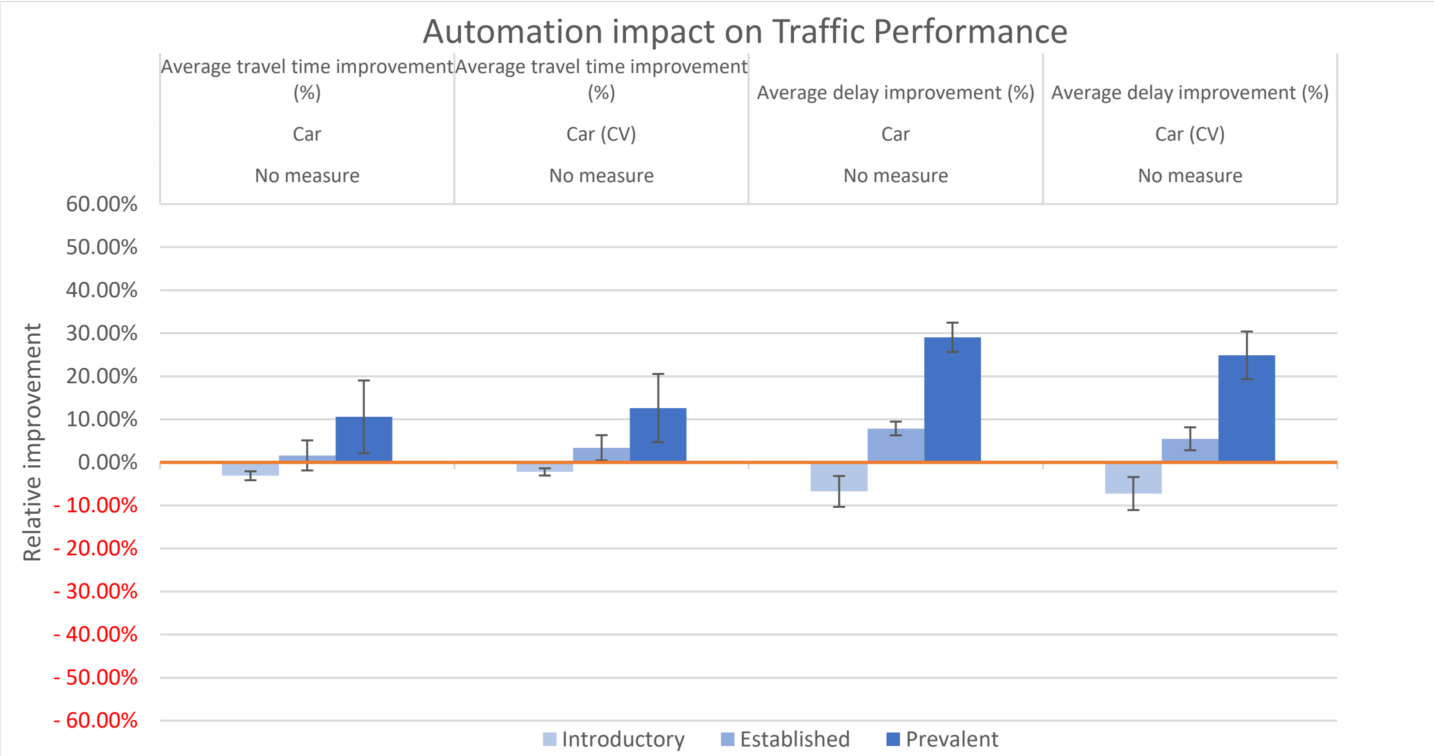

Figure 82 Traffic performance assessment tool output results for no measures

Description measure 1: pick-up and drop-off points

The first measure was the implementation of how the handover of passengers within AVs and conventional vehicles would take place on the edge of the city centre. This was achieved by developing pick-up and drop-off locations at the edges the centre where passengers would shift into PODs or minibuses. The process through which the pick-up and drop-off locations were tested mostly was through an iterative process where modifications with lane numbers and bay areas were done and the output was visually verified. The pick-up and drop-off locations were developed based on the total amount of vehicles that were going through to the centre immediately. The cars were not allowed to return from within a set distance once they had used the pick-up and drop-off location and they had to exit till the second arterial roads and then be allowed to come back. This was done as otherwise empty AVs could be idling around the city with no passengers. Considerable thought was given within the city council as to how best devise the platforms. This resulted in the 14-lane pick-up and drop-off roads with three individual parking bays per platform marked in blue and shown in Figure 83.

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Figure 83 Illustration of measure 1 introduction of the pick-up and drop-off points on the edge of the city

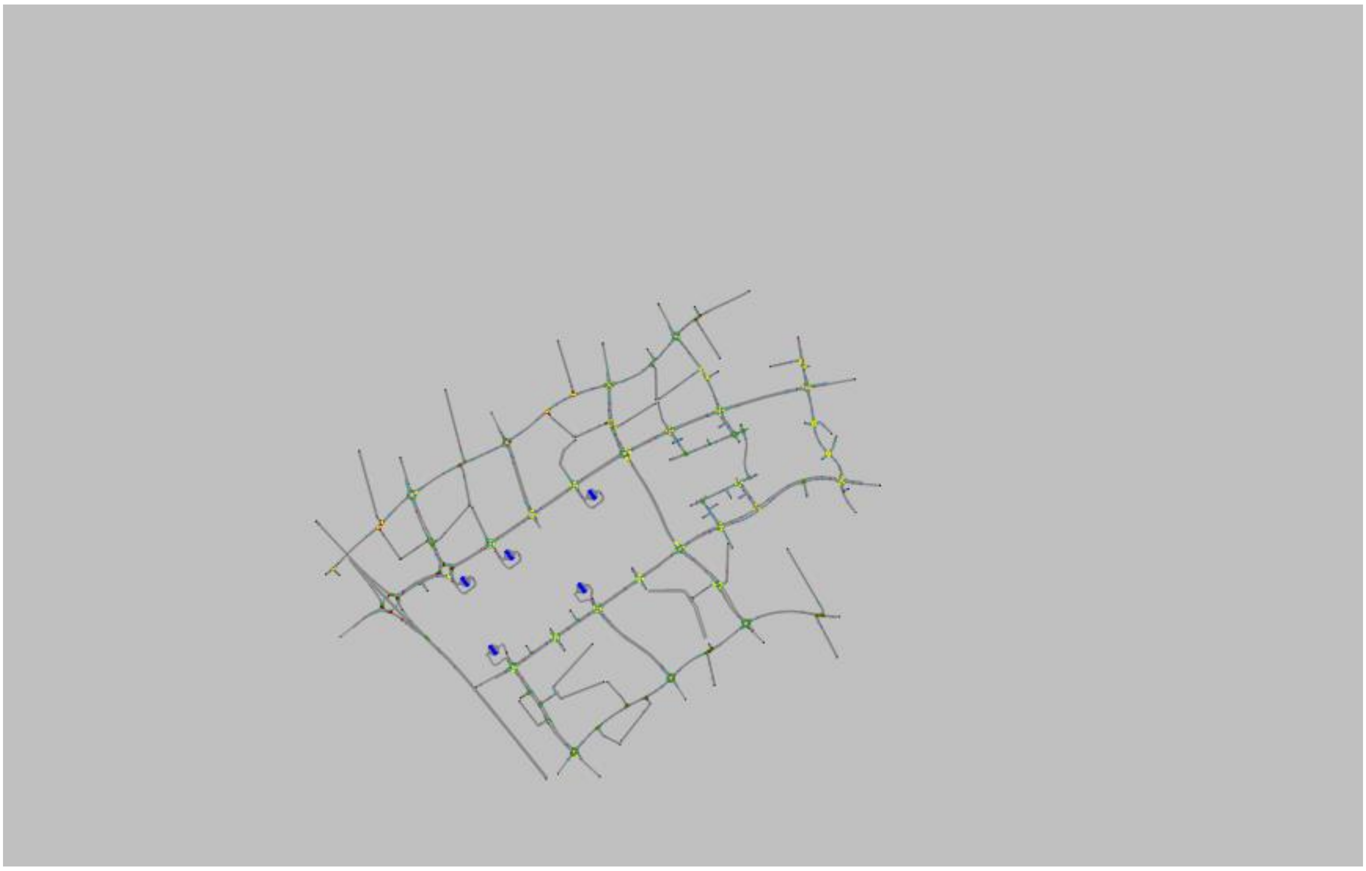

Figure 84 points of pick-up and drop-off at the edge measure1

Impact on traffic performance, Measure 1: pick up and drop off

The graph in Figure 85 shows the average travel time and delay improvement in traffic performance after implementing measure 1 within the city model. The increasing intensity of colours are for different mixes of AVs starting with the Introductory then Established and finally Prevalent stages.

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It is noticed that with the Introductory stage with mainly Basic AVs which operates according to the Cautious driving logic are quite close to the base model without any measure for the pick-up and drop-off. There seem to be marked improvements once vehicles start becoming less cautious. A general improvement is noticed as cars become more confident within the AV mix. This can be due to less time taken to queue at the approaches to the pick-up and drop-off points, as the time for drop-off and pick-up is similar for all three AV classes. This was set to be the same since a human would take the same amount of time to alight a vehicle or get off it regardless of the type of vehicle. Due to this the improvements seen are more from the way vehicles move after and before the drop-off points for PODs. There is also a marked improvement on the conventional vehicles within the mix in the same manner as with the mix it can be thought of them being able to move more freely and having improved travel times because of less congestion on the roads leading up to the bay points. With the Advanced AVs that are more confident there would be less backlog observed onto the arterial roads that approach the intersections and entry points. Therefore, a substantial decrease in delay can be noticed once the Prevalent stage is reached.

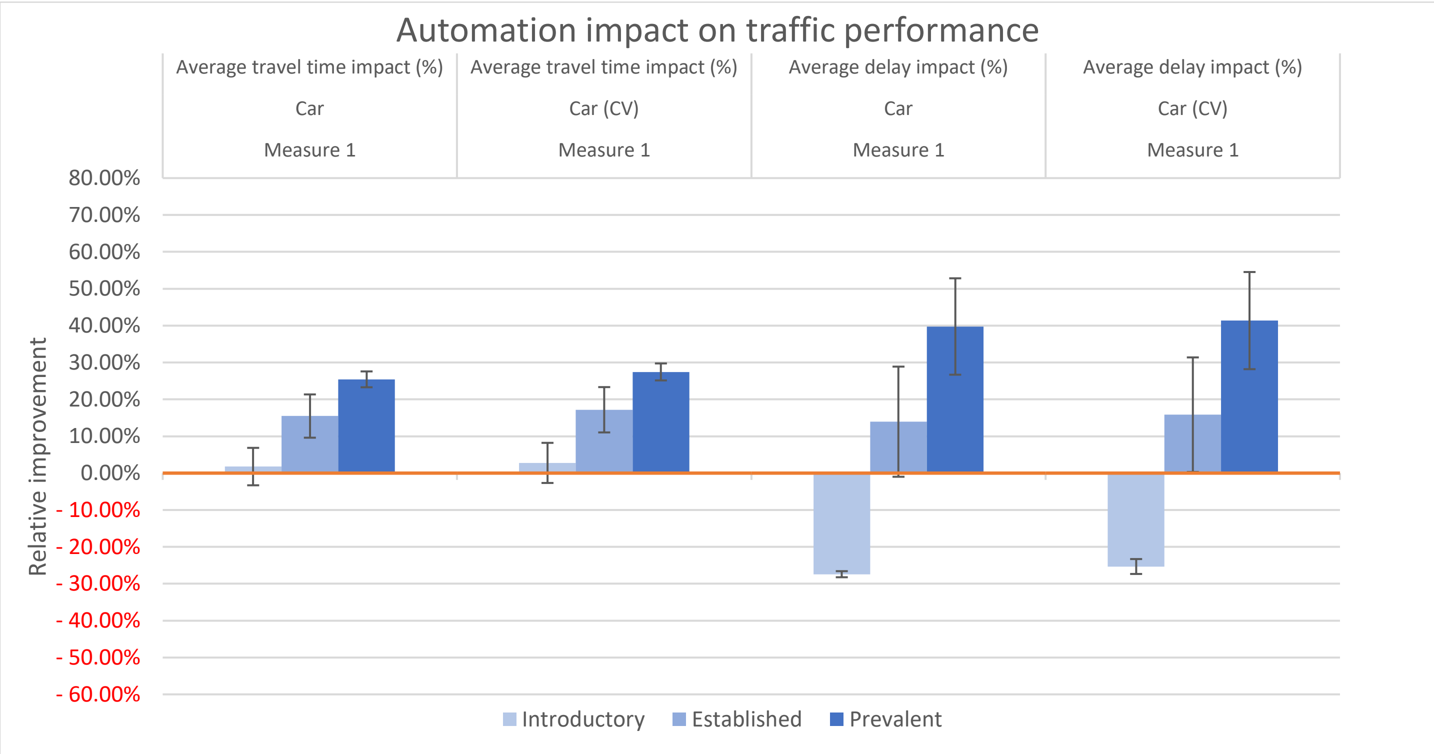

Figure 85 Traffic performance assessment tool output results for Measure 1 - Pickup and drop off points

Description Measure 2: Car Parks

In the second measure access was blocked to the city centre and car park facilities were designed on the edges of the centre. There were six car parks that were introduced into the model. These were envisaged to be multi-storey cark parks where the car parks internal area is designed in such a manner that the queue accumulates within the car park and goes around the multiple storeys in a rectangular fashion on every floor. These were designed to be ungated multi-storey car parks where payments would be done through an automatic number-plate recognition (ANPR) system. This was done so that there should be minimum backlog onto the main arteries within the centre of the city. Even though they

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had been designed in a way to decrease wait time yet there was expected to be some minor delay near the entrances. The car parks are shown as a green box in the network diagram labelled from 1 to 6 in Figure 86 .

To cater for the minor slowing down near entrances, delays were introduced near the car park entrance through reduced speed areas. These were approximately 10km/h through the complete edge. Cars going to the centre through other areas in between the car parks such as in between car park 1 and 2 were re-routed to the new introduced car parks. An example of this is shown in Figure 87. This was based on relative flow probabilities.

Figure 86 measure 2 building car parks for AVs and CVs on the city centre perimeter

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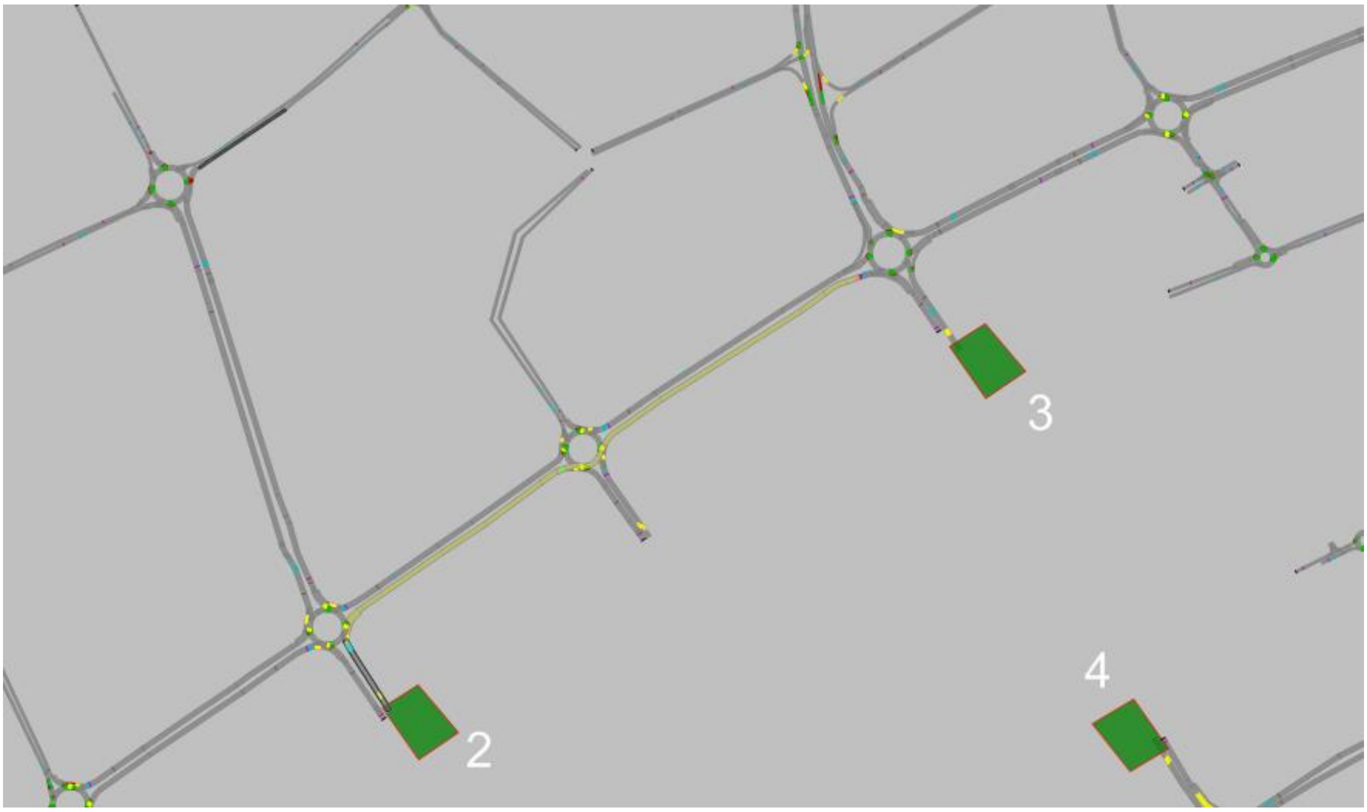

Figure 87 Rerouting of cars that would normally go straight into the centre

Impact on traffic performance, Measure 2: Car Parks

The graphs in Figure 88 shows the average travel time and delay improvement in traffic performance after implementing measure 2 within the city model. With the parking areas introduced as a measure to the base model we see a worsening of traffic during the Introductory stage for the average travel time. This could be due to the queuing of vehicles that are entering the car park. The reduction in speed and redirection of vehicles (AV & CVs) onto one of the car parks increases the travel time of vehicles within the network. In the Established stage the cars have a delay similar to that of todays with no measure. Given that no cars are flowing in yet since AV logics are much better, they generally would conform similar to the todays scenario even with the measure introduced. With the Prevalent stage we see an improvement of around 10% in average travel time with cars. This is a considerable improvement given the measure introduced for AVs and CVs is to head into designated parking spots. In the future if the AVs are connected to the parking spot they will know where an empty spot is hence reducing any idling time even further. As CAVs would have tighter margins leading into car-parks the more confident they get the margins such as headway distance would decrease. This is noticed in the delay difference between the Introductory stage and Prevalent stage.

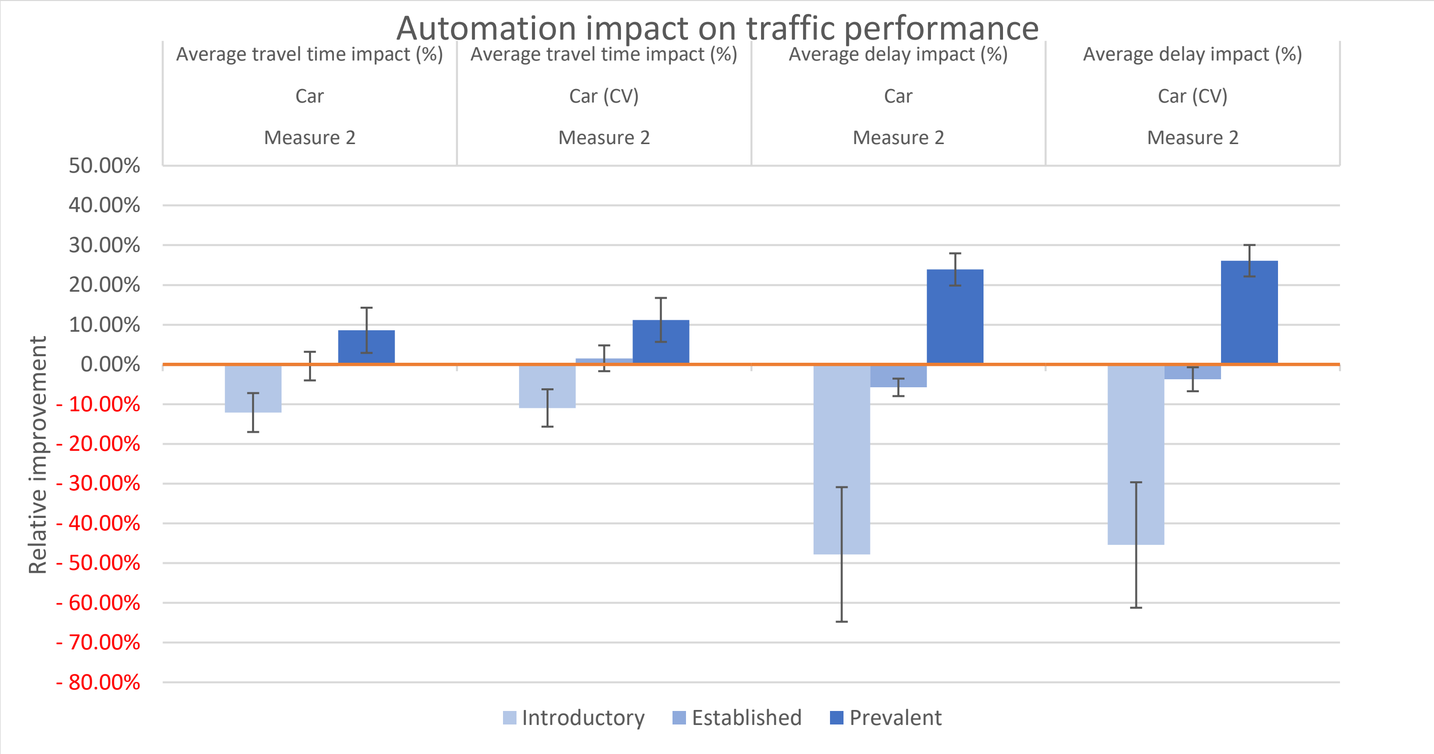

Figure 88 Traffic performance assessment tool output results for Measure 2 - Car parking spaces

Description Measure 3: Addition of a third lane

The third measure introduced another lane within the same road width. As AVs start emerging, they will have closer lateral tolerances compared to traditional human drivers. The premise was that AVs due to onboard sensors such as lidar along with accurate precision maps would know down to a very small fraction of where it is on the road. Consequently, they will be able to maintain closer proximity with cars in adjacent lanes whilst still maintaining similar desired speeds on a straight stretch of road.

This measure was added to the model as a third lane that is painted however without change the total width of the roads. The previous lane width was 3.5 m per lane and 7 m in total for a dual carriageway within the base model. These were changed systematically to 2.33m per lane width. Figure 89 shows the addition of a third lane within the same model.

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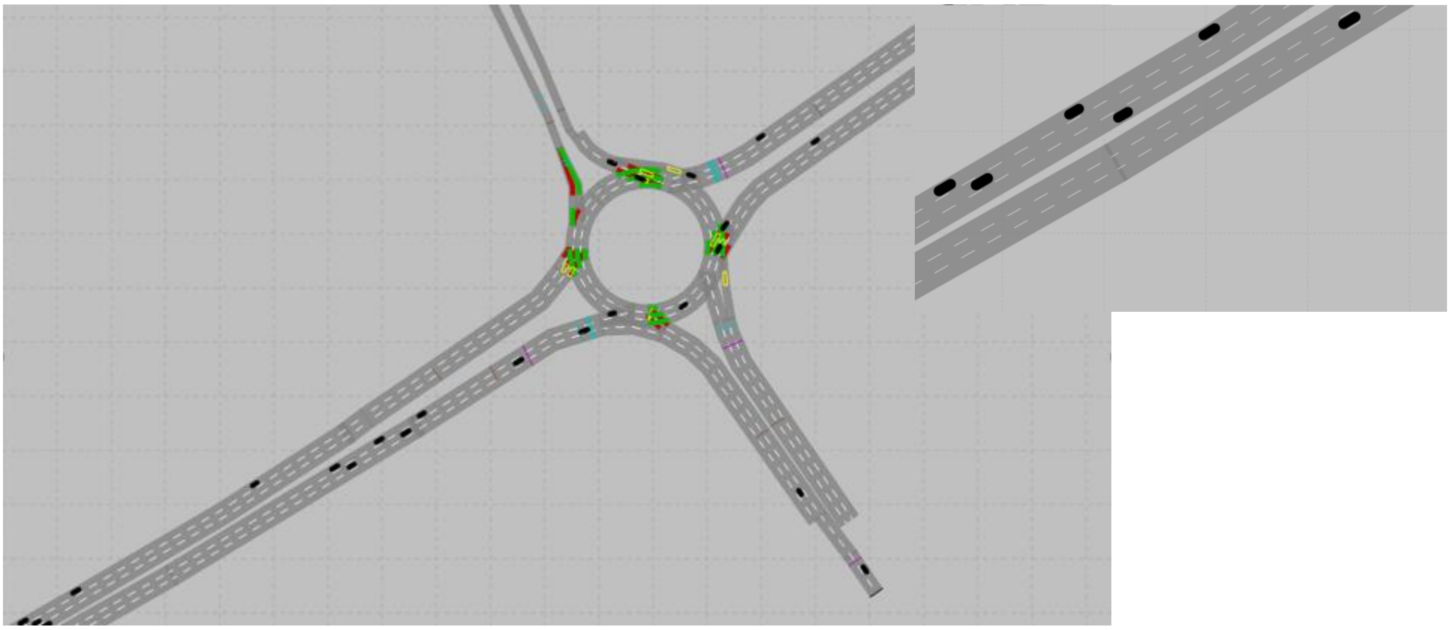

Figure 89 Illustration of measure 3 which implies painting more lanes for AVs within the same road width

Impact on traffic performance, Measure 3: Addition of a third lane

The graph in Figure 90 shows the average travel time and delay improvement in traffic performance after implementing measure 3 within the city model. This measure introduced lateral lane expansion for AVs. In the Introductory stage the measure leads to a slight improvement of travel time by 5% and a decreasing delay of around 20%. With the Established stage vehicles with the Normal driving logic have better tolerances and hence are able to go around the network more easily as compared to the Introductory stage. This is shown by about a 20% improvement in average travel time in Figure 90. As a result of this human driven vehicles (CVs) also have a marked improvement in the total travel time. This is due to humans having more space freed to travel around the network much faster than before. Finally, with the Prevalent stage when Advanced AVs dominate the mix, we can see a marked improvement of 30% due to be improved tolerances.

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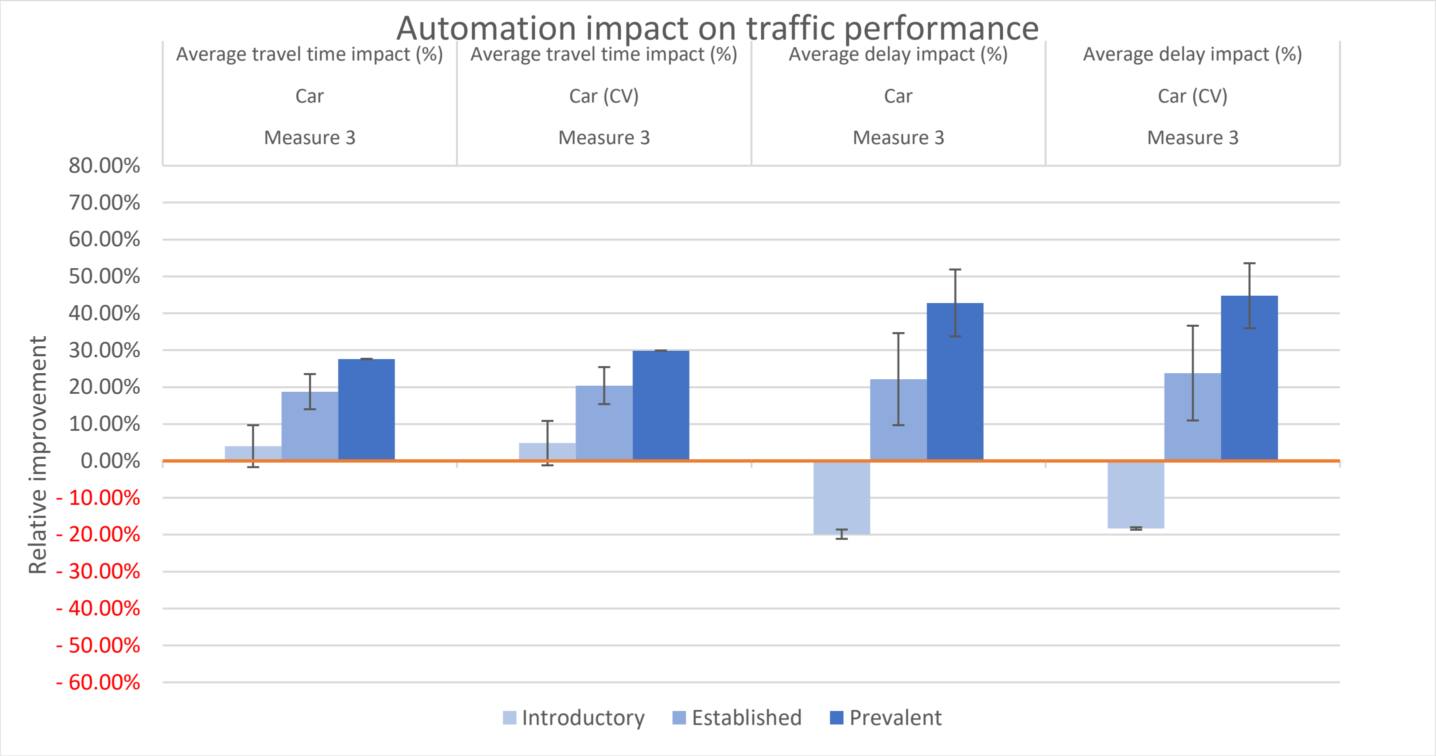

Figure 90 Traffic performance assessment tool output results for Measure 3 - Addition of third lane

Overall comparison of all three measures

Graphs in Figure 91 and Figure 92 compares all the measures tested out by the city within simulation to ascertain what possibility would be the best one to make the city AV ready. The graphs provide summative comparisons for both the average travel time and average delay improvements.

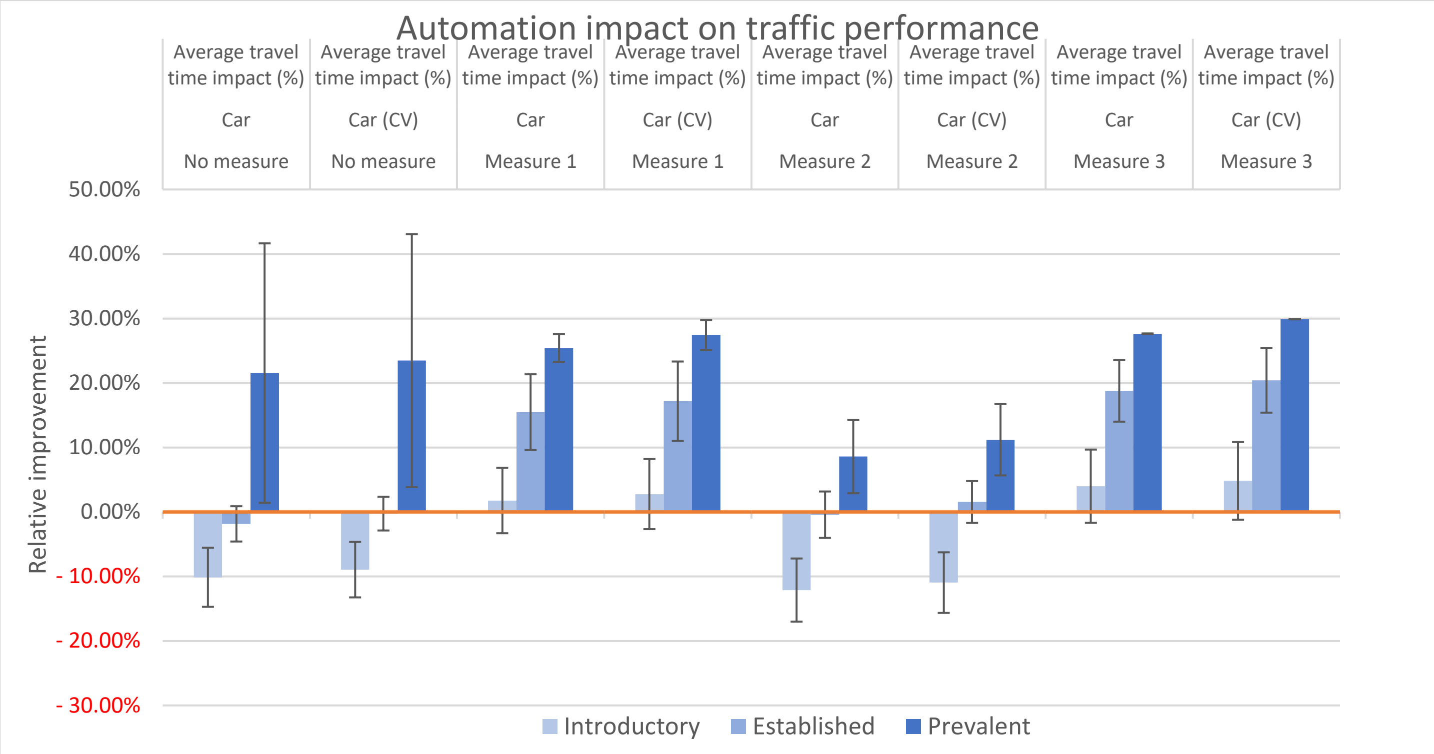

Figure 91 Comparison graphs of all measures showing travel times improvements

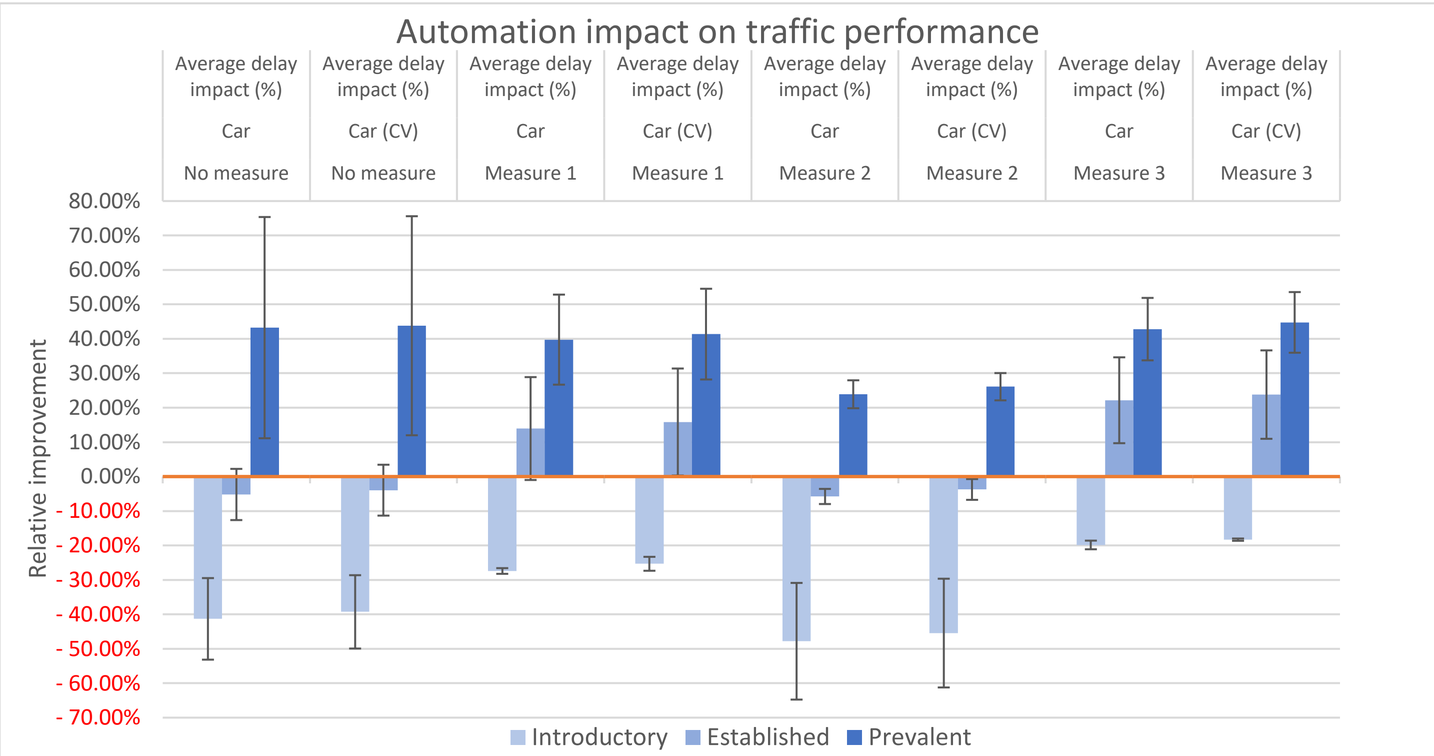

Figure 92 Comparison graphs of all measures showing delay improvements

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7.2 Qualitative safety assessment

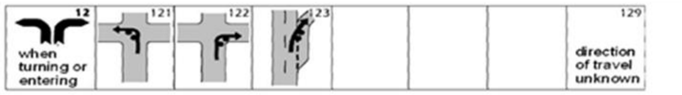
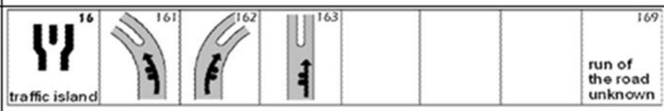
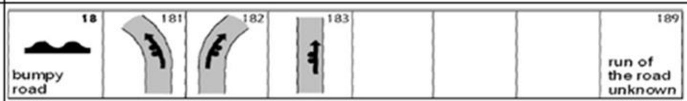
This section illustrates the identified relevant accident types for use case 5. Accident types most of the time within Milton Keynes the accidents are between vehicles. Milton Keynes' master plan was devised in such a manner that pedestrians and cyclists are grade separated in the arterial corridor as well as within the urban city centre area. This means the chances of a road-faring CAV to be involved in an accident with pedestrians are next to negligible.

The type of accidents that would affect this use case are accident type 1, type 2, type 6 and type 7. These different types are explained below from Table 37 - Table 44. The result tables are classed according to road type i.e. arterial or urban road types.

7.2.1 Type 1 Driving Accidents

Type 1 accidents are single car accidents. There are four potential type of accidents discovered within the urban road case shown in Table 37. These are potentially possible within the city centre of Milton Keynes as there are some traffic islands and occasionally roads can be uneven. Given that there are some unsignalized areas where there is also chance of turning off to another road.

Table 37 Type 1 Urban road driving accidents that could occur in use case 5

Type of accident	Description	Sketch
Type 12	Turning in or off to another road	
Type 14	On a straight road	
Type 16	On a traffic island	
Type 18	On a uneven road	

For the arterial road there were seven accident subtypes discovered shown in Table 38. The arterial roads are mostly roundabouts and there is risk of accident within a curve and including curves with priority. There are some roads that sway around a bit and there is difference in gradients as well within the arteries of Milton Keynes. The dual carriage ways are sometimes separated by a traffic island as well.

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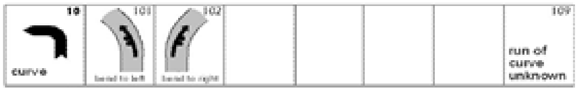
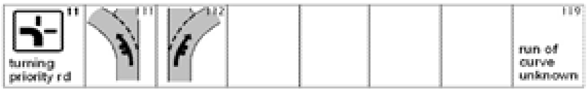
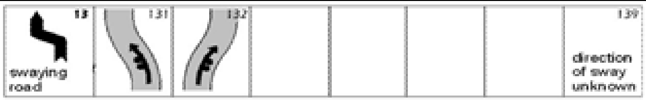
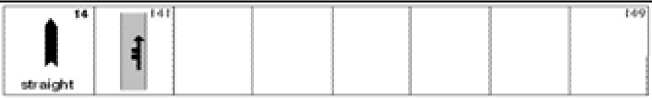
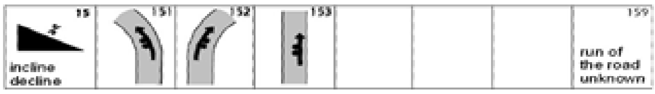
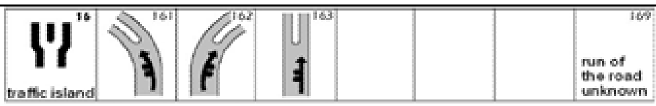
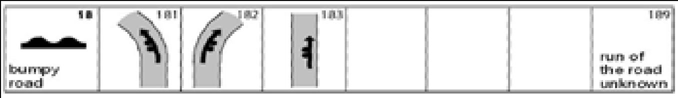
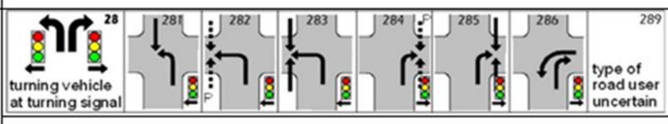
Table 38 Type 1 Arterial road driving accidents that could occur in use case 5

Type of accident	Description	Sketch
Type 10	In a curve	
Type 11	In a curve with turning priority	
Type 13	At a swaying road	
Type 14	On a straight road	
Type 15	On a gradient	
Type 16	On a traffic island	
Type 18	On a uneven road	

7.2.2 Type 2 Turning off Accidents

Turning off accidents would be quite common at intersections within Milton Keynes. The urban road turning off accidents identified are displayed in Table 39. There are a few points within the city centre main midsummer boulevard where there are signals that allow a turning off vehicle to interact with another user coming from the opposite direction hence having a potential chance of an accident.

Table 39 Type 2 Urban road turning off accidents that would occur in use case 5

Type 21	Conflict between a vehicle turning off to the left and oncoming traffic	
Type 28	Conflict between a turning off vehicle and another road user coming from the same or the opposite direction when the turning traffic is regulated by traffic lights	

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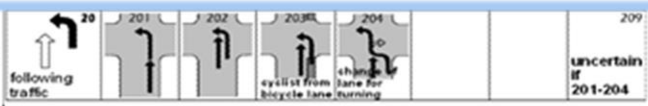
The arterial road turning off accidents selected are displayed in Table 40. There are three different subtypes that would effect AVs. There are some key roundabouts that would have these types of interactions classified.

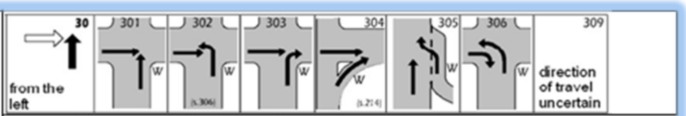
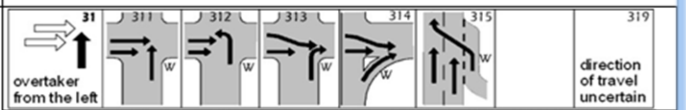
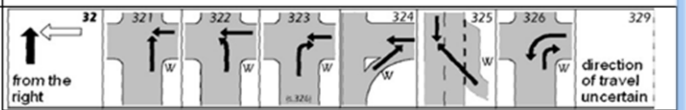
Table 40 Type 2 Arterial road turning off accidents that could occur in use case 5

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

7.2.3 Type 3 Turning in /crossing Accidents

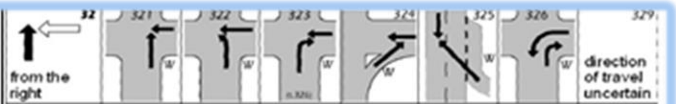
These types of accidents consider conflicts that mainly occur at the unsignalized intersections between road users with priority. The accidents subtypes that could cause the most concern within the urban roads in Milton Keynes mostly in the centre of the model are shown in Table 41.

Table 41 Type 3 Urban road turning in/crossing accidents that could occur in use case 5

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.	

There is only one subtype identified for turning in accidents within arterial roads. This is displayed in Table 42.

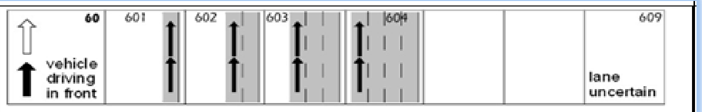
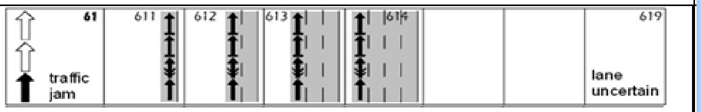
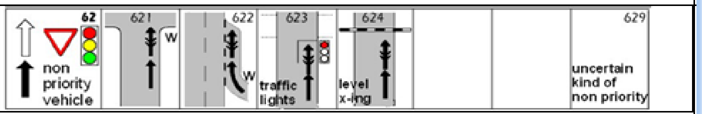
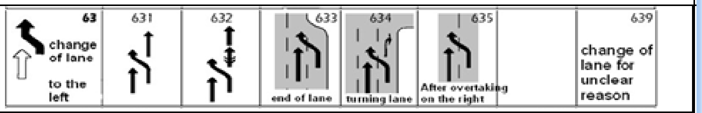
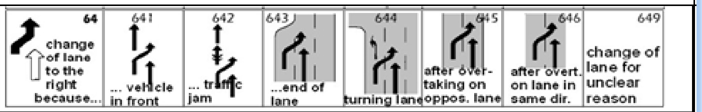
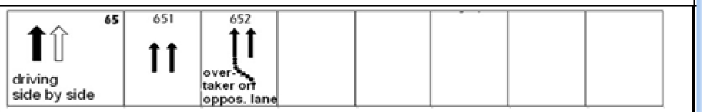
Table 42 Type 3 Arterial road turning in/crossing accidents that would occur in use case 5

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

7.2.4 Type 6 Accidents with lateral traffic

These accident types are for vehicle to vehicle interactions within laterally moving traffic. As Milton Keynes has quite a few dual carriage ways separated with islands in between within the urban area there are six different subtypes of accident that were selected. These are summarized in Table 43.

Table 43 Type 6 Urban road accidents in lateral traffic that could occur in use case 6

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

The external arteries of Milton Keynes are dual carriage ways. There is a high chance of lateral moving traffic interactions. These subtypes of accidents discovered for arterial roads are displayed in Table 44.

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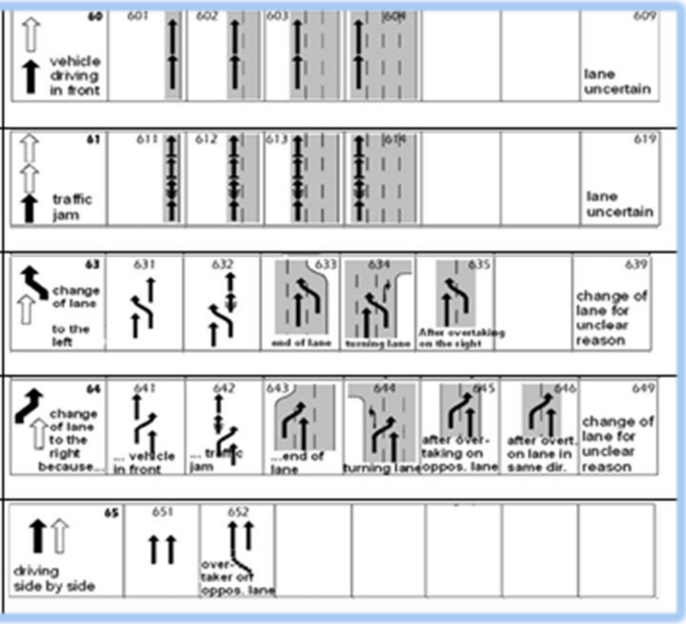
Table 44 Type 6 Arterial road accidents in lateral traffic that could occur in use case 5

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



7.2.5 Type 7 Other accident types

This category of accident covers the unusual case of accident that are normally not expected. The accident subtypes discovered for these were six for urban roads and five for arterial roads. This is show in Table 45 and Table 46. Vehicles can break down within Milton Keynes and as there are a few warehouses on the external areas there is a probability that a fixed object is dropped by a vehicle on the roads. There is also a chance of wild foxes and badgers crossing the road occasionally.

Table 45 Urban road type of other accidents that could occur in this use case

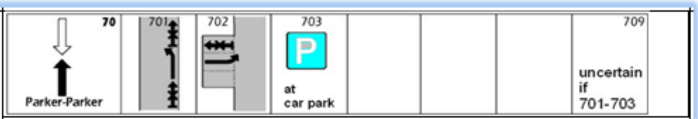
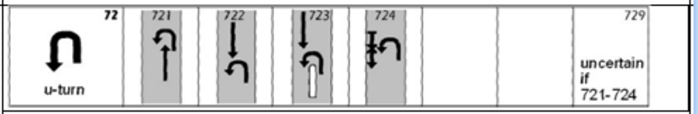
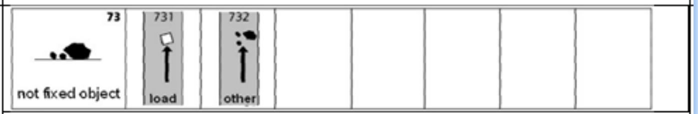
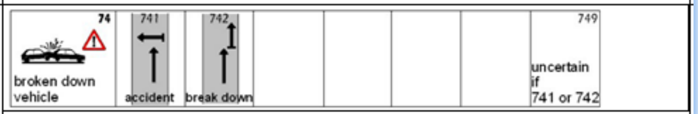
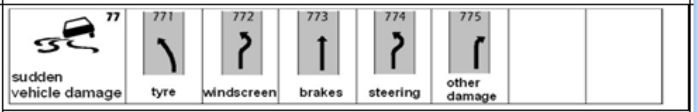
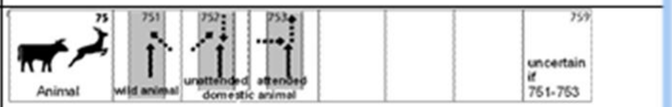
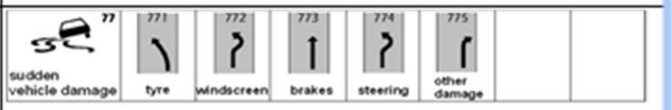
Type 70	Accident with two parking vehicles.	
Type 72	Accident due to a u-turn.	
Type 73	Accident due to a not fixed object.	
Type 74	Accident due to a broken down vehicle.	
Type 76	Accident due to a sudden physical disability of a road user.	
Type 77	Accident due to a sudden technical defect on the vehicle.	

Table 46 Arterial road type of other accidents that could occur in this use case

Type 73	Accident due to a not fixed object.	
Type 74	Accident due to a broken down vehicle.	
Type 75	Accident due to an animal on the road.	
Type 76	Accident due to a sudden physical disability of a road user.	
Type 77	Accident due to a sudden technical defect on the vehicle.	

7.2.6 Results

The city model constructed is mostly arterial with an urban city centre. Hence it covers both major road types within the model. The results from the qualitative assessment tool are presented in Table 47 and

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Table 48. Table 47 shows the results for urban roads whilst Table 48 shows the results for arterial roads. The table results depict qualitatively how the road safety would be impacted and the number of accident types. The colours range from red to green where red would be a negative impact and green is the most positive impact. It is observed that in general the advent of CAVs would impact the city safety positively. As expected, due to better lane control, better surrounding awareness there would be less accidents on both road types. As there is grade separation within Milton Keynes a lot of type 4 (accident with pedestrians) and type 5 (accidents with parked vehicles) accidents are already avoided regardless of CAVs within the mix. It is noticed that in both cases in the city during level 4 and level 5 vehicles that the CAVs will reduce the number of accidents. It is observed that in the case of the arterial roads for type 2 and type 3 accident types the roads safety increases but marginally less than in the case of the urban roads. It is observed that for other types of road safety we see a general improvement in both accident types. However, this is an active area of research and actually one of the major hindrances to having fully autonomous level 5 vehicles. To quantify every single case that could potentially be harmful data has to be manually labelled and trained. Due to the stochastic nature of the environment and how different human agents and objects interact this although seems positive could have a neutral impact in reality even after the level 5 vehicles are deployed.

Table 47 Qualitative safety assessment for use case 5 for urban roads. The number shows how many sub-accident types the driving function is estimated to imply negative, none, positive or very positive impacts on safety. Grey marked cells are accident types that are considered irrelevant for the driving function in the use case.

	Type of accident	Urban Pilot				Fully automated private vehicles			
		☹️	😐	🙂	😀	☹️	😐	🙂	😀
1	Driving				4				4
2	Turning off				2				2
3	Turning-in / Crossing				4				4
4	Pedestrian								
5	Accident with parking vehicles								
6	Accident in lateral traffic				6				6
7	Other accident type			1	5			1	5

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Table 48 Qualitative safety assessment for use case 5 for arterial roads. The number shows how many sub-accident types the driving function is estimated to imply negative, none, positive or very positive impacts on safety. Grey marked cells are accident types that are considered irrelevant for the driving function in the use case.

	Type of accident	Arterial Pilot				Fully automated private vehicles			
1	Driving				7				7
2	Turning off			1	2				3
3	Turning-in / Crossing			1					1
4	Pedestrian								
5	Accident with parking vehicles								
6	Accident in lateral traffic				5				5
7	Other accident type			1	4			1	4

7.3 Conclusions

The work for the use case analysed how the city of Milton Keynes could be best prepared to tackle the coming of automated vehicles in the near future. City scale microscopic modelling is a field of active research and growth. Building a microscopic model on such a large scale of a city caused its unique set of problems. However, to notice the real effect of CAV driving models on a city and to be able to visualise the CAVs it is concluded that this was the right approach to take.

The city of Milton Keynes in anticipation of AVs becoming a part of road faring vehicles has implemented three measures within the city model to see the impacts. This work considered three measures that were implemented on top of a large microscopic model. With no measures we see a marginal improvement of around 5% with the coming of AVs at their best within the Prevalent stage.

The measure of pick and drop points has shown improvements which trump the improvements shown by car parks. This shows that building a pick and drop lane for AVs and CVs with the correct throughput and regulations can ease congestion within the city. The optimum solution would be found out through the iteration of the correct number of lanes and parking bays required for the pickup and drop off points. However, in this measure, given that robot-taxis might also be prevalent they shouldn't be allowed to roam around the city's arterial corridors unnecessarily. It is also of importance to ensure that no AVs are allowed to roam around the pickup points and have to complete a full leg out before entering again into the area. The addition of a third lane on its own as compared to the no measures case shows a compelling case for different painted lanes for AVs in later stages of coexistence. This marked improvement can be attributed to better lane discipline and tighter gaps. During the later stages of coexistence painting three lanes for AVs have shown the best improvement in average travel times followed by pick-up and drop-off points and finally car parks.

The measure of pick-up and drop-off points with future POD/AV shuttle handovers is deemed to be the best for all three stages of coexistence for the city of Milton Keynes to alleviate congestion and manage the advent of CAVs. Pick-up and drop-off points show the potential improvement of average travel time by 28% and delay times improve by 38% in the Prevalent stage.

A qualitative assessment was undertaken to understand the impacts on safety due to CAVs. It is noticed that in both cases in the city during level 4 and level 5 vehicles that the CAVs might reduce the number of accidents and impact the city positively in most majority types of accidents.

Through a combination of quantitative and qualitative analysis it is realised that for the city of Milton Keynes in this use case, with appropriate measures in place there could be significant benefits in terms of safety and congestion with AVs in the mix.

8 Traffic impact of automation in use case 6: Priority Junction (roundabouts) Operation

The focus of this use case was to evaluate the impact on existing and future infrastructure at roundabouts with the introduction of CAVs. How the vehicles behave at the roundabouts is critical with regards to dwell time, approach speeds for traffic performance at the major arterial roads within Milton Keynes. Milton Keynes unlike typical cities has a high number of roundabouts and intersections. These roundabouts are almost mostly un-signalised. There are 124 roundabouts in total, the most in any UK town. The area that was modelled is located at H3 Monks Way Milton Keynes. This modelled area is approximately 2.5 km by 1 km covering three key roundabouts. The area of interest is displayed in Figure 93 below.

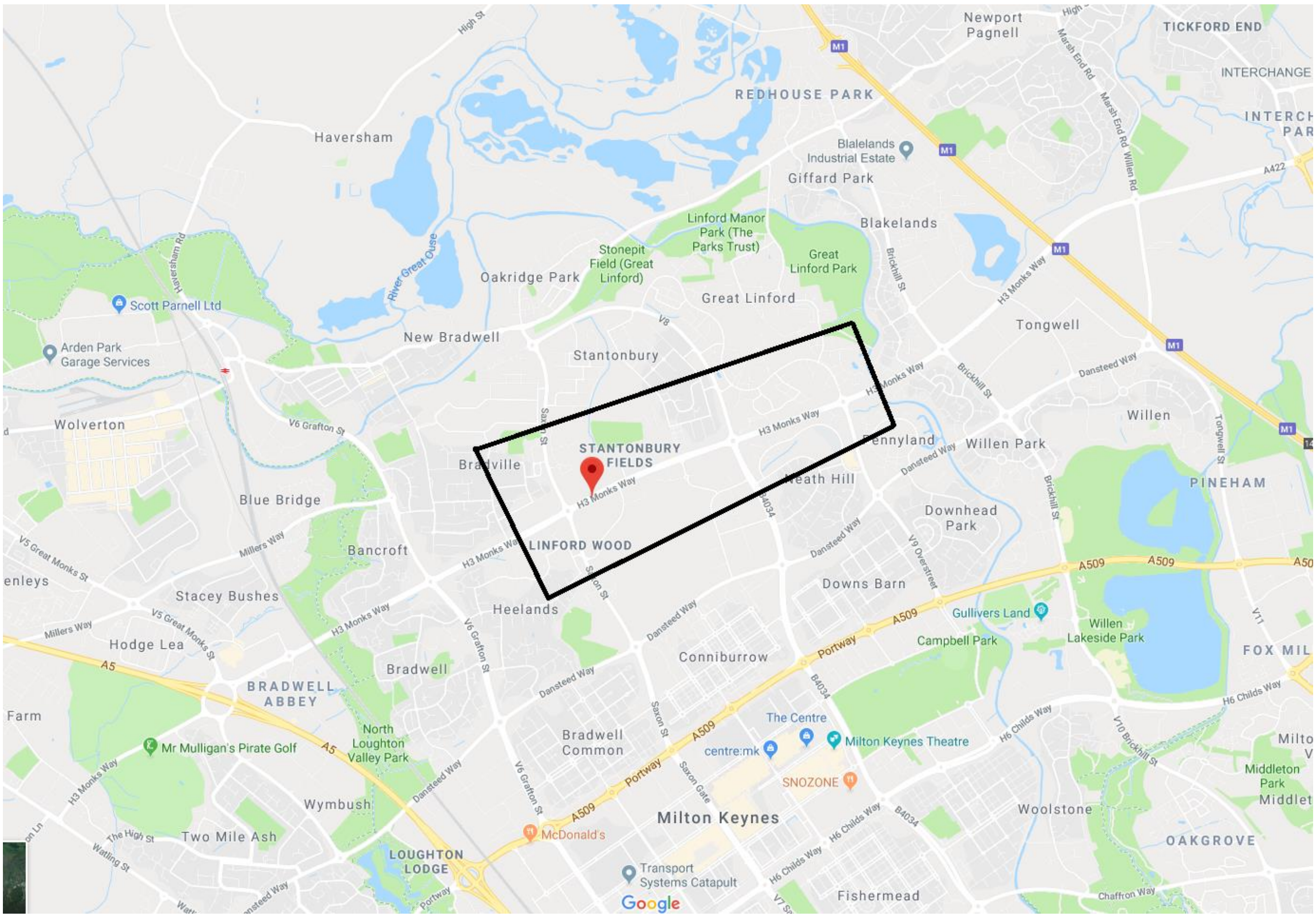

Figure 93 Area of interest modelled within the use case

The exact road network that was modelled is displayed in Figure 94. The road is a dual carriageway having 3 roundabouts and 3 T-type intersections. The base scenario was the current situation of traffic with conventional vehicles in Milton Keynes without the introduction of CAVs.

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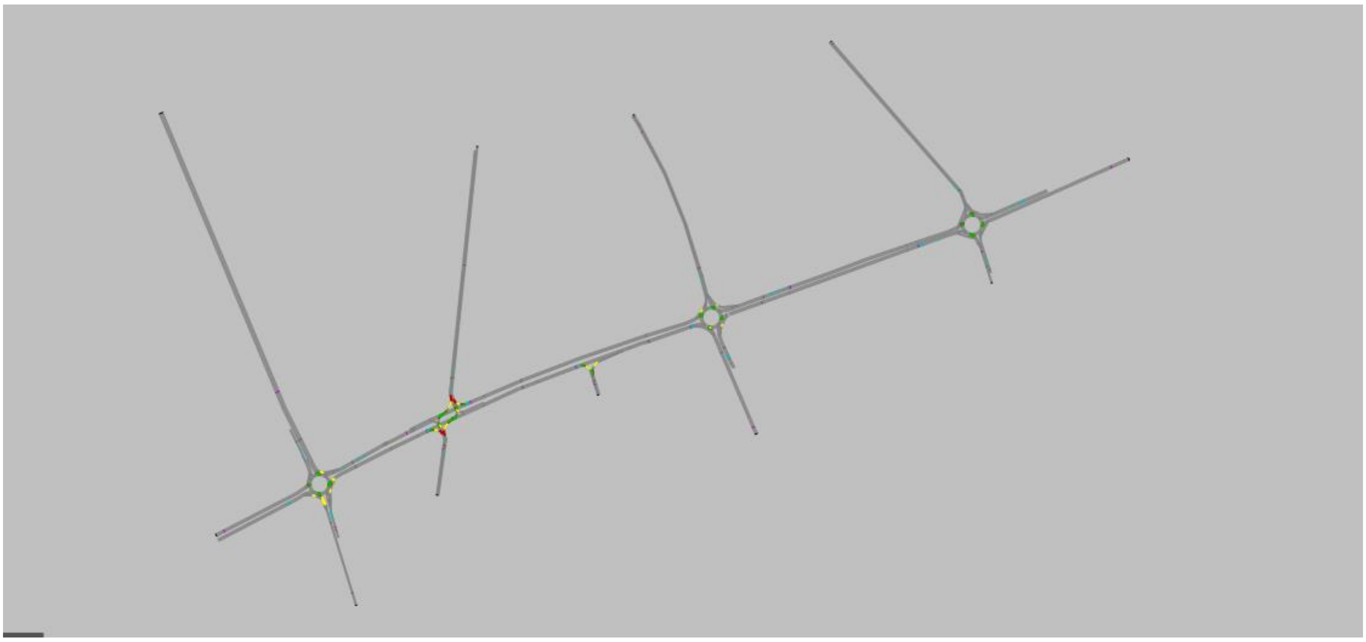

Figure 94 Exact base microsimulation model within Vissim

8.1 Traffic performance and space efficiency

The work for the use case analysed how the city of Milton Keynes could be best prepared to tackle the coming of automated vehicles at intersections within the city. The focus of this use case was to evaluate the impact on existing and future infrastructure at roundabouts with the introduction of CAVs. How the vehicles behave at the roundabouts is critical with regards to dwell time, approach speeds for traffic performance at the major arterial roads with Milton Keynes. Milton Keynes, unlike typical cities, has a high number of roundabouts and intersections. These roundabouts are mostly unsignalized. Milton Keynes has a total of 124 roundabouts in total, the most in any UK town. This work considered two measures that were implemented on top of a microscopic model.

The main metrics that were important for our study have been the average travel time improvement and average delay improvement. These two metrics were key to understanding congestion that might occur within the roundabouts as a result of AVs becoming a part of the mix of cars in the near future. It is also believed that these two metrics combined are what would affect travellers the most. Travellers feel strongly about sitting in traffic jams approaching an intersection or their total journey times being increased.

The main mode that was modelled for the purpose of this use case was cars, as cars make a majority of the proportion of transportation within Milton Keynes on the arterial roads such as the dual carriageway simulated within this use case. It was statistically insignificant to add other modes in the mix. Relative improvements are visualised however with the given uncertainty it is hard to denote any threshold number that would signify the city as being automation ready.

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8.1.1 Parameter settings in the assessment tool

As car was the mode modelled hence within the automation impact car and car (CV) are the only modes that were visualised. The average travel time/delay improvement for Car shows results for a mix car (CV) and car (AV). The result car (CV) just shows the results of conventional vehicles within the mix. car is the only mode visualised within the assessment tool as that is the only mode that has a significant difference to the overall flows.

The assessment tool was used to visualise the results of all scenarios that were simulated. The tool was set to generate a default baseline within the traffic performance input data tab. The baseline was today's situation with no AV's and the corresponding two demand levels of (1.0X and 1.2X, where X denote the current traffic demand). This default baseline was used as the baseline to compare the relative improvement of the metrics for every scenario. The results presented show the two demand levels averaged out.

8.1.2 Results and discussions

Impact on traffic performance, No measure

The Figure 95 presents the average travel time and the minimum, maximum and median over two demand configurations for each stage of coexistence. This case is the no measure case where nothing is changed in the baseline model and what would happen to intersections in the city with the gradual increase in CAV penetration. The result confirms the general trend that would be observed in AVs as their capabilities generally start to improve within the coexistence period between Cautious to All-knowing. It is noticed that if with the current demand when CAVs are allowed to enter the roundabouts during the Introductory stage due to their cautious nature they would cause a much worsening of traffic. This is observed by a decrease in average travel time of cars in Figure 95. During the Established stage the cars within the intersections would be the equivalent of today's human driven vehicles. Given the gaps would be quite similar for a Normal AV and humans, if the AVs are not connected this is the expected result. In the Prevalent stage, the All-knowing cars generally would have difference in their driving behaviour on the dual carriage way approaching intersections and hence an improvement to today's traffic is observed.

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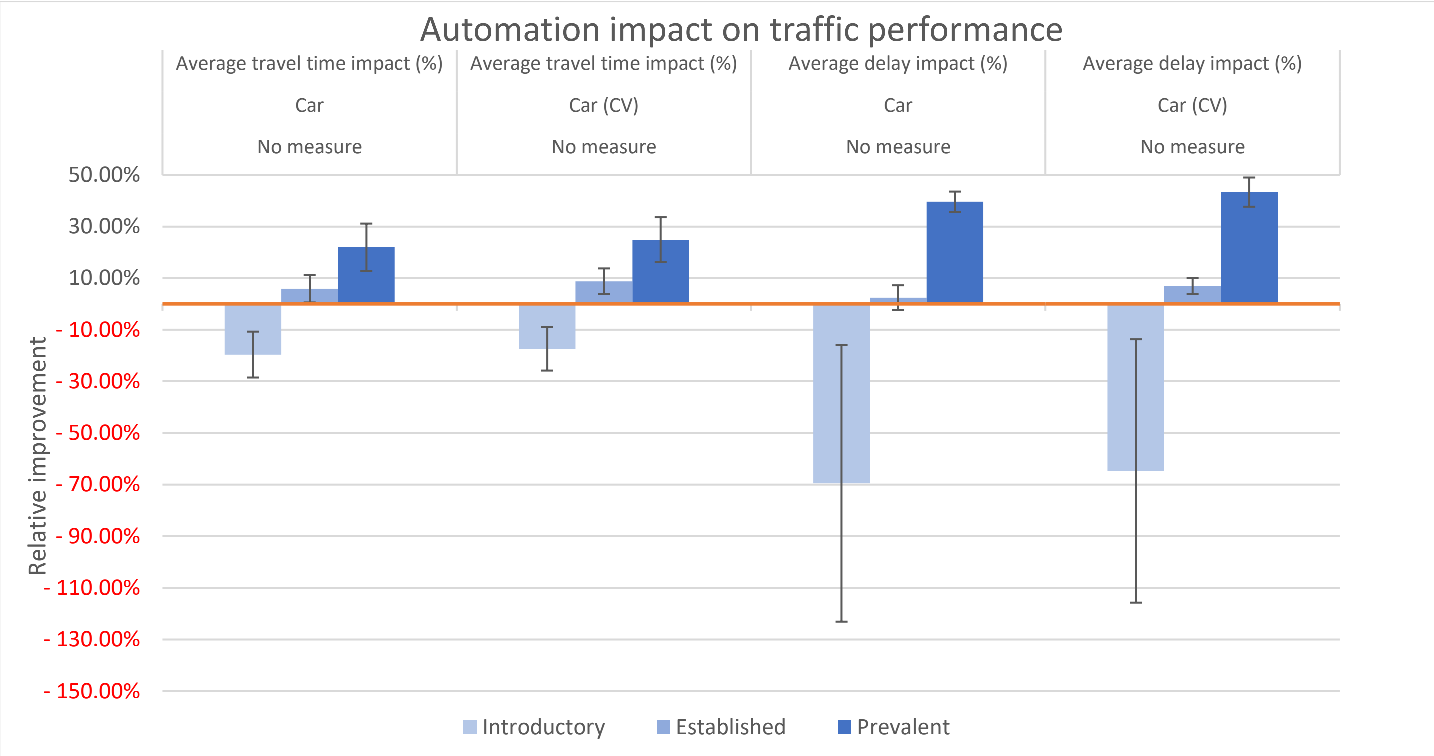

Figure 95 Traffic performance assessment tool output results for no measures

Description of Measure 1: Traffic control

To implement this measure it was assumed that when CAV's approach a roundabout they would be connected. All three types of CAVs would have varying levels of gap acceptance. The steps for a CAV as it approaches a roundabout are summarised in Figure 96. Figure 97 shows a simulation with the measure implemented. The three different coloured vehicles being CAVs of different types while human driven cars are in black. Figure 97 also shows a priority rule at an approach to a roundabout.

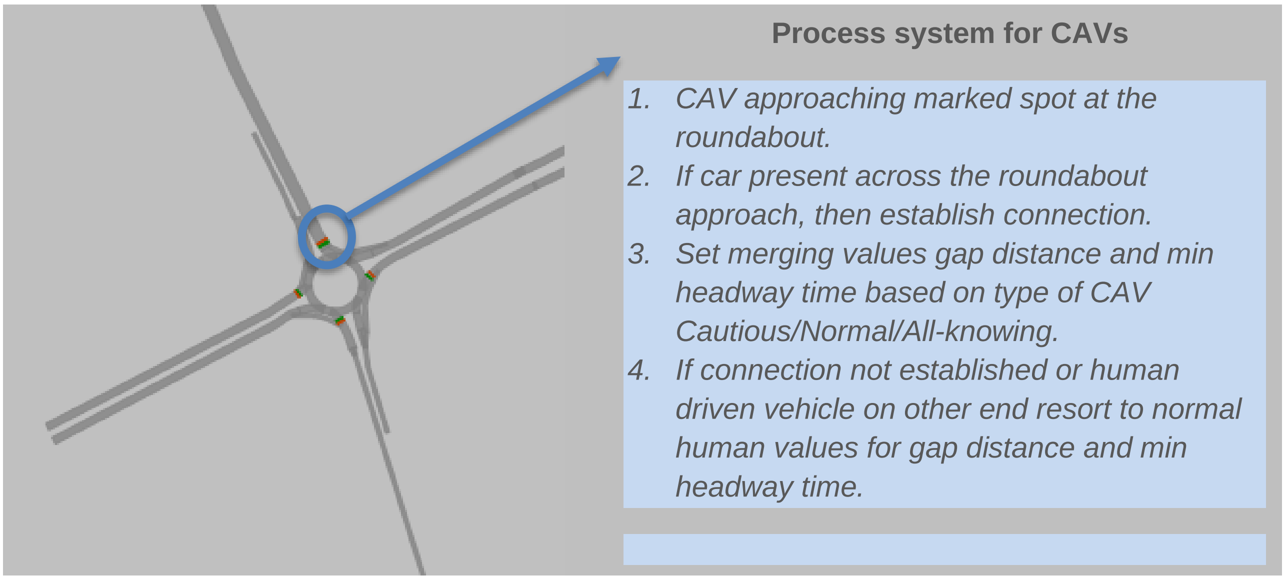

Figure 96 Process summary for CAV approaching roundabouts

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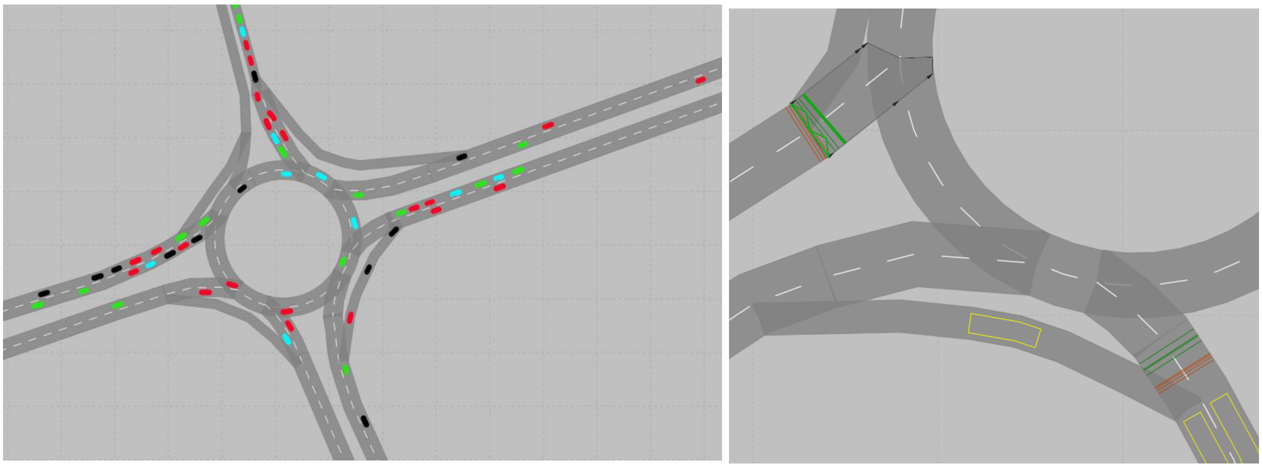

Figure 97 Shows real simulation with CAVs in the mix and priority rules on entrances to intersections

Impact on traffic performance, Measure 1: Traffic control

The first measure was introducing V2V communication on merging intersections. Figure 98 shows the average travel time and average delay time after the first measure is implemented for all demand configurations.

By introducing the V2V communication, it is noticed that the average travel time for the introductory step increases significantly and so does the delay. This is shown by the negative relative travel time improvement noticed in Figure 98. The reason for this can be attributed to the Cautious vehicles in the mix. As Cautious vehicles have large time gaps even with a V2V communication established they cause a significant delay on the road network. It is noted the delay extends to the conventional vehicles as well in the mix. What was visually observed during simulation runs is the fact that if two Cautious vehicles approach a roundabout, together they will cause all the vehicles at their back to queue, even though those vehicles might have better gap times and headway distance.

Within the Established stage due to communication between vehicles it is observed that the average travel time decreases significantly compared to the base case. This can be seen by an improvement of around 30%. With the Prevalent stage cars have a strategy of very aggressive merging onto roundabouts. During this stage they know exactly where the other car is down to a high level of accuracy. Due to this it is observed that average travel time decreases significantly and there is an improvement of around 50% to the baseline. This causes as a result a very large increase in improvement in average delay also noticed in Figure 98.

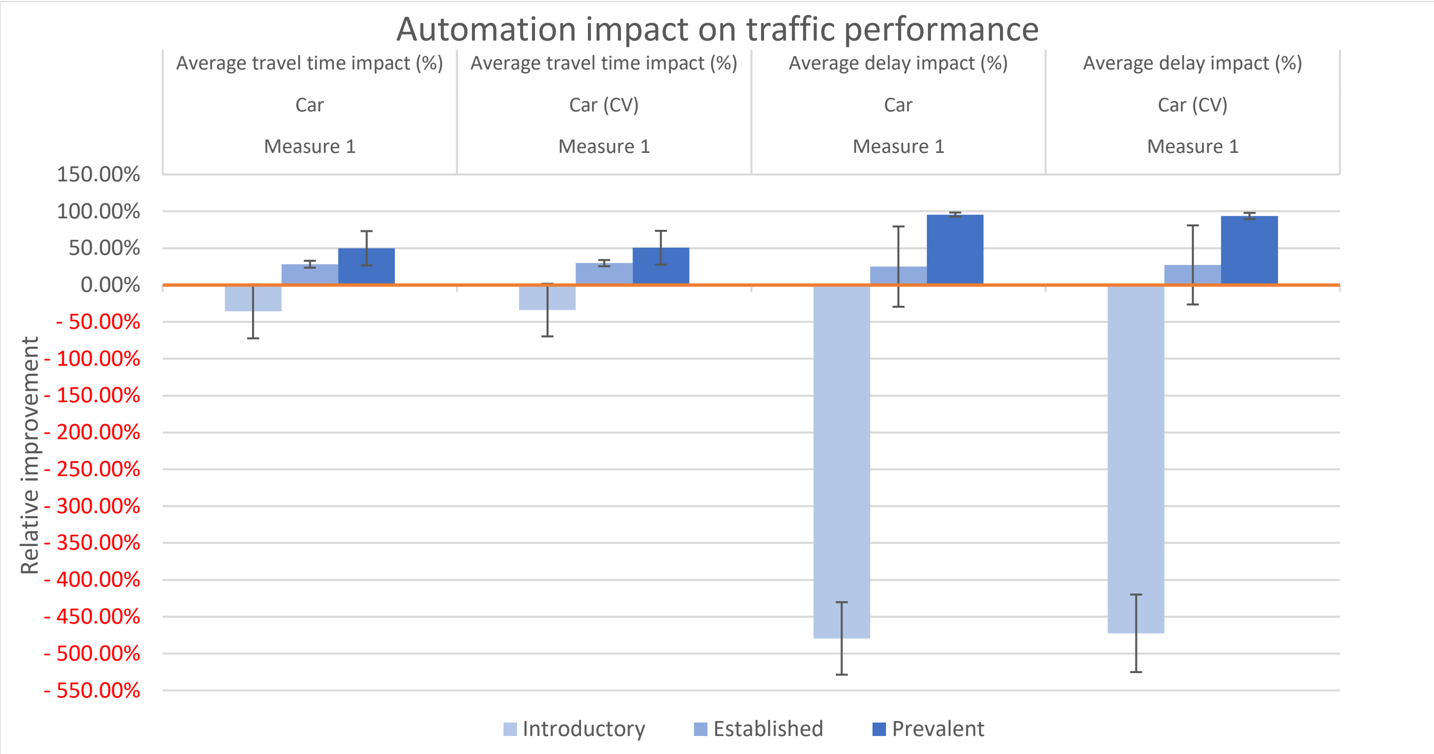

Figure 98 Traffic performance assessment tool output results for Measure 1 – Traffic control

Description of Measure2: Adding a third lane

The second measure introduced another lane within the same road width approaching the intersections. As AVs start emerging, they will have closer lateral tolerances compared to traditional human drivers. The premise was that AVs due to onboard sensors such as lidar along with accurate precision HD-maps would know down to a very small fraction of where it is on the road. Consequently, they will be able to maintain closer proximity with cars in adjacent lanes whilst still maintaining similar desired speeds on a straight stretch of road such as the H3. This measure was added to the model as a third lane that is painted however without change the width of the roads. The previous lane width was 3.5 m per lane and 7 m in total for a dual carriageway within the base model. These were changed systematically to 2.33 m per lane width. Figure 99 shows the addition of a third lane within the same model. All approaches to the six intersections within the base model were modified as shown below in Figure 99.

There are a few ways how this measure might be implemented in reality. One way could be through V2V communication when a vehicle has other automated vehicles around those close the lateral gaps and shift to 3 lanes. The second way could be through a combination of behaviour adaptation and the implementation of on road sensors specifically for AVs hence no repainting of lanes would be needed. In this case however it would be important to see as to how humans react when AVs are travelling in front or behind them with such close lateral tolerances.

Figure 99 Changes to lane allocation approaching intersections

Impact on traffic performance, Measure 2: Adding a third lane

The second measure introduced lateral lane expansion for AVs as they approach intersections. The graphs in Figure 100 shows the average travel time and delay improvement in traffic performance after implementing measure 2 within the city model. It can be observed that even with the Introductory stage where we have Cautious vehicles this still improves throughput within the network and the average travel time improves by 20%. With the Established stage the AVs with the Normal driving logic have better tolerances and hence are able to go through the carriageway and intersections more easily as compared to Introductory stage. This is shown by an improvement of a 12% in Average travel time in Figure 100. As a result of this human driven vehicles (CVs) also have a marked improvement in the total travel time. This is due to humans having more space freed to travel around the network much faster than before. Finally, with the Prevalent stage when confident AVs dominate the mix, we can see a marked improvement of 40% compared to the Introductory stage due to be improved tolerances. There is a marked difference of 60% observed in of the delay between the introductory and prevalent phase which can also be associated with better lane tolerance on the roads leading to the intersections.

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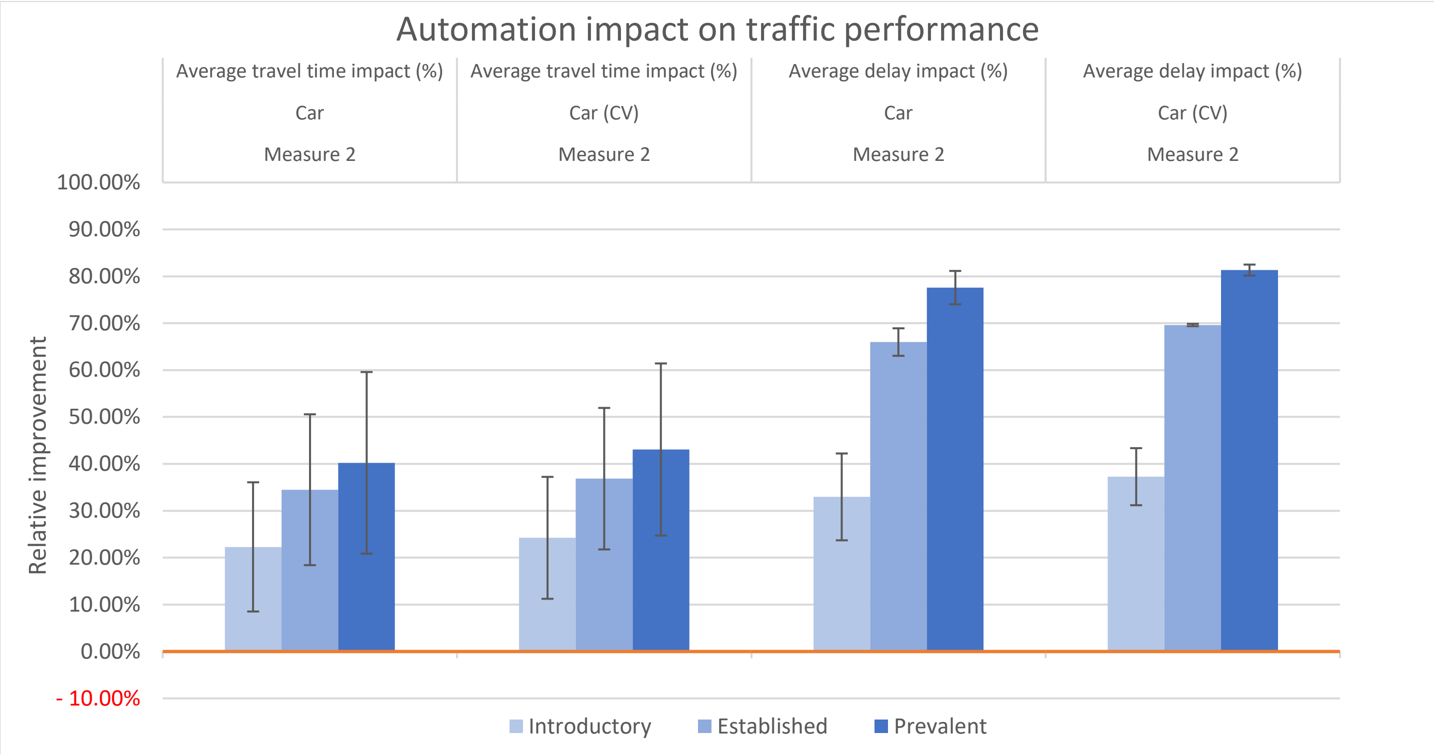

Figure 100 traffic performance assessment tool output results for measure 2 – addition of a third lane

8.2 Qualitative safety assessment

8.2.1 Type 1 Driving Accidents

Type 1 accidents are single car accidents. For the arterial road there were seven accident subtypes identified as shown in Table 49. The arterial road on H3 has three roundabouts and there is chance of accident within a curve and including priority curves. There are some points where the dual carriageways around a bit. The dual carriageways are separated by a traffic island. There are differences in gradients as well within the H3 from one end to the other its elevation goes from 66 m to a high of 85 m.

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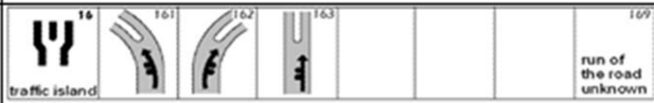
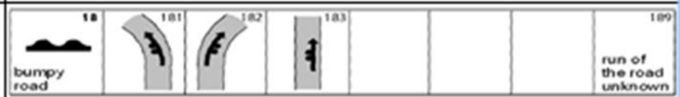
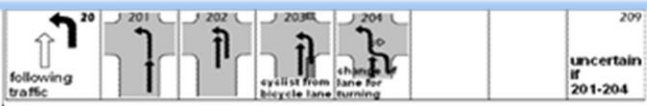
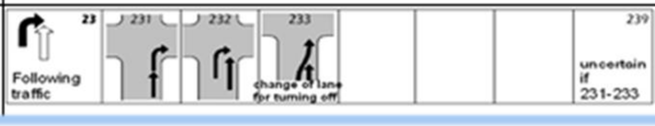
Table 49 Type 1 Arterial road driving accidents that could occur in use case 6.

Type of accident	Description	Sketch
Type 10	In a curve	
Type 11	In a curve with turning priority	
Type 13	At a swaying road	
Type 14	On a straight road	
Type 15	On a gradient	
Type 16	On a traffic island	
Type 18	On a uneven road	

8.2.2 Type 2 Turning off Accidents

These types of accidents are quite common at intersections within Milton Keynes. The arterial road turning off accidents selected are displayed in Table 50. There are three different subtypes that could affect CAVs. There are some key roundabouts that could have these types of interactions classified.

Table 50 Type 2 Arterial road turning off accidents that could occur in use case 6

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

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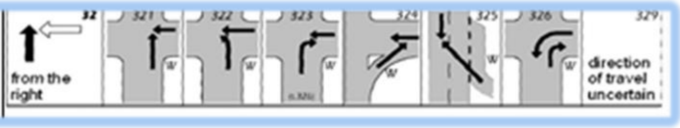
8.2.3 Type 3 Turning in /crossing Accidents

These types of accidents consider conflicts that mainly incur at the unsignalized intersections between road users with priority. There is only one subtype discovered for turning in accidents within arterial roads. This is displayed in Table 51.

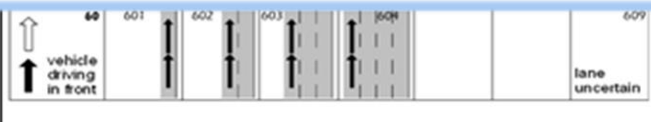
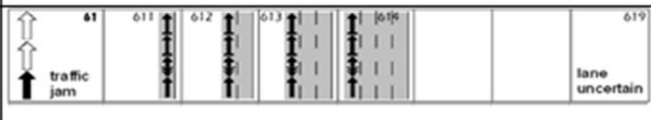
Table 51 Type 3 Arterial road turning in/crossing accidents that could occur in use case 6

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

8.2.4 Type 6 Accidents with lateral traffic

These accident types are for vehicle to vehicle interactions within laterally moving traffic. As the H3 dual carriage way is a separated arterial road these types might be quite prominent. People tend to drive faster on these dual carriageways compared to people in other cities.This type of local behaviour would also need to be incorporated into a CAV to understand its lateral surroundings. The subtypes of accidents identified for arterial roads are five in total and are displayed in Table 52.

Table 52 Type 6 Arterial road accidents in lateral traffic that could occur in use case 6

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

8.2.5 Type 7 Other accident types

This category of accident covers the unusual cases of accident that are normally not expected. The accident subtypes selected for these were six differently types for urban roads. This is show in Table 53. Vehicles can break down within Milton Keynes and as there are a few warehouses on the external areas which means there is a probability that a fixed object is dropped by a vehicle on the roads. There is also a chance of wild foxes and badgers crossing the road occasionally.

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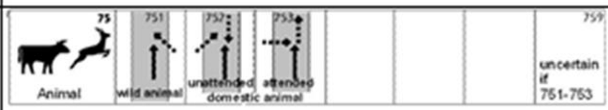
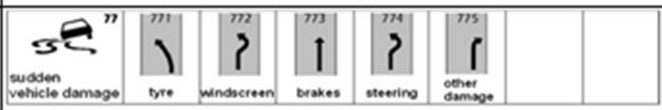
Table 53 Type 7 Arterial road type of other accidents that could occur in use case 6

Type 73	Accident due to a not fixed object.	
Type 74	Accident due to a broken down vehicle.	
Type 75	Accident due to an animal on the road.	
Type 76	Accident due to a sudden physical disability of a road user.	
Type 77	Accident due to a sudden technical defect on the vehicle.	

8.2.6 Results

The city model constructed is mostly arterial with an urban city centre. Hence it covers both major road types within the model. The results from the qualitative assessment tool are presented in Table 54. The table results depict qualitatively how the road safety would be impacted and the number of accident types. The colours range from red to green where red would be a negative impact and green is the most positive impact. It is observed that in general the advent of CAVs would impact the city safety positively. As expected, due to better lane control and better surrounding awareness (Lidar, radar, vision) there would be less accidents. As there is grade separation within Milton Keynes a lot of type 4 and type 5 accidents are already avoided regardless of CAVs within the mix. It is noticed that in both cases the CAVs might reduce the number of accidents. It is observed that for type 7 i.e. other types of road safety, a general improvement is expected. However, this is an active area of research and actually one of the major hindrances to having fully automated (level 5) vehicles. To quantify every single case that could potentially be harmful data has to be manually labelled and trained. Due to the stochastic nature of the environment and how different human agents and objects interact this although seems positive could have a neutral impact in reality even after the level 5 vehicles are developed and deployed.

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Table 54 Qualitative safety assessment for use case 6. The number shows how many sub-accident types that the driving function is estimated to imply negative, none, positive or very positive impacts on safety. Grey marked cells are accident types considered irrelevant for the driving function in the use case.

	Type of accident	Arterial Pilot				Fully automated private vehicles			
1	Driving				7				7
2	Turning off			1	2				3
3	Turning-in / Crossing			1					1
4	Pedestrian								
5	Accident with parking vehicles								
6	Accident in lateral traffic				5				5
7	Other accident type			1	4			1	4

8.3 Conclusions

The work for the use case analysed how the city of Milton Keynes could be best prepared to tackle the coming of automated vehicles in the near future. The city with its large number of roundabouts, had significant concerns on what measures to take to visualise the impacts across the arteries of the city's road network. The city chose one of the busiest arterial roads to test this use case. With no measures an improvement of around 20% was observed in average travel time with the advent of AVs during the Prevalent stage.

This work considered two measures that were implemented on top of the base model. These two measures were classified within traffic control and lane allocation. The measure of traffic control where CAVs are allowed to communicate has shown to have significant improvement at intersections in Prevalent stage. However, it seems during the Introductory stage due to Cautious vehicles it will worsen the initial traffic patterns at intersections. How to implement V2V or V2I communication systems or

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provide the supported infrastructure necessary is now the question underhand. The city finds the results quite promising for CAVs but as of yet it is still not clear what is the best approach to take to be able to make it possible. The intricate details to consider are whether it will be a vehicle to vehicle communication or a vehicle to infrastructure system where the city installs some communication towers at the intersections to relay signals further down. The results achieved by the measure in the Prevalent stage by improving the average delay approximately by 100% makes it seem that the benefits would be substantial for Milton Keynes.

The lane allocation on the approach to intersections shows a compelling case for different painted lanes for AVs. Even with the Cautious CAVs during the Introductory stage there is an improvement in average travel time. This marked improvement can be attributed to better lane discipline and tighter gaps. During the first two stages of coexistence (introductory & established) lane allocation approaching intersections for AV's have shown the best improvement in average travel times followed by traffic control.

A qualitative assessment was undertaken to understand the impacts on safety due to CAVs at the intersections. It is noticed that in both cases during level 4 and level 5 vehicles that the CAVs is expected to reduce the number of accidents and impact the dual carriageway (H3 monks way) positively in most types of accidents.

Intersections are a key part of any city network. How CAVs behave at un-signalised intersections plays an important role in a city's preparedness for automated vehicles. The arteries like H3 monks way in Milton Keynes are almost at the point of saturation with present demand. Milton Keynes is a city filled with intersections and any such city with a large number of major intersections could see a noticeable difference with the measure of traffic control. Hence, observing the results from the use case, it can be concluded to make the city AV ready and to avoid having congestion hotspots on unsignalized intersections, measures need to be introduced on how CAVs would interact within these areas. The most promising of these measures seems to be to introduce traffic control for CAVs.

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9 Traffic impact of automation in use case 7: Impacts of CAV on travel time and mode choice on a network level

The study area for this use case covers the entire Stuttgart Region, an area with 2.7 million inhabitants. Figure 101 shows a map of the study area. Stuttgart is the capital of the state of Baden-Württemberg and forms with about 180 other cities and smaller towns in five counties the Stuttgart Region. The Region is the economic center of the state with one quarter of the state's population and nearly one third of the economic power on 10% of the land's space. Stuttgart City is the cultural and political centre of the region. It is the home of several large international companies (Bosch, Daimler, Porsche), two universities and several polytechnics. It offers a large number of workplaces in the service and industry sector. Stuttgart central station, Stuttgart airport and Stuttgart harbour connect Stuttgart and the Region to other places in Germany and Europe.

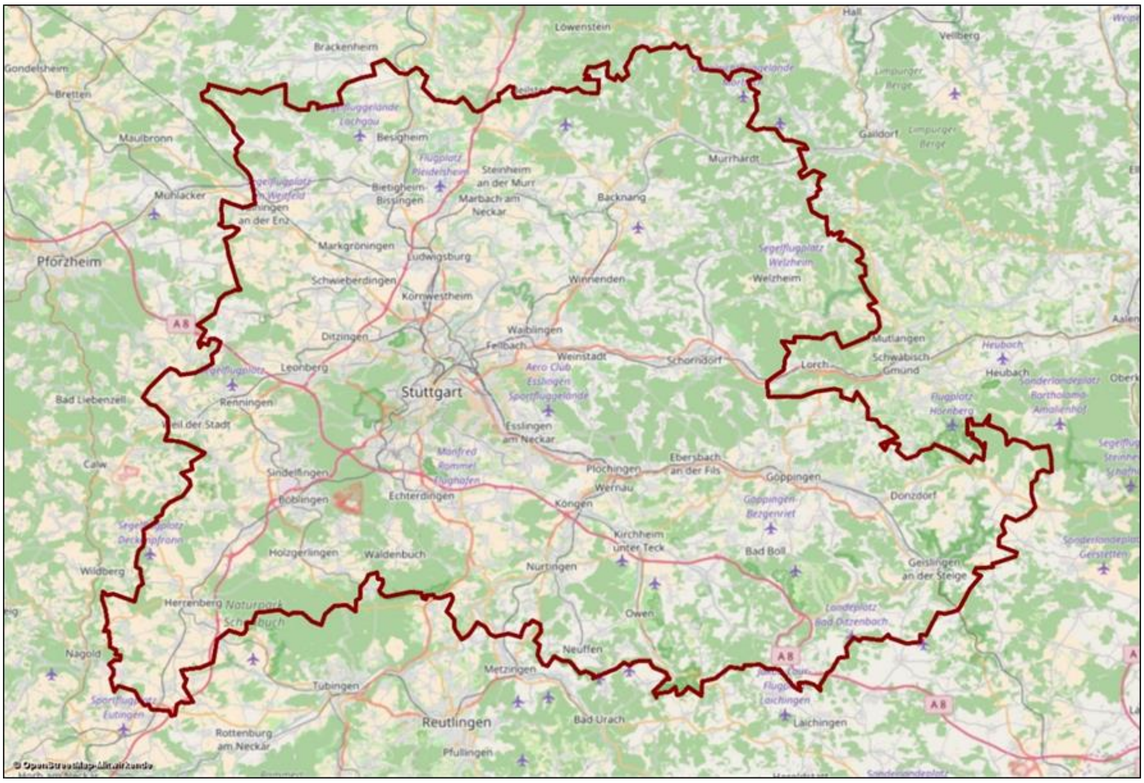

Figure 101: Study area Stuttgart Region (source map: OpenStreetMap)

The local authority and transport planners in Stuttgart City start thinking about the potential impacts of CAV on the traffic situation in and around the City. Since Stuttgart suffers from heavy congestion problems, one main question is, if and at what penetration rate CAV can improve road capacity. A second question addresses the concern, if CAV will make cars more attractive thus leading to a modal shift from public transport to car. The use case shall enable responsible stakeholders to understand potential developments and to consider appropriate measures to reach a desirable state for the City.

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Use case 7 includes modelling methods to integrate impacts of highly, but not fully automated vehicles into macroscopic travel demand models. The methods shall enable users of existing urban and regional models to easily extend their model.

Incorporating effects of CAV on traffic performance is done by using specific passenger car unit (PCU) factors dependent on the roadway type and the capabilities of the particular CAV class. This method does not require new capacities in the model. The PCU factors are determined by evaluating data of microscopic traffic flow simulations. The driving behaviours used for the simulations are partly derived from observations on a test track in Helmond in the Netherlands and partly based on assumptions. In the Introductory stage, CAV perform worse than CV and cannot operate automated on urban streets. In the Established stage, CAV perform better than CV, except for urban streets. In the Prevalent stage, the performance of CAV is better on all roadway types.

Highly automated vehicles allow their drivers to spend some of the driving time on other activities. This leads to the assumption that the perception of travel time in CAV differs from that in CV. The daily commute time including delay from congestion can then be used more efficiently turning a car gradually into a limousine service or a private door-to-door vehicle. The presented method uses a given CAV penetration rate and a travel time perception factor for every road link as input. Within use case 7, changes of +/-0%, -15% and -30% of automated travel time are considered as perception factor.

Another important assumption is the CAV-ready network, i.e. the parts of the network where CAVs can operate without input from a driver, where CAV will have an effect on performance and perception. There are two cases: a CAV-ready network consisting of motorways and motorway-similar roads and an extended one including all main roads.

9.1 Traffic performance

For this use case, the relevant type of metrics is limited to traffic performance. The evaluations presented in this chapter are created with the assessment tool and help to deepen the understanding of possible impacts of CAV.

9.1.1 Parameter settings in the assessment tool

The assessment tool requires input on reference levels for what should be considered acceptable relative impact on traffic due to the introduction of automated vehicles. However, the assessment of impact on automation in terms of relative improvement is difficult for this use case. On the one hand, given the assumptions made, the deterioration in traffic performance metrics is not large enough for any scenario to definitely conclude that impact on traffic of automation is not acceptable. On the other hand, an increase of vehicle kilometres in the network is not a state the decision makers aim for. It depends on the desired impact and to what extent impacts due to changes regarding car usage and traffic performance are acceptable. Thus, no specific values for acceptable relative improvement thresholds are set in the figures.

The assessment tool needs inputs regarding the traffic performance metrics, the traffic mode in question and the measure applied within the scenarios. The tool then accordingly filters the results and combines them to finally create the desired figures. These figures generally show bars, displaying the median value and lines, which represent ranges from minimum to maximum value. All values represent changes

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in comparison to the baseline scenario. To also be able to differentiate between various road-user behaviours (assumed benefits through travel time perception) additionally, the tool was supplemented to this criterion.

The used settings for each evaluation are included directly in the figures' labelling. Furthermore, the mode Car incorporates the metrics for car drivers (CV and CAV) as well as car passengers.

9.1.2 Results and discussion

Figure 102 shows a selection of traffic performance metrics for car and both CAV-ready network alternatives: 'netw=motorways' represents motorways and motorway-similar roads to be CAV ready, 'netw=extended' includes arterials and urban streets as well. More precisely, the average improvement for travel time, travel time per kilometre and delay is displayed. Visualizations above zero correspond to an improvement and are therefore equivalent to a reduction in those metrics' absolute magnitude.

The average travel time experiences throughout almost all scenarios an increase. The reason for this is not necessarily delays only, because there are also cases where delay is improved (=reduced), but travel time increases nevertheless. It is important to take account of the average trip length affecting the travel time. Further trips, even with less delay, can lead to longer travel times.

Average travel time per kilometre implies traffic efficiency and correlates to the performance of the CAV class in each stage. PCU factors of CAV above 1.0 worsen this metric and vice versa. For most of the established and some of the prevalent scenarios, average delay shows a deterioration despite the performance gain. If car users travel further, they can also collect more delay, although travel time is shorter per distance unit.

For all three metrics it applies that the impacts are stronger when Arterials and Urban streets are also included in the CAV-ready network. Variance for travel time and delay improvements is very large, consequently it is reasonable to further evaluate those in the following.

Figure 103 shows the average travel time improvement broken down by each assumption on travel time perception. In the first two groups, some of the established and most of the prevalent scenarios show shorter travel times. As soon as the perceived travel time in CAV is reduced, travel times increase. The changes roughly double for each CAV-ready network setting respectively if perceived travel time is assumed to be reduced by 30% (perc = -30%) compared to a reduction of 15% (perc = -15%).

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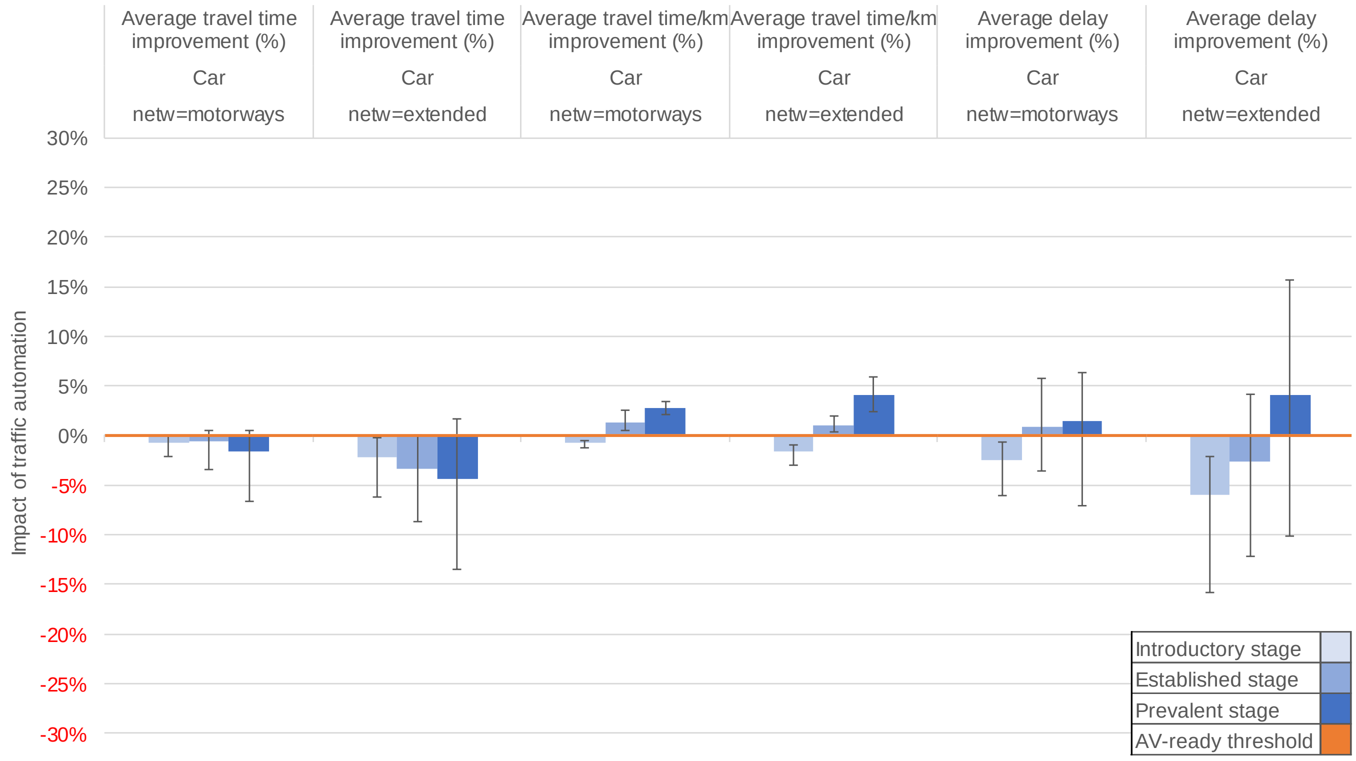

Figure 102 Average travel time, travel time per km and delay improvements for car

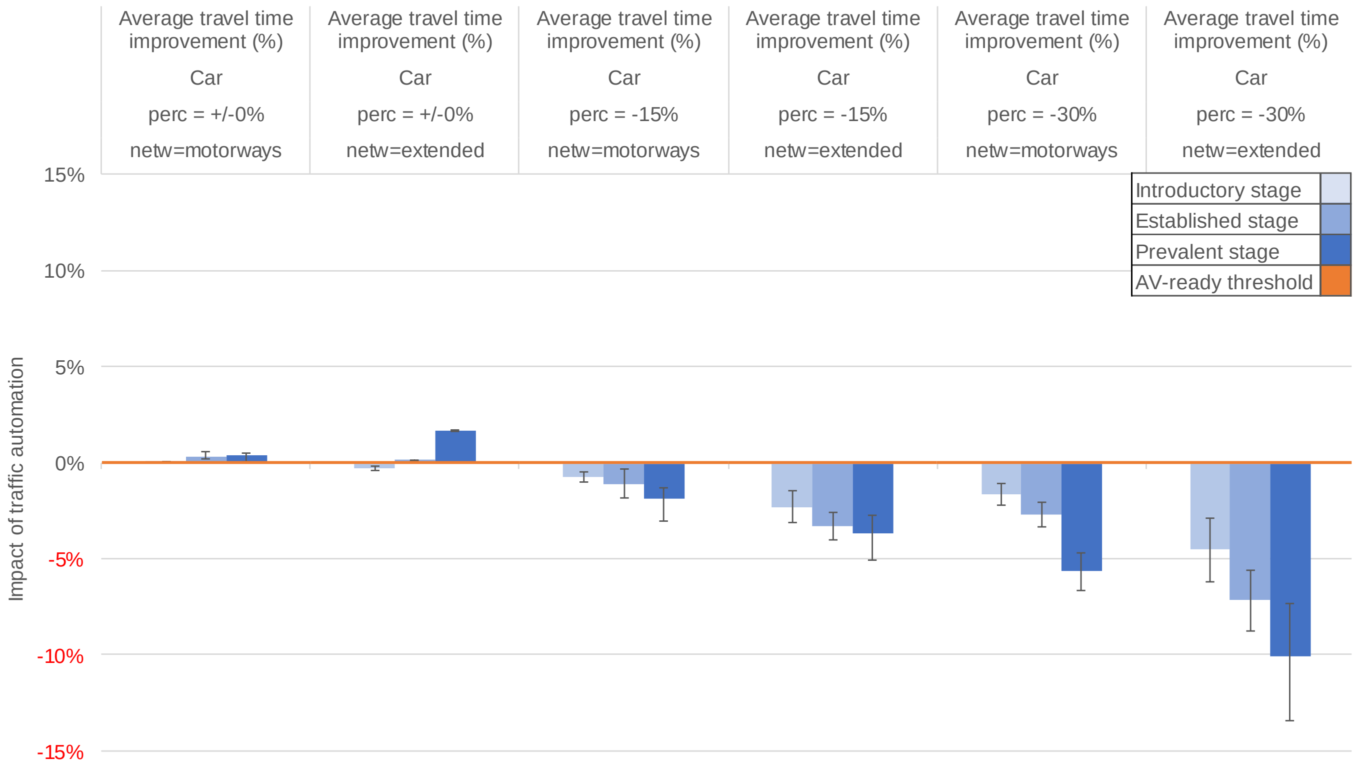

Figure 103 Average travel time improvement for car

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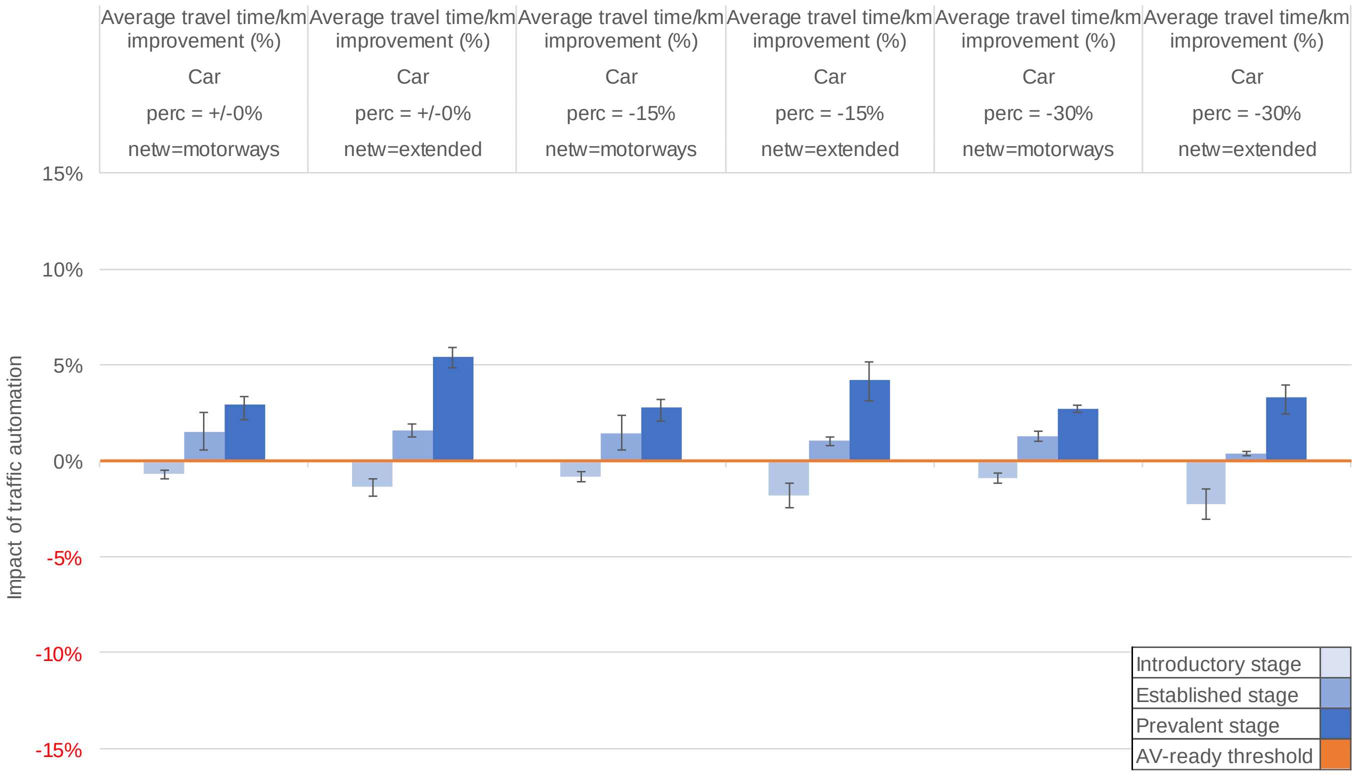

Figure 104: Average travel time per km improvement for car

Travel time per distance unit shows the smallest variance out of all three indicators (see Figure 104). Introductory scenarios show a decline in contrast to established and prevalent scenarios, which at all times show an improvement. The biggest benefit compared to the baseline can be found for the group of simulations in the Prevalent stage, where only performance effects of CAV are considered. This can be explained by the total number of car trips being minimal in comparison to the counterparts with perception impacts. Looking at all prevalent scenarios of the extended network, we observe a decline from perc = 0% towards perc = -30% due to a higher demand for car trips and consequently a higher saturation in the network. This demand increase is based on the higher attractiveness of the car modes as it is very comfortable to use those because travellers are able to spend their time on other things than driving.

Figure 105 shows the average delay for the six different combinations of assumptions. In general, the bigger the benefit from perception impacts is for travellers, the more delay can be observed. For all introductory scenarios, car travellers experience more delay than in the baseline case. For perc = -15%, established and prevalent scenarios show an opposite development, if the CAV-ready network is extended: delay can be further improved for the Prevalent stage, but worsens for the Established stage. The reason is the performance of the CAV classes on Urban streets, which is lower than CV for the Established stage, but better in the Prevalent stage. For even more perception benefits, the delay improvement for the Prevalent stage also turns into deterioration due to a higher demand for car trips as mentioned above. This causal relationship can also be called rebound effect.

The vehicle distance travelled (shown in Figure 106) increases for all scenarios throughout all settings except for the Introductory stage with performance impacts only. The relationship between the CAV share and the magnitude of travel time perception is obvious.

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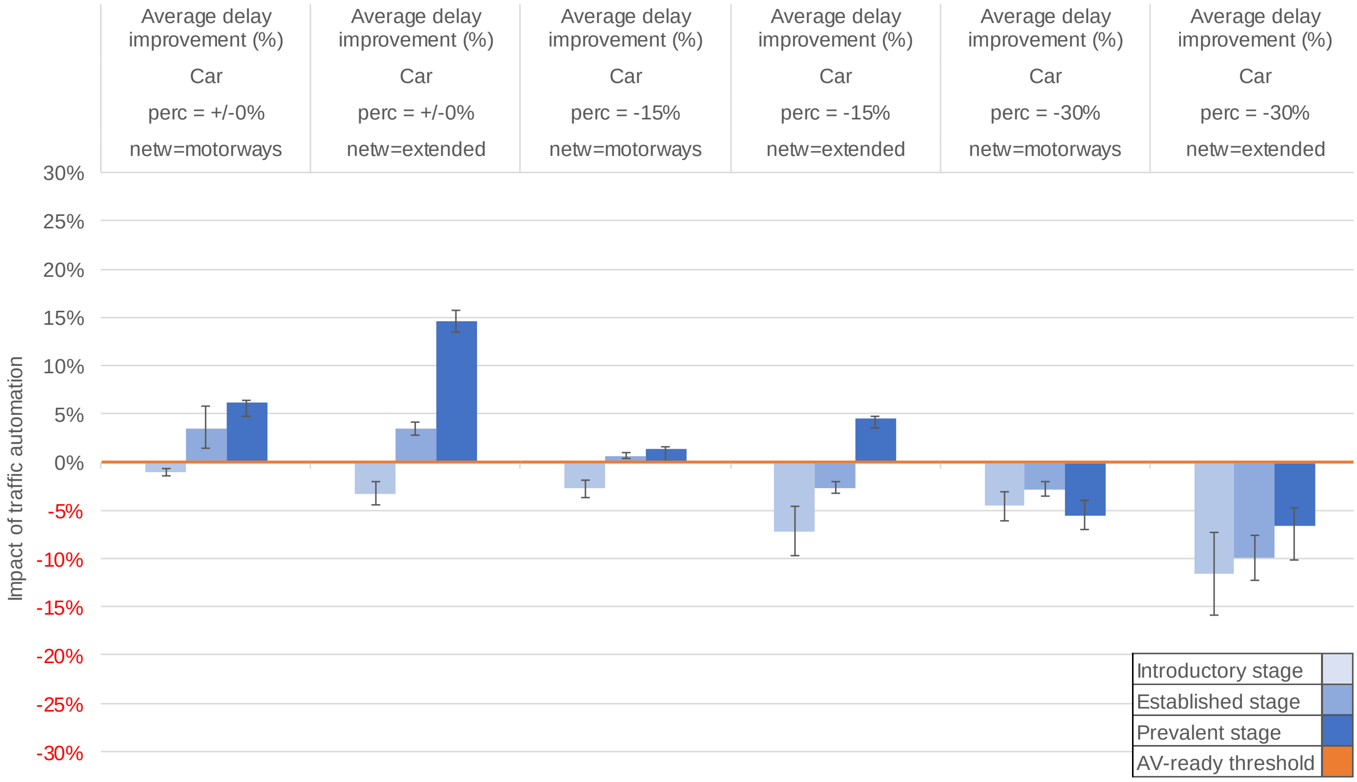

Figure 105 Average delay improvement for car

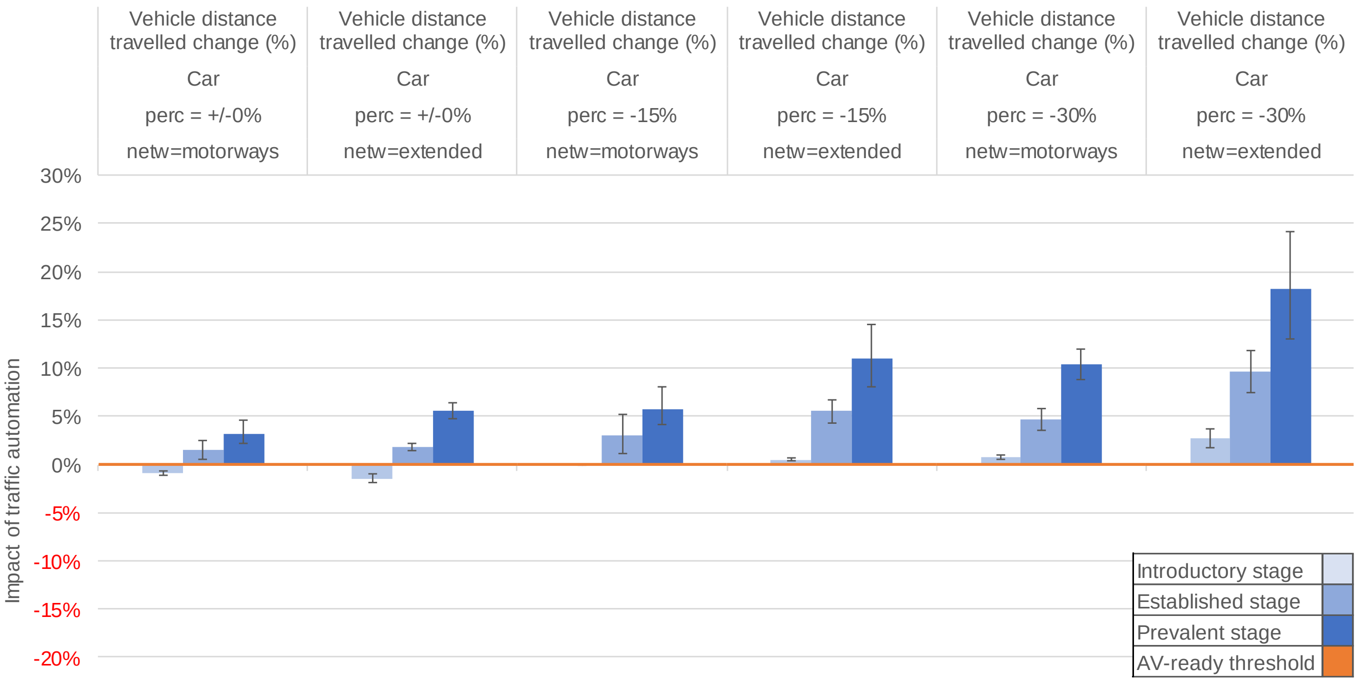

Figure 106 Vehicle distance travelled changes for car

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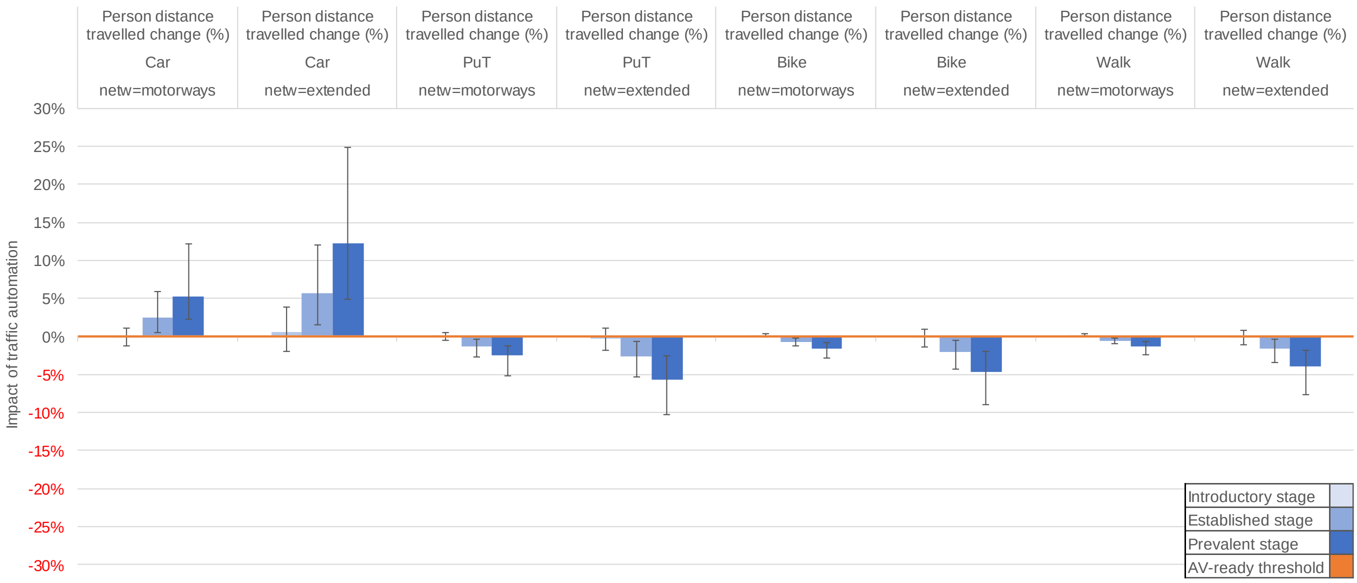

Figure 107 Person distance travelled changes for the modes car, public transport, bike and walk

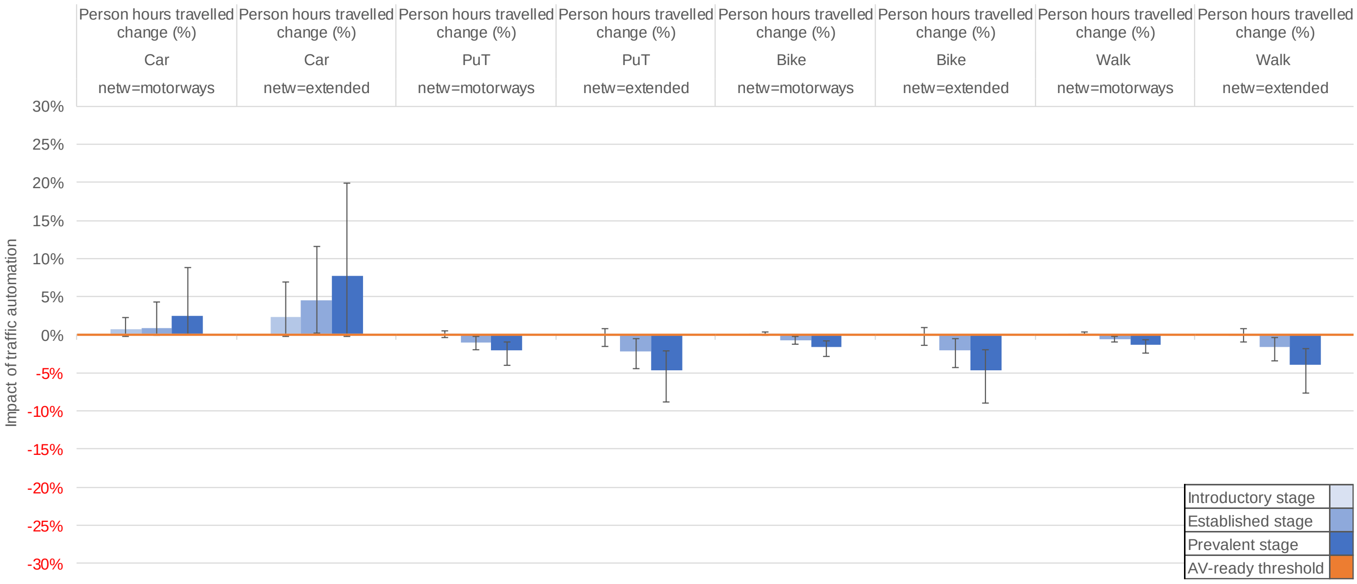

Figure 108 Person hours travelled changes for the modes car, public transport, bike and walk

Figure 108 and Figure 109 show person distance and person hours travelled respectively in another way as presented in Deliverable 4.2, grouped by mode and CAV-ready network. Both metrics show very similar trends in general: increase for car modes implies reduction for the other modes. The changes' magnitude is also bigger if the network is extended. Variance grows from the Introductory stage to the Prevalent stage.

9.2 Qualitative safety assessment

The Stuttgart Region travel demand model is a macroscopic model which does not provide data or sufficient information for assessing impacts of CAV on safety. However, it is still possible to analyse

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effects on vehicle kilometres. An increase in kilometers driven imply more accidents if the accident probability per vehicle kilometers stay the same. That's is true for conventional vehicles and that's probably also true for AVs. For use case 7 the more advanced AVs imply an increase in the vehicle kilometers travelled by car and the effect is enlarged if the travel time perception decrease. Hence, there might be a risk of decreased safety due to more car kilometers when AVs are introduced.

It is also possible to analyze the effects on velocity. Higher velocities imply higher severity of an accident due to higher kinetic energy at higher speeds. This is true for CVs and is expected to be true also for AVs. The travel speed decrease in the Introductory stage but as the AVs become more advanced the travel speed increase compared to the baseline. It is important to note that the macroscopic modelling do not capture the effect of full speed compliance of AVs compared to CVs since the AVs and CVs use the same travel time function and the same free flow speed /travel time. Thus, safety gains on roads with lower flows due to higher speed compliance are not visible in the macroscopic use cases.

9.3 Conclusions

The modelling methods on integrating effects by CAV through changes in traffic performance and travel time perception as described in the introduction are applied to the macroscopic travel demand model of the Stuttgart Region to examine possible impacts. If first generation CAV are assumed to be rather cautious and thus performing worse than CV, this would somewhat increase travel times for all road participants. For this case the model suggests minor modal shifts from car to other modes. As soon as CAV improve traffic performance, traveling by car, either CV or CAV, becomes more attractive, causing a modal shift towards car. Additionally, people are willing to spend more time in their CAV, allowing them to travel further. Both circumstances lead to an increase in the distance travelled and the time spent. The impact on the modal split and the distance travelled correlates to the CAV-share. The results indicate that road traffic may increase by up to 24% solely because of the advanced capabilities of highly automated vehicles.

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10 Traffic impact of automation in use case 8: Impact of driverless car- and ridesharing services

The study area for this use case covers the entire Stuttgart Region, an area with 2.7 million inhabitants. Figure 109 shows a map of the study area. Stuttgart is the capital of the state of Baden-Württemberg and forms with about 180 other cities and smaller towns in five counties the Stuttgart Region. The Region is the economic center of the state with one quarter of the state's population and nearly one third of the economic power on 10% of the land's space. Stuttgart City is the cultural and political centre of the region. It is the home of several large international companies (Bosch, Daimler, Porsche), two universities and several polytechnics. It offers a large number of workplaces in the service and industry sector. Stuttgart central station, Stuttgart airport and Stuttgart harbour connect Stuttgart and the Region to other places in Germany and Europe.

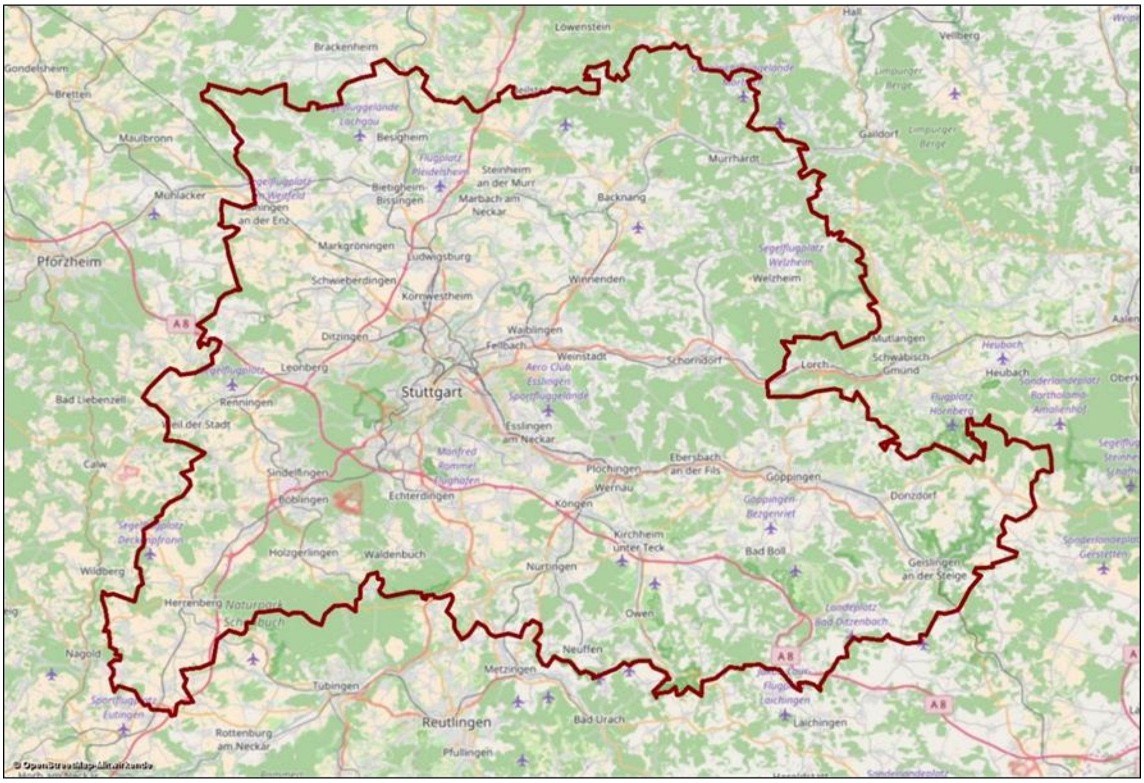

Figure 109 Study area Stuttgart Region (source map: OpenStreetMap)

Local authorities, the public transport operator and transport planners in Stuttgart City start thinking about the potential impacts of driverless car- and ridesharing systems on the traffic situation in and around the City. Since Stuttgart suffers from heavy congestion problems, the question is, if and to which extent car- or ridesharing services may improve or worsen the situation. The use case shall enable stakeholders to understand potential developments and to consider appropriate measures to reach a desirable state for the City.

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10.1 Application of the assessment tool

The assessment tool will not be used to evaluate use case 8 because it is not directly applicable. Traffic modes available in the tool do not cover the available modes present in the scenarios. Newly introduced modes and classical modes are combined in various ways. Thus, it is additionally challenging to directly compare the metrics automatically. It would be inevitable to adapt the tool with extensive effort for only one use case, which is out of scope. Nonetheless, there are still general impacts of automation on traffic performance, which we can derive from the simulations results available in the deliverable D4.2.

10.2 Traffic performance

In use case 8, the impacts of automated vehicles (AV) on traffic performance is not considered through adapted passenger car unit (PCU) factors as in use case 7. This would have additionally increased the long runtimes for the scenarios and the corresponding impact would have blurred the original ambition of the use case that is to focus on the impacts of driverless mobility services. Evaluation of traffic performance for use case 8 mainly takes the aggregated indicators total vehicle mileage and number of needed vehicles into consideration.

Vehicle distance travelled

The introduction of either carsharing or ridesharing not integrated into public transport as solely new mobility service in the Stuttgart Region leads to an increase of almost 5% of vehicle distance travelled in the region. The additional total mileage compared to the baseline scenario corresponds to the mileage of the respective mobility service including empty vehicle kilometres. The reason are modal shifts from public transport and active modes towards the mobility service.

Empty vehicle mileage accounts for about one fifth of the shared vehicles' mileage. In the city of Stuttgart, the increase is 7% for both cases with a slightly lower share of the empty mileage representing a quarter of the shared fleet mileage.

Ridesharing integrated into public transport, with or without bus service or with additional carsharing, leads to an increase of the total mileage of 6-7% in the Region, whereas ridesharing vehicles represent a relevant share of the total vehicle mileage through a large modal share of direct trips. Empty vehicle kilometres within the mileage of shared vehicles account for roughly 10%. In the city, the total increase of vehicle mileage is around 40%. The reason is that direct ridesharing trips replace a lot of traditional public transport trips as well as trips made by foot or bike in the baseline. Furthermore, empty ridesharing trips are responsible for 20% of the shared vehicles' mileage. Regarding the total vehicle distance travelled, empty mileage represents a share of 9%.

Number of vehicles needed

The number of needed vehicles to serve the total travel demand can also be interpreted as an indicator for traffic performance or efficiency. If the number of vehicles can be reduced while serving the same or even a higher demand, this is a higher performance from the vehicle fleet's point of view.

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For the scenarios with carsharing or ridesharing not integrated into public transport, the change of vehicles needed is very small. The shared vehicles are not replacing any privately owned cars because car owners rather use their own car which is less expensive. Hence, every shared vehicle is an additional vehicle. The total increase of the necessary vehicle fleet is around 1%. In comparison to a private car, which is used for 3.2 vehicle trips per day on average, the shared vehicles are naturally used more efficiently: 26 trips a day are covered by a ridesharing and 20 trips a day are covered by a carsharing vehicle.

In the cases with ridesharing integrated into public transport, the total number of vehicles needed could be reduced substantially by around 24% because many travellers owning a car still use the new mobility service. On average, each ridesharing vehicle is able to replace seven privately owned cars and is used for 23 vehicle trips a day.

10.3 Qualitative safety assessment

The Stuttgart Region travel demand model is a macroscopic model which does not provide data or sufficient information for assessing impacts of CAV on safety. Furthermore, the developed safety assessment methodologies are nor applicable on a regional level nor for the introduction of new mobility services.

10.4 Conclusion

With regard to the two presented indicators for traffic performance and efficiency, the impact of a carsharing or a ridesharing service (not integrated into public transport) is present, but not disruptive. Minor modal shifts towards these new modes lead to an increase in vehicle mileage and number of vehicles needed.

As ridesharing integrated into public transport is currently implemented, the model suggests a larger impact towards an increase in vehicle distance travelled, especially in the city, leading to more congestion and delay for road traffic participants. However, the model results also show the potential of shared vehicles replacing privately owned cars. In the end, it is crucial how this specific kind of service is implemented in the model and how it is assumed to be integrated into traditional public transport.

For all three types of mobility services, the vehicle fleet is used much more efficiently. However, with more car trips in total, the overall traffic situation will still not improve for this reason alone.

The results in detail, related discussion and conclusions for use case 8 can be found in deliverable D4.2.

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11 Conclusions and lessons learnt

The successful application of the tool for assessment of traffic performance and space efficiency to seven out of eight CoEXist use case demonstrate the applicability of the tool to a wide range of cases. The tool summarizes the results concisely while still presenting the uncertainties of the results. The incompatibility of the tool and use case 8 highlights that the tool is developed for a specific type of scenarios, assessing the traffic performance and space efficiency impact of the gradual introduction of automated vehicles on the non-automated road users; it is not designed to handle the extreme case of 100% self-driving vehicles in combination with new mobility services as car- and ride-sharing.

The traffic performance assessment tool indicates the uncertainties related to the impact assessment for each stage of coexistence, which in many cases are significant. Understanding these uncertainties is crucial for making well informed decisions based on simulation-based impact assessment; simulation results are easily over interpreted if the uncertainties are not emphasised. However, not all uncertainties are presented by the tool; it only presents uncertainties that have been explicitly included for investigation in the experimental design, which means that it can still be misused through an improper experimental design that exclude important uncertainties.

The qualitative safety assessment tool and the safety inspection-based assessment approach highlight the difficulties on assessing safety impacts of the introduction of automated vehicles. The focus in both approaches is to estimate if automation can decrease the risk of certain accident types. The qualitative safety assessment tool focus on which types of accidents in different types of road environments that different automation functions can help while the safety inspection-based assessment approach focus on detailed safety inspection for a specific site that identify site specific potential accident risks and how the different driving logics and mix of logics might affect the crash risk compared to the current situation without AVs. Both approaches highlight the need on further research on safety assessment for the transition period.

This deliverable presents the results of applying the assessment tools to the CoEXist use cases. It is followed by D3.4, which aims at presenting conclusions from the use cases based on the results presented here, and at giving design recommendations based on these conclusions.

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