D53.1: Traffic system impacts of green driving support systems

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Abstract	This report describes the methodology and results of the traffic simulation modelling of the ecoDriver systems, which is a part of the scaling up sub project in the ecoDriver project.

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Control sheet

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Executive summary

The global aim of the ecoDriver project was to deliver the most effective advice to drivers on fuel efficient driving by optimising the driver-powertrain-environment feedback loop. The ecoDriver advice to drivers covers the whole spectrum, from previewing the upcoming situation, over optimising the current driving situation, to post-drive feedback and learning. Both fully embedded and nomadic systems were developed for a wide range of vehicles — e.g. cars, light trucks and vans, medium and heavy trucks and buses — covering both individual and collective transport. The systems developed were tested and evaluated in both controlled and naturalistic field trials. Evaluations of effects on fuel consumption, emissions, travel speed, etc. were both conducted for individual drivers and for the traffic system as a whole. This report present the evaluation of the effects on the traffic system.

The share of vehicles equipped with the ecoDriver systems can be assumed to increase over the future years, from a low percentage in the year they are introduced to moderate or high levels depending on which direction the future takes. A scenario based evaluation approach was taken to enable evaluations of the effects on the traffic system not only for the introduction year but for up to 20 years into the future for three different possible future scenarios. The scenarios used were called Green Future, Policy Freeze and Challenging Future. Policy Freeze is the closest to a 'Business-as-Usual' scenario, whilst Green Future and Challenging Future present alternatives on either side of this. Green Future assumes high fuel prices, supportive attitudes and policies and fast technology development. Challenging Future assumes low fuel prices, unsupportive attitudes and policies and slow technology development. In the scenarios, the traffic mix and ecoDriver market penetration were varied, as well as the vehicle fleet mix, new vehicle purchase shares by fuel type/powertrain and the overall traffic demand by road type.

The traffic system impacts of the scenarios were quantified by means of traffic simulation modelling at a microscopic level for small networks. For each scenario, three different road environments (i.e. motorway corridors, rural roads and urban street networks), were modelled and simulated. Different road designs were considered within each road environment. The full set of networks included: urban and interurban motorway; flat and hilly rural roads with low or high intersection density; and flat and hilly urban roads in a compact or spacious city. To facilitate analysis of development in the scenarios over time, models of the road environments for every fifth year up to 20 years into the future was created and simulated. The scenarios are assumed to have a common starting point in 2015 for which the penetration rates of ecoDriver systems are assumed to be zero. There were in total 48 different cases for each simulated road network (3 scenarios times 4 future years' times 2 traffic demand levels with and without ecoDriver systems).

Microscopic traffic simulation is a common tool for estimating impacts of driver support systems on the traffic system. However, current state-of-the-art microscopic traffic simulation modelling do not handle driver behaviour effects of driver support systems. Hence, existing microscopic traffic simulation models need a supplement to handle the functionality of driver-support systems and the changes in driver behaviour that these systems may induce. This can either be done by modelling the behaviour of drivers equipped with the system, without separate modelling of the system and the drivers' interaction

with the system, or by modelling the support system and the driver interaction separately. The ecoDriver simulations requires that the drivers' compliance with the system can be varied for the different scenarios and future years, without changing the functionality of the ecoDriver systems. To manage this, a traffic simulation framework that includes separate modelling of the ecoDriver system and the driver's interaction with the ecoDriver system was developed, see illustration in Figure S.1. The framework consists of four main parts: a Traffic Simulation program; an External Module handling the ecoDriver systems and drivers interaction with the systems, a traffic simulation program specific Application Program Interface which handles the connection between the traffic simulation program and the external module, and a Performance Indicator calculation module. The external module consists of three modules: a model of the ecoDriver system(s); a Driver Model; and a Vehicle Model.

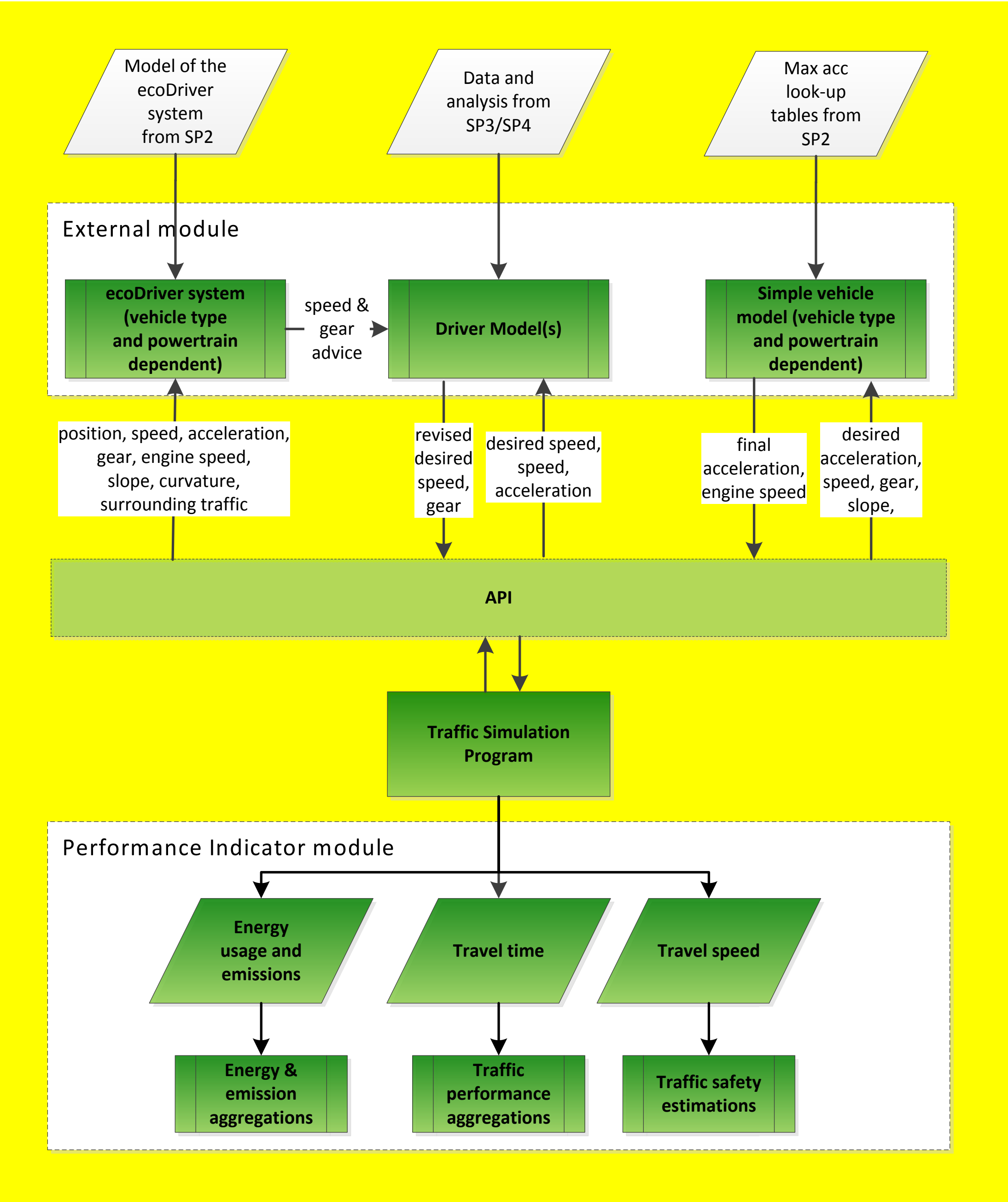

Figure S.1: The traffic simulation framework.

The ecoDriver system module are vehicle class (passenger car, van, truck) and powertrain (petrol/diesel, hybrid, electric vehicle) specific models of the ecoDriver system that were developed in subproject 2 in ecoDriver. The ecoDriver models generate speed and gear advice to the drivers. The driver models simulate how drivers respond to that advice, in particular their compliance with the speed and gear advice under different circumstances. These models are based on data collected in the field tests (subprojects 3 (field trials) and 4 (analysis of field trials)). The drivers' choices (speed, acceleration, gear) are fed into a simple vehicle model that determines the engine speed and whether the vehicle can deliver the requested acceleration. The data are then fed into the simulation model which updates the vehicles' positions. This way, vehicle trajectories and aggregated statistics are generated, which are used to determine the impacts of the ecoDriver system on traffic performance (e.g. travel times), traffic safety (e.g. risk of fatal incidents), and the environment (energy use and emissions). Safety effects were estimated using the speed power model while energy usage and emissions were estimated based on an already available emissions database.

The results indicate relatively moderate savings in CO_2, NO_x and energy consumption, large safety savings but also rather large increases in travel time. The CO_2 savings are smaller than the average savings found in the field trials, which is natural since the field trial results only include savings from equipped vehicles while the traffic simulations present the average saving for a mix of equipped (Embedded and Nomadic) and non-equipped vehicles.

The savings are in general largest on the rural roads, somewhat lower on motorways and there is in principle only safety effects in the urban setting. This is quite natural since all the types of advice (speed, gear and upcoming lower speed limit) appears and may influence the drivers on the rural roads. Motorway driving commonly imply driving at the highest gear, thus gear advice is not frequent. The number of speed limit changes is also less frequent on motorways. Thus, the main contributing part on motorways is the speed advice. Urban road driving implies more frequent gear changes while the possibility to freely choose the speed and for speeding is more limited. The main contributing part on urban roads is therefore the gear advice.

Figure S.2: shows the CO_2 results for motorways and rural roads, for cars, vans and trucks (buses were not simulated explicitly for these road types, as their share is very low, but they were assumed to behave similarly to how trucks behave), and for the flat networks with low demand. The scenario considered is the Green Future scenario, in 2035. This is the scenario with the largest effect sizes (because of relatively high penetration rates and compliance). The CO_2 emissions decreased on all road types; the largest decrease found was over 8%. On motorways, the largest effects can be found for trucks due to a substantial decrease in speed (in the without case, most trucks are assumed to drive at speeds over the speed limit of 80 km/h; for cars and vans a much smaller share of vehicles is assumed to drive at speeds over the prevailing speed limit). On rural roads, the largest effects are for cars and vans. Overall, the effects are larger for rural roads, as cars have by far the highest share in the traffic composition (for motorways, the car share is approximately 85%).

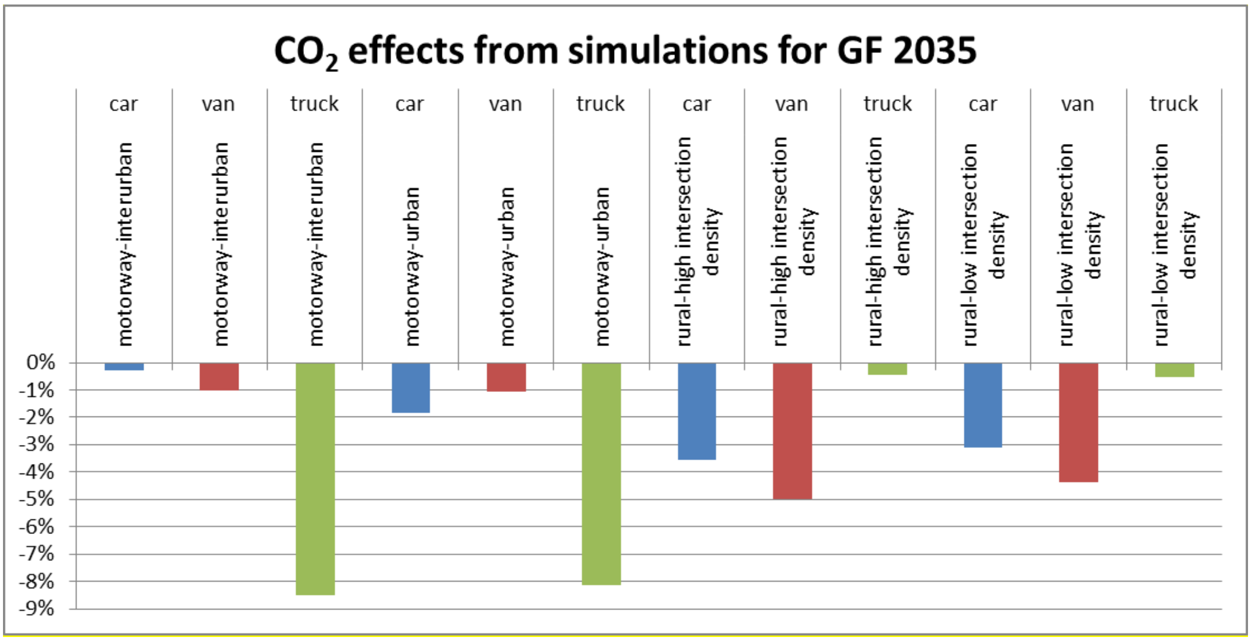

Figure S.2: CO_2 effects from the simulations, motorways and rural roads (car/van/truck, flat, low demand)

For fuel consumption and energy consumption, the effects are very similar. For NO_x, the effects are somewhat different, because in the motorways and rural roads simulations some unexpected and rather large increases in emissions were found for trucks. These increases could not be explained in a satisfactory way, but could be caused by the nature of the emission model used (a regression model). The aim in ecoDriver was to apply a model that reflects reality as much as possible, i.e. based on real-world measurements (as opposed to chassis dynamometer measurements). However, there aren't enough real world measurements yet to answer this discussion. We've tried to use the best possible data (based on raw measurements), but they're just now started to be collected. It has become clear that models based on chassis dynamometer measurements also have weaknesses. Thus, there is a need for further research and development of real world driving based energy and emission models. One also have to bear in mind that emissions from trucks is complex and depend on for which payload in relation to engine power and speed level that the engine is optimised for. Furthermore, the performance indicator used in ecoDriver is NO_x in g/km. Cruising at a higher speed means that the vehicle needs a shorter time to travel each kilometre. So even if the emissions per second is lower at a lower speed this does not always imply that the emissions per kilometre is lower. The NO_x results have been included in the scaling up and CBA (and the uncertainties about the NO_x results have been accounted for in a sensitivity analysis).

For hilly roads, the effects are in the same order of magnitude as for flat roads. When comparing low and moderate demand situations, the effects are slightly smaller for moderate demand situations on rural roads. For motorways, the differences between low and moderate demand are very small.

Figure S.3 shows the uncorrected travel time effects. The travel times increase in all cases. On motorways, truck travel times are most affected (because of the reduced speed). On rural roads, all vehicle classes are affected. When corrected for speeding, the travel time effects are much smaller (going from several % when uncorrected to almost 0% when corrected).

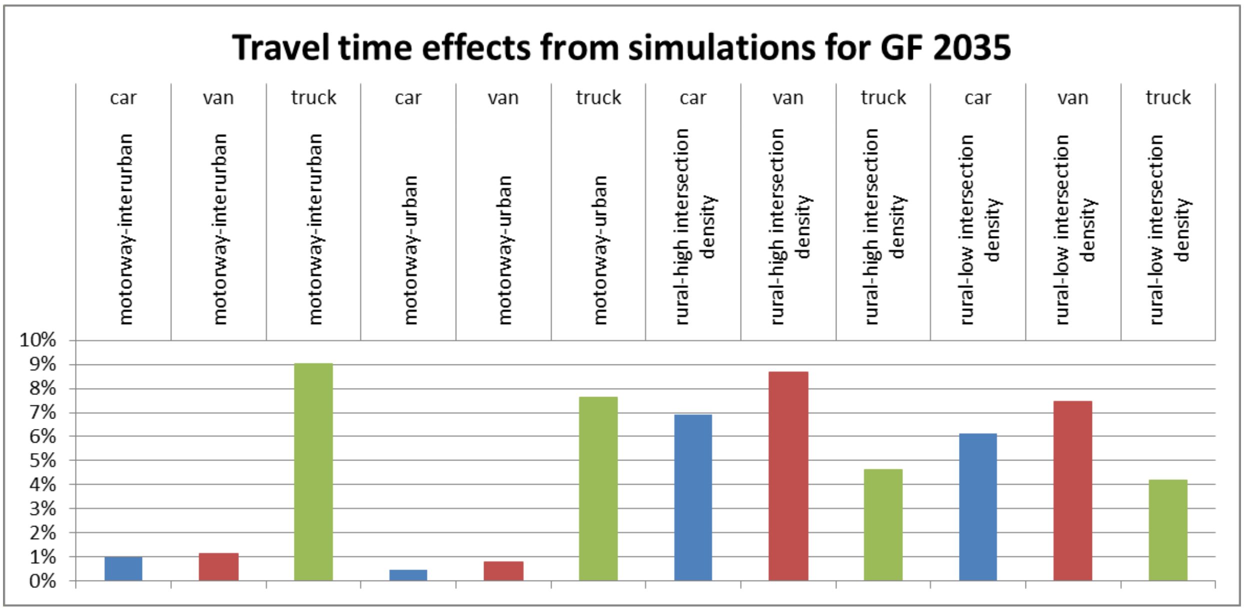

Figure S.3: Travel time effects from the simulations, motorways and rural roads (car/van/truck, flat, low demand)

Figure S.4: shows the safety effects. These were calculated using the Power model (Elvik et al., 2004) for all vehicle classes combined. The safety effects are large, compared to the other indicators, and are largest on rural roads, with the number of fatal accidents/fatalities being reduced the most (20-25%). Since there are no significant effects of the ecoDriver system on speeds for urban compact roads, there are no safety effects on these roads.

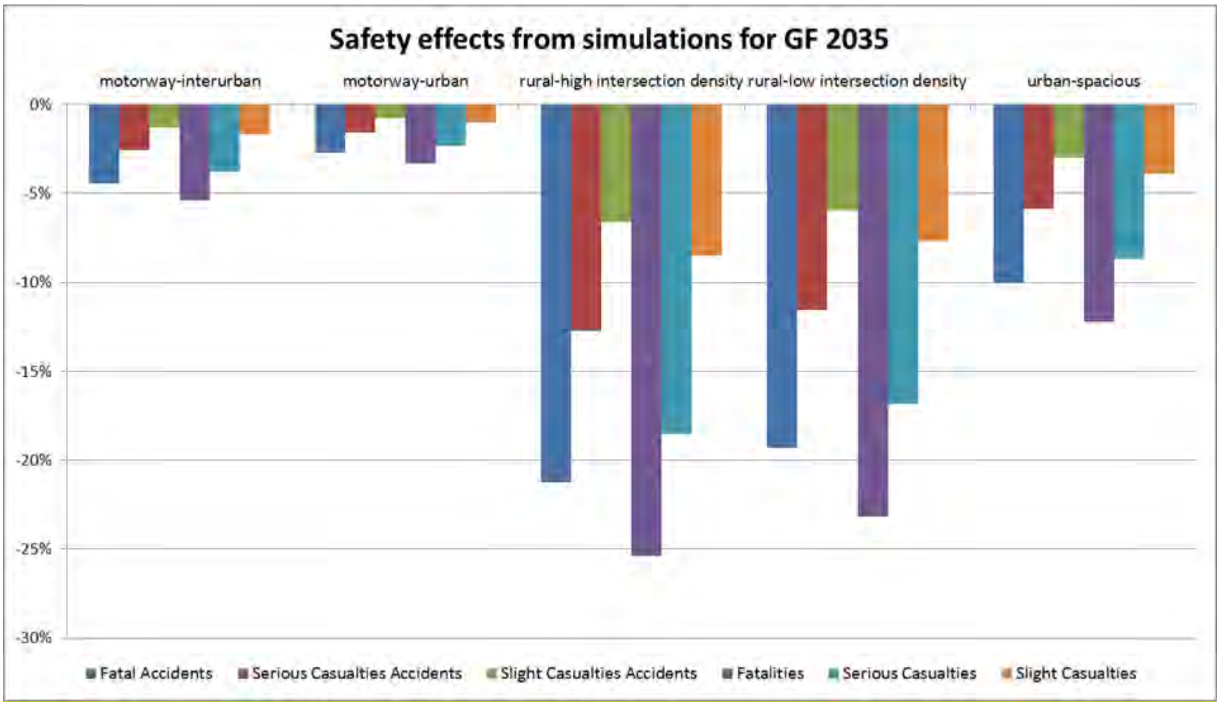

Figure S.4: Safety effects from the simulations on motorways, rural roads and urban spacious roads (car/van/truck/bus, flat, low demand)

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Glossary of terms

Term	Description
Cost-benefit analysis	A cost-benefit analysis can be defined as a systematic process for calculating and comparing benefits and costs of a project, in this case the roll-out of different variants of the ecoDriver system in different future scenarios
ecoDriver system	A device that supports eco-driving. This might be a mobile app, or system built into a vehicle including recording devices providing data for later analysis or real-time feedback to drivers.
Eco-driving	Driving in a way that minimises fuel consumption, thus maximising efficiency and minimising Greenhouse gas emissions without trading off safety.
Scaling up	Translating results (e.g. effects of a system) on a small or local scale to results on a larger scale (e.g. EU level)
Vehicle class	Classification of vehicles depending on size and transportation purpose, e.g. car, van, bus, truck, etc.
Vehicle type	Classification of vehicles depending on vehicle class and powertrain, e.g. petrol driven car, electric car, hybrid bus, etc.

Acronyms

Acronym	Description
API	Application Program Interface
BL	Baseline
CBA	Cost Benefit Analysis
CF	Challenging Future (scenario name)
DM	Driver model
ED	ecoDriver system
EM	External Module
EV	Electric vehicle
FeDS	Full ecoDriver system
GF	Green Future (scenario name)
HMIs	Human Machine Interfaces
ICE	Internal Combustion Engine

Acronym	Description
IEM	Instantaneous Emission Model
PF	Policy Freeze (scenario name)
PHEV	Plug-in Hybrid Electric Vehicle
PI	Performance Indicator
RPM	Rotations Per Minute
SP1	Sub Project 1
SP2	Sub Project 2
SP3	Sub Project 3
SP4	Sub Project 4
SP5	Sub Project 5
TR	Treatment
TS	Traffic simulation
vkm	Vehicle kilometres
VE3	Vehicle Energy and Environmental Estimator
VM	Vehicle Model
VSP	Vehicle Specific Power

1. Introduction

The global aim of the ecoDriver project was to deliver the most effective advice to drivers on fuel efficient driving by optimising the driver-powertrain-environment feedback loop. More specifically, the focus of the project was on the interaction between technology and the driver, since the behaviour of a driver is a critical element in energy efficiency. By increasing the acceptance of eco-driving applications through intelligent HMI and advice solutions, the ecoDriver project substantially contributes to the Europe 2020 goals through a much needed reduction of gas emissions and energy usage in transport, and thereby a significant reduction in the negative impact of transport on the environment.

The ecoDriver advice to drivers covers the whole spectrum, from previewing the upcoming situation, over optimising the current driving situation, to post-drive feedback and learning. The aim of the project was to optimise human machine interfaces (HMIs) and advice to drivers for both portable devices within the vehicle which provide assistance to the driver (nomadic devices) and built-in systems, and to compare the effectiveness of each. This was addressed across a wide range of vehicles — e.g. cars, light trucks and vans, medium and heavy trucks and buses — covering both individual and collective transport. Lastly, the project did not only examine driving with current and near-term powertrains, but also with a full range of future vehicles, including hybrid and plug-in electric vehicles.

The detailed aims of the ecoDriver project were to:

1. Investigate how best to win the support of the driver to obtain the most energy-efficient driving style for optimal energy use, with regard to preview, the current situation, and post-drive feedback and learning
2. Assess this across a wide range of vehicles — e.g. cars, vans, light and heavy trucks and buses – covering both individual and collective transport
3. Explore and evaluate alternative HMIs and styles of advice
4. Consider driver behaviour with a wide range of current and future powertrains, including internal combustion (both petrol and diesel), hybrid and electric, and provide the optimum advice for each powertrain
5. Consider driver style, driver learning, and consider how the systems can affect driving style
6. Look at the impacts of eco-driving support on driver attention and safety
7. Look at a variety of impacts: CO_2 (carbon dioxide), NO_x (nitrogen oxide), particulates etc. and the balance between impacts
8. Consider how the observed effects on driving style would affect network-wide energy use and a variety of aspects of network performance including network efficiency
9. Consider scenarios for future powertrain adoption, and how eco-driving might affect the road networks of the future
10. Perform a cost benefit analysis considering a range of scenarios of powertrain adoption.

The programme of work is arranged into five sub projects (SP1-5), each containing a number of work packages. WP53 on which the document reports is part of SP5 (Scaling up and future casting).

1.1 Scope of SP5 – Scaling up and future casting

The aim of SP5 is to predict the environmental impact of a variety of systems and solutions in future scenarios, drawing on all the evaluations carried out in the project. The four major work items to be carried out in SP5 are:

- Development of scenarios (WP52),
- Traffic simulations (WP53),
- Scaling up (WP54, T54.1),
- Cost-benefit analysis (WP54, T54.2).

These four steps follow each other and make use of each other's output. Besides this, data from other parts of the project (i.e. from other SPs) and external data are needed. This is illustrated in Figure 1, where an overview of the work in SP5 and the data flows is given. The green blocks contain the work items of SP5 and the white blocks contain input data, from within the project (white blocks on the left) and external data (white blocks on the right).

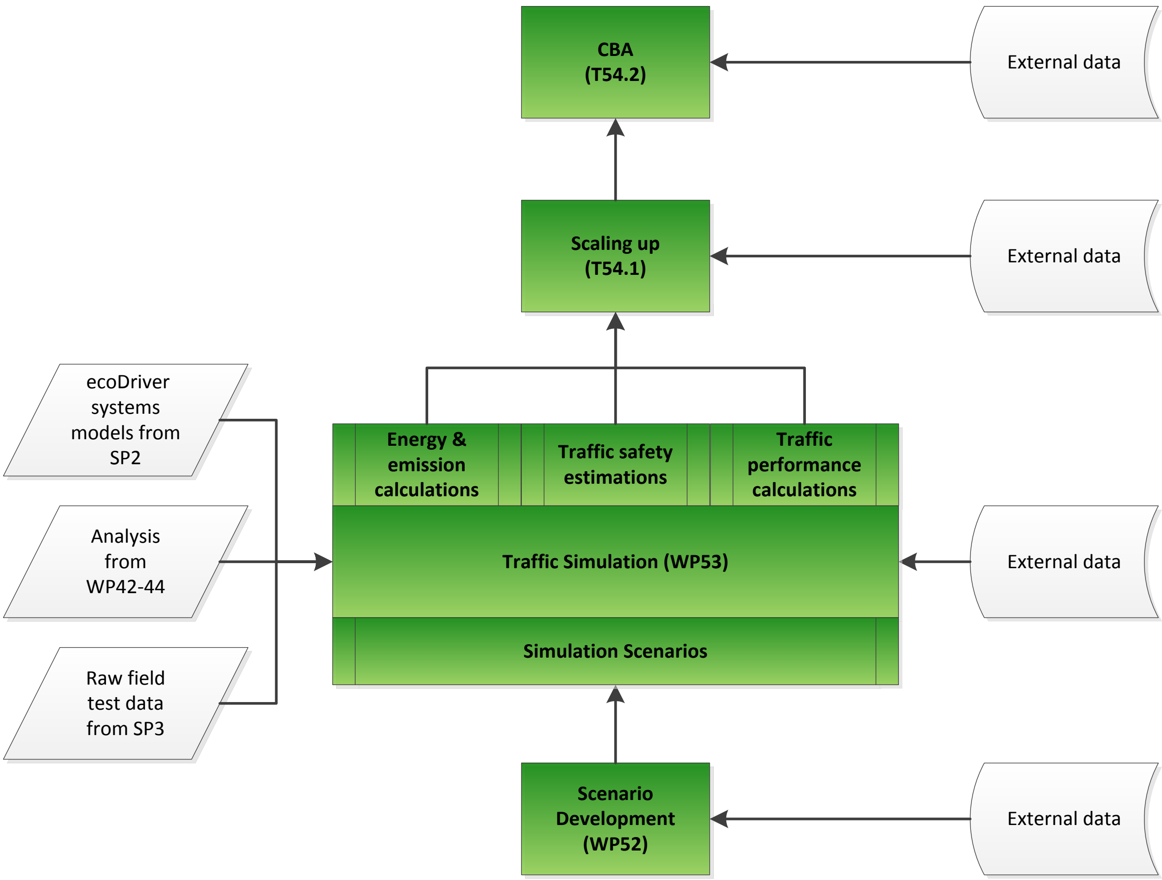


Figure 1: Overview of SP5 and SP5 internal data flow and driver behaviour analysis conducted in SP4 using the field trials data collected in SP3.

First, scenarios were developed in WP52. These scenarios describe the traffic of the future (20 years ahead) with respect to powertrain distributions, the distribution of private and public transport, etc. These scenarios were used as input for the simulations in WP53 – in which the scenarios were transformed into specifications for traffic simulation models. For the modelling of green driving support systems, results on driver behaviour from SP4 (WP42, WP43 and WP44) were needed. For the traffic simulations on micro level (on a small network) raw field test data from SP3 were used to estimate and model drivers' compliance with the ecoDriver systems developed in SP2. The outputs of the traffic simulations (traffic efficiency impacts, energy usage and emissions impacts on a small scale) serve as input for the scaling up in T54.1. Here, the results are translated to the whole of the European Union. This scaling up is done based on statistical data, for example vehicle kilometres by vehicle type. The last step in SP5 is the cost-benefit analysis (T54.2). In this task all costs and benefits for the EU on a societal level (as well as for some specific stakeholder perspectives) are determined.

1.2 Scope of the report

This report is the result of WP53 in the ecoDriver project: Simulation of future traffic. The objective of this work package was to quantify the traffic system impacts of the scenarios developed in WP52. The focus is on impacts in terms of energy consumption together with greenhouse gas and pollutant emissions, but traffic efficiency and road safety measures are also considered. The quantification was conducted by an extensive microscopic traffic simulation experiments for a limited but representative set of rural roads, motorways and urban networks.

The first task (T53.1) of the work package transformed the WP52 scenarios into specifications for the traffic simulation models. This implied specification of traffic demand, vehicle class distribution, powertrain mix, ecoDriver penetration rates, etc. for each combination of scenario, future year and road network.

In the second task (T53.2) microscopic traffic simulation models were adapted for modelling of future traffic systems including green driving support systems. The work also included adaptation of powertrain, energy consumption and emission models to allow estimations of impacts of alternative powertrains and green driving support systems.

In the third task (T53.3) the results of the simulations performed were analysed. The simulation experiment set up implied a large set of simulation cases not only including the combinations of the scenarios and the future years. Different traffic demands and several rural, motorway and urban road networks were also taken into consideration. For each case both a simulation of the situation if, and if not, the ecoDriver systems are introduced were conducted, in order to estimate and analyse the changes due to the ecoDriver systems.

1.3 Structure of the report

The report starts with a description of the transformation of the scaling up scenarios to sample traffic simulation cases. This includes description of the traffic simulation cases in terms of the type of road networks, ecoDriver systems, vehicles and powertrain types that were simulated. Chapter 2 ends with a description of the performance indicators that were calculated and handed over to the scaling up task. Chapter 0 gives a more detailed descriptions of the 10 different road networks that were simulated. An overview of the traffic simulation framework developed to allow simulations of the ecoDriver equipped vehicles is given in chapter 4. The details of the different modules in the traffic simulation framework are given in chapters 5 - 8, with a description of the utilised traffic simulators in chapter 5, the implementation of the ecoDriver systems in chapter 6, the modelling of driver compliance in chapter 7, and vehicle dynamics in chapter 8.

The methods used to evaluate the performance indicators are described in chapter 9 (energy and emission calculations), 10 (traffic safety estimations) and chapter 11 (traffic efficiency). Chapter 12 presents verification simulations of the traffic simulation framework as well as verification simulations for the simulator representations of the 10 different road networks. Chapter 13 discuss the statistical aspects that need to be considered when applying stochastic traffic simulation. The results from the conducted simulations for the scaling up is presented and analysed in chapter 14. The report ends with chapter 15 which presents the overall conclusions and implications for the ecoDriver project.

2. Scenarios and simulation set-up

In order to quantify the traffic system impacts of the scenarios developed in WP52, the WP52 scenarios need to be transformed to a set of traffic simulation cases. The traffic simulation cases can be seen as samples of motorway, rural road and urban networks. This chapter first briefly recalls the ecoDriver systems and the scenarios developed in WP52. The chapter then describes the set-up of the traffic simulations, containing descriptions of the different simulation cases, versions of the ecoDriver systems and vehicle types used in the simulations. In addition, this chapter also contains a description of how the future projections of traffic mix and ecoDriver penetration rates were transformed from the WP52 scenario descriptions into the traffic simulation cases. The chapter also includes a description of the performance indicators that were calculated based on the conducted traffic simulation and used as input to the scaling up.

2.1 The scenarios

The Simulation of Future Traffic (WP53) and the Scaling-Up and CBA (WP54) both required projections of future vehicle fleet, traffic and market penetration of ecoDriver systems. WP52 developed a set of scenarios to meet these needs, including qualitative and quantitative descriptions of the scenarios (D52.1, Jopson et al, 2015). The scenarios are based on the research team's synthesis of the evidence emerging from: the data collection work; a set of focus groups held across different countries (Table 1); and original stated preference (SP) analysis examining consumers' preferences for ecoDriver systems (Jopson et al., 2015).

Table 1: Focus Groups

Country	Topic/Market Segment
UK	Passenger systems
UK	Freight systems
Sweden	Energy policy
Italy	Technical feasibility
Netherlands	Lease/fleet systems
Netherlands	Vehicle equipment and manufacturers

2.1.1 Contextual scenarios

Three overarching scenarios were developed: these were called 'Green Future' (GF), 'Policy Freeze' (PF) and 'Challenging Future' (CF). They cover a range of assumptions about the level of support for green driving, given: the outlook for fuel prices over the next 20 years; the pace of technological development in vehicle efficiency; drivers' acceptance and likely uptake of systems; and wider policy and economic contexts. 'Policy Freeze' is the closest to a 'Business-as-Usual' scenario, whilst 'Green Future' and 'Challenging Future' present alternatives on either side of this, in terms of the factors cited above – see Table 2.

Table 2: Contextual scenarios in ecoDriver

	Fuel price outlook	**Supportive attitudes and policy**	**Technology development**
'Green Future'	High	Yes	Faster
'Policy Freeze'	Central	No	Slower
'Challenging Future'	Low	No	Slower

For the traffic simulations (WP53), the key data requirement was the future traffic mix, by road type, vehicle type and powertrain/fuel type. Table 3 gives an example of the scenario results for this indicator: this is the urban traffic mix in the 'Green Future' scenario. The results for the other road types (rural roads and motorways) and contextual scenarios were given in Jopson et al. (2015).

Table 3: Projected traffic shares by road type and vehicle type, 2015-2035, 'Green Future' scenario, Urban (non-motorway) roads, % of vehicle km

Vehicle type	Fuel type	2015	2020	2025	2030	2035
Car	Petrol	55.3%	49.6%	45.4%	41.1%	34.3%
	Diesel	43.7%	48.4%	50.0%	48.6%	42.0%
	Hybrid	0.7%	1.5%	3.4%	7.8%	18.2%
	Gas	0.1%	0.1%	0.0%	0.0%	0.0%
	EV	0.1%	0.3%	0.8%	1.9%	4.1%
	PHEV	0.0%	0.1%	0.3%	0.6%	1.4%
	Other	0.0%	0.0%	0.0%	0.0%	0.0%
	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%
Van	Petrol	2.7%	2.1%	1.7%	1.5%	1.3%
	Diesel	97.0%	97.5%	97.7%	97.2%	95.4%
	Gas	0.2%	0.1%	0.1%	0.1%	0.0%
	EV	0.1%	0.2%	0.4%	0.9%	2.2%
	Hybrid+Other	0.0%	0.0%	0.1%	0.4%	1.1%
	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%
Truck	Diesel	100.0%	100.0%	99.9%	99.7%	99.2%
	Hybrid	0.0%	0.0%	0.0%	0.0%	0.0%
	EV	0.0%	0.0%	0.1%	0.3%	0.8%
	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%
Bus	Diesel	99.7%	99.4%	98.7%	97.0%	92.7%
	Hybrid	0.2%	0.5%	1.1%	2.6%	6.3%
	Gas	0.0%	0.1%	0.1%	0.1%	0.1%
	EV	0.0%	0.0%	0.1%	0.3%	0.9%
	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%

Key: EV - full electric vehicle; PHEV - plug-in hybrid electric vehicle.

2.1.2 Market penetration of ecoDriver systems

It was also important to have predictions of the take-up of ecoDriver systems, in order to compare the 'with ecoDriver' and 'without ecoDriver' scenarios. The take-up of ecoDriver systems was assumed to be influenced by their availability on one hand and the demand for them on the other. Key aspects of equipment availability are: the ownership of smartphones, which enables use of the mobile app; the presence of the embedded system pre-fitted to vehicles; and the prices associated with each option. We assumed that the embedded system is not available for retrofit to existing vehicles: this was considered and rejected as a possibility within reasonable cost limits. We also assumed that the ecoDriver App is itself essentially free of charge (a nominal charge of €15 was assumed) – Focus Groups found that this was expected by the market, and take-up would be deterred otherwise. The lifetime cost of the embedded system was assumed to be €250 based on an analysis of available data. Figure 2 and Figure 3 show the results in terms of shares of the vehicle fleet.

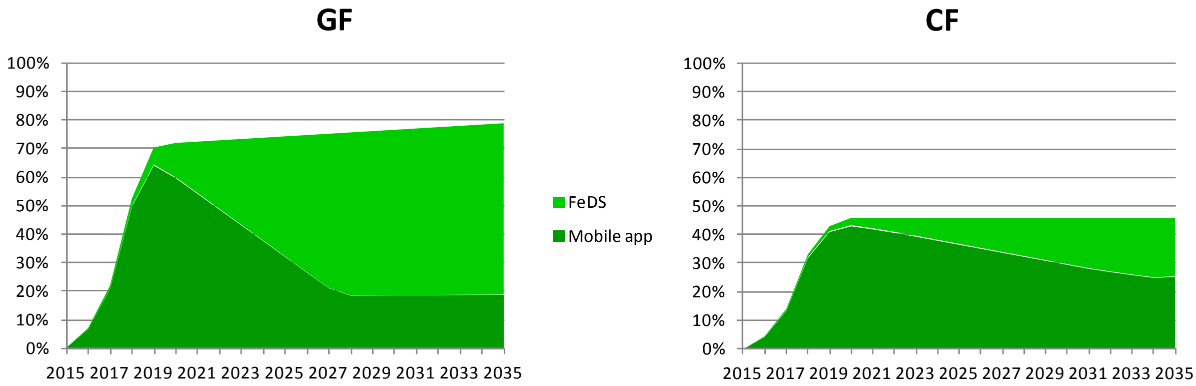


Figure 2: Projected market penetration of ecoDriver systems, Green Future and Challenging Future scenarios, use by car drivers, 2035

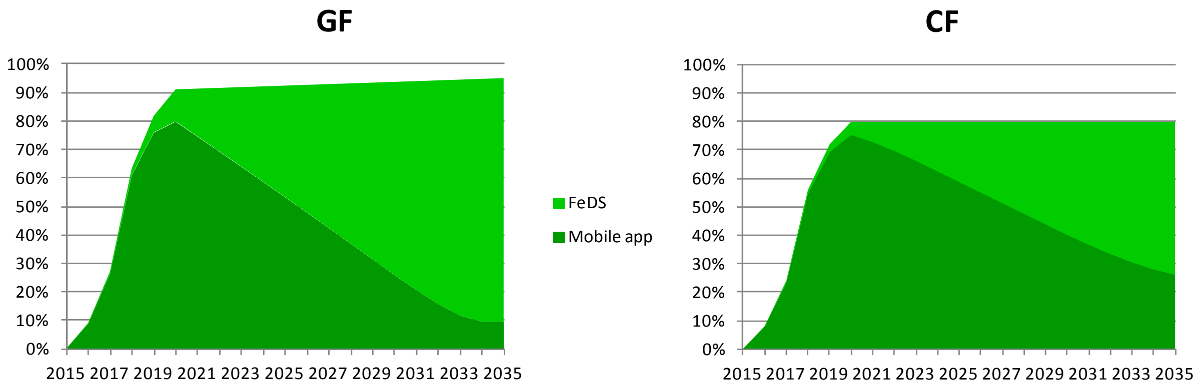


Figure 3: Projected market penetration of ecoDriver systems, Green Future and Challenging Future scenarios, use by goods and bus drivers, 2035

In the early years, Mobile app take-up is strongest, because the main user requirement is simply ownership of a smartphone (since the App is assumed to be essentially free of charge), whereas the Full ecoDriver System (FeDS) takes longer to integrate into the vehicle fleet. However, the FeDS offers an advantage in fuel savings, which is attractive to most users – except those who drive a low mileage or have attitudes that are resistant to the use of in-vehicle technologies to improve driving efficiency. Consequently, over time the FeDS becomes dominant in the Green Future. In the Challenging Future, the FeDS share is smaller, since private car drivers are assumed to maintain their current attitudes (evident from the Stated Preference survey) such that 38% will not use an ecoDriver system if fitted. For goods vehicles and buses, ecoDriver systems are assumed to be purchased purely on cost saving grounds. These vehicles also have high annual mileages. This leads to higher market penetration for these vehicle types. Take-up is not instantaneous for the Mobile app or the FeDS: instead there is assumed to be an S-shaped product take-off curve in the first 5-9 years starting from 2015. Combined with the Mobile app's early year's advantage, this results in an n-shaped profile of market share for the Mobile app, rising initially and then falling as the FeDS replaces it in the fleet.

2.2 Traffic simulation cases

The traffic system impacts of the scenarios ('Green Future' (GF), 'Policy Freeze' (PF) and 'Challenging Future' (CF)) developed in WP52 are quantified by means of traffic simulation modelling on microscopic level for small networks. For each scenario, a set of different road environments (i.e. motorway corridors, rural roads and urban street networks), is modelled and simulated. To facilitate analysis of development in the scenarios over time, models of the road environments for every fifth year up to 20 years into the future was created and simulated. The scenarios are assumed to have a common starting point in 2015 for which the penetration rates of ecoDriver systems are assumed to be zero. The traffic conditions in terms of vehicle class and vehicle type mixes, ecoDriver penetration rates, ecoDriver compliance distributions for the future years varies between the scenarios. There are also different projections for traffic demand and mileage for the different scenarios, but these variations are handled in the scaling up task. Figure 4 illustrates the traffic simulation cases, in total there are 24 different cases for each simulated road network (3 scenarios times 4 future years' times with and without ecoDriver systems).

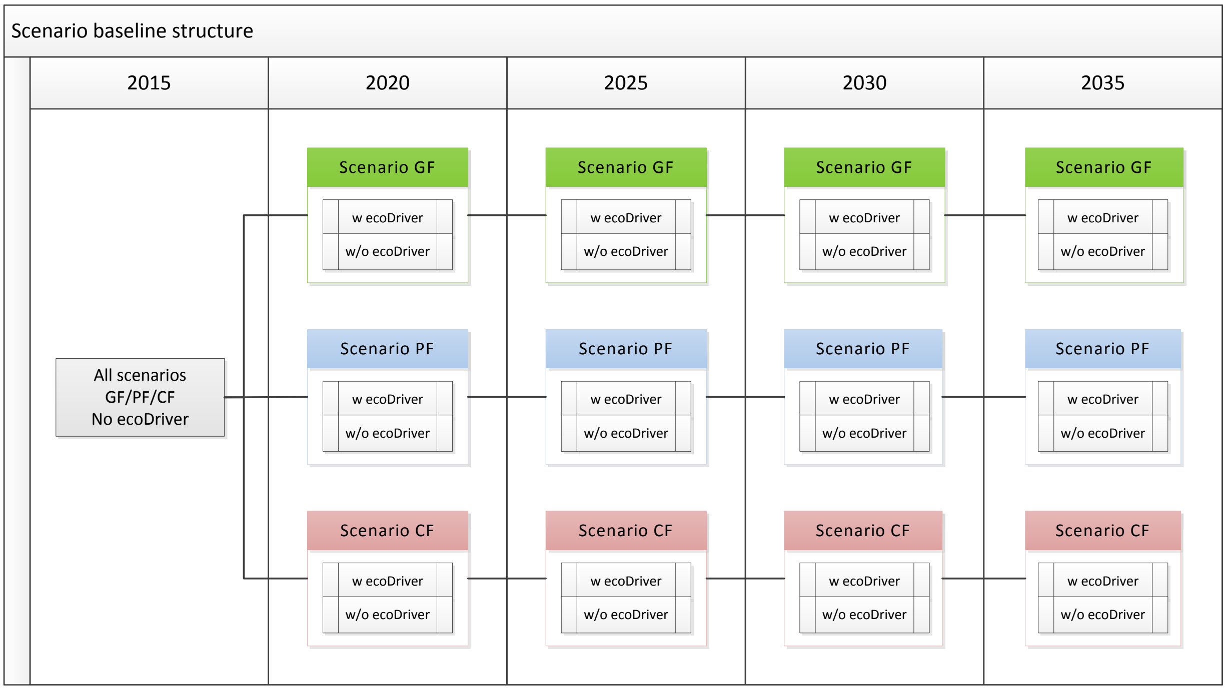


Figure 4: Illustration of the scenario structure. GF stands for the 'Green Future' scenario, PF for the 'Polizy Freeze' scenario and CF for the 'Challenging Future' scenario.

For each type of road environment (motorway, rural and urban), the set of modelled and simulated road networks include networks in flat and hilly terrain with different levels of traffic demand. The complete set of networks that was considered for modelling and simulation is presented in Table 4. Detailed descriptions of the networks are given in chapter 0.

Table 4: Overview of modelled networks

	Motorway	Rural road	Urban roads
Type of road	• Urban • Interurban	• Low intersection density • High intersection density	• Spacious city • Compact city
Terrain		• Flat • Hilly	• Flat • Hilly
Traffic demand	• Low • Moderate	• Low • Moderate	• Low • Moderate

A total of 10 different networks (2 motorways, 4 rural roads and 4 urban networks) and two traffic demand levels were simulated. By combining the number of networks and demands together with the 24 different cases per road network, the total number of simulation cases ends up at 480 different combinations. The traffic demands were chosen so that 'Low' demand correspond to more or less free flow conditions (volume-to-capacity ratio less than 0.3) and the 'Moderate' demand describes a traffic conditions in which vehicles constrain each other to some extent but not yet congested situation (i.e. a volume-to-capacity ratio around 0.5-0.8). The 'spacious city' urban road type / network reflects suburban areas, with a lower density of intersections and major road junctions being both roundabouts and signal controlled. The compact city represents higher density Cities and urban centre environments. The compact city network reflects those with a high density of junctions that area largely signal controlled.
It is important to note that the simulations do not consider the introduction of other driver support systems, (C-)ITS, automated vehicles, etc. that can increase the capacity of existing roads, as this would be difficult to model and would make it difficult to separate the effect of ecoDriver from the effect of such systems.

2.3 The simulated ecoDriver systems

The ecoDriver systems give advice to drivers on fuel efficient driving by optimising the driver-powertrain-environment feedback loop. The system can either be embedded (built-in) or nomadic (on a portable device). The ecoDriver system uses a vehicle energy and environment estimator (named VE^3), that runs on-line in vehicles utilising on-board (sensor) information and an e-horizon functionality based on digital map data. With these data, a signal is generated for eco-friendly driver guidance, which is relayed to the driver via a human-machine interface.

The system provides the driver with speed and gear advice together with pop up warnings/advice on upcoming speed limit changes, intersections, sharp curves, etc. The ecoDriver system has been implemented in test vehicles driven in field tests in France, Germany, the Netherlands, Spain, Sweden and the UK (see Woldeab et al. (2014) and Lai et al. (2014) for descriptions of the different test sites). A mix of controlled and naturalistic tests was carried out, with various types of vehicles (e.g. passenger cars, trucks and buses) with different powertrains (ICE (petrol), ICE (diesel), hybrid, plug-in hybrid and fully electric vehicles).

In the simulation, the Full ecoDriver System (FeDS) and the nomadic ecoDriver system (the ecoDriver App) were chosen as representatives of an embedded and nomadic system, respectively. The OEM embedded systems and the TomTom nomadic system have not been simulated due to the fact that proprietary limitations do not allow sharing of details or program code describing the system. A more detailed description of the FeDS and the ecoDriver App are available in the ecoDriver deliverables D22.1 (Ivens et al., 2014b) and D22.2 (Ivens et al., 2014a). A detailed description on how the systems were modelled in the simulations is given in chapter 6.

2.3.1 The Full ecoDriver System

The HMI of Full ecoDriver System (FeDS) was developed within the project. Since it was used in different vehicles the information to the driver was presented on a tablet. The main screen of the FeDS is presented in Figure 5. The speedometer was shown with the current speed and the speed advice (in green), the current gear was indicated including gear shift advice, performance of the driver was indicated through green circles against a background of a tree indicating the eco-driving performance (five filled circles indicated excellent eco-driving performance and none a poor performance). The FeDS had the possibility to distinguish eco-driving performance at different levels (the level was indicated by a bronze, silver or gold coin on which your chosen 'avatar' was standing). Figure 5 show a situation when current speed is at the advised speed and the current used gear is equal to the advised gear.

Figure 5: Main screen of FeDS.

The advised speed was shown continuously. Advice to change the speed was provided for the following events:

- approaching an intersection
- approaching a lower speed limit
- approaching a curve
- approaching a preceding vehicle

After one of the events the driver received feedback on her/his performance. This was done by rating the performance using stars, where five highlighted stars indicate the best performance. As an example the advice and feedback for a curve are presented in Figure 6.

Figure 6: Advice to slow down for a curve (left) and feedback on perfect performance (right).

2.3.2 ecoDriver App

The ecoDriver "app" developed by the project shares HMI features with the FeDS as described in the previous section. The ecoDriver App provides feedback analysis on acceleration, deceleration and gear shifting behaviour but it also displays feedforward information and advice about upcoming events (junctions, sharp curves, slopes, traffic lights, roundabouts, speed limits). The main difference from the FeDS is the sensor information used to provide advice and feedback to the driver. Another difference is that it does not give continuous speed advice. The main screen of the ecoDriver App is presented in Figure 7. Drivers could choose to show the performance tree or a map that was used for navigation.

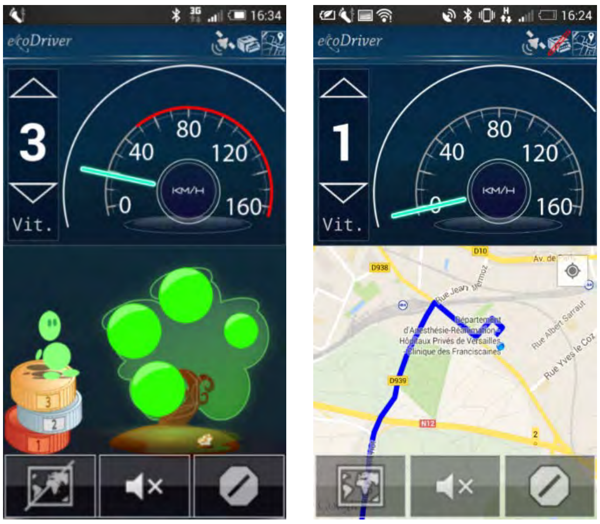


Figure 7: The main screen of the ecoDriver App with the performance tree (left) or map (right).

The ecoDriver App provided information, feedback and advice on the following events

- crossing an acceleration/deceleration threshold (see Figure 8)

- on time or too late gear shift (see Figure 9)
- approaching intersection
- going downhill
- approaching a curve (see Figure 10)
- approaching a pedestrian crossing
- the posted speed limit

Figure 8: Feedback on harsh acceleration (left) and deceleration (right)

Figure 9: Feedback on gear shift performance

Figure 10: Example of an advice to decelerate and the reason for deceleration (here, a sharp curve)

2.4 Types of vehicles and powertrains

The FeDS was customised and tested for specific vehicle brands and models. That implied ecoDriver equipped vehicles in the simulation to be of a specific vehicle type. Traffic simulations normally include modelling of populations of vehicle classes (car, van, truck, etc.) using statistical distributions to either describe the distribution of vehicle types (brands and models) or more common distributions of vehicle characteristics (length, width, max acceleration, etc.). Here, each vehicle class had to be represented by the vehicle types that the FeDS system was customised for. Table 5 shows the vehicle types used in the simulation, several of these vehicle types were used in the field tests. Models for a van (VW Transporter) and truck (a DAF EURO V 15t rigid truck for the urban and motorway environments and a DAF EURO V 30t semi-trailer truck for the rural environments) were added to the simulation set because those vehicle types are needed to realistically model traffic flow. Although an embedded system for a Daimler truck were developed within the project, detailed information about how the Daimler ecoDriver system works was not accessible and a integration with the traffic simulators were not possible. However, the consortium was able to make a truck version of the FeDS using an already developed vehicle model for a DAF truck. The simulations did not include modelling of ecoDriver equipped buses.

Table 5: Simulated vehicle types, including their fuel type and gear box.

Vehicle type	Vehicle class	Used in field test
Nissan Leaf (electric, automatic)	Car	Spain
Renault Clio (petrol, manual)	Car	France
Renault Scenic (diesel, manual)	Car	Spain
VW Transporter (diesel, manual)	Van	No
DAF Truck (diesel)	Truck	No

The share of buses are low for all scenarios and years (see Jopson et al. (2015)) and independently of the effect on individual vehicles the effect on the effect on the traffic system would still have been small. Furthermore, on motorways and rural roads buses can be assumed to be mostly coaches which to some extent have similar characteristics as trucks, and the bus share were added to the share of trucks without trailers. In urban roads the buses constituted a very small percentage of the vehicle fleet and the total mileage. Furthermore, the ecoDriver system for buses developed within the project was not finalized until after the traffic simulations were performed (due to technical problems).

2.5 Transformation of traffic mix and penetration rates from the scenarios to the traffic simulation cases

The vehicle type mix used in the simulations varies per road type, scenario and future year. Also, the vehicle class mix depends on the OD matrices for each road network. The OD matrix typically has a number of vehicle types represented for each origin-destination pair - usually only for the vehicle classes cars and trucks. This OD-matrix needs to be split up in an OD matrix containing trips for each individual vehicle type listed in Table 5. The translation from scenario numbers to input for the simulation models for each traffic simulation case was conducted as follows:

- First step: The vehicle type shares specified in the WP52 scenarios (see example in section 2.1.1 and complete description in Jopson et al. (2015)) were aggregated to the vehicle types used in the simulations (see Table 5). This was done by assigning the vehicle types for which we have no information from the field trials or from other sources to another vehicle type.
- Second step: The penetration rates of embedded and nomadic ecoDriver systems given in the WP52 scenario specification were used to calculate the penetration rate of each vehicle type – equipment type combination (e.g. car petrol with embedded system).

The first step required aggregation for those powertrains and fuel types with corresponding ecoDriver systems available in the simulation. This means vans and trucks are only represented by diesel engines and cars are represented by petrol, diesel and electric engines exclusively. The aggregation for trucks and vans assumes 100% diesel (the total share of other types are only about 1% independently of scenario and future year). The aggregation for cars is more complex since different powertrains need to be split into diesel, petrol and electricity. The aggregation was performed in several steps utilising the share between the different vehicles and assumptions of proportional powertrain uses for hybrids. The aggregation of cars was conducted in the following procedure:

- Gas and other powertrains were ignored and equally distributed over the remaining powertrains. The motivation for this is that Gas and other powertrains are few and the most reasonable approach is to ignore them, which implies that their share is split on the remaining vehicle types based on their relative shares.
- Hybrids and plug in hybrids were assumed to be represented by electric and petrol powertrains only. The main reason is that there were no FeDS or ecoDriver App developed for hybrid or plug in hybrids and thereby no hybrid vehicle model including max acceleration and engine speed calculation. The split was decided based on discussions between the partners (expert judgment), and the observation that the combination hybrid/petrol is unlikely (therefore no shift to car diesel). The share of use between the different powertrains is

different for rural, motorway and urban roads. The motivation is that the average trip length on a rural road and on motorways are longer and the share of the time that running on the battery is possible would therefore be lower than in an urban setting. The split is assumed to be independent of years and scenarios.

The split between electric and petrol usage for hybrids and plug in hybrids are presented in Table 6.

Table 6: Proportional split of hybrids and plug in hybrids to electric and petrol use for the different road types in the simulation

Road type	Hybrids		Plug in hybrids	
	Petrol	Electric	Petrol	Electric
Motorway	85%	15%	70%	30%
Rural	85%	15%	70%	30%
Urban	15%	85%	30%	70%

The aggregation into three car types (diesel, petrol and electric) and vans, trucks and buses gives a maximum flexibility and is consistent with later needed aggregations to the vehicle classes (car, van, truck, bus). The traffic mixes and the penetration rates for all the scenarios and future years are presented in Annex A.

2.6 Performance indicators

A set of performance indicators (PIs) need to be extracted from the simulations to be used as input to the scaling up task. The scaling up needs relative change per vehicle-km (vkm) from baseline (without ecoDriver system) to treatment (with mixed traffic, so with part of the vehicles equipped with the ecoDriver system) for all traffic simulation cases (e.g. for Green Future / year 2025 / urban motorway / moderate demand, etc.). Table 7 presents the utilised performance indicators, how they were calculated and at what aggregation level. Detail descriptions on the calculation process for each indicator are given in chapter 9 (Environmental PIs), chapter 10 (Safety PIs) and chapter 11 (Traffic efficiency PIs). The set of PIs is not the same as the PIs used to analyse the driving behaviour in SP4 (Saint Pierre et al., 2016). The SP5 PIs are defined based on the needs of the cost benefit analysis. The PIs are defined as effect size changes per vehicle-km. The reason is that the PI values extracted from the simulations are scaled up per vehicle class, road network, scenario, and year by the number of vehicle-km driven for each such combination, see D54.1 (Jonkers et al., 2016) for a detailed description of the scaling up procedure.

Table 7: Performance indicators

PI	Unit	Formula	Disaggregation
CO_2	g/vkm	Total CO_2 emissions / total kilometres travelled	Per vehicle class & network
NO_x	g/vkm	Total NO_x emissions / total kilometres travelled	Per vehicle class & network
Fuel Consumption	l/vkm	Total fuel consumption / total kilometres travelled	Per vehicle class & network
Energy Consumption	kJ/vkm	Total energy consumption / total kilometres travelled	Per vehicle class & network
Travel time	s/vkm	Total time travelled / total kilometres travelled	Per vehicle class & network
Travel time corrected for speeding	s/vkm	Total time travelled not driving faster than the speed limit / total kilometres travelled	Per vehicle class & network
Fatalities	vkm^{-1}	Speed power model applied to average speed	Per network
Serious Casualties	vkm^{-1}	Speed power model applied to average speed	Per network
Slight Casualties	vkm^{-1}	Speed power model applied to average speed	Per network
Fatal accidents	vkm^{-1}	Speed power model applied to average speed	Per network
Serious injurie accidents	vkm^{-1}	Speed power model applied to average speed	Per network
Slight injurie accidents	vkm^{-1}	Speed power model applied to average speed	Per network

3. Descriptions of the road networks

The networks should be good representatives of motorways, rural roads and urban networks for the EU-28 countries. It would require a huge set of different networks to capture the range of variations both in road design and standards, traffic control, driving behaviour, etc. The networks simulated captures a range of variations in urban and rural environments, road alignment and city structure. The networks should rather be seen as samples than trying to model the 'average EU-28 road'.

3.1 The motorway networks

The motorway networks derived from two parts of the Dutch motorway network, namely the A13 and the A67. The choice for these networks was firstly based on a practical limitation, namely that implementing and calibrating microsimulation networks is time consuming and dependent of data availability. For the mentioned networks, a basic implementation was already available for the ITS Modeller microsimulation model, which is especially suitable for simulation of motorways. Secondly, representativeness was an important criteria. Those two motorway networks together are considered representative for European motorway networks, considering the speed limits and traffic demand levels. The road lay-out was implemented according to the real road networks. For both networks, dynamic origin-destination matrices were estimated to reflect low and moderate traffic demand and to realistically model the amount of through traffic (about 40% for the A13) versus traffic entering/leaving the motorway at the various on and off ramps. The traffic demand was calibrated roughly such that no congestion occurred anywhere in the networks. The resulting flows are representative for low and moderate traffic situations at these networks in reality, though at the A13 during peak hours the traffic demand is usually higher. This was however not considered relevant for the ecoDriver system, since in high traffic demands, the system will be less effective.

3.1.1 The flat urban motorway network

The flat urban network is a motorway network is based on the A13 from The Hague to Rotterdam in the Netherlands (between junction Prins Clausplein (The Hague) and Kleinpolderplein (Rotterdam)). The simulated network is 16.4 km, see Figure 11. It partly consists of four and partly three lanes. It has six entrances and five exits, which is considered representative. The speed limit is 100 km/h.

Figure 11: The flat urban motorway network: A13 (Netherlands)

With the flat urban network, two scenarios have been simulated: a scenario with low traffic demand, and a scenario with moderate traffic demand. No congestion occurred in any of the scenarios. Some characteristics of the flat inter-urban network are given in Table 8. Each of the mentioned vehicle types can be equipped with the nomadic or embedded ecoDriver system in the simulations, depending on the scenario.

Table 8: Characteristics of the flat urban motorway network

Network characteristics	**Description**
Road number	A13 (Netherlands)
Number of lanes	3 and 4
Length	16.4 km (one direction)
Vehicle types	car (Renault Clio, Renault Scenic, Nissan Leaf), van (VW Transporter), truck (DAF XF 15t)
Speed limit (km/h)	100
Demand	Low (maximum flow ~5000 veh/h), moderate (maximum flow ~6250 veh/h)

3.1.2 The flat inter-urban motorway network

The flat inter-urban network is a 12.5 km long, two-lane motorway network which resembles the A67 near Eindhoven in the Netherlands (between junction Leenderheide and Someren). There is one junction with on- and off ramps after about 4 km from the west, see Figure 12 for an illustration. In order to account for the effect of a change in the speed limit, on the west part up to 6 km, the speed limit is 100 km/h, after which it changes to 130 km/h. Accordingly, for the other driving direction from east to west, the initial speed limit is 130 km/h and drops to 100 km/h at about 6 km before the end of the network.

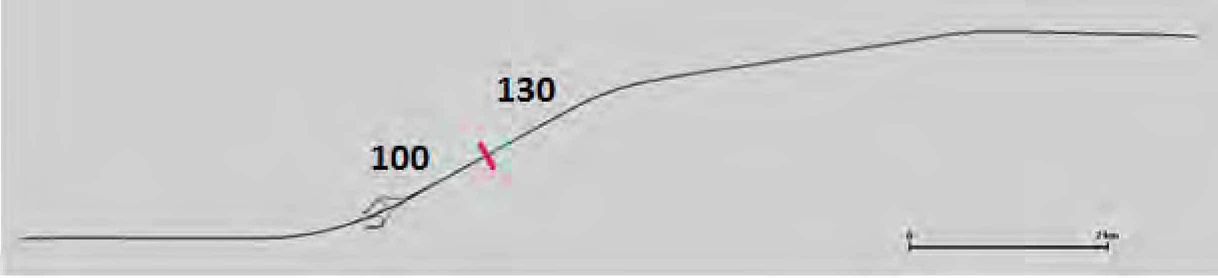


Figure 12: The flat inter-urban motorway network.

With the flat inter-urban network, two scenarios have been simulated: a scenario with low traffic demand, and a scenario with moderate traffic demand. No congestion occurred in any of the scenarios. Some characteristics of the flat inter-urban network are given in Table 9.

Table 9: Characteristics of the flat inter-urban motorway network

Network characteristics	**Description**
Road number	A67 (Netherlands)
Number of lanes	2 (both directions)
Length	12.5 km (one direction, 25 km in two directions)
Vehicle types	car (Renault Clio, Renault scenic, Nissan Leaf), van (VW Transporter), truck (DAF XF 15t)
Speed limit (km/h)	100, 130
Demand	Low (flow 2300 veh/h), moderate (flow 2400 veh/h)

3.2 The rural road networks

This section contains a brief description of the four different rural road networks used in the simulation. It has not been possible to include rural roads from all different countries in Europe, instead a sample of different roads have been used to represent the variety of characteristics at rural roads. The networks were chosen based on data from real Swedish rural roads (Carlsson and Björketun, 2004) in order to capture different characteristics of rural roads including slopes, overtaking restrictions and visibility. The reason why Swedish roads are selected to represent the rural roads in Europe is because the traffic simulator RuTSim is tailor made for simulations of traffic states at rural roads. Because of that, calibrated networks of rural roads were available within the project. It would not have been possible to set up and calibrate new networks within the time frame of the project.

3.2.1 The flat and low intersection density rural road network

The flat road network represents a 22 km long rural road stretch with default speed limit of 90 km/h. The network is mainly based on characteristics from different Swedish rural roads with 90 km/h as default speed limit.

Local speed limits of 70 km/h appear at intersections, overtaking is prohibited by solid lines at these locations. The intersections are modelled as speed limit changes, but no traffic is allowed to enter or leave the network at these locations. There are only two origins and destinations in the network, located in the beginning and the end of the network, respectively.

The network is a single carriageway road with one lane in each direction and no extra lanes are available for overtaking or turning traffic. No median barrier is used in the network which means traffic is allowed to use the opposite direction for overtaking, whenever there is no solid line. There are several locations were possible overtaking may be performed. Due to the long sight distance, drivers are allowed to have a clear overview of oncoming traffic which simplifies overtaking. An overview of the curvature and the location of the local speed limit is illustrated in Figure 13.

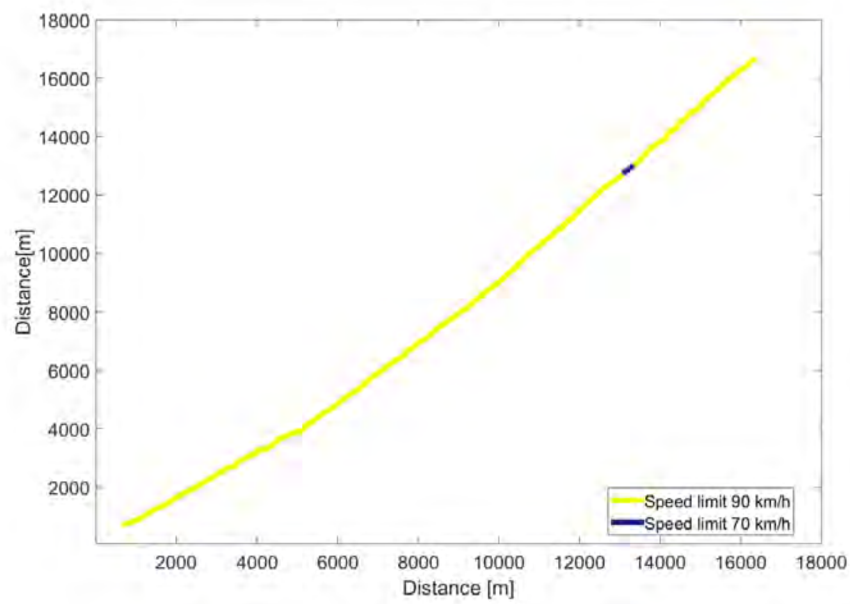


Figure 13: Curvature and location of local speed limits for flat and low rural road intersection density network

Detailed characteristics of the flat low intersection density network is presented in Table 10. The traffic demand is chosen as representative of free flow and moderate traffic conditions according to measured flows on a standard Swedish rural roads with speed limit 90 km/h.

Table 10: Characteristics of the flat and low intersection density rural network

Network characteristics	**Description**
Road number	Based on different rural roads in Sweden with default speed limit 90 km/h
Number of lanes	1 in each direction (no median barrier)
Length	22.989 km (one direction)
Vehicle types	car (Renault Clio, Renault Scenic, Nissan Leaf), van (VW Transporter), truck (DAF XF 30t)
Speed limit (km/h)	90, 70 (mostly 90 km/h, only 1 local speed limit of 70 km/h)
Demand	Low (maximum flow ~200 veh/h), moderate (maximum flow ~744 veh/h)

The characteristics of the network invites cruising mode due to the limited number of slopes, curves and local speed limits. The network only contains a few curves and none of them are sharp enough to cause decelerations more than engine breaking. The steepest hill is 2% and none of the vehicles in the simulation needs to shift down in order to get sufficient engine power when travelling with a speed of speed limit.

The local speed limits are added to the network at flat and straight locations with good sight distance. Figure 14 presents the sight distance, curvature, slope and location of the local speed limit at the road. The black line presents the location of the local speed limits (70 km/h), else the speed limit is 90 km/h.

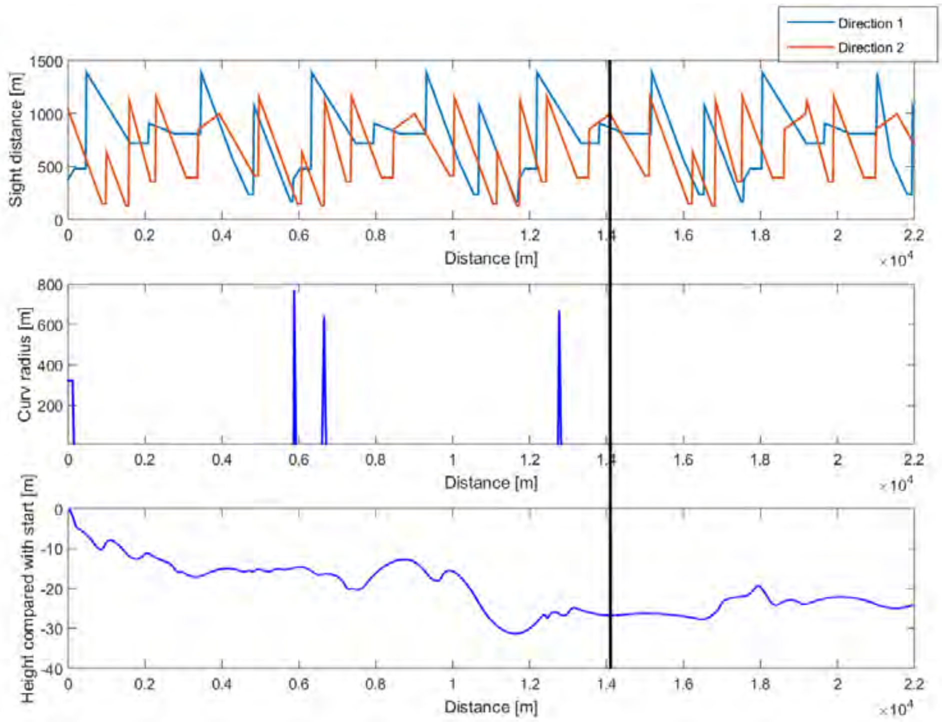


Figure 14: Visibility, curve radius and slope profile for flat and low intersection density rural network. The curve radius was only plotted for non-infinity values (i.e. non straight road sections).

3.2.2 The flat and high intersection density rural road network

The flat and high intersection density network is identical to the flat and low intersection density network in all characteristics, except for the number of intersections (local speed limits). Five different local speed limits of approximately 500 meters each, have been added to the network. The locations are selected in order to satisfy safety, meaning no slopes, curves or obstacles reducing the sights distance should be located close to the intersection. An overview of the flat and high intersection density network is presented in Figure 15.

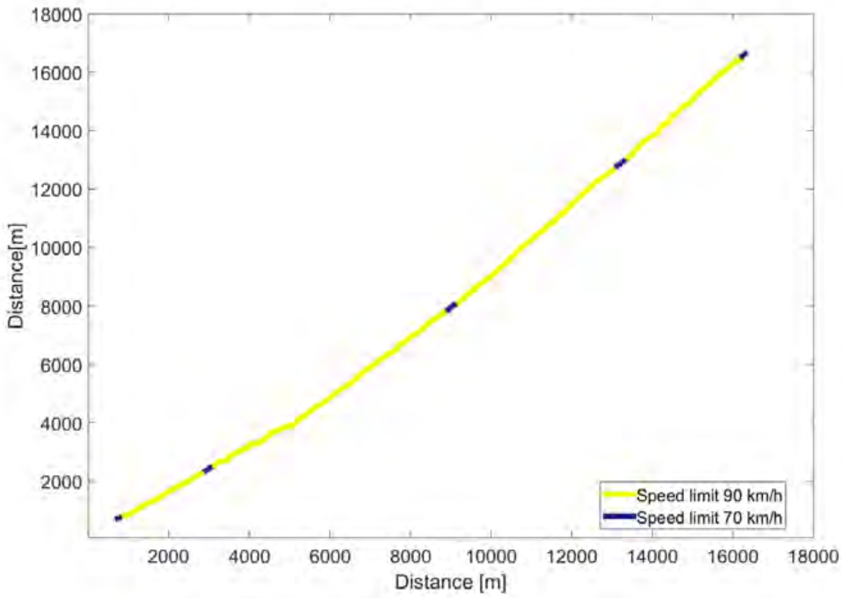


Figure 15: Curvature and location of local speed limits for flat and high intersection density rural network

As can be observed from Figure 16, the fundamental characteristics of the network is identical to the flat low intersection density network. There are no steep hills or sharp curves affecting drivers' desired speed and their ability to drive at a constant speed in-between the local speed limits. The black line presents the location of the local speed limits (70 km/h), else the speed limit is 90 km/h.

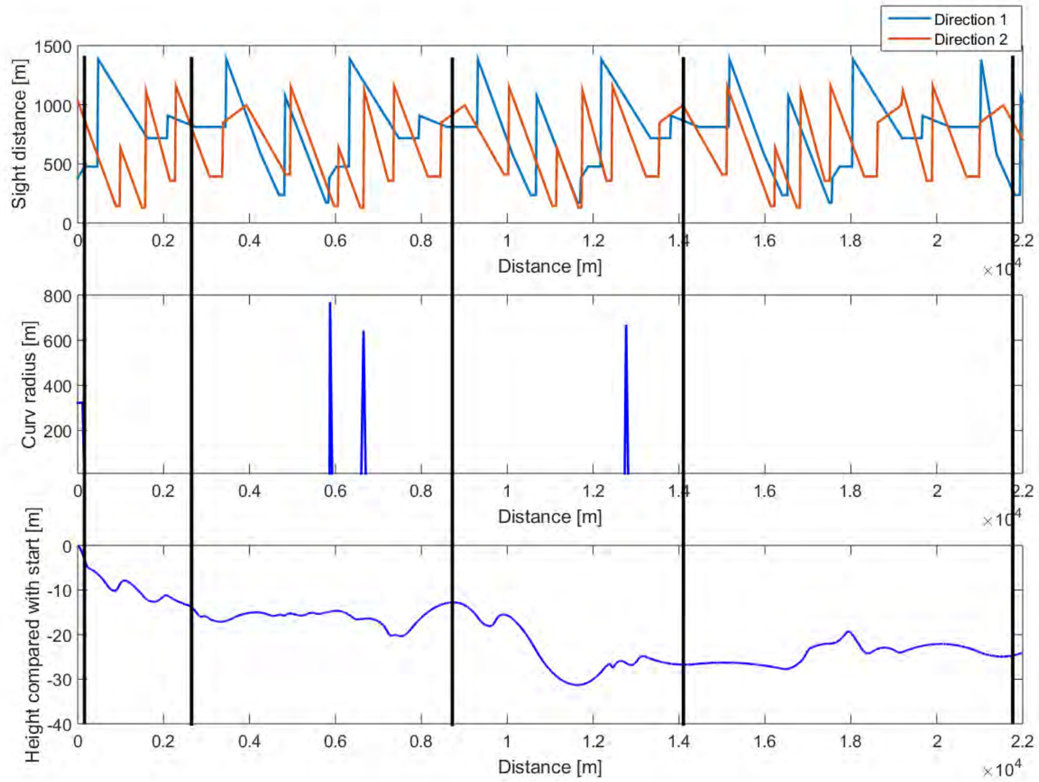


Figure 16: Visibility, curve radius and slope profile for flat and high intersection density rural network. The curve radius was only plotted for non-infinity values (i.e. non straight road sections)

3.2.3 The hilly and low intersection density rural road network

The hilly and low intersection density network is a 23 km long single carriageway road rural road with one lane in each direction. The network characteristics are developed by combining several Swedish rural roads with default speed limit 90 km/h. Local speed limits have been added to the network afterwards in order to represent varying intersection density. The road alignment profile is less attractive for overtaking since the main part of the network consists of limited visibility due to ambient environment, slopes or curves. Overtaking is prohibited at several locations by solid lines. The default speed limit is 90 km/h and there is a single local speed limit of 70 km/h. An overview of the curvature and location of the local speed limit is presented in Figure 17. Detailed characteristics of the hilly and low intersection density network is presented in Table 11.

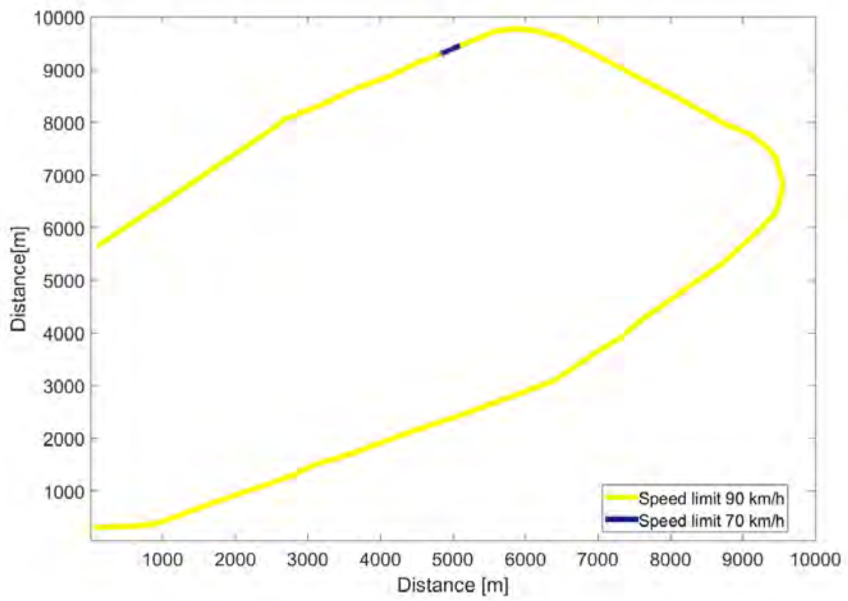


Figure 17: Curvature and location of local speed limits for hilly and low intersection density rural network

As may be observed in Figure 17, the visibility profile is clearly deteriorated compared to the flat network. The excepted effect would be increased number of constrained vehicles meaning that the average speed will decrease given the same desired speed distribution as for the flat network.

Table 11: Characteristics of the hilly and low intersection density rural network

Network characteristics	**Description**
Road number	Based on different rural roads in Sweden with default speed limit 90 km/h
Number of lanes	1 in each direction (no median barrier)
Length	23.009 km (one direction)
Vehicle types	car (Renault Clio, Renault scenic, Nissan Leaf), van (VW Transporter), truck (DAF XF 30t)
Speed limit (km/h)	90, 70 (mostly 90 km/h, only 1 local speed limit of 70 km/h)
Demand	Low (maximum flow ~200 veh/h), moderate (maximum flow ~744 veh/h)

The road alignment consists of several locations where drivers are required to adapt their speed and gear in order to maintain safe driving. There are several sharp curves requiring decelarions by using the braking pedal and several slopes requiring drivers to shift down in order to have sufficient engine power to maintain the desired speed. The steepest slope in the network is 6% at a hill located 2600 meters within the network.

The road alignment of the network is summarised in Figure 18 containing visibility, curvature, slope and speed limits for each position in the network. The black line presents the location of the local speed limits (70 km/h), else the speed limit is 90 km/h.

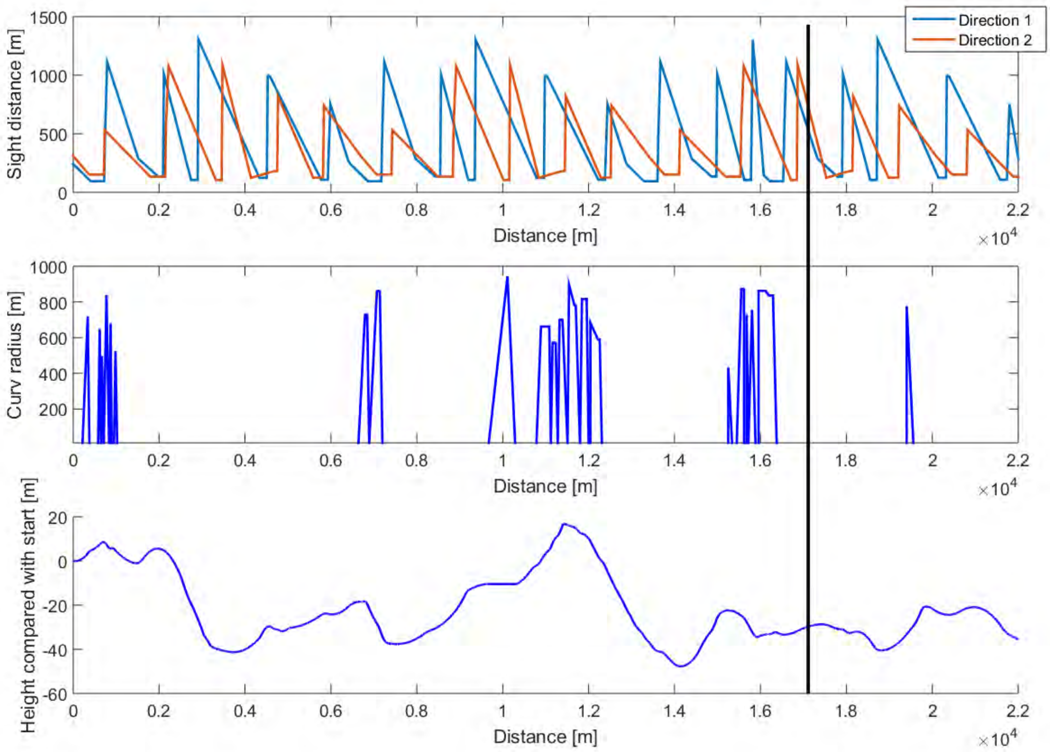


Figure 18: Visibility, curve radius and slope profile for hilly and low intersection density rural network. The curve radius was only plotted for non-infinity values (i.e. non straight road sections).

3.2.4 The hilly and high intersection density rural road network

The hilly and high intersection density network is identical to the hilly and low intersection density network in all characteristics, except for the number of local speed limits. In comparison to the hilly and low intersection density network, four additional sections of approximately 500 meters each have been assigned 70 km/h as speed limit. It gives a total of five local speeds limits and the locations of these are presented in in Figure 19.

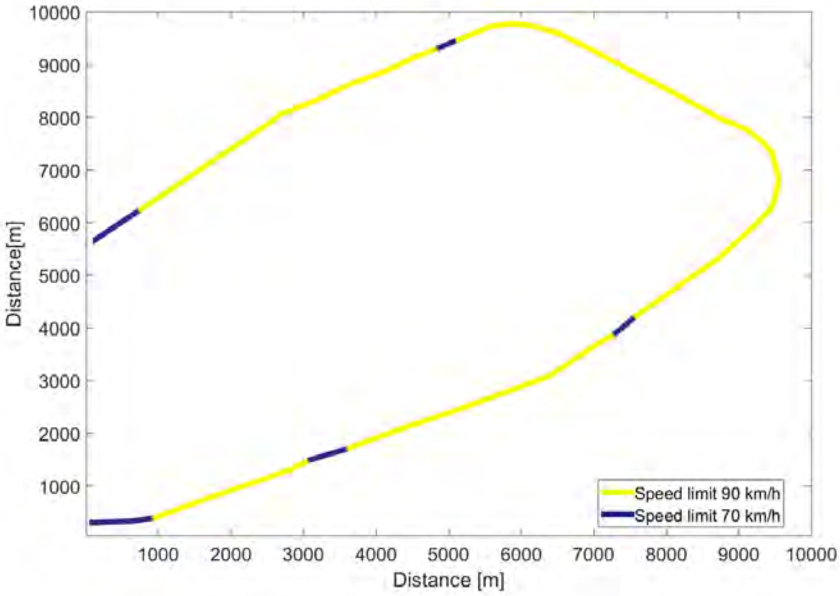


Figure 19: Curvature and location of speed limits for hilly and high intersection density network

The location of the intersections are selected in order to satisfy security, meaning no slopes, curves or obstacles reducing the sights distance are located close to any intersection. Overtaking is prohibited at the location of the intersections by a solid line. A compilation of visibility, curvature, slope and location of local speed limits are presented in Figure 20. The black line presents the location of the local speed limits (70 km/h), else the speed limit is 90 km/h.

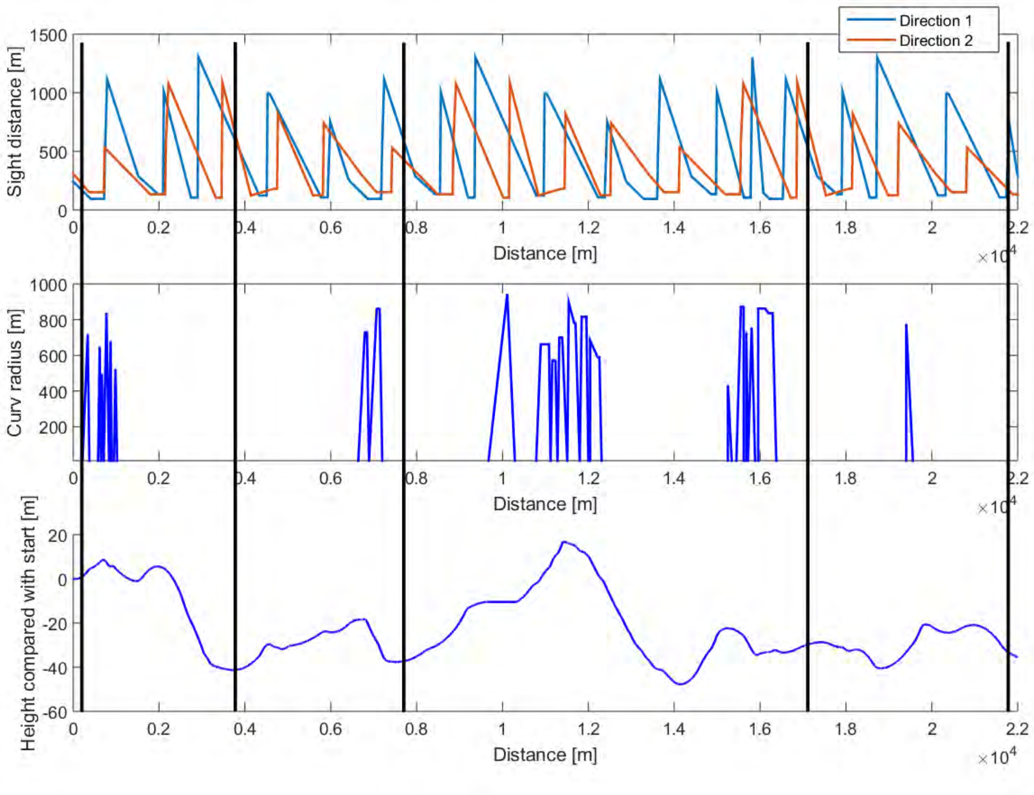


Figure 20: Visibility, curve radius and slope profile for hilly and high intersection density network. The curve radius was only plotted for non-infinity values (i.e. non straight road sections).

3.3 The urban road networks

The urban road networks are based on urban road networks in the United Kingdom. The compact city urban network is largely restricted to a single lane in either direction, with a typical proportion of public transit Buses passing through and also servicing Bus stops. The network reflects the dynamics and interactions of vehicles with signal control systems and pedestrian crossings, as found across Europe. The main route in the spacious city network is a dual carriageway with a mixture of signal controlled and roundabout intersections. The network also includes Bus routes that service stops, as commonly found across Europe in suburban areas.

3.3.1 The flat and compact urban road network

The flat and compact urban network represents a section of the A660 corridor in the Headingley suburb of Leeds. The simulated network is 3.8 km in length comprised of 145 junctions and 374 road sections with an average length of 81.6 m (Figure 21). The speed limit throughout the network is 30 mph. (48 km/h).

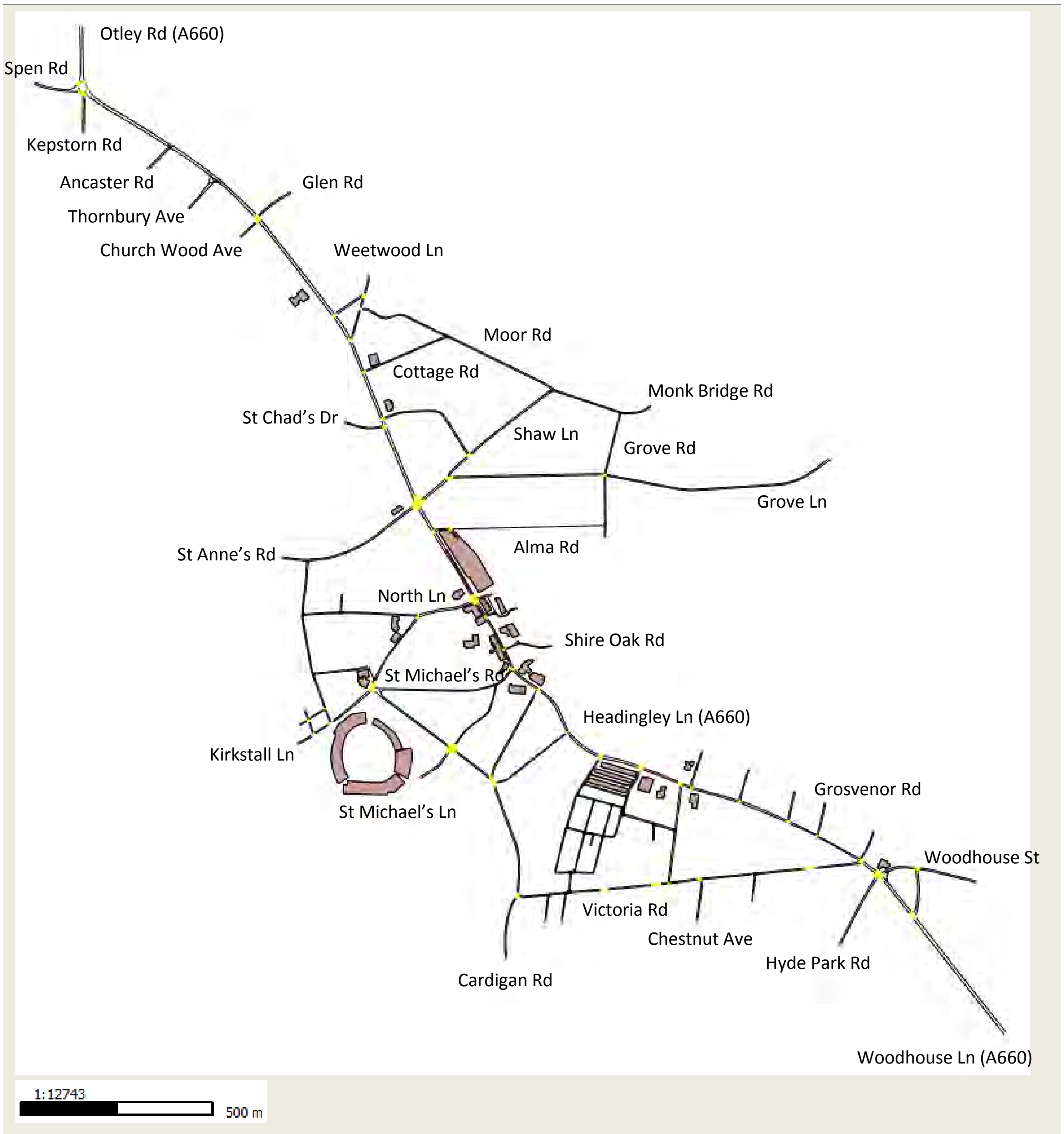


Figure 21: Extent of the Headingley A660 AIMSUN Model (compact urban)

The network was created using geo-referenced aerial photography downloaded from the Landmap Kaia service hosted at MIMAS (Millin-Chalabi et al., 2011), which provided a spatially accurate representation of the Headingley road network. For the flat version of this compact urban network all road sections were set to have 0% gradient.

Traffic demand data for the network was estimated based on observations from observed traffic count data from the Leeds City Council (LCC) Highways and Transportation Department. All available Manual Traffic Count (MTC) data and measured traffic flows by Automatic Traffic Counters (ATCs) available from Highways and Transportation as of November 2014 was harvested from a Leeds City Council GIS database. In total, there were 42 ATC surveys and 20 MTC surveys for calibration of the traffic networks is collect between March 2006 and July 2014, with a majority recorded post-2008. Wherever possible the more recent data was used and data recorded between September and November was given priority in an effort to minimise any seasonal disparities. This data was used to estimate initial link input flows.

The network contains six traffic signal controlled junctions, which have been coded to accurately reflect the on-street situation at each time period. The four junctions on the A660 were modelled using signal and stage plans (stages, green times and intergreen times) provided by Leeds City Council. The timings were also ratified by direct field observation.

There are a total of 53 bus stops in the modelled area. The bus stop locations and type (whether a bus bay, where the bus pulls off the road, or a normal stop where the bus stops on the road) have been modelled from the geo-referenced aerial photography (Millin-Chalabi et al., 2011) and Google Maps (www.google.co.uk/maps). Public transport lines servicing these were obtained from timetable and routing information available at the Metro (Metro, 2014) and via their real time bus information tool (Metro, 2015). The frequency of some of these services were adjusted slightly to reflect the fleet shares for the simulation cases (see section 2.5 and Annex A). The model was calibrated for two scenarios:

- One with a moderate traffic demand, selected as the inter-peak between 13:00 and 14:00 hours; and
- The other a low flow scenario representing traffic movements in the evening period between 21:00 and 22:00 hours.

In-line with ‘best practice’ (Dowling et al., 2004) calibration was conducted comparing real observed and modelled flows as the ‘measure of performance’. A total of 26 virtual detectors were included within the AIMSUN network where traffic count data was available. These detectors record the simulated vehicle per hour flow (over the road section on which they are located) every 30 simulation minutes, as well as the average vehicles per hour flow over the two hour simulation period. The simulated model flows were compared to the real-world flows (defined by the traffic count data) at each of the 26 detector sites using a GEH statistic (Dowling et al., 2004, DFT, 2014). The DfT Transport Analysis Guidelines (TAG) criteria for link flow validation were met. The characteristics of the flat urban compact network are documented in Table 12.

Table 12: Characteristics of the flat urban compact network

Network characteristics	Description
Road number	A660 (Headingley, Leeds, UK)
Number of lanes	1 and 2
Length	3.8 km (two directions)
Vehicle types	car (Renault Clio, Renault Scenic, Nissan Leaf), van (VW Transporter), truck (DAF XF 15t), bus
Speed limit (km/h)	48
Demand	Low (maximum flow ~700 veh/h per lane), moderate (maximum flow ~1250 veh/h per lane)

3.3.2 The flat and spacious urban road network

The Scott Hall Road (A61), the main route heading north from Leeds City centre was selected as the spacious urban network (see Figure 22). The main arterial is largely a dual carriage-way in both directions, broken by roundabouts and signalised crossings. The North-South route simulated is 4 km in length.

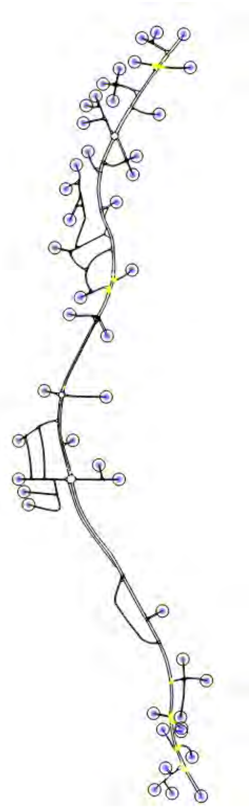


Figure 22: Extent of the A61 AIMSUN Model (spacious urban)

The traffic demand and routes were initially specified to replicate flows and origin-destination patterns in a strategic traffic model of the City (http://www.saturnsoftware.co.uk/). The strategic model represented an AM peak period. Traffic junctions were configured to represent those in the strategic model, cross-referenced to the geo-referenced aerial photography downloaded from the Landmap Kaia service hosted at MIMAS (Millin-Chalabi et al., 2011) of the corridor. Public transport lines servicing the Bus stops on the route were again obtained from timetable and routing information available at the Metro (Metro, 2014).

A series of iterations adjusting the strategic model demand levels to match observed Manual and Automatic Traffic Count data (27 sites) provided by Leeds City Council were made. The final AIMSUN version of the AM peak model fulfilled the DfT GEH statistic (Dowling et al., 2004, DFT, 2014) criteria at these 27 sites.

The moderate and low-flow demand scenarios were developed by factoring the AM peak demand levels by 10% and 50% respectively. The flow levels then broadly matched the flows in inter-peak and evening periods, so comparable with the urban compact networks. The characteristics of the flat urban spacious network are documented in Table 13.

Table 13: Characteristics of the flat urban spacious network

Network characteristics	Description
Road number	A61 (Leeds, UK)
Number of lanes	2 on main arterial, 1 on side roads
Length	4 km (two directions)
Vehicle types	car (Renault Clio, Renault Scenic, Nissan Leaf), van (VW Transporter), truck (DAF XF 15t), bus
Speed limit (km/h)	60 on main arterial, 48 on side roads
Demand	Low (maximum flow ~500 veh/h per lane), moderate (maximum flow ~1000 veh/h per lane)

3.3.3 The hilly and compact urban road network

The hilly and compact urban network is identical to the flat version (see section 3.3.1), except the road section gradients in AIMSUN were set for the “slope percentage” (road grade) derived from a Digital Terrain Model (DTM). The altitude at each section location was extracted and input to AIMSUN, which generates a road grade for each road section within the simulation. The distribution of road gradient is illustrated in Figure 23.

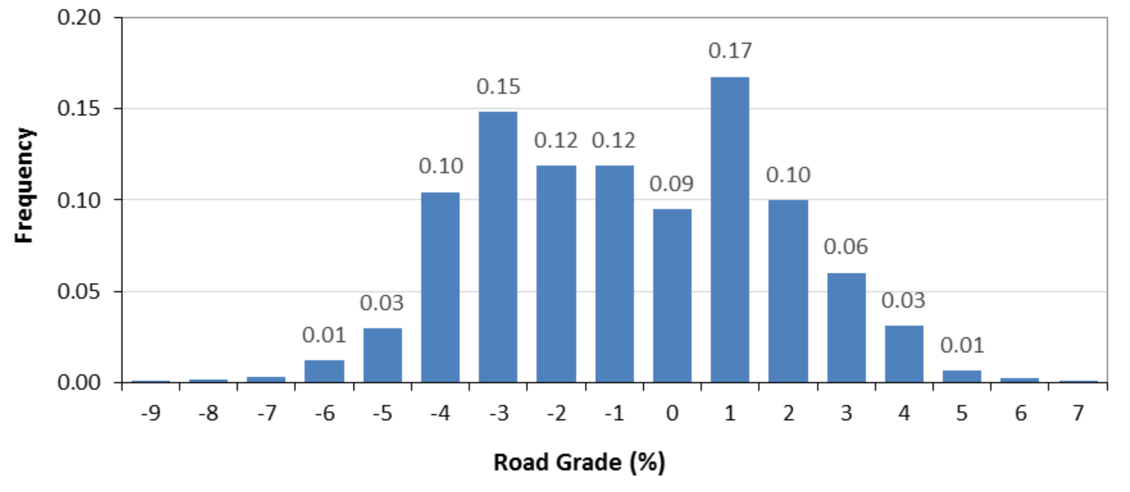


Figure 23: Road gradient frequency distribution for the (A660) compact urban AIMSUN network

The network is not excessively hilly, with 60% on link distance with road gradient in the range ±2%. There are some occasional steeper up-hill and corresponding down-hill sections.

3.3.4 The hilly and spacious urban road network

The hilly and spacious urban network is identical to the flat version (see section 3.2.2), except the road section gradients in AIMSUN were set for the “slope percentage” (road grade) derived from a Digital Terrain Model (DTM) of the area. The altitude at each section location was extracted and input to AIMSUN, which generates a road grade for each road section within the simulation. The southern end of the network lies at an altitude of ~40m rising to ~115 m as one travels North “up” the first 1.5 kms of the A61 corridor. This equates to an average gradient of +5%, the maximum gradient being +8%. The road continues to climb more gradually for the next 2.5 kms at an average gradient of +1%. The network is therefore up-hill on sections heading North, and down-hill on south-bound links.

4. Simulation framework

Microscopic traffic simulation models are a common tool for estimating impacts from driver support systems on the traffic system. Traffic simulation analysis of adaptive cruise control (ACC) is the most common type of study (Davis, 2004, Davis, 2007, Kesting et al., 2007a, Kesting et al., 2007b, Van Arem et al., 2006, Minderhoud and Bovy, 1999, Klunder et al., 2009, Tapani, 2012), but other systems such as intelligent speed adaptation (ISA) (Liu and Tate, 2004, Toledo et al., 2007) and overtaking assistants (Hegeman et al., 2009) have also been examined. However, Tapani (2011b, 2011a) concluded that many of these studies considered only system functionality and not the changes in driver behaviour that the systems may induce. It is also clear that current state-of-the-art microscopic traffic simulation modelling excludes the driver behaviour effects of driver support systems. Hence, existing microscopic traffic simulation models need to be supplemented to handle the functionality of driver-support systems and the changes in driver behaviour that these systems may induce (see e.g. (Klunder et al., 2009)). This can either be done by modelling the behaviour of drivers equipped with the system, without separating modelling of the system and the drivers' interaction with the system, or by modelling the support system and the driver interaction separately. The ecoDriver simulations requires that the drivers' compliance with the system can be varied for different scenarios and future years, without changing the functionality of the ecoDriver systems. To manage this, a traffic simulation framework that includes separate modelling of the ecoDriver system and the driver's interaction with the ecoDriver system was developed, see Figure 24. The framework consists of four main parts:

- a **Traffic Simulation program (TS),**
- an **External Module (EM)** handling the ecoDriver systems and drivers interaction with the systems,
- a traffic simulation program specific **Application Program Interface (API)** which handles the connection between the traffic simulation program and the external module, and
- a **Performance Indicator calculation module (PI)**.

The external module (EM) consists of three modules:

- the **ecoDriver system(s) (ED)**,
- a **Driver Model (DM)**, and
- a **Vehicle Model (VM)**

The ecoDriver system module are vehicle class (passenger car, van, truck) and powertrain (petrol/diesel, hybrid, electric vehicle) specific models of the ecoDriver system that were developed in SP2. The ecoDriver models generate speed and gear advice to the drivers. The driver models simulate how drivers respond to that advice, in particular their compliance with the speed and gear advice under different circumstances. These models are based on data collected in the field trials in SP3 and analysed in SP4. The drivers' choices (speed, acceleration, gear) are fed into a simple vehicle model that determines the engine speed and whether the vehicle can deliver the requested acceleration. The data are then fed into the simulation model which updates the vehicles' positions. This way, vehicle trajectories and aggregated statistics are generated, which are used to determine the impacts of the ecoDriver system on traffic performance (e.g. travel times), traffic safety (e.g. risk of fatal incidents), and the environment (energy use and emissions).

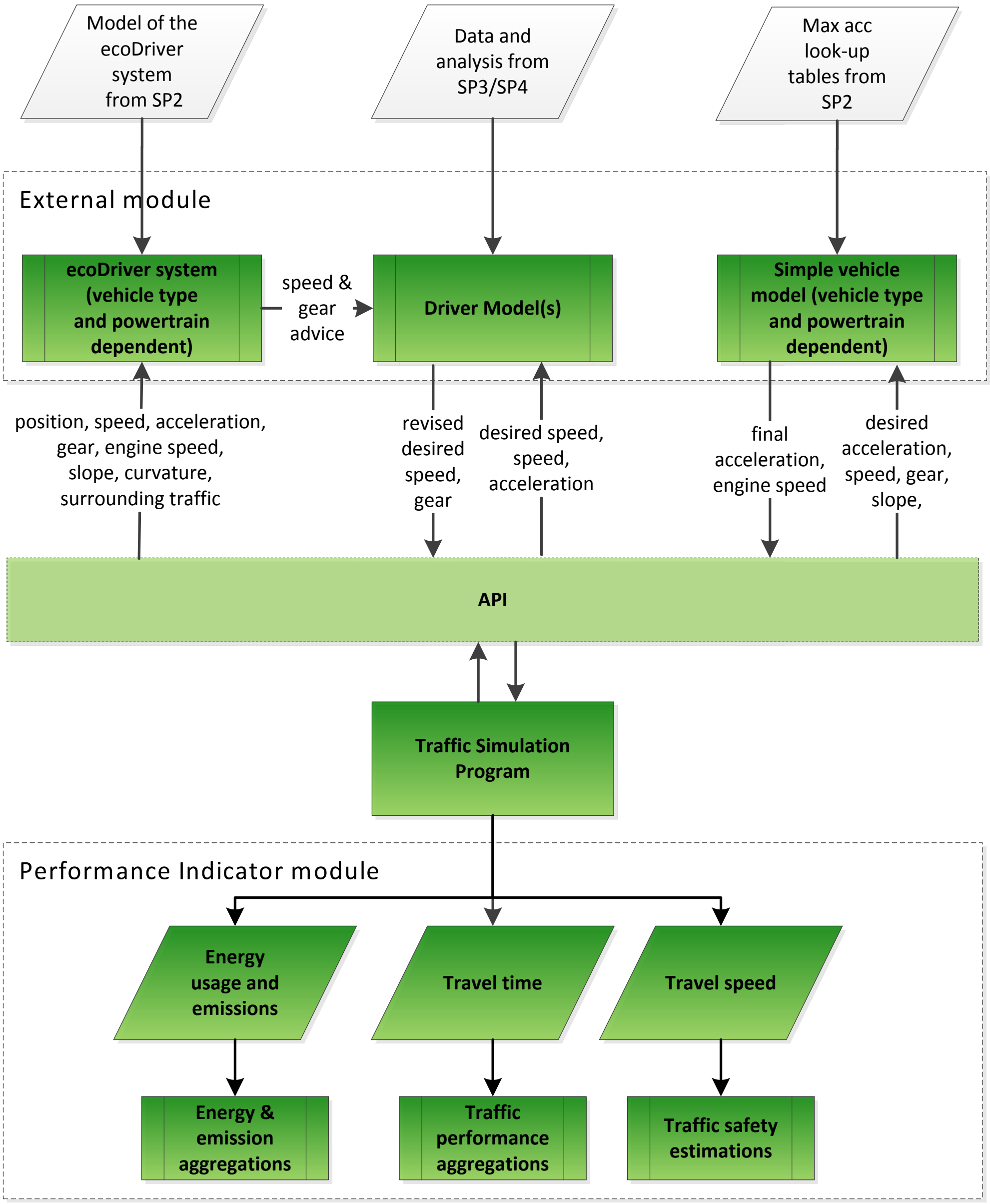


Figure 24: The traffic simulation framework.

Microscopic traffic simulation models are often used to evaluate, ex-ante, the potential impacts of innovative in-vehicle systems on traffic flows. It has become easier to integrate external models into microscopic simulation environments and this offers the possibility to use realistic vehicle and support system models in simulation – for example real-world vehicle models (see e.g. Tapani et al. (2012) and Olstam and Elyasi-Pour (2013)). This saves effort on modelling, helps to create more realistic simulations, makes simulation results from different tools more comparable, and allows the use of proprietary “black box” models in simulation. Initially in the ecoDriver project, the FeDS systems used in the equipped vehicles in the field tests, were integrated into the three microscopic traffic simulation environments used. This was done by compiling Dynamic Link Library versions (DLLs) of the Vehicle

Environment and Emission Estimator (VE^3), which is the underlying advice calculator in the FeDS (see the ecoDriver deliverables D22.1 (Ivens et al., 2014b) and D22.2 (Ivens et al., 2014a) for details). This approach made it possible to use the same ecoDriver models that were used in the test vehicles also in the traffic simulation environments, without any simplification.

Compiling the DLLs and integrating them into the simulations turned out to be more complicated and time consuming than initially expected. The technical implementation issues were solved and the DLLs were integrated with the three different traffic simulators. However, the verification simulations conducted sometimes indicated strange behaviour of the speed and gear advice given by the FeDS DLL. Furthermore, it turned out that the execution time of the simulations increased extensively and running several simulations replications of scenarios and future years involving substantial penetration rates would take much too long time. In the end, an alternative approach had to be selected. A FeDS emulator was developed and implemented based on extensive simulation analysis using the FeDS DLLs and initial analysis of field trial data. In addition also an emulator of the ecoDriver App was developed and implemented based on initial analysis of field trial data.

The details of the FeDS and ecoDriver App emulators are presented in chapter 6. Initial analysis of field trial data was also used to develop and calibrate the additional driver models, which are described in chapter 7. An additional simple vehicle model estimating engine speed and maximum available acceleration was developed since the ecoDriver systems gives gear advice and microscopic traffic simulators commonly do not include gear modelling. The details of the vehicle model are given in chapter 8.

Extracting travel times from microscopic traffic simulation models are straightforward while estimation of emissions and safety effects requires additional modelling. For the estimation of energy consumption and emissions an external emission model was developed based on Ligterink et al. (2014). The details of the emission model and how it was applied is given in chapter 9. The safety assessment is conducted using the speed power model (Elvik, 2009, Andersson and Nilsson, 1997). How the speed power model was applied to the traffic simulation output data is presented in chapter 10.

5. Description of the traffic simulation programs

This section gives a brief description of the different traffic simulations used. The three traffic simulation programs used are:

- for urban roads: Aimsun (Casas et al., 2010, TSS, 2013a),
- for rural roads: RuTSim (Tapani, 2005b),
- for motorways: ITS Modeller (Tideman and Van Noort, 2013).

There are several reasons why different models were used for different road environments. There are few traffic simulator models that can handle simulations of rural roads with a single carriageway and overtakings using the oncoming lane. RuTSim (Tapani, 2005b) is one of few traffic simulations models for rural roads, and for which the consortium had access to already calibrated rural road networks. ITS Modeller (Tideman and Van Noort, 2013) is a traffic simulation model specifically developed for evaluation of ITS, currently only for motorways (see further details in section 5.1). Furthermore, the consortium had access to already calibrated ITS Modeller motorway networks. The choice of simulator for the urban case was based on the availability of already calibrated urban networks within the consortium.

5.1 ITS Modeller

ITS Modeller is a micro-simulation tool developed by TNO particularly to model the effect/impact of ITS applications. The modelling environment can simulate the ITS applications whether in-vehicle or infrastructure based and newly developed applications can be added by modelling and linking them to the ITS Modeller. Several roadside and in-vehicle systems, as well as cooperative systems are incorporated in the model. It functions as a shell for existing traffic simulation models allowing modelling of non-standard driver and vehicle behaviour. It offers a flexible tool for testing different algorithms and different penetration rates. The ITS Modeller differs from other commercially available simulators by allowing researchers to include tailor-made models that describe the technical and behavioural aspects of ITS applications, and thereby allowing the investigation of the effect of these applications on the traffic system's performance. The ITS modeller is most suitable for motorway networks. The actor models are currently (only) calibrated for motorway driving behaviour. Specific urban components such as traffic light control for (urban) intersections are not yet included in the model.

In the ITS Modeller vehicle motions are controlled by defined model configurations; the models define the behaviour of the vehicle and its driver (actors). The general philosophy of the tool is to have one actor model for each aspect of driving, for example for car following and for lane changing. These models are then combined to create a comprehensive driving model. Different vehicle types can be implemented, using different actor models per vehicle type. The core of the model is programmed in Java and users can implement new actor models in separate Java classes. Network manipulations can be done manually via a simple HMI. Output is stored in MySQL databases and it contains both detailed output on the individual vehicle level and aggregated output indicators on link or network level. Additional output models can be integrated into the ITS modeller, such as emission models.

5.2 RuTSim

The Rural Traffic Simulator RuTSim (Tapani, 2005b) is a microscopic time-discrete simulation tool developed by VTI. The model is designed to handle simulation of traffic on common types of rural roads stretches, i.e. rural road networks are not considered. The main road may incorporate intersections and roundabouts and the main road traffic may be interrupted by vehicles entering and leaving the road at intersections located along the simulated stretch. The modelling is focused on the vehicles that travel on the main road. Vehicle movements to and from secondary roads are modelled with a level of detail necessary to take into account secondary road vehicles' impact on vehicles on the main road. Travel times are also only recorded for vehicles on the main road. Queuing on secondary roads is therefore not considered.

The requirements on a model used to simulate the traffic flow on a rural road are substantially different from the requirements on a model used for traffic in an urban or motorway network, due to fundamental differences in the interactions between vehicles and the infrastructure. The travel time delay in an urban or motorway network is dominated by vehicle-vehicle interactions, whereas the travel time delay on a rural road is also significantly influenced by interactions between vehicles and the infrastructure. For example, speed adaptation with respect to the road geometry has a more prominent role on rural roads than it has on urban streets. A model describing traffic flows on rural roads must therefore consider the interaction between vehicles and the infrastructure in greater detail than models for urban or motorway traffic. Interactions between vehicles are nevertheless important on rural roads, particularly in overtaking and passing situations on two-lane rural roads. RuTSim includes detailed modelling of vehicles' speed adaptation with respect to the road geometry (in terms of curvature, slope and road width) as well as interactions between oncoming traffic in overtaking situations on two-lane rural roads. Time headways between vehicles that are to enter the simulation are also determined according to a platoon generation model that takes into account the ease of overtaking slower vehicles on the modelled road.

RuTSim has been calibrated and applied for several Swedish (Tapani, 2005a, Tapani, 2005b, Tapani, 2006, Tapani, 2007, Akililu, 2012, Bergqvist and Runn, 2014) and Dutch (Hegeman et al., 2009) rural roads.

5.3 Aimsun

The urban networks were simulated using the www.AIMSUN.com model (version 8.0.8). AIMSUN was chosen as base networks were available for the City Leeds, ITS staff have experience with the software and importantly, it has a well-developed and documented API (Advanced Programming Interface) so the ecoDriver can be coded into the WP53 simulations. Sample calibration and validation datasets such as vehicle tracking data were also available. The API also facilitates the coding of the Energy and emission assessment method, so these calculations can be efficiently be made each simulation step, rather than harvesting potentially very large volumes of trajectory data for post-processing.

Panwai and Dia (2005) also demonstrated that the Gipps model (Gipps, 1981) which simulates the car-following behaviour in AIMSUN performed better than the psychophysical spacing models used by

PARAMICS and VISSIM in estimating the desired following distance between two moving vehicles. The car-following model and lane-changing model are considered the two main critical components in dictating the accuracy of traffic-simulation models (Panwai and Dia, 2005). AIMSUN also has fewer modelling parameters for calibration than PARAMICS and VISSIM, which is recommended for delivering accurate results for multiple simulations (Anya et al., 2014, TSS, 2013b).

Each vehicle category within the AIMSUN simulation (e.g. Car, Bus, LGV, etc.) is defined by physical parameters such as vehicle dimension and performance, as well as by behavioural characteristics which model influences like driver awareness, aggression and reaction time (Dia et al., 2006). The transit of an individual vehicle through the network is simulated through behavioural models that control vehicle longitudinal (e.g. acceleration; deceleration) and lateral response (e.g. overtaking; lane-changing) to stimuli within the system. These reactions are driven by operational algorithms which describe behaviours such as car-following, lane-changing and gap-acceptance (Dia et al., 2006, Anya et al., 2014, TSS, 2013b).

The operational algorithms and therefore the speed profiles of vehicles within the model are influenced by controllable parameters at three scales:

- Vehicle attributes, which are specific to each vehicle type in the model e.g. maximum desired speed, maximum acceleration, normal deceleration, maximum deceleration;
- Local parameters, e.g. road section speed limit;
- Global parameters, which are universal across the network e.g. simulation step, reaction time, reaction time at stop.

The algorithms which control the movement of vehicles within the simulated network, including the influence of the ecoDriver advice on equipped vehicles, are calculated at fixed time iterations (simulation steps) and the position and speed for each vehicle are updated at each simulation step. The data for every individual vehicle can be exported from the model, detailing the position and speed at each iteration. A full description of the AIMSUN methodology is available in the AIMSUN User Guide (TSS, 2013b) and the Dynamic Simulators Users' Manual (TSS, 2013a).

It is important that the vehicle fleet is correctly described within the simulation not only because it defines the proportion of vehicles assigned to the energy and emission calculations, but also because the dynamic characteristics of each vehicle type influence the overall behaviour of the traffic flows within the simulations. The parameters controlling the dynamic behaviour of each vehicle type in AIMSUN can be adjusted from default values to correspond to the observed behaviour of the vehicle type in the real-world conditions that are being modelled by the simulation. To represent real-world vehicle dynamics accurately, the AIMSUN vehicle parameters should be tailored for each vehicle type (Madi, 2014). Discrete dynamic parameters such as acceleration, deceleration and speed limit acceptance, for each vehicle type, result in the possibility of different fleet compositions producing markedly different average simulated second-by-second vehicle trajectories and therefore modelled emissions.

The vehicle dynamics data were adjusted to represent observed trajectories on urban networks, described by Wyatt et al. (2014). The selected 'Maximum acceleration', 'Normal deceleration' and 'Maximum deceleration' for each vehicle type are set out below in Table 14, Table 15 and Table 16 respectively.

Table 14: Maximum Acceleration rates for each Vehicle Type in the Headingley AIMSUN Network

Vehicle class	Maximum Acceleration Rates (m/s^2)			
	Mean	**Standard Deviation**	**Minimum**	**Maximum**
Car / Taxi	1.69	0.10	1.54	1.85
LCV	1.45	0.05	1.4	1.5
HGV, BUS	1.10	0.25	0.7	1.3

Table 15: Normal Deceleration Rates for each Vehicle Type in the Headingley AIMSUN Network

Vehicle class	Normal Deceleration Rates (m/s^2)			
	Mean	**Standard Deviation**	**Minimum**	**Maximum**
Car / Taxi	0.51	0.07	0.42	0.63
LCV	0.42	0.05	0.37	0.45
HGV, BUS	0.50	0.05	0.80	0.5

Table 16: Maximum Deceleration rates for each Vehicle Type in the Headingley AIMSUN Network

Vehicle class	Maximum Deceleration Rates (m/s^2)			
	Mean	**Standard Deviation**	**Minimum**	**Maximum**
Car / Taxi - IP	2.97	0.49	2.17	3.93
LCV	2.38	0.08	2.29	2.44
HGV, BUS	*No data so set to the same as LCV			

6. Modelling the ecoDriver systems

Two versions of the ecoDriver system are modelled in the simulation:

- Embedded
- Nomadic

The embedded system is represented by a version of the FeDS and the nomadic system is represented by a version of the ecoDriver App. The following vehicles are modelled in the simulation having one embedded and one Nomadic system adapted for each vehicle type:

- Nissan Leaf (electric, no gear)
- Renault Clio (petrol, manual 5 gears)
- Renault Scenic (diesel, manual 6 gears)
- VW Transporter (van, manual 5 gears)
- DAF XF (truck, automatic 10 gears)

6.1 Embedded system

The embedded ecoDriver system is modelled providing the driver with the following advice:

- When to start anticipation to a lower speed limit (t_{ED}^{a}),
- Which speed to drive at (v_{ED}^{a}),
- At which engine speeds (r_{ED}^{a+} and r_{ED}^{a-}) to shift gear (up and down)

The advised time on when to start anticipating a lower speed limit is decided based on the current speed limit v_{lim} and the time when the popup advice "lift your foot of the pedal" t_{ED}^{a} is assumed to appear. The advised time t_{ED}^{a} is assumed to be appear 12 seconds before reaching the speed limit change when driving at the current speed limit v_0. The advised time t_{ED}^{a} is estimated as

$$t_{ED}^{a} \quad = d_{v_{\mathrm{lim\,next}}}/v_{\mathrm{lim}}, \tag{1}$$

where $d_{v_{\mathrm{lim\,next}}}$ is the distance to upcoming lower speed limit. For the speed advice, it is assumed that for each speed limit v_{lim} there is an optimal target speed which is assumed to be less than or equal to v_{lim}. The ecoDriver system never encourages the driver to drive faster than the driver's desired speed. The speed advice is thereby always limited to the driver's current speed v when the driver desires to travelling slower than the current speed limit, i.e.

$$v_{ED}^{a} = \begin{cases} v_{\mathrm{lim}}, & v_{\mathrm{lim}}<v \\ v, & otherwise \end{cases}. \tag{2}$$

The speed advice is also dependent on the start to anticipate towards a lower speed limit. It means that the advised speed may be adapted to the next speed limit $t_{v_{\mathrm{lim}\,next}}$ rather than the current speed limit if the pop-up advice to "lift your foot of the pedal" has been provided to the driver. Equation (2) may then be extended to include the anticipation advice as

$$v_{ED}^{a} = \begin{cases} v_{\text{lim}}, & v_{\text{lim}} < v \text{ and } t_{v_{\text{lim}\,next}} \geq t_{\text{advice}} \\ v_{\text{lim next}}, & v_{\text{lim next}} < v \text{ and } t_{v_{\text{lim}\,next}} < t_{\text{advice}} \\ v, & \text{otherwise.} \end{cases} \quad (3)$$

Figure 25 presents an example of how the combination of speed advice and start of deceleration advice may affect the driving behaviour assuming full compliance towards the advice given. The example is for a driver assumed to have a desired speed 10% faster than speed limit and no pre-anticipation to upcoming speed limit changes. The unequipped driver will start anticipating the new speed limit at the location of the speed limit sign (at time 12 seconds in Figure 25). An equipped and compliant driver will adapt its desired speed towards the speed limit and starts anticipating 12 seconds ahead of the speed limit change (at time 0 seconds in Figure 25).

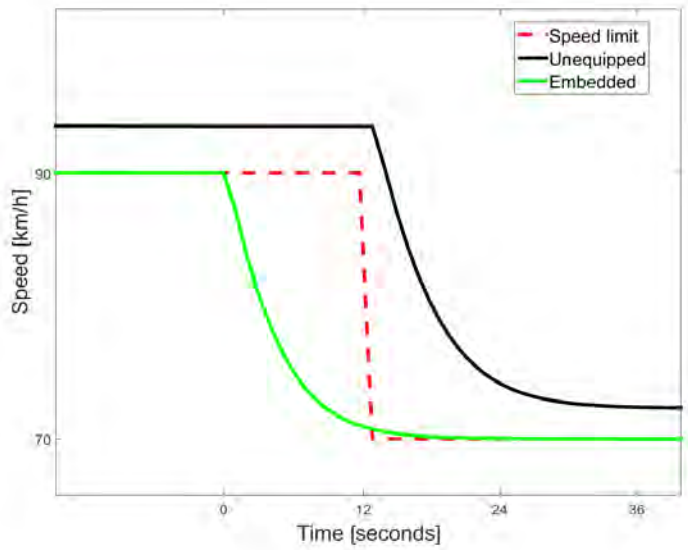


Figure 25: The effect of the embedded system on anticipation of speed advice

The embedded system also provides the driver with advised engine speeds $r_{ED}^{a\pm}$ for shifting up and down. The optimal engine speeds for gear shifting are dependent on the vehicle type V, the gear g and the system variant I, i.e.

$$r_{ED}^{a\pm} = r_{ED,0}^{a\pm}(g, V, I), \quad (4)$$

where the optimal engine speeds $r_{ED,0}^{a\pm}$ is given by tables of values for each valid combination of g, V and I. See Annex B for gear shift thresholds for each vehicle type.

Figure 26 illustrates the difference in gear shift behaviour comparing an unequipped with an equipped and compliant driver in a Renault Scenic (diesel 6 gears). As may be observed from Figure 26, the compliant driver is using lower shifting points compared to the unequipped driver. The same goes both for upshifting and downshifting behaviour.

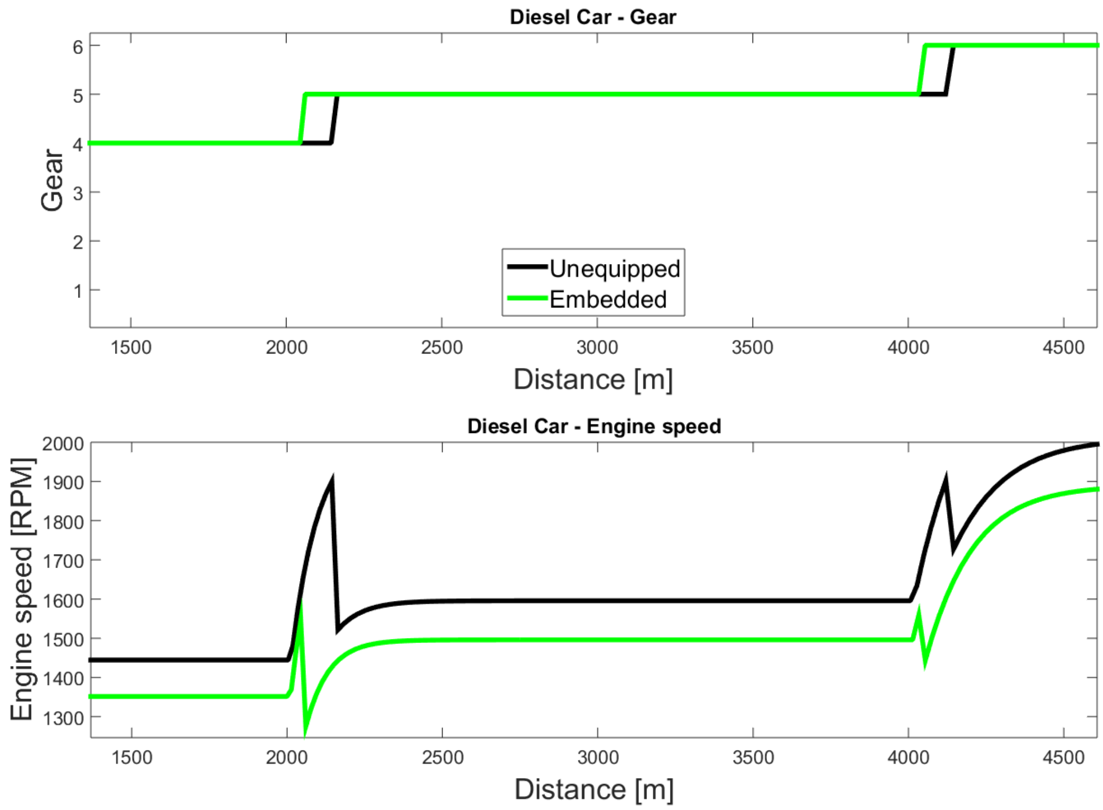


Figure 26: The effect of the embedded ecoDriver system on gear choice and shifting points

6.2 Nomadic system

The Nomadic ecoDriver system is modelled providing the driver with the following advice:

- When to start anticipation to a lower speed limit (t_{ED}^{a}),
- At which engine speeds (r_{ED}^{a+} and r_{ED}^{a-}) to shift gear (up and down)

Note that the Nomadic ecoDriver system does not support the driver with continuous advice on driving speed. The system shows the current speed limit in the HMI but this does not seem to have any effect on the driver's speed choice, see further analysis and discussion in section 7.1.3. The system provides the driver with an advised starting point of deceleration in order to anticipate an upcoming lower speed limit. The advised time to start decelerating is estimated according to equation (1), which is identical to the embedded ecoDriver system. A comparison of an unequipped driver and a Nomadic compliant driver is presented in Figure 27. The example assumes an unequipped driver with desired speed 10% faster than speed limit and no pre-anticipation to upcoming speed limit changes.

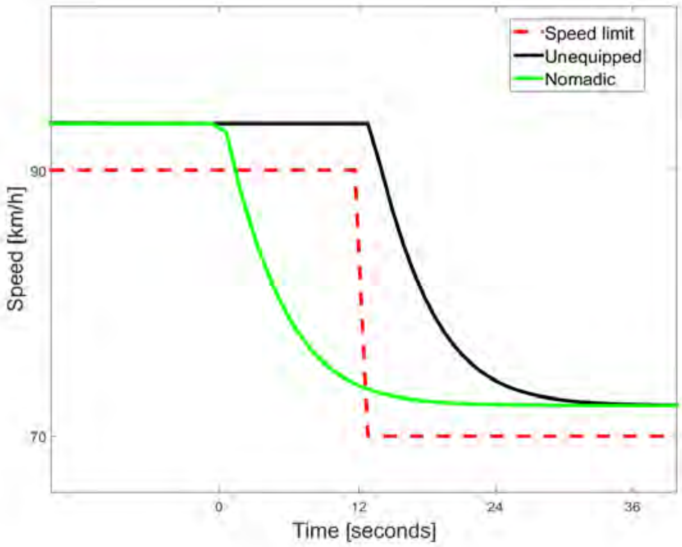


Figure 27: The effect of the Nomadic system on anticipation of speed advice

The Nomadic ecoDriver system does also support the driver with gear shifting points. The calculation is identical to the advice provided by the embedded system which is presented in equation (4). The recommended shifting points are also identical to the ones provided by the embedded system, which means the gear shift procedure will be identical to the illustration in Figure 26.

7. Additional driver models

The traffic simulators have to be complemented with driver models considering the drivers compliance with the advice given, i.e.

- when to start anticipation to a lower speed limit (t_{ED}^{a}),
- which speed to drive at (v_{ED}^{a}),
- at which engine speeds (r_{ED}^{a+} and r_{ED}^{a-}) to shift gear (up and down)

Since the traffic simulators do not model gear shifting and the systems gives advice with respect to gear shifting, an additional gear shifting driver model was also developed. This chapter describes these additional driver models and the process of incorporating the advice from the system into the driving behaviour. The chapter also describes the calibration of these additional driver models using data from the field trials. The simulated drivers are assumed to have passed the learning phase and to be long-term habituated to the ecoDriver systems. The data from the field trials used to calibrate the additional driver models include a mix of drives with short-term and long-term habituated drivers. This is of course not optimal but if only considering the drives with long-term habituated drivers the data set is too small.

7.1 Speed and deceleration compliance with the ecoDriver system(s)

This section contains a description of the model and calibration of the speed compliance and anticipation with respect to upcoming speed limit compliance. There are dependencies between compliances with respect to speed and start of deceleration, even if the advice provided from the ecoDriver system are separated. In order to cover these dependencies, the driver perspective of both speed and start of deceleration are included in this section.

7.1.1 Model description – start of deceleration with respect to upcoming speed limit

The driver model includes a start of deceleration compliance model estimating when the driver desires to start anticipating towards upcoming lower speed limits. The model estimates the time when the driver desires to start decelerating in order to adapt its speed with respect to the upcoming speed limit. The output of the model is a revised desired time t_{DM}^{des} which is calculated as

$$t_{DM}^{des} = (1 - c_{\mathrm{deceleration}}) \cdot t_{TS}^{des} + c_{deceleration} \cdot t_{\mathrm{ED}}^{a}, \qquad (5)$$

where t_{TS}^{des} is the original desired time and t_{ED}^{a} is the time advised from the ecoDriver system according to equation (1) and $c_{deceleration} \in [0,1]$ is to what extent the driver take the advice into account. A full compliant driver ($c_{deceleration} = 1$) will start the deceleration at the advised time t_{ED}^{a} and a no compliant driver ($c_{deceleration} = 0$) will start decelerating at t_{TS}^{des}. Since the original desired time to start decelerating is assumed to be when the driver arrives to the sign of the new speed limit, t_{TS}^{des} is set to zero. The calculations may be then be simplified to

$$t_{DM}^{des} = c_{\mathrm{deceleration}} \cdot t_{ED}^{a}. \qquad (6)$$

7.1.2 Model description – speed compliance

The driver model contains a speed compliance model that takes the instantaneous advice v_{ED}^{a} given by the ecoDriver system and the driver's current desired speed v_{TS}^{des} as input. Output from the model is a modified desired speed v_{DM}^{des} representing the driver's compliance to the advice given.

It is reasonable to assume that the drivers will not fully comply with, nor totally disregard, the advice given by the system. To represent such situations, the revised desired speed is calculated as a linear combination of the original desired speed and the advice given, i.e.

$$v_{DM}^{des} = c_{speed} \cdot v_{ED}^{a} + \left(1 - c_{speed}\right) \cdot v_{TS}^{des}, \qquad (7)$$

where $c_{speed} \in [0,1]$ is a parameter representing the driver's compliance to the system advice. This model allow any degree of compliance to the advice from full compliance, $c_{speed} = 1$ implying $v_{DM}^{des} = v_{ED}^{a}$, to no compliance, $c_{speed} = 0$ implying $v_{DM}^{des} = v_{TS}^{des}$.

There is though one exception from the calculation in equation (7) concerning the driver's desired speed v_{DM}^{des}. The exception is related to changes in speed advice as a consequence of upcoming lower speed limits. The exception is necessary in order to ensure consistency between desired speed and desired start of deceleration with respect to an upcoming lower speed limit. If the speed advice changes towards the upcoming speed limit according to equation (3), it does not necessarily mean that the driver will start decelerating towards the new speed advice as given by equation (7). Whether the driver will follow the new speed advice for the upcoming speed limit depends on if the driver decides to adapt the speed according to the pop-up advice "lift your foot of the pedal". The driver will accept the new speed advice if the time to reach the upcoming speed limit $t_{v_{\lim next}}$ is shorter than the desired time to start anticipation towards the next speed limit t_{DM}^{des}. If the driver does not accept the new speed advice, the desired speed remains the same as in the previous time step $v_{DM}^{des}(t - dt)$. This imply that equation (7) has to be extended and v_{DM}^{des} is in the end calculated as

$$v_{DM}^{des} = \begin{cases} c_{speed} \cdot v_{ED}^{a} + \left(1 - c_{speed}\right) \cdot v_{TS}^{des} & v_{ED}^{a} = v_{\lim} \\ c_{speed} \cdot v_{ED}^{a} + \left(1 - c_{speed}\right) \cdot v_{TS}^{des} & v_{ED}^{a} = v_{\lim \text{next}} \text{ and } t_{v_{\lim next}} < t_{DM}^{des} \\ v_{DM}^{des}(t - dt) & \text{otherwise.} \end{cases} \qquad (8)$$

An example of how the driver's decision of applying the advised speed may vary during the deceleration phase, is illustrated in Figure 28, which assumes a 50% compliant driver with desired speed 10% above the speed limit.

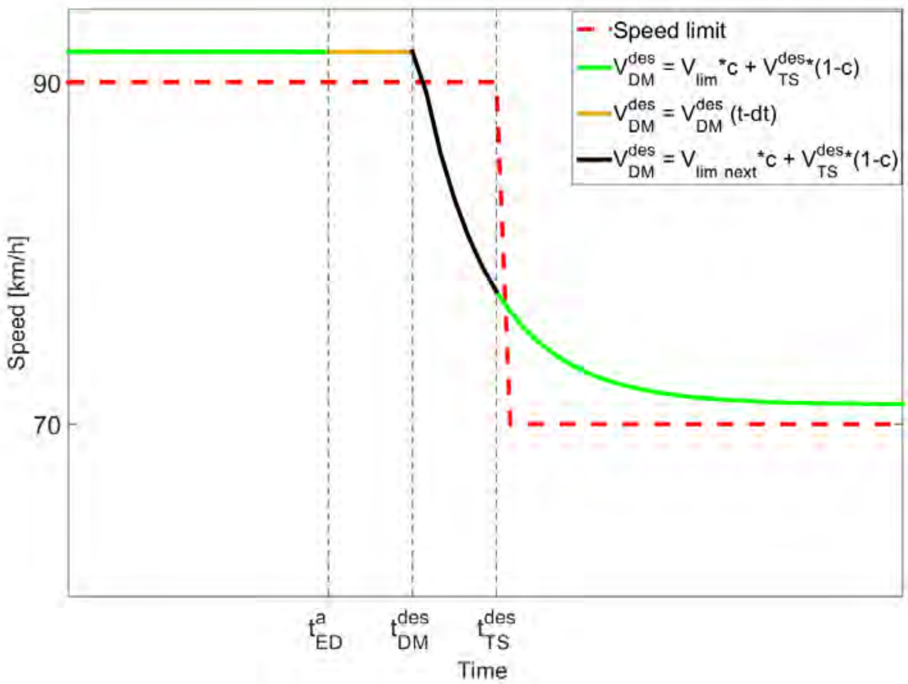


Figure 28: Example of how the desired speed may vary during the deceleration phase.

7.1.3 Speed compliance calibration using field data

The speed compliance model includes one parameter c_{speed}, that need to be estimated. In order to estimate c_{speed}, data from the controlled experiments in the field trials have been used to estimate the participants' desired speed with and without the system (for different sets of situational variables). To estimate the desired speeds, sections of free driving and cruising were extracted from the drives. Free driving was specified by a time headway larger than 6 seconds and cruising by |acceleration| < 0.6 m/s ². This is the same definition as used in the field trial analysis and was chosen in order to ensure consistency with the SP4 analysis (Saint Pierre et al., 2016). Furthermore this is in line with the findings of e.g. Vogel (2002). Sections of free driving and cruising shorter than 10 seconds were ignored, see Figure 29 for an example of a cumulative distribution of the duration of the free driving and cruising segments at the Swedish trial (with a Volvo V70 equipped with the FeDS).

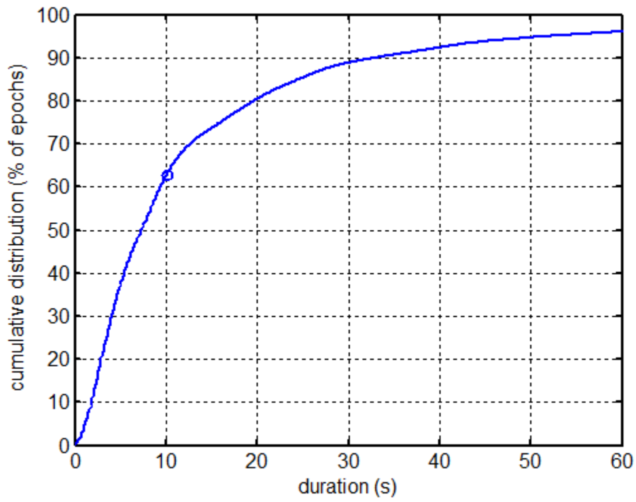


Figure 29: Duration of segments classified as free driving and cruising in the Swedish trial

The compliance calibration is based on pre analysis of the field trial data that were available and which could be rudimentarily map matched at the time when the calibration needed to be conducted. The data available were controlled drives with the FeDS using a Volvo V70 (Diesel), Renault Scenic (Diesel) and the Nissan Leaf (Electric) and drives with the ecoDriver App using a Renault Clio (Petrol).

The trial with the most extensive data available was the Volvo V70 trial in Sweden with two baseline drives and six treatment drives, for which each drive was ~90 km long. The Spanish trials with the Renault Scenic and the Nissan Leaf had only one baseline and two treatment drives on four different routes (between 8-40 km long). Even though the number of participants was higher in the Spanish drives the amount of data per participant was much lower. For a complete specification of the routes see Woldeab et al. (2014). Due to technical limitations and time constraints the speed compliance estimation for the FeDS was calibrated using data only from the Swedish trial with the Volvo V70, exclusively. It would of course been desirable to include the data from the trials with the Renault Scenic, Renault Clio and the Nissan Leaf since these are the vehicle types actually modelled in the simulations. But limited data in combination with technical limitations and time constraints made it impossible. The limited data set decrease the confidence of the compliance estimation. However, since the data set from the Swedish field trial was both the most extensive and furthermore the data set that best represent the long term usage of the FeDS (the highest number of treatment drives among the controlled tests), it was one of the most important and crucial data set. Hence, it would have been more devastating to lose this data set than the others.

Given the desired speed estimates and recordings of the advice, v_{ED}^{a} have been estimated. Speed compliance was only estimated for the embedded system since the simulated nomadic system (the ecoDriver App), does not provide any continuous speed advice. The ecoDriver App shows the speed limit in the HMI, but no statistical significant difference in desired speed distributions with and without the Nomadic system was identified from the field trials data. Figure 30 show cumulative distributions of “cruising and free driving” in the treatment (TR) and baseline (BL) drives of the controlled trials in France with the ecoDriver App in a Renault Clio. The results for the 90 km/h speed limits do not seem to be trustworthy, but the “error” for the lower half of the speed observations is present in both the baseline and treatment drives. The conclusion was therefore to neither include the speed limit reminder nor any effect on desired speed in the simulation modelling of the ecoDriver App.

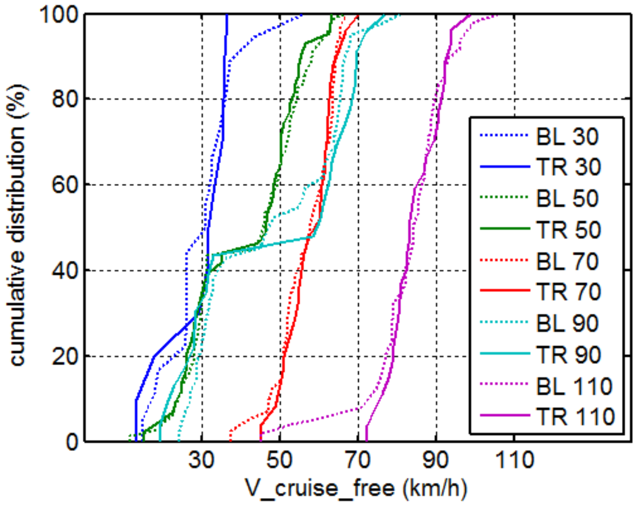


Figure 30: Change in cruising and free-driving speed with (TR) and without (BL) the nomadic ecoDriver system

Due to the limited number of observations, the distribution of speed compliance is assumed to be independent of powertrain and vehicle type. Professional drivers are though assumed to have higher compliance compared to public drivers. But since no data was available of professional drivers at controlled routes, professional driver compliance is represented by a 15% scaling factor of the public driver compliance.

Figure 31 presents the change in desired speeds from the field trials comparing treatment (TR) and baseline (BL) drives in the Swedish trial with a Volvo V70 equipped with the FeDS. The general observation is decreasing desired speed when using the embedded ecoDriver system. The number of observations are too few in order to estimate different compliance levels for each speed limits.

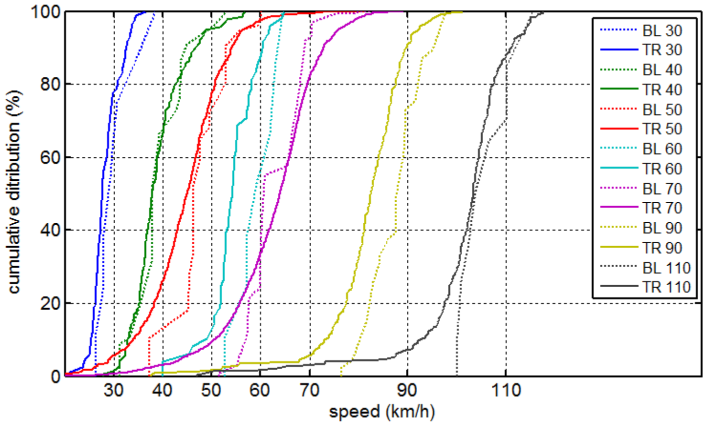


Figure 31: Change in cruising and free-driving speed with (TR) and without (BL) the embedded ecoDriver system

The estimated desired speeds were used to calculate estimates of the compliance factor c_{speed} by comparing specific driver's desired speed in each free driving and cruising section with the same driver's average desired speed in the baseline drives and the speed advice by the FeDS. Figure 32 illustrates cumulative distributions of the estimated speed compliance at different slope classes (downhill (<-3%), level (>-3% and < 3%) and uphill (>3%)) and if driving above or below the speed limit. The green profile represents speed compliance when driving above speed limit and blue profile when driving below the speed limit. The conclusion drawn from the pre analyse was that drivers with desired speed below the speed limit will have almost 100% compliance, which is natural since the system adapts its advice towards the driver's desired speed when driving slower than the speed limit. Another conclusions was that there were too few observations of free driving and cruising on downhill segments to be able to analyse if the compliance differs compared to driving on flat segments. Therefore, no difference between compliance at downhill and flat sections were assumed. Separate compliance was though estimated for uphill and flat sections since the field trial results indicate that compliance is increased when driving at uphill sections. These assumptions might imply that the compliance on downhill segments are either under- or overestimated, but this was judged to be the most reasonable assumption given the available data.

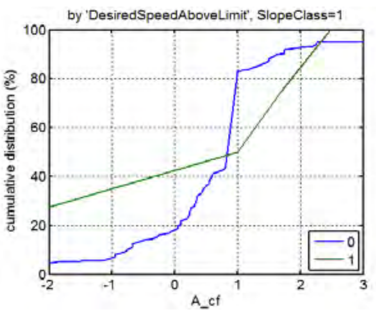
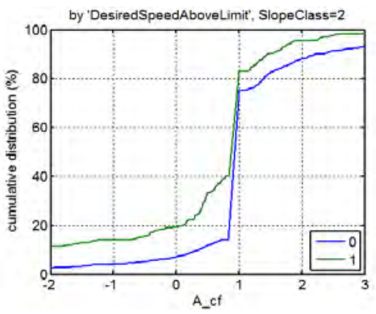
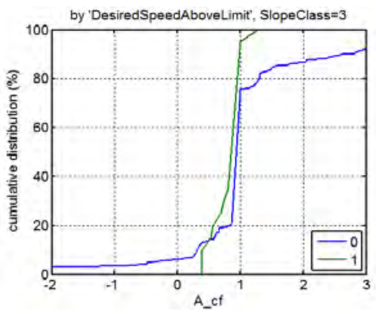
Downhill segments	**Flat segments**	**Uphill segments**
		

Figure 32: Speed compliance distributions for free and cruising segments in the field trials.

Based on the centre and right hand subfigure in Figure 32, speed compliance distribution was approximated using piecewise linear distribution as illustrated in Figure 33. The approximated distribution assumes only compliance between zero and one meaning all drivers estimated having negative compliance will be modelled as unequipped and drivers having more than 100% compliance will be treated as if they fully comply but not driving slower than the advised speed.

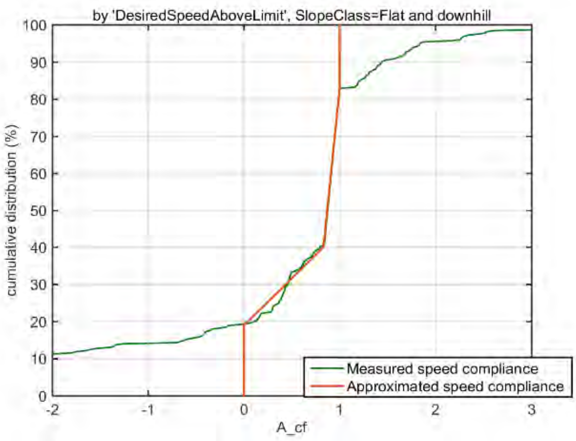
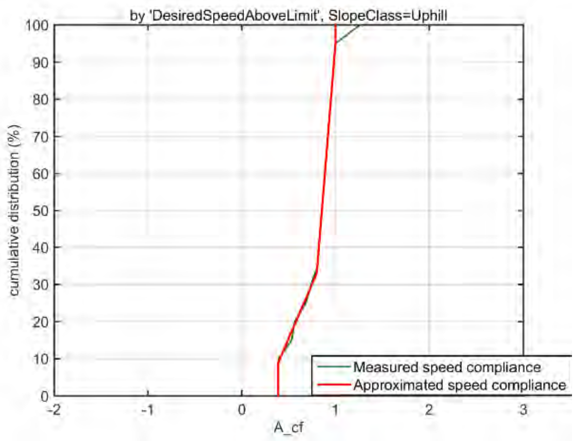
Flat and downhill segments	**Uphill segments**
	

Figure 33: Estimated and approximated compliance distributions based on field trial data using the embedded system.

According to Figure 33, drivers are more willing to comply with the system at uphill segments (>3%) than at flat or downhill road segments. The system does not take slopes into account estimating any advice provided to the driver.

7.1.4 Deceleration compliance calibration using field data

Full correlation is assumed between speed compliance and distance starting anticipating to lower speed limit, since no data is available regarding variations in compliance. This means that the deceleration compliance is a function of the speed compliance $c_{\text{deceleration}}(c_{\text{speed}})$.

It was revealed from the initial analysis of the field trials that the average distance of anticipation using ecoDriver system is around 6 seconds (150 m at speed limit 90 km/h). According to the field trials analysis, unequipped drivers do not start anticipating before the speed limit change, unequipped drivers are by default assigned 0 seconds. Two examples from the field trial analysis are illustrated in Figure 34 presenting acceleration and speed behaviour comparing treatment and baseline drives. The X-axis represent distance to speed limit change. According to Figure 34, there are obvious changes in anticipation behaviour comparing equipped and unequipped drivers.

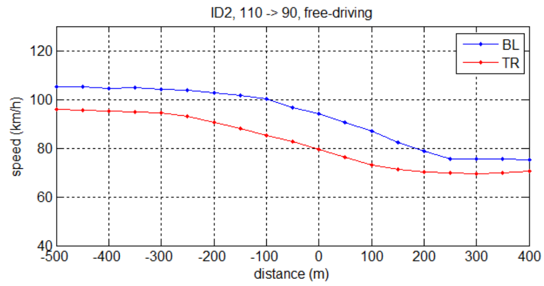
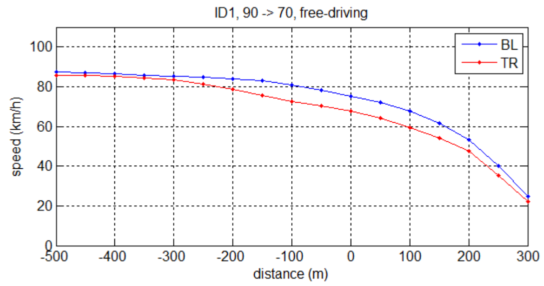
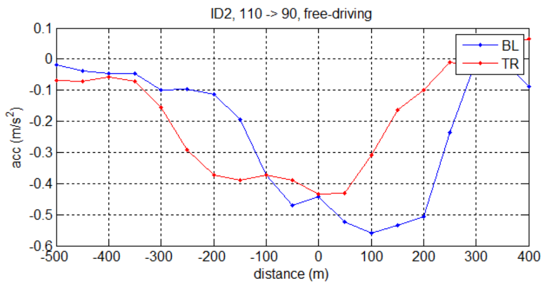
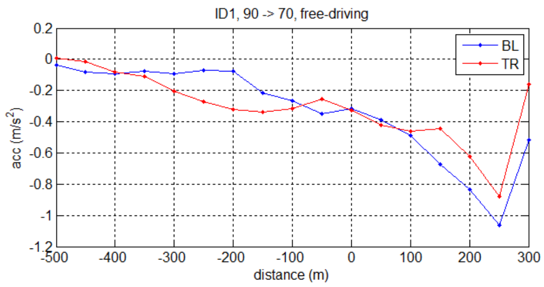
Speed limit change from 110 to 90 km/h	**Speed limit change from 90 to 70 km/h**
	
	

Figure 34: Change in starting point of deceleration towards upcoming lower speed limit between baseline (BL) and treatment (TR) field trial drives.

The deceleration compliance function $c_{\text{deceleration}}(c_{\text{speed}})$ is assumed to be a piecewise linear function. The function $c_{\text{deceleration}}(c_{\text{speed}})$ is synchronized so that the $t_{ED}^{a} \cdot c_{\text{deceleration}}(\tilde{c}_{\text{speed}}^{*}) = 6\ s$ given that $\tilde{c}_{\text{speed}}^{*}$ represents the optimum median speed compliance estimated according to equation (9). $\tilde{c}_{\text{speed}}$ represents all point where the median speed compliance is obtained.

$$\tilde{c}^*_{speed} = \max\{\tilde{c}_{\text{speed}}: P(\text{speed compliance} \leq \tilde{c}_{\text{speed}}) \leq 0.5\} \qquad (9)$$

In most cases, there will be a unique value $\tilde{c}_{\text{speed}}$ where $P(\text{speed compliance} \leq \tilde{c}_{\text{speed}}) = 0.5$ (namely, this is the case if the cumulative distribution graph has a slope that is not vertical and not horizontal at the point $(\tilde{c}_{\text{speed}}, 0.5)$). If there is a unique value of $\tilde{c}_{\text{speed}}$ equation (9) may be simplified to $\tilde{c}^*_{speed} = \tilde{c}_{\text{speed}}$. The value of $c_{\text{deceleration}}$ is in the end calculated as

$$c_{\text{deceleration}}(c_{\text{speed}}) \begin{cases} \dfrac{c_{\text{speed}}}{2\,\tilde{c}_{\text{speed}}}, & c_{\text{speed}} < \tilde{c}^*_{speed} \\ 1 - \dfrac{1 - c_{\text{speed}}}{2\,(1 - \tilde{c}_{\text{speed}})}, & c_{\text{speed}} > \tilde{c}^*_{speed} \\ 0, & c_{\text{speed}} = \tilde{c}^*_{speed} = 0 \\ 1, & c_{\text{speed}} = \tilde{c}^*_{speed} = 1 \\ \frac{1}{2} & 0 < c_{\text{speed}} = \tilde{c}^*_{speed} < 1 \end{cases} \qquad (10)$$

The last three rows in equation (10) handle the exceptional cases where the first two would lead to a division by zero, and follow the principle that speed compliance of 0 or 1 corresponds to a deceleration compliance of the same value.

Figure 35 illustrates an example of how the piecewise linear distribution of speed and the piecewise linear deceleration compliance function may look like.

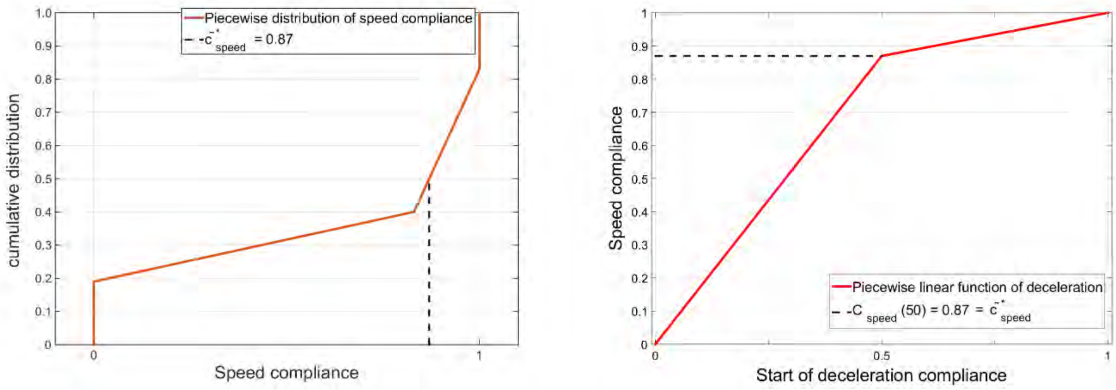


Figure 35: Piecewise distribution of deceleration compliance $c_{\text{deceleration}}$ (right) and how it is related to the piecewise distribution of speed (left)

In the given example, the piecewise linear function for $c_{\text{deceleration}}$ may then be formulated as

$$c_{\text{deceleration}}(c_{\text{speed}}) = \begin{cases} c_{\text{speed}} \cdot 0.57 & c_{\text{speed}} \leq \tilde{c}^*_{speed} \\ -2.85 + c_{\text{speed}} \cdot 3.85 & c_{\text{speed}} > \tilde{c}^*_{speed} \end{cases} \qquad (11)$$

We assume that the deceleration anticipation also apply for vehicles equipped with the nomadic system. This means that In order to be able to assign $t_{\text{deceleration}}$ to nomadic equipped vehicles, a speed compliance value has to be drawn according to the speed compliance distribution function for FeDS equipped vehicles.

7.2 Gear shifting strategy

The driver model also includes a gear shifting strategy model based on Ligterink (2015). The model is mainly based on the engine speed s, which is estimated from gear ratios multiplied with the current speed, see section 8.2 for details. Drivers are assumed to be shifting up to the next gear $(g+1)$ when the engine speed $s(t)$ exceeds

$$s(t) > RPM_g^{UP} + \Delta RPM_g^{UP} \cdot a(t), \tag{12}$$

where RPM_g^{UP} is the shifting up engine speed threshold for the current gear g. The second term $\Delta RPM_g^{UP} \cdot a(t)$ delays the gear shift ΔRPM_g^{UP} in order to represent driver's behaviour. Aggressive driving usually imply high accelerations and the model therefore includes a correlation between aggressive driving and higher engine speed shifting points. The delay is given in rpm per 1 m/s^2 acceleration. This part is only used for determining up-shifts of gear.

The shifting down procedure is only based on engine speed levels. A shift to a lower gear $(g-1)$ is conducted if the current engine speed decreases below the RPM threshold of the specific gear (RPM_g^{DOWN}). The engine speed based gear shift model estimates the desired gear to be used by the driver in the next step $g(t+dt)$ as

$$g(t+dt) = \begin{cases} g(t)-1 & \text{if } s(t) < RPM_g^{DOWN} \\ g(t)+1 & \text{if } s(t) > RPM_g^{UP} + \Delta RPM_g^{UP} \cdot a(t) \\ g(t) & \text{otherwise} \end{cases} \tag{13}$$

The gear shift model needs to take into account the desired acceleration in comparison to the acceleration that the engine can deliver at the current gear choice. Else, there may be suboptimal gear choices, where the desired acceleration cannot be met with the current gear choice, but a better choice is available. $a_{\text{physmax}}(v,g)$ represents the maximum acceleration that the engine can deliver at the current speed and gear, taking into account all external forces (rolling resistance, air resistance, and gravity in case of slope). Let $a_{\text{physmax}}(v) = \max_g a_{\text{physmax}}(v,g)$ be this maximum acceleration maximized over all gears. The set of gears for speed v where the maximum acceleration is achieved is denoted $\mathcal{G}(v)$ and obtained as

$$\mathcal{G}(v) = \{g: a_{\text{physmax}}(v,g) = a_{\text{physmax}}(v)\}. \tag{14}$$

A reasonable assumption is to let $\mathcal{G}(v)$ be an interval. Let $g_-(v)$ and $g_+(v)$ be the boundaries of this interval defined as.

$$g_-(v) = \min \mathcal{G}(v) \text{ and } g_+(v) = \max \mathcal{G}(v). \tag{15}$$

If the desired acceleration a_{desired} is larger than the maximum acceleration at the desired gear, and a better gear is available, then a gear shift override will be applied. The desired gear g_{desired} is given as

$$g_{\text{desired}} = \begin{cases} g + \Delta g_{\text{combined}}, & 1 \le g + \Delta g_{\text{combined}} \le n \\ g, & \text{otherwise} \end{cases}. \quad (16)$$

Thus a gear shift override is applied if the conditions (17) and (18) are satisfied.

$$a_{\text{desired}} - \Delta a_{\text{min}} > a_{\text{physmax}}(v, g_{\text{desired}}) \quad (17)$$
$$a_{physmax}(v) > a_{physmax}(v, g_{desired}). \quad (18)$$

Switching to another gear is helpful if the current gear g cannot deliver the desired acceleration, and there is another gear that can do that, that is if the condition in (19) is satisfied.

$$a_{\text{desired}} > a_{\text{physmax}}(v, g) \text{ and } a_{\text{physmax}}(v) > a_{\text{physmax}}(v, g). \quad (19)$$

In this case, the gear shift should be towards the interval $\mathcal{G}(v)$. Note that g is not in this interval if (19) holds. Thus, the procedure leads to the overridden gear shift $\Delta g_{\text{override}}$ calculated as

$$\Delta g_{\text{override}} = \begin{cases} \Delta g_{\text{combined}} & \text{(17) does not hold} \\ -1 & \text{(17) and (19) hold and } g > g_{+}(v) \\ +1 & \text{(17) and (19) hold and } g < g_{-}(v) \\ 0 & \text{otherwise} \end{cases} \quad (20)$$

7.2.1 Calibration using field trial data

The gear shift model behaviour has been calibrated using field trial data from the runs performed without the system. Each vehicle model has been calibrated separately for each gear, identifying RPM for down shifts, upshifts and delays due to acceleration. Figure 36 shows that at higher accelerations, gear shifts start at a higher speed (and thereby RPM). This effect gets less pronounced at higher gears.

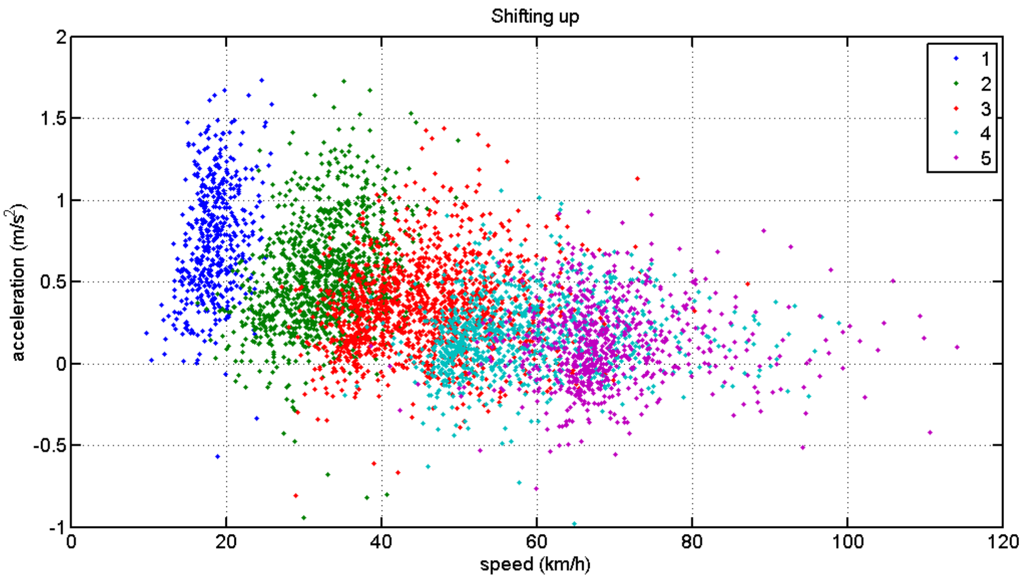


Figure 36: Acceleration and speed at actual gear shifts from different gears from the field trials using Volvo V70 (6 gears diesel).

The effect is less clear if plotting the relation between acceleration and engine speed, see Figure 37.

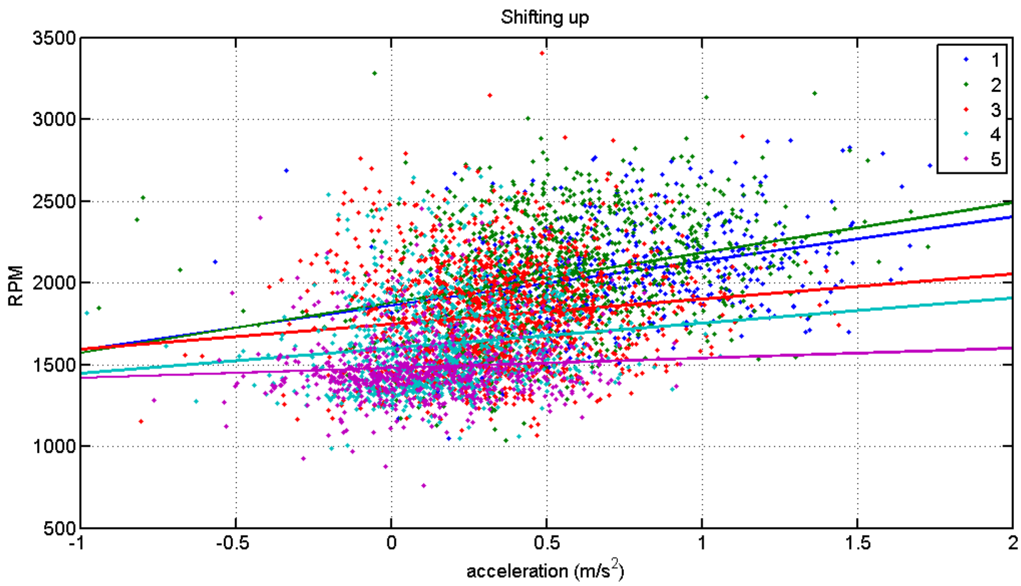


Figure 37: Gear shifting thresholds (RPM) and delay due to acceleration from the field trials using Volvo V70 (6 gears diesel).

By using linear regression to estimate the effect of acceleration, a gear shifting threshold and a delay factor was adapted for each gear. Based on the data in Figure 37 the corresponding thresholds and delay factors were estimated as in Figure 38. The same method was also used estimating downshift thresholds, except no delay factor was adapted since the acceleration is assumed to have no effect on downshifts.

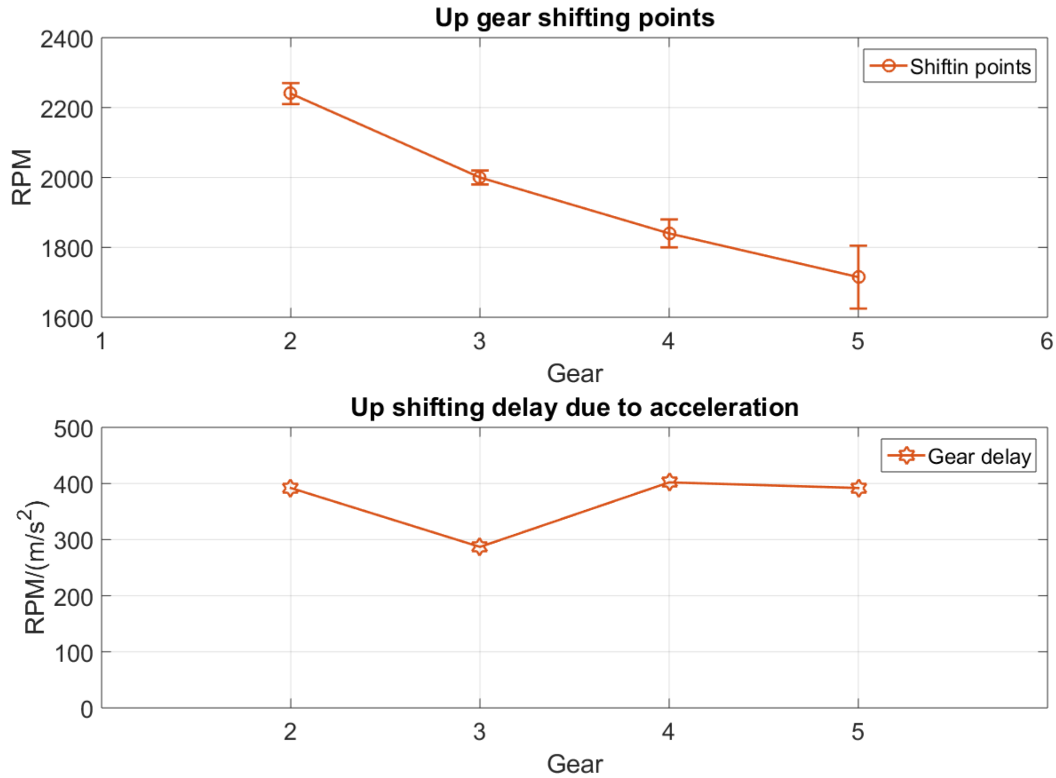


Figure 38: Approximated gear shifting points and how shifting points are delayed by acceleration based on the field trials data for Volvo V70 (6 gears diesel). Lack of data gives no estimation for 1st gear.

Only sequential gear shifts have been investigated (jumping between gears is neglected due to the number of observations). The final output is gear shifting points (averaged to the closest 100 RPM) for each gear calibrated for Renault Clio and Renault Scenic. The other vehicles used in the simulation does not have any field data to be used for calibration. The Volkswagen Transporter is assigned similar shifting points as the Renault Scenic since both vehicles are having diesel engines. Nissan leaf and DAF XF does not require any shifting points nor gear shift strategy since they are equipped with automatic gear boxes. Calibrated shifting points and delays are presented in Annex D.

7.3 Gear advice compliance

This section describes how a driver selects its current gear and how the desired gear is affected by the gear advice provided from the ecoDriver system. The change in gear shifting behaviour is estimated based on data from the field trials and the he selected gear is a weighted composition of advised and desired gear shifting points.

7.3.1 Model description

The driver model contains a gear compliance model which estimates the driver's selected gear. The ecoDriver system provides the driver with an instantaneous gear advice $g_{ED}^{a}$and at the same time, the driver has it's own desired gear g_{TS}^{des}. The model combines the advised and desired gear into a weighted composition representing a modified desired gear g_{DM}^{des}.

Since continuous gear advice is difficult to capture in a model perspective, the gear choice is represented by RPM shifting points rather than the gear advice itself. It means drivers are assigned desired shifting points while the system provides drivers with advised shifting points in order to optimize the gear shifting in a fuel perspective. This representation is more realistic since it makes more sense comparing when drivers are adapting to the advice rather than model however drivers are adapting to the advice or not. The changed approach is suitable since the ecoDriver system uses fixed RPMs to estimate the gear advice provided to the driver.

The gear compliance model is thereby only based on engine speeds and the modified desired shifting points r_{DM}^{des} consists of a weighted composition of desired shifting points r_{TS}^{des} and advised shifting points r_{ED}^{a} according to equation (21).

$$r_{DM}^{des} = c_{gear} \cdot r_{ED}^{a} + \left(1 - c_{gear}\right) \cdot r_{TS}^{des} \tag{21}$$

where $c_{gear} \in [0,1]$ is a parameter representing the compliance to the system advice, which is estimated based on data from the field trials. This model will allow any degree of compliance to the advice from full compliance, $c_{gear} = 1$ and $r_{DM}^{des} = v_{ED}^{a}$, to no compliance, $c_{gear} = 0$ and $r_{DM}^{des} = r_{TS}^{des}$. The model works the same for both upshifting and downshifting advice.

The gear shifting strategy model described in 7.2 is then applied using the revised gear shifting points provided from the gear compliance model, which are and adjusted according to the level of compliance. The principle of gear choice is presented in equation (22) including the revised gear shifting points within the gear shifting strategy. Details about the gear shifting strategy is described in equations (13) to (20).

$$\Delta g_{\mathrm{combined}} = \begin{cases} -1, & r < r_{\mathrm{DM}}^{des-} \\ +1, & r > r_{\mathrm{DM}}^{des+} \\ 0, & \text{otherwise} \end{cases} . \qquad (22)$$

7.3.2 Calibration using field data

In contrast to speed compliance, gear compliance is not drawn from a distribution but rather set to a fixed value depending on the gear g, the scenario S, the year Y, the vehicle type V and the ITS variant I: $c_{\mathrm{gear}}^{\pm} = c_{\mathrm{gear}}^{\pm}(g, S, Y, V, I)$. Different compliance values are applied depending on whether it is an up-shift or a down-shift procedure.

The compliance is estimated using data from the field trials. Gear shifting points has been compared with and without the ecoDriver system for individual drivers. Figure 39 illustrates an example of gear shifting point variations between baseline and treatment drives. The same graph also presents how shifting points are affected by acceleration.

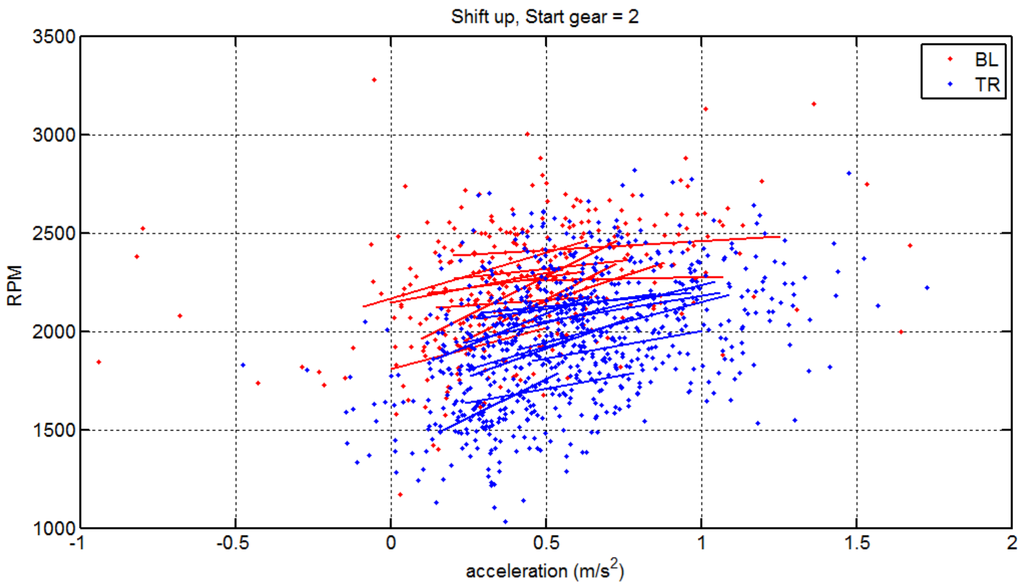


Figure 39: Gear shifting procedure in relation to acceleration at field trials using Volvo V70 (6 gears diesel) with (TR) and without (BL) the embedded ecoDriver system

Since the advised gear shifting points are known, the level of compliance was estimated as the ratio between the observed shifting points at baseline and treatment runts according to equation (23).

$$c_{gear} = \frac{r_{DM}^{des} - r_{TS}^{des}}{r_{ED}^{a} - r_{TS}^{des}} \qquad (23)$$

In equation (23), r_{TS}^{des} is represented by the desired gear shifting which is the same as the shifting points in the baseline runs. The r_{DM}^{des} is the combined gear shifting points which may be represented by the gear shifting points from treatment drives. The r_{ED}^{a} is the advised shifting points and are already known for the specific gear, vehicle and type of system. Figure 40 illustrates baseline, treatment and advised engine speeds for upshifts using the Volvo V70 (6 gears diesel).

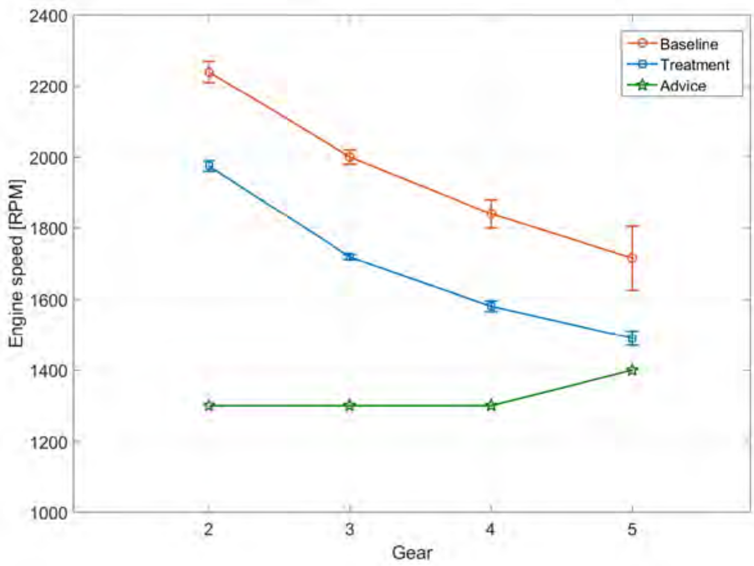


Figure 40: Up shifting behaviour Volvo V70 (6 gears diesel) comparing treatment, baseline and optimal gear shifting points.

The gear compliance has been estimated using the data from the Volvo V70 used in the field trials in Sweden. There were no field trial data available for the Renault Clio with FeDS. The data for the Renault Scenic was not trustworthy due to inconsistency in the initial gear estimations (the gear was not measured). The relative change between the desired and advised shifting points have been applied for the other vehicles representing optimal shifting points for those vehicles. The relative change for upshift and down shifts for Volvo V70 is illustrated in Figure 41.

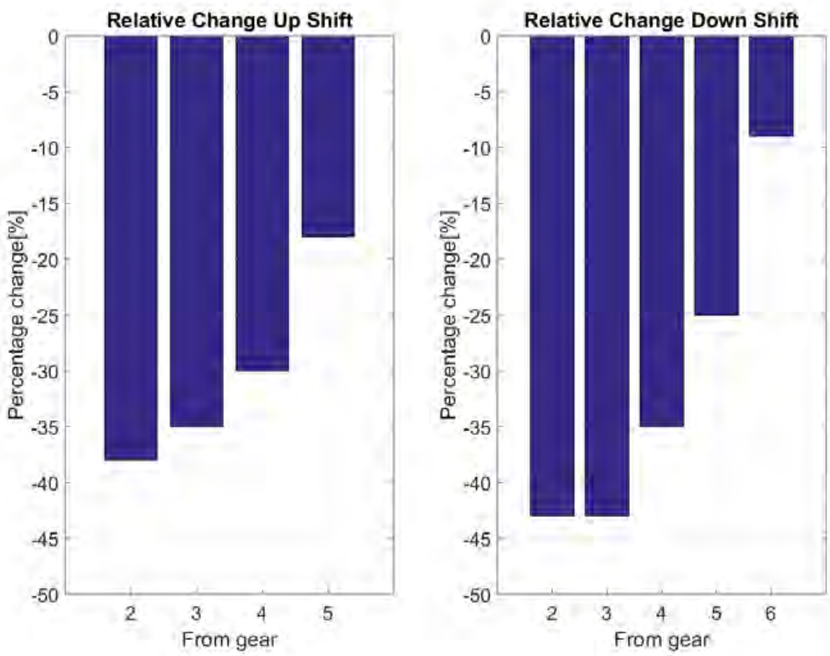


Figure 41: The relative change between baseline and advised shifting points for Volvo V70 (6 gears diesel)

The optimal shifting points are assumed to be the same for Nomadic and embedded systems. This is not the actual case and in reality the advised RPMs were higher in the Nomadic system. However, this was discovered after the final simulations and could not be incorporated. However, complementary analysis show that this mainly affects the compliance level and leads to a minor overestimation of the effect in scenarios with high increase in compliance. Figure 42 illustrates the up shifting compliance data for Renault Clio when estimating the optimal shifting points based on the relative change for Volvo V70. The optimal shifting points are estimated based on the relative change between baseline and optimal RPMs for Volvo V70.

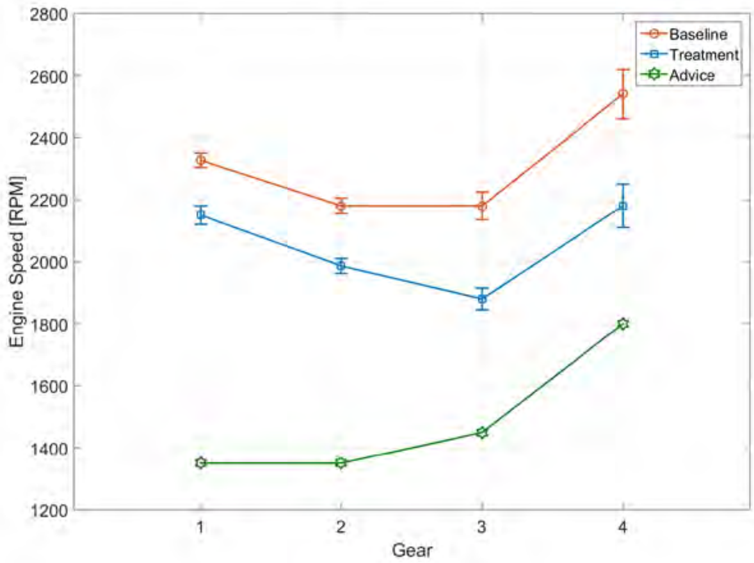


Figure 42: Up shifting behaviour for Renault Clio (5 gears petrol) comparing treatment, baseline and optimal gear shifting points.

Compliance rates of the embedded system are estimated from field trial data using the Volvo V70. The results has been applied for all vehicles independent of powerline and number of gears. The same approach goes for the Nomadic system using field trials data from Renault Clio. The measured gear compliance from the field trials for both Nomadic and Embedded systems are presented in Figure 43. Gears without sustainable results are applied compliance levels from the closest gear with reliable results.

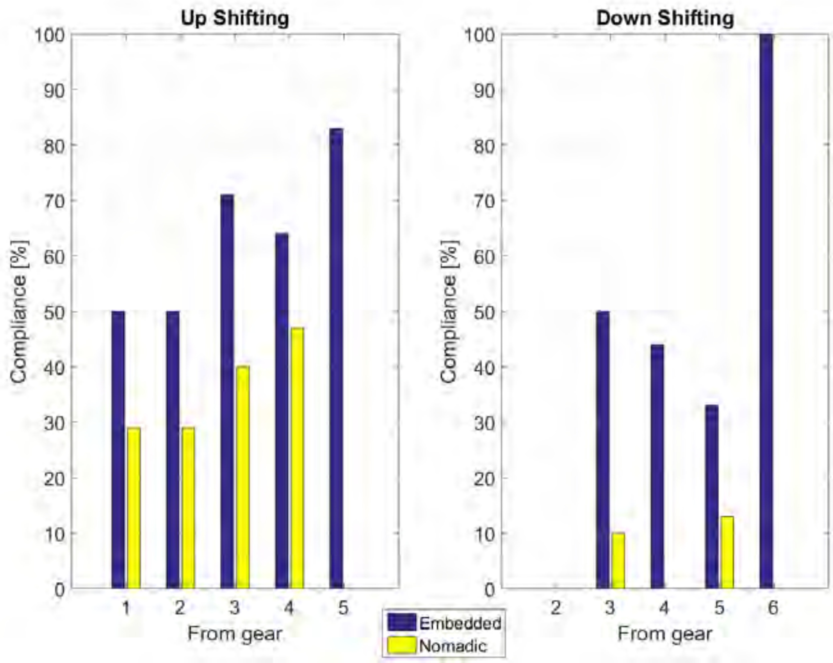


Figure 43: Measured compliance from the field trials using Volvo V70 (Embedded) and Renault Clio (Nomadic).

7.4 Projections for scenarios and future years

Projections of change in compliance over future years are based on the scenario descriptions in order to remain consistent between different scenarios and years. The projection of compliance is the same for speed, start of deceleration and gear shifts. No difference may be assumed between projections for different vehicle classes or powertrains except for professional drivers which assumes to have larger savings (+15% compared to public drivers). This assumption is based on the findings of the focus groups conducted as a part of the scenario development (see Jopson et al. (2015)). The results from the Focus Groups suggested that the benefits are greater and the commercial imperative to fit and use ecoDriving systems is stronger in the commercial vehicle market (goods vehicles and buses). Changes in compliance for all years, scenarios and vehicle types are presented in Table 17.

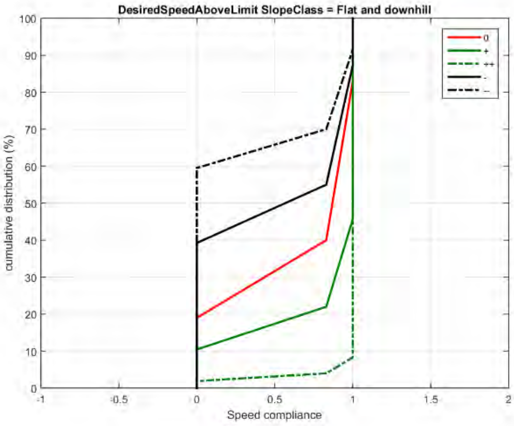
Table 17: Projections of future years, '+' means 45% increase related to the original value and full compliance, '++' gives 90 %. '-' represents 25% decrease related to the original value and no compliance, '--' gives 50% decrease.

Scenario:	EV car		Petrol car		Diesel car		Diesel van		Diesel truck	
	embedded	nomadic	embedded	nomadic	embedded	nomadic	embedded	nomadic	embedded	nomadic
GF										
2015	o	o	o	o	o	o	o (high)	o (high)	o (high)	o (high)
2020	+	+	+	+	+	+	+ (high)	+ (high)	+ (high)	+ (high)
2025	+	+	+	+	+	+	+ (high)	+ (high)	+ (high)	+ (high)
2030	++	++	++	++	++	++	++ (high)	++ (high)	++ (high)	++ (high)
2035	++	++	++	++	++	++	++ (high)	++ (high)	++ (high)	++ (high)
PF										
2015	o	o	o	o	o	o	o (high)	o (high)	o (high)	o (high)
2020	o	o	o	o	o	o	o (high)	o (high)	o (high)	o (high)
2025	o	o	o	o	o	o	o (high)	o (high)	o (high)	o (high)
2030	o	o	o	o	o	o	o (high)	o (high)	o (high)	o (high)
2035	o	o	o	o	o	o	o (high)	o (high)	o (high)	o (high)
CF										
2015	o	o	o	o	o	o	o (high)	o (high)	o (high)	o (high)
2020	o	o	o	o	o	o	o (high)	o (high)	o (high)	o (high)
2025	-	-	-	-	-	-	- (high)	- (high)	- (high)	- (high)
2030	-	-	-	-	-	-	- (high)	- (high)	- (high)	- (high)
2035	--	--	--	--	--	--	-- (high)	-- (high)	-- (high)	-- (high)

The changes in Table 17 are based on the desire to get as wide representation as possible. It would be irrelevant to investigate different scenarios with only limited differences. The changes are estimated in order to represent a large variety but at the same time remain realistic. In order to represent the changes in compliance from projections, the piecewise distributions has been scaled. The scaling factors are developed with respect to the original compliance distributions compared with full compliance and non-compliance for increasing and decreasing projections respectively.

The increase is a weighted composition between the original distribution and a fully compliant driver. The notation + gives a distribution which is 55% based on the original distribution while 45% is based on a fully compliant driver. The notation ++ is weighted 95% towards an optimal drive. The projected decrease is a weighted composition between the original distribution and a non-compliant driver. The notation – represents a weighted composition 25% towards a non-compliant driver while – represents a composition of 50% each. Figure 44 illustrates the different combinations of speed compliance distributions for public drivers.

Flat and downhill segments	Uphill segments



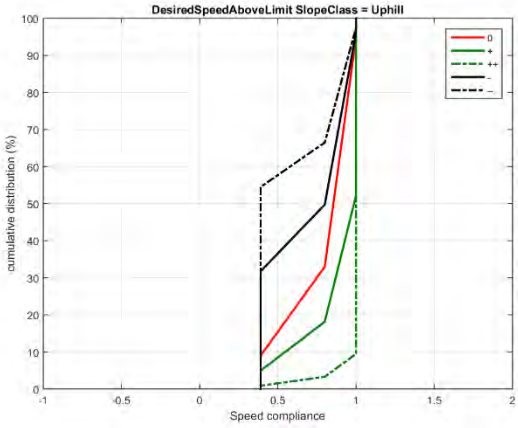
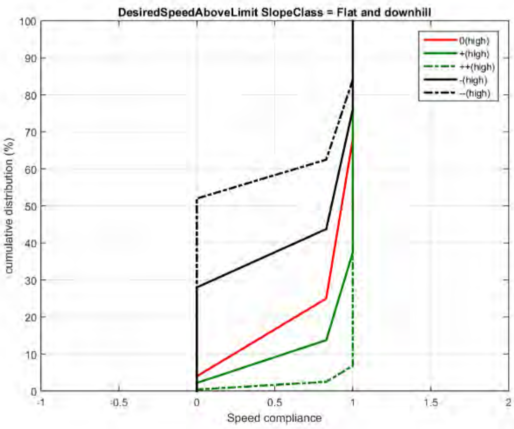


Figure 44: Projections of speed compliance for public drivers.

Figure 45 illustrates the different combinations of speed compliance distributions for professional drivers. The original distribution is scaled 15% compared to the distribution for public drivers but the composition for increase and decrease remains the same for both public and professional drivers.

Flat and downhill segments	Uphill segments



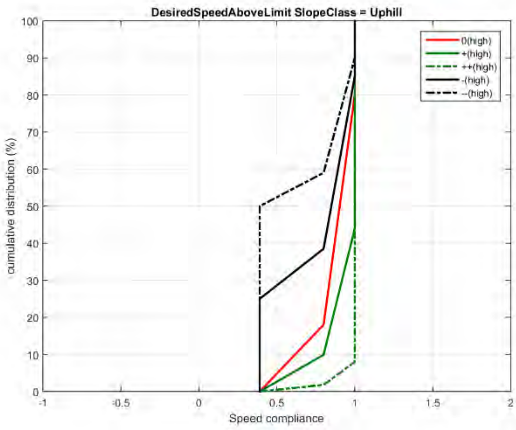


Figure 45: Projections of speed compliance for professional drivers.

Speed compliance distributions for all scenarios and future years are available in Annex C. Actual values of gear shifting points for projections of future years and scenarios are available in Annex E.

8. Vehicle model

An external vehicle model is required in the simulation framework since none of the traffic simulation tools used in this study supports gear shifting. The vehicle model represents the vehicle behaviour using different gears in different situations. The model estimates the vehicles engine speed and maximum acceleration available given a specific speed and gear.

8.1 Calculation of maximum acceleration

The maximum acceleration estimation is based on the engine map developed for each specific vehicle. It is a look up table function identifying the maximum acceleration available during current circumstances. Each gear and velocity has its own value and include energy losses caused by air resistance, rolling resistance and engine frictions. The only external force affecting the maximum acceleration given from the lookup function, is caused by the slope of the road $\theta(x(t))$. The maximum acceleration from the look up table a_m is adjusted with respect to the slope of the road θ according to equation (24).

$$a_{max} = a_m(g(t), v(t)) - 9.81 \cdot \theta(x(t)) \tag{24}$$

The remaining acceleration a_{max} denotes the maximum acceleration available at time t when using gear g traveling in the speed of v m/s. Figure 46 illustrates maximum accelerations available at different gears and speeds for Renault Clio. Similar illustrations for the other vehicles used in the simulation are presented in Annex F.

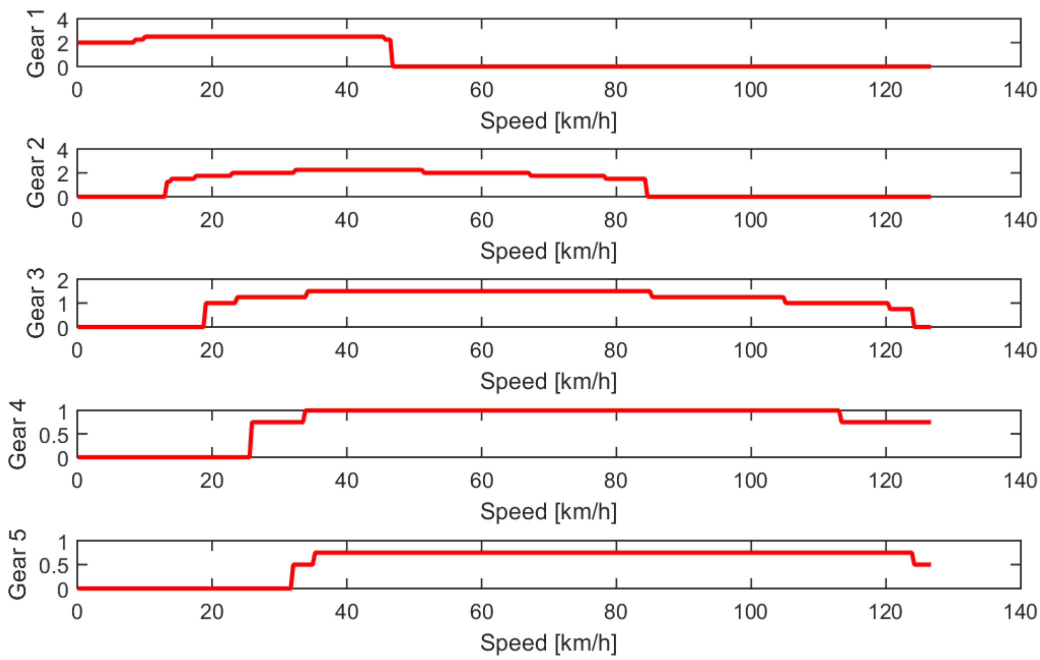


Figure 46: Maximum acceleration available [m/s^2] for Renault Clio (petrol) for all possible combinations of speed and gears.

8.2 Calculation of engine speed

Vehicle engine speed is required in order to estimate the driver's gear shift behaviour. The engine speed is utilising the engine map performed for each vehicle type including the gear ratio of each gear. The unit of the gear ratio is $\frac{km/h}{min}$, engine speed can be estimated by multiplying the gear ratio with the current speed v in km/h. The engine speed, s for the next time step $(t + dt)$ is calculated according to equation (25) where GR_gdenotes the gear ratio of the current gear used by the driver.

$$s(t + dt) = GR_g \cdot v(t). \tag{25}$$

Gear ratios for Renault Scenic and Renault Clio are presented in Table 18.

Table 18: Gear ratios for Renault Scenic and Renault Clio

Gear	Gear ratio (Renault Scenic) [h/km min]	Gear ratio (Renault Clio) [h/km min]
1	255	255
2	120	120
3	50	50
4	25	25
5	18	18
6	13	N/A

9. Energy and emission assessment method

9.1 Model description

To evaluate how the impact of ecoDriving advice affects driving behaviour and speed profiles (trajectories) it is necessary to use an Instantaneous Emission Model (IEM). IEMs consider the changes in power demands on the engine during driving i.e. speed and rate of acceleration, forces to overcome rolling resistance and aerodynamic drag, plus potential energy needed/ gained during changes in road elevation. Although established IEMs for the European fleet of vehicles are available e.g. PHEM (Passenger car and Heavy-duty Emission Model; Hausberger et al., 2015), these are only available as stand-alone packages. Their complexity and restricted access to source code means they cannot be coded within the traffic simulator environments.

Instead an empirically derived IEM, initially developed by Ligterink et al. (2014) and extended to include vans and trucks in 2015 is used in the project. This instantaneous energy and emission model is considered to be robust as it borne out of thousands of European Real Driving Emission (RDE) measurements.

The formulation of the IEM is similar to that of the Vehicle Specific Power (VSP) equation (26) derived by Jimenez-Palacios (1999).

$$\mathrm{VSP} = \frac{\frac{d}{dt}(KE + PE) + F_{rolling} \cdot v + F_{aerodynamic} \cdot v}{m}. \tag{26}$$

This can be simplified if parameters are introduced for a typical European car. Then the Vehicle Specific Power can be calculated as

$$\mathrm{VSP}_{Passenger\ car} = \mathrm{v} \cdot ((1.1\mathrm{a}) + (9.81 \cdot \ \sin(\mathrm{atan}(\theta)) + 0.128) + (0.000318\mathrm{v}^3), \tag{27}$$

where VSP is vehicle specific power (kW/t), KE is kinetic energy (J), PE is potential energy (J), $F_{rolling}$ is rolling resistance (N), $F_{aerodynamic}$ is aerodynamic drag (N), m is the vehicle mass (tonnes), v is vehicle speed (m/s), a is vehicle acceleration (m/s^2) and θ is road grade (dimensionless).

When the four parameters of the model are statistically derived from observations, this IEM can robustly predict tail-pipe CO_2 emissions second-by-second. NO_X emissions do rely on the predicted CO_2 emission levels (time series) but additional non-instantaneous and non-linear terms are needed. The derivation of the IEM and parameters used are documented in Annex H.

There were some minor issues with parameterising the emission models for some conditions, as the underlying measurements informing the parametrisation of the model didn't cover the conditions in the simulations. For example the emission testing did not cover trucks cruising at 80 km/h, yet these conditions were present in some simulations. These were missing from the underlying data as in the Netherlands trucks drive either at the delimiter speed of about 90 km/h or at lower velocities with increased dynamics (speed fluctuations) due to congestion. Hence, the minor differences in fuel consumption at 90 km/h and 80 km/h cruising seem to show some bias due to the fact that 90 km/h data is mainly collected from constant driving, and data at 80 km/h is from dynamic driving. Consequences of such bias in the emission data are difficult to repair without further testing. In future emission test programs it is therefore important to cover all the different driving and circumstances deemed relevant.

The empirical vehicle fuel and emission data are collected at 1Hz (second-by-second). Although the model was adjusted to provide predictions for shorter time steps e.g. 10Hz (1/10th of a second interval), results were not reliable. This is considered to be due to the non-linear nature of the statistical relationships and averaging issues of input and output data. It is recommended the IEM is only applied at a 1 second (1Hz) time step. The relative simplicity of the model and equations means it can be implemented within the traffic simulators and simulations without unduly impacting on processing time. The robustness of the final version of the energy and emission model was determined by comparing its predictions to independent measurements of a petrol and a diesel car, a van and a truck.

The IEM is configured to represent typical northern European driving conditions. The IEM reflects empirical measurements collected on dry days only, with ambient temperatures above freezing (0^{o}C). Although freezing temperatures and wet weather are now known to inhibit driver behaviour, with drivers accelerating more slowly (Pellecuer et al., 2016), like the majority of vehicle emissions studies and models this effect is not considered. Although light rain conditions are quite common in northern Europe, driver behaviour is only observed to be impeded when rain is heavy, which is infrequent and therefore is not considered to be a major limitation. Freezing temperatures with icy road surface conditions also result in drivers in the UK observed to drive more cautiously (Pellecuer et al., 2016). Whilst below freezing temperatures are common across Northern Europe and more mountainous regions in the winter months, in many areas it is compulsory to fit winter tyres, partly negating the impact of freezing road conditions. Therefore the impact of freezing road conditions on driver behaviour and consequently is only considered to be minor when averaged across the year and all EU states.

Lower ambient temperatures are also now known to impact engine management and exhaust control systems on the latest light- and heavy-duty diesel vehicles. At lower ambient conditions EGR (Exhaust Gas Recirculation) and SCR (Selective Catalytic Reduction) are not implemented as frequently so engine wear is minimised, alongside maintaining fuel efficiency and performance. Studies are only just appreciating the impact this may have on emissions. It is expected this effect will have the greatest impact on Euro 6a and 6b light-duty diesels (cars and LGVs). Euro 6c with stronger legislation regarding Real Driving Emissions (RDE) is expected to significantly reduce the impact of lower temperature, higher emission engine management settings. With the IEM constructed from RDE (PEMS testing) measurements across a range of ambient temperatures, this effect is partially considered in this study, to a greater degree than many other vehicle emission evaluations.

9.2 Validation

The IEM has been validated with second-by-second Transport for London (TfL) chassis dynamometer (Millbrook) measured data. Representative Euro 5 vehicles have been tested over a drive-cycle (speed profile) intended to represent the broad range of London (real-world) driving conditions. The 'London Drive Cycle' for light-duty vehicles has been developed by TfL as part of an on-going Vehicle Emission Study (Transport for London, 2015). The drive cycle was developed in association with Millbrook, who were commissioned to track a car (VBox GPS and CAN Bus link) making repeated circuits of a set route in the North-East of London at different times of day: AM peak, Inter-peak and in Free-flow conditions. The route contained sections of (urban-) motorway, suburban and urban (central London) driving conditions. The speed profile (time-series) of the London Drive Cycle are illustrated in Figure 47. The drive-cycle is considered to represent typical driving style/ behaviour in the UK. Unfortunately the drive-cycle doesn't yet consider fluctuations in road gradient. The IEM's consideration of road gradient has therefore not been verified, but as it is simply imposing an additional load on the engine similar to a more aggressive acceleration, this is not considered to be a major limitation. The distribution of engine power demands broadly reflects the WLTP (Worldwide harmonized Light vehicles Test Procedures) suggesting it reflects typical driving conditions but not perhaps more aggressive, power intensive driving behaviour and micro-events. Summary statistics for the different elements of the drive cycle (road type and time period) are documented in Table 19.

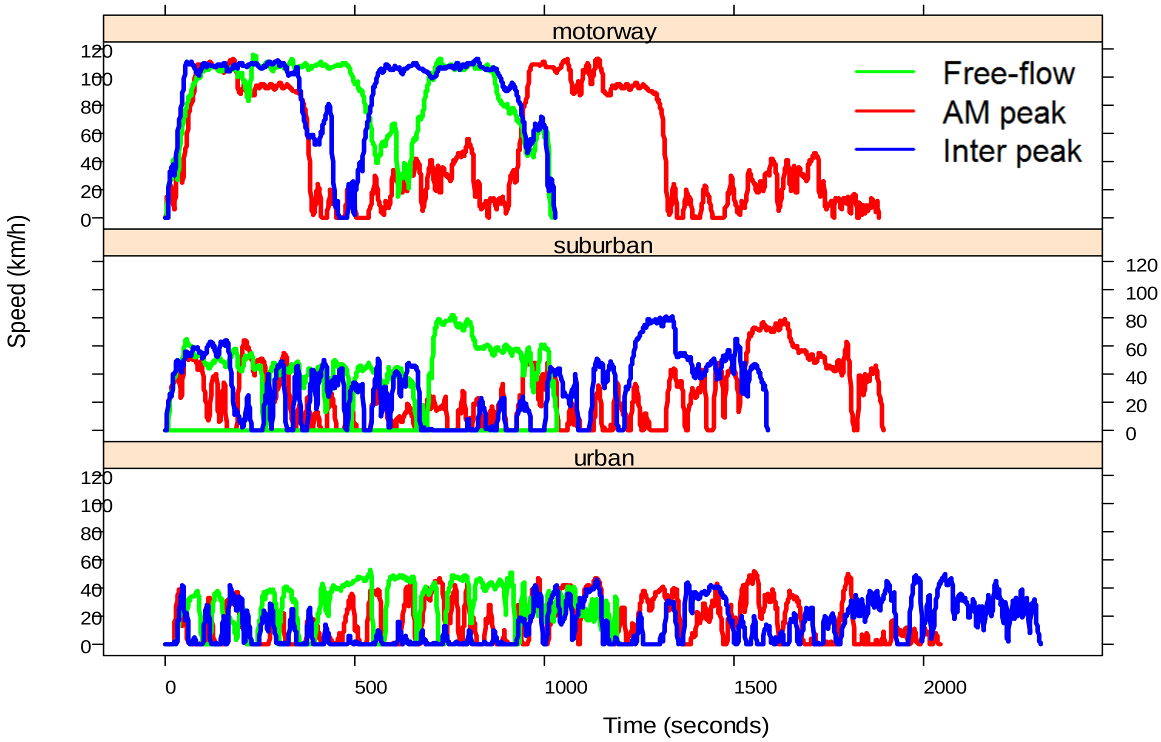


Figure 47: Average speed (modelled) in each simulation hour

Table 19: The London Drive Cycle statistics.

Road Type	Time Period	Duration (seconds)	Distance (km)	Average Speed (km.h^{-1})	Maximum Acceleration (m.s^{-2})	Section ID
Urban	Free-flow	1202	8.92	26.73	2.67	7
Urban	AM peak	2048	8.93	15.69	1.97	8
Urban	Inter-Peak	2311	8.93	13.91	2.48	9
Suburban	Free-flow	1036	13.33	46.31	2.4	10
Suburban	AM peak	1894	13.33	25.33	2.67	11
Suburban	Inter-Peak	1591	13.33	30.16	2.31	12
Motorway	Free-flow	1023	24.61	86.60	1.62	13
Motorway	AM peak	1884	24.61	47.03	1.69	14
Motorway	Inter-Peak	1030	24.61	86.02	2.46	15

The ecoDriver and comparator vehicles (tested - laboratory measurements), both light- and heavy-duty are documented in Table 20. The ecoDriver vehicles were simulated over the TfL drive cycles by a stand-alone (executable) version of the ecoDriver instantaneous emission model (IEM). Emission testing data is rare and whilst data is not available for the same make (marque) and model, broadly comparable vehicles in terms of their size, weight and fuel type have been selected. The results are not expected to be directly comparable on a second-by-second basis but they should replicate trends in dynamics and their averaged emission factors should be broadly comparable.

Table 20: Modelled and observed vehicles

Vehicle class	Euro standard	ecoDriver vehicles			Measured		
		Vehicle	Fuel	Weight (kg)	Vehicle	Fuel	Weight (kg)
Car	5	Renault Clio	Petrol	1146	Peugeot 107, 1.0L,	Petrol	900
Car	5	Renault Scenic	Diesel	1460	Ford Galaxy 2.0L TDCi, Zetec	Diesel	1890
Van	5	VW Transporter	Diesel	1971	Ford Transit, 2.0L	Diesel	2670
Truck	V	DAF XF	Diesel	14 000	MAN TGM 18.250	Diesel	13 500

A sample section of the second-by-second measured and modelled emission predictions for the urban sub-cycle are illustrated in the time series figures (Figure 48) overleaf.

a) Diesel car – ecoDriver Renault Scenic (Euro 5); and
b) Diesel Van (Light-commercial vehicles) – ecoDriver VW Transporter.

Differences in the transient emission performance would be expected between cars/ LCVs, even of the same make and model. Also at this 1Hz resolution smoothing of the ‘raw’ speed and emission measurements influences the traces. There is impressive similarity between the second-by-second observed and modelled CO_2 and NO_X for these light-duty diesel vehicles, Figure 49. The IEM is considered fit for purpose for evaluating the impact of the ecoDriver systems.

The summary emission factors for the petrol (compact) car, diesel (MPV) car, van and truck are documented in Table 21 for the different driving sub-cycles (urban, suburban and motorway). Unfortunately no observations were available for passenger cars over the urban cycle. The observed CO_2 per kilometre driven from the petrol car are lower than predicted by the ecoDriver IEM. This is because the car measured by TfL is smaller and lighter (900kg as opposed to 1146kg for the Renault Clio) than the ecoDriver petrol car. As would be expected for a modern petrol car equipped with a three-way catalyst (TWC) NO_X emissions per kilometre driven are at a low level (both observed and modelled). Similarly the ecoDriver diesel passenger car (Renault Scenic) is smaller and lighter (≈ 23%) than the MPV tested by TfL, hence it CO_2 emissions are less. NO_X emissions from diesel passenger cars however are more a function of the engine and emission controls used e.g. Lean NO_X Trap (LNT), Selective Catalytic Reduction (SCR) than weight. The observed and modelled NO_X emissions per kilometre travelled are comparable.

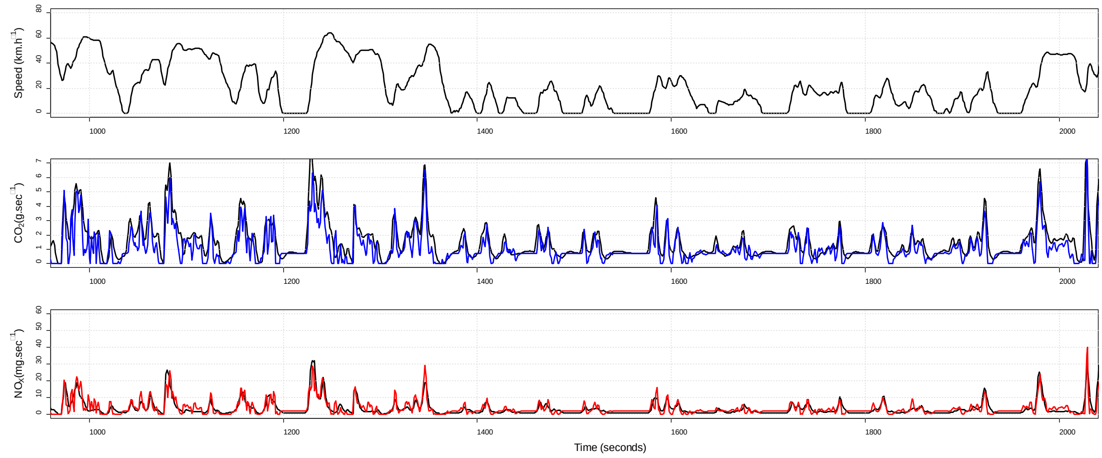
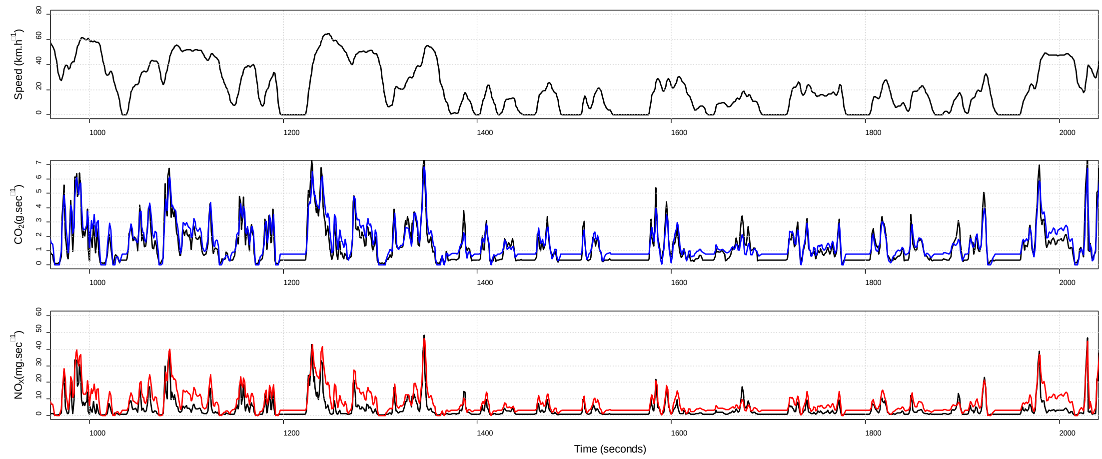
Vehicle	Time Series
Diesel car	
Diesel van	

Figure 48: Sample 1000 seconds time series of modelled and observed speed, CO_2 and NO_X emissions for the diesel car and van (suburban sub-cycle). The measured data, whether speed, tail-pipe CO_2 or NO_X emissions are illustrated as a [**BLACK**] line. The modelled vehicle tail-pipe CO_2 emissions are the [**BLUE**] line, with NO_X as a [**RED**] line. Note the data for the petrol (compact) car is not illustrated as the NO_X emissions are at a low-level.

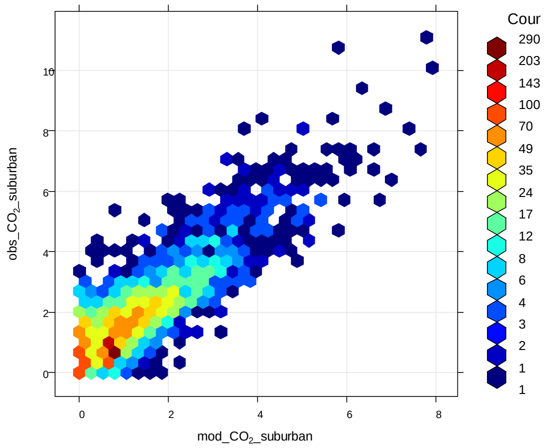
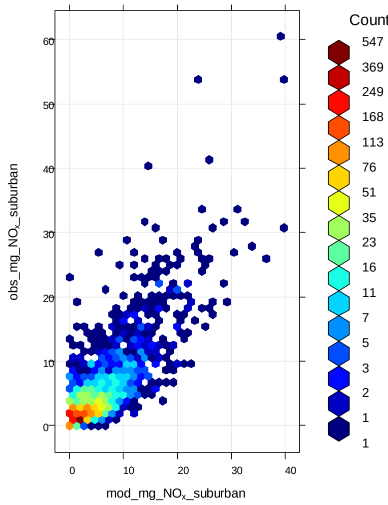
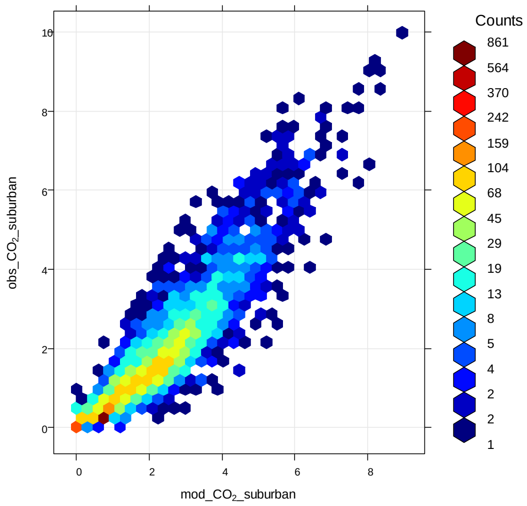
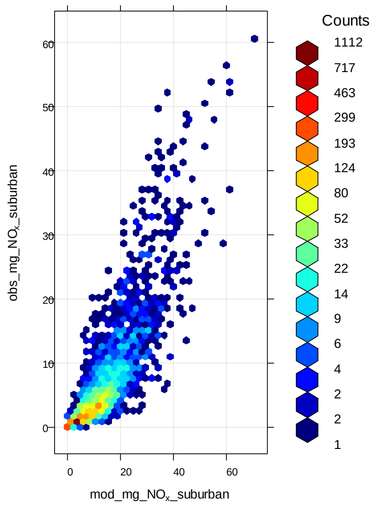
<table>
<tr><th>Vehicle</th><th>CO_2</th><th>NO_X</th></tr>
<tr><td>Diesel car</td><td>
</td><td>
</td></tr>
<tr><td>Diesel van</td><td>
</td><td>
</td></tr>
</table>

Figure 49: Scatter plots of the modelled and observed CO_2 and NO_X emissions for the diesel car and van (suburban sub-cycle)

Table 21: Summary - Comparison of the emission performance (CO_2 and NO_X) of the observed and modelled observed vehicles

	Urban (average speed 27 km/h)				**Suburban (average speed 40 km/h)**				**Motorway (average speed 74 km/h)**			
Vehicle type	**CO_2 (g/km)**		**NO_X (g/km)**		**CO_2 (g/km)**		**NO_X (g/km)**		**CO_2 (g/km)**		**NO_X (g/km)**	
	Observed	**Modelled**	**Observed**	**Modelled**	**Observed**	**Modelled**	**Observed**	**Modelled**	**Observed**	**Modelled**	**Observed**	**Modelled**
Petrol Car	Not avail.	Not avail.	Not avail.	Not avail.	105.4	136.8	0.013	0.02	109.7	121.2	0.018	0.02
Diesel Car	Not avail.	Not avail.	Not avail.	Not avail.	203.2	120.9	0.44	0.46	224.0	120.7	0.81	0.84
Diesel Van	232.0	289.3	0.64	1.34	181.0	223.9	0.54	1.15	187.6	234.0	0.80	1.64

9.3 Applying the energy and emission model to the traffic simulation outputs

The ecoDriver IEM was coded to simulate tail-pipe emissions every one-second in the ecoDriver traffic simulators. As the IEM is considered to only provide valid predictions at a 1Hz time resolution. As the traffic microsimulators operate at a higher frequency than this (2 or 10Hz), the emission calculations were coded to only be made every other time step if 2Hz e.g. AIMSUN or every 10th simulation step for RuTSim.

10. Traffic safety assessment method

The traffic safety assessment of the traffic simulation results have been conducted using the "Power Model", originally proposed by Andersson and Nilsson (1997) and by Nilsson (2004), who presents a useful summary of the relationship between traffic speed and accidents of various severities. The chapter starts with a brief description of the power model before describing how the power model was applied to the traffic simulation output data.

10.1 The Power model

The initial modelled relationship is that changes in all injury accidents are proportionate to a change in mean speed for a length of road squared, serious injuries change with speed cubed and fatalities with speed to the fourth power. That means that, in general, a 10% reduction in mean speed with translate into a 34% reduction in fatalities. So quite small changes in speed have a dramatic effect on serious injuries and fatalities. Since that initial work, the Power Model has been further refined both in theoretical terms and by being calibrated to more extensive data. In the general form of the Power Model the accidents in an after case (changes in road layout, regulation, enforcement, etc.) are calculated as

$$Accidents_{after} = accidents_{before} \cdot \left(\frac{speed_{after}}{speed_{before}}\right)^{exponent}, \qquad (28)$$

where the $accidents_{before}$ is the accident level before the change and $speed_{after}$ and $speed_{before}$ are the average speed before and after the change to be evaluated, respectively.

Elvik et al. (2004) pointed out that the injury categories in the first version of the Power Model overlapped, and recalculated the model based on studies from across the world. The best estimates of the model from that calculation are shown in Table 22. It can be seen that the exponent for fatalities is even larger than in the original formulation.

Table 22: Exponents of the Power Model (Elvik et al., 2004)

Injuries		Accidents	
Severity	**Exponent**	**Severity**	**Exponent**
Fatalities	4.5	Fatal	3.6
Serious injuries	3.0	Serious	2.4
Slight injuries	1.5	Slight	1.2

Five years later, Elvik recalculated the exponents in the Power Model using an updated set of studies (Elvik, 2009). Table 23 shows the new set of exponents. It can be seen that the exponents have fallen somewhat, perhaps because of improved vehicle design which provides better protection to occupants and vulnerable road users.

Table 23: Exponents of the Power Model (Elvik, 2009)

Injuries		Accidents	
Severity	**Exponent**	**Severity**	**Exponent**
Fatalities	4.3	Fatal	3.5
Serious injuries	3.0	Serious	2.0
Slight injuries	1.3	Slight	1.0

Elvik (2013) reanalysed the data comparing exponential models with the Power Model. Exponential models better fitted the relationship between speed changes and overall injury accident numbers and the Power Model provided a better fit with fatal accidents. He suggests that the exponential model was more plausible in that changes of speed at the high end had a greater impact on accident number than changes in speed at the low end. However, the differences in predictions from the two formulations were not very large. It can thus be argued that the Power Model remains a reasonable predictor, and provides a useful shorthand for the fundamental rule that changes in traffic speed will have a far greater proportional effect on the numbers of severe accidents than on the numbers of slight accidents.

10.2 Applying the speed power model to the traffic simulation outputs

The input to the power model is the proportional change in mean speed. In this case, it is the proportional change in mean speed between the with-ecoDriver and without-ecoDriver traffic simulation cases (see section 2.2 and Figure 4 for a description and illustration of the with- and without-cases). The simulated networks consist of road sections with different speed limits and the mean speed have therefore been calculated per speed limit. The output from the traffic simulations to the scaling up step is the proportional change in the defined PIs. This implies a minor reformulation of equation (28) and the proportional change in accidents on road with speed limit j is calculated as:

$$\Delta Accidents_j = \frac{Accidents_{with,j}}{accidents_{without,j}} = \left(\frac{speed_{with,j}}{speed_{wihtout,j}}\right)^{exponent}, \qquad (29)$$

where $speed_{with,j}$ and $speed_{wihtout,j}$ are the average travel speed over the homogeneous (with respect to speed limit) road segment j for the with and without ecoDriver case, respectively. The $exponent$ is taken from Table 23. The calculation of the average speed and the proportional change in injuries and accidents where conducted using the following procedure:

1. Extract meter-by-meter vehicle trajectories from the simulations
2. Sort the individual observations by speed limit
3. Calculate mean speed per speed limit based on all observations per speed limit
4. Calculate proportional change in mean speed for each corresponding with ecoDriver and without ecoDriver case per speed limit.
5. Calculate proportional change in injuries and accidents for each corresponding with ecoDriver and without ecoDriver case per speed limit.
6. Calculate a weighted average of the proportional change in injuries and accidents for the whole network based on number of vehicle km driven at each speed limit.

11. Traffic efficiency assessment method

The traffic efficiency related PIs considered in the scaling up and cost benefit analysis is travel time. Within the cost benefit analysis research field there exists two different approaches to how travel times are included in the analysis (van Wee, 2011). The first approach is to use the actual travel time, this implies that driving faster than the speed limit counts as a benefit compared to driving at the speed limit. The second approach is to discard travel time benefits arising from speeding. To allow sensitivity analysis in the cost benefit analysis both the actual travel time (described in section 11.1) and a travel time corrected for speeding (described in 11.2) is calculated based on the traffic simulation output.

11.1 Calculation of travel time

It is straightforward to calculate the actual travel time for a single vehicle. The individual travel times then need to be aggregated to an average travel time per vehicle type for the whole network and in the end a proportional change in the average travel time. As further discussed in section 13.1 it is important to ensure that the travel time aggregation is conducted for the same time periods for the with ecoDriver and without ecoDriver cases. This implies that the time period of investigation includes a "cooling down" which allows calculation of the travel time of the vehicles entering the road section during the actual study period but exiting the section after the end of the actual study period.

11.2 Calculation of travel time corrected for speeding

The travel time corrected for speeding is calculated by estimating what the travel time would have been at a short time interval (e.g. simulation time step) or space interval (e.g. per meter) if the speed does not exceed the current speed limit. In case of time sampling the following procedure is applied for each individual vehicle:

1. For time steps that the speed **exceeds** the speed limit, calculate the travel time it would have taken to travel the distance travelled since the last time step using the speed limit speed instead of the actual speed.
2. For time steps that speed does **not exceed** the speed limit, calculate the travel time as the duration of the time step.
3. Sum the travel time for all time steps within the defined study period and road section

In case of space sampling (meter-by-meter trajectories) the following procedure is applied for each individual vehicle:

1. For each meter space sample calculate the travel time of travelling the length of the space sample using the minimum value of the actual speed and the speed limit.
2. Sum the travel time for all space steps within the defined study period and road section.

12. Verification simulations

12.1 Verification simulations of traffic simulation framework

Verification simulation has been performed in order to ensure consistent behaviour of the ecoDriver system independent of the simulation tool. The verification simulation has been performed using a basic scenario simulating the driver's anticipation due to different speed limits. This chapter includes a brief description of the network used in the basic scenario together with results from simulations using ITS modeller, RuTSim and Aimsun. The evaluation includes simulations of both the Nomadic and the embedded ecoDriver system.

All different vehicle classes have been tested and evaluated, but only data from Renault Scenic is presented in this section. Desired speed is identical for all other vehicles (except for trucks which are limited to 80 km/h) but the gear shift behaviour may vary due to engine size and available acceleration.

This section contains a comparison of three different types of drivers:

- Unequipped (or no compliance against the advice provided from the ecoDriver system),
- Half compliant (50% compliance against the advice provided from the ecoDriver system),
- Fully compliant (100% compliance against the advice provided form the ecoDriver system).

The level of compliance is consistent between gear, speed and start of deceleration. The unequipped driver is assumed to be driving 10% faster than the speed limit and have a more aggressive gear shift strategy (use higher RPM shifting points) compared to a fully compliant driver using the ecoDriver system.

12.1.1 The sample network used for the verification

The basic scenario consists of a 13 km long single road stretch with six speed limit changes according to Figure 50. It is a flat road without any curves, intersections or obstructions causing decreased visibility.

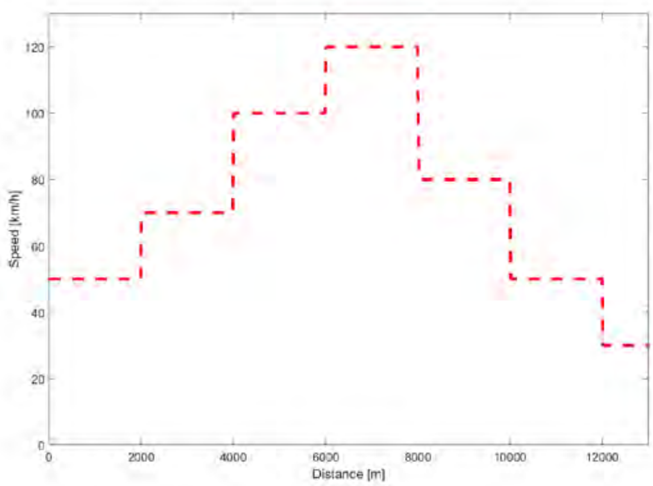


Figure 50: Speed profile of basic scenario

The aim of the basic scenario is to evaluate drivers' anticipation of the ecoDriver system, since the system is mainly related to the speed limit. The gear advice is only related to the engine speed and, since the system ecoDriver does not take engine load into account, slopes may be neglected in the verification simulations. The traffic demand is set to only one single vehicle which means there will be no interactions with other vehicles in the simulation.

12.1.2 ITS modeller simulations

The different behaviours using the embedded ecoDriver system are presented in Figure 51 containing speed and acceleration profiles for an unequipped vehicle, 50% compliance and 100% compliance.

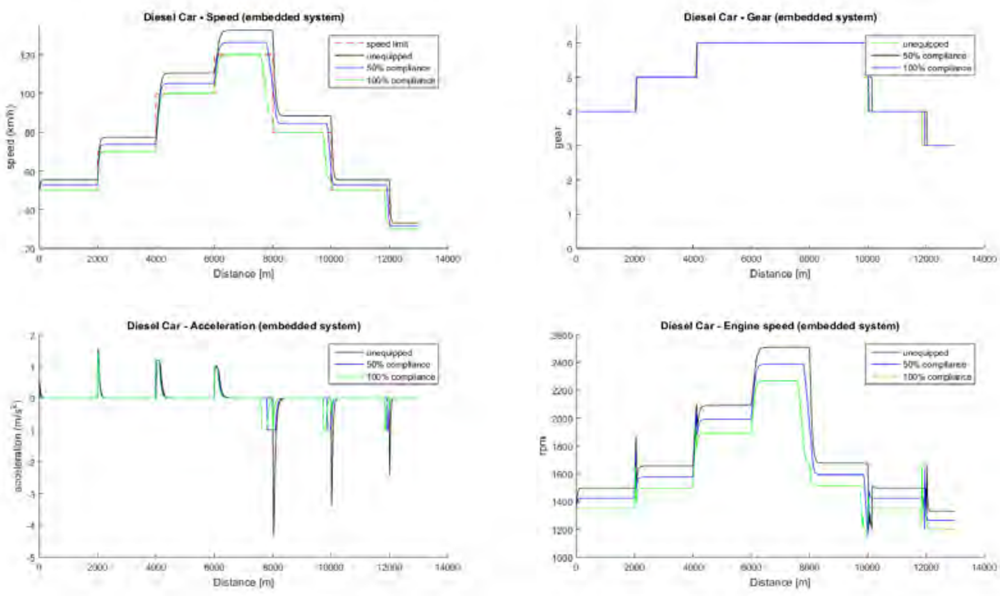


Figure 51: ITS Modeller Simulations of a 0, 50, and 100% compliant driver equipped with the embedded ecoDriver system

As can be observed in Figure 51 the level of compliance towards the embedded ecoDriver system affects desired speed, start of deceleration and the minimum deceleration value. Figure 52 presents the saving that can be made using the embedded ecoDriver system within simulations using the ITS Modeller. Savings are a little bit larger for NO_x than for CO_2 for this specific case.

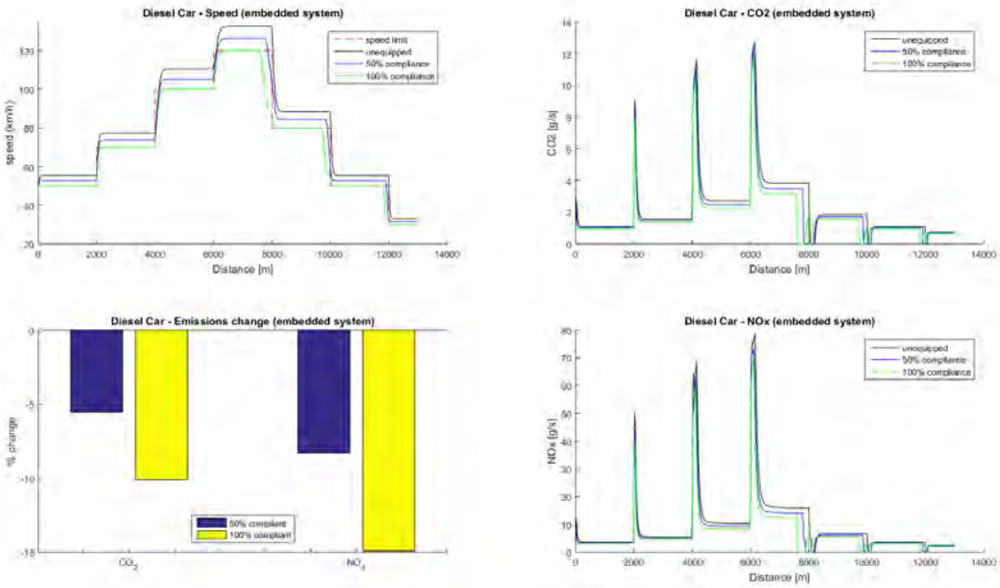


Figure 52: Estimated savings of using the embedded system, using ITS Modeller

In comparison to the advanced embedded system, the Nomadic ecoDriver system only provides the driver with shifting points and when to start anticipation to upcoming lower speed limits. A similar visualisation of the driving behaviour with different compliance levels is presented in Figure 53.

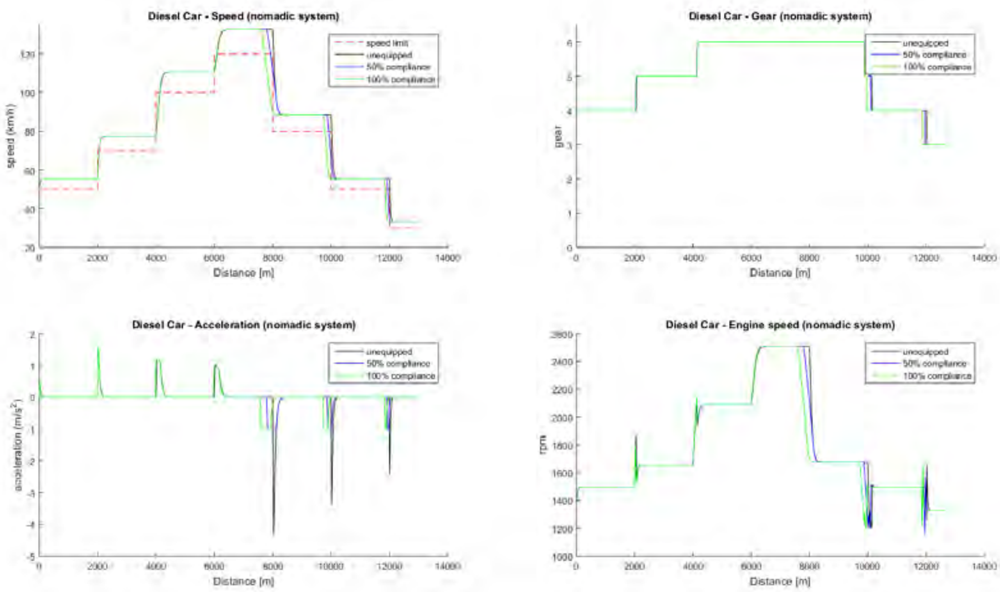


Figure 53: ITS Modeller Simulations of a 0, 50, and 100% compliant driver equipped with the Nomadic ecoDriver system

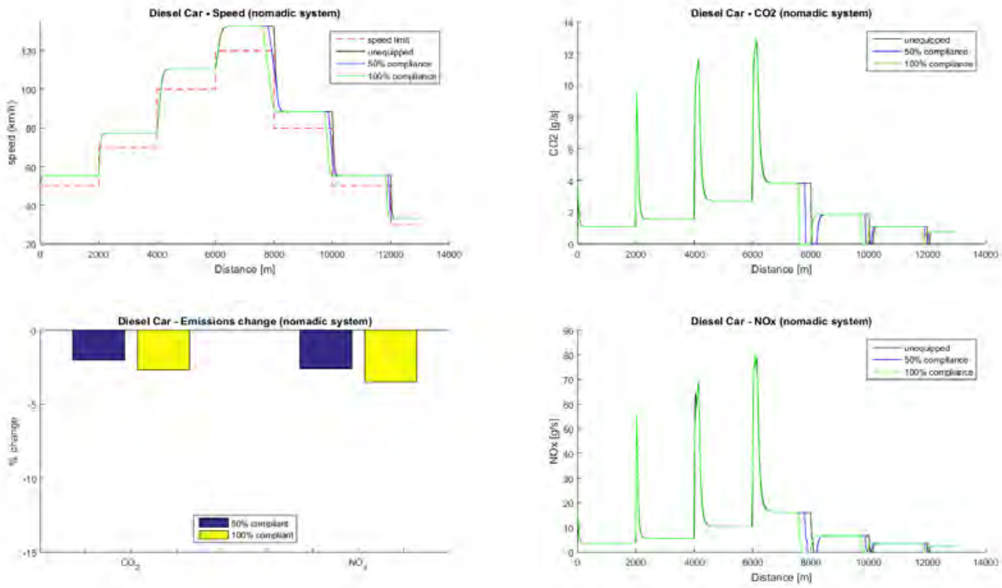


Figure 54: Estimated savings of using the Nomadic system using ITS Modeller

The Nomadic system does not affect the desired speed (see section 2.3.2 and 7.1.3) but there are still substantial potential savings for CO_2 according to Figure 54. The relative change of the CO_2 and NO_x savings has decreased compared with the embedded system. This is probably due to the higher speeds with the nomadic system, since we based this on the field trial analysis (see section 7.1.3) and assumed that users of the nomadic system do not change their desired speed when driving with the system. Apparently NO_x emissions are more correlated with the level of desired speed compared with CO_2 which seems to be more correlated with anticipation of upcoming speed limits and gear shifting points.

12.1.3 RuTSim simulations

A compilation of the different behaviours using the embedded ecoDriver system is presented in Figure 55 containing speed, acceleration, gear and engine speed profiles. It can be seen that the level of compliance towards the embedded ecoDriver system affects desired speed, start of deceleration and gear shifting points.

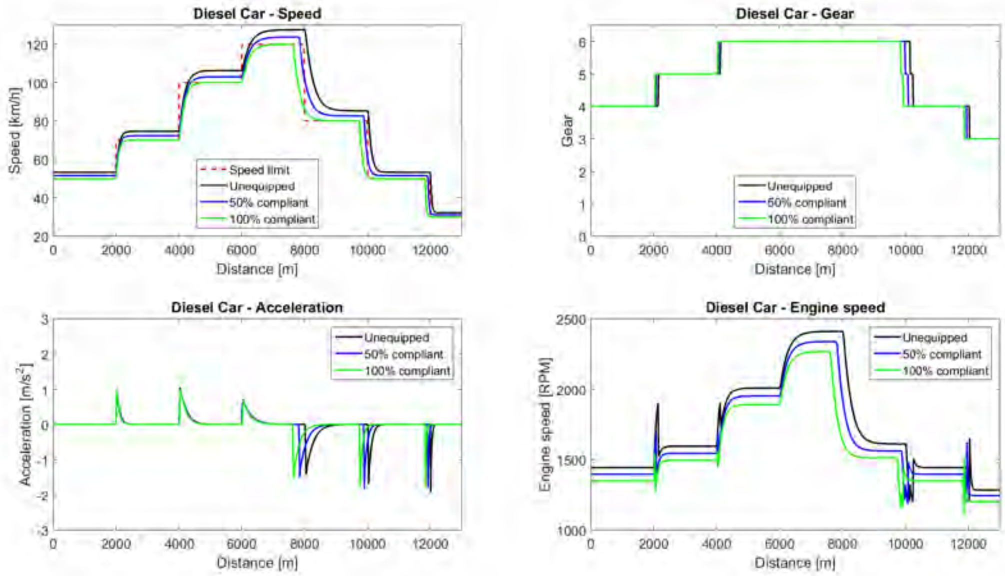


Figure 55: RuTSim Simulations of a 0, 50, and 100% compliant driver equipped with the embedded ecoDriver system

Figure 56 presents the saving that can be made using the embedded ecoDriver system within simulations using RuTSim. The desired acceleration is set to 1 m/s^2 giving no rapid accelerations. Savings are more comprehensive for NO_x than for CO_2 for this specific case, since the Renault Scenic is a diesel car consuming less fuel and polluting more NO_x than a petrol car.

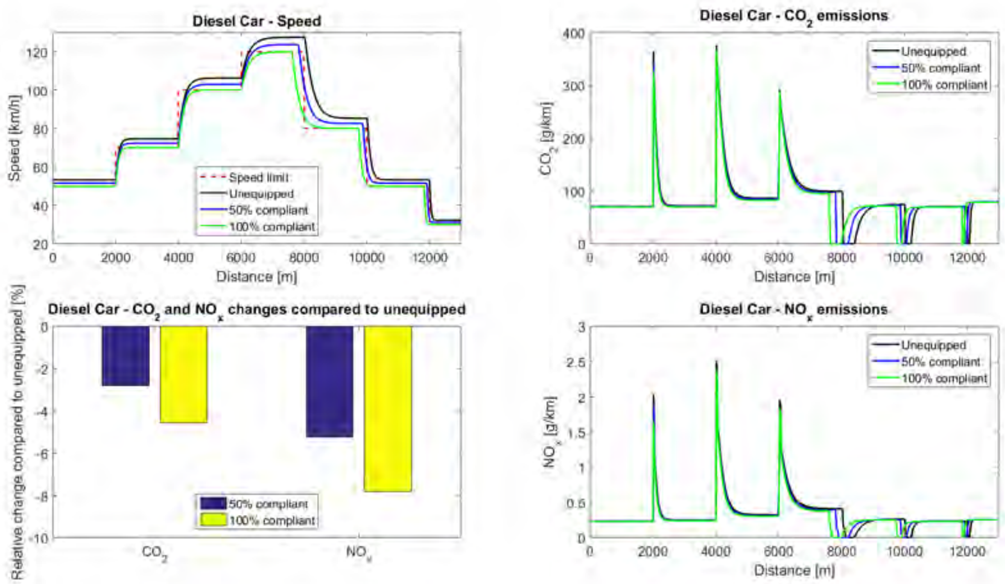


Figure 56: Estimated savings of using the embedded system using RuTSim

As shown in Figure 56, there are significant savings in fuel and emissions due to decrease desired speed, start anticipation to lower speed limits earlier and use lower shifting points. In comparison to the advanced embedded system, the Nomadic ecoDriver system only provides the driver with shifting points and when to start anticipation to upcoming lower speed limits. A similar compilation of the driving behaviour with different compliance levels are presented in Figure 57.

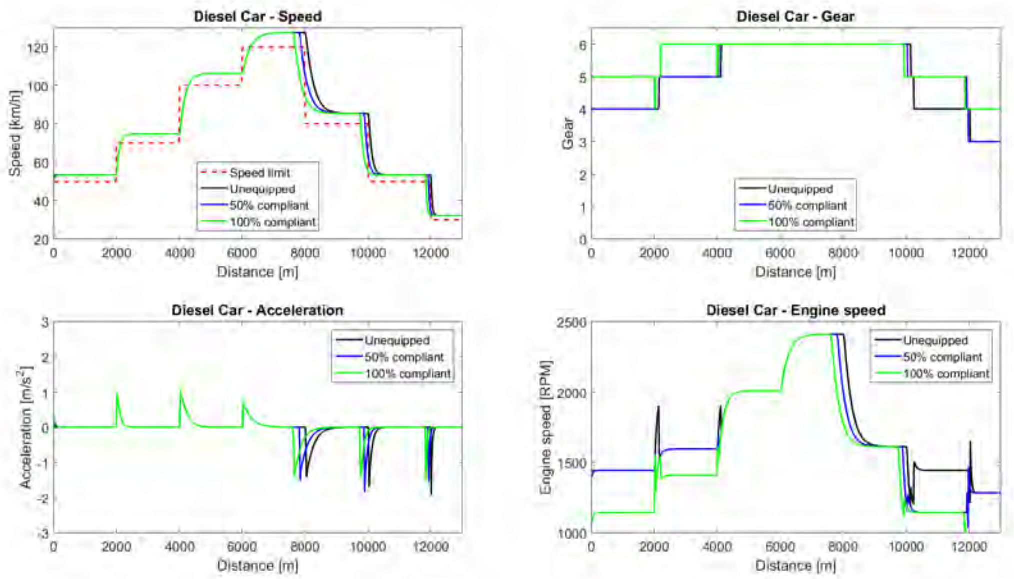


Figure 57: RuTSim Simulations of a 0, 50, and 100% compliant driver equipped with the Nomadic ecoDriver system

The Nomadic system does not affect the desired speed (see section 2.3.2 and 7.1.3) but there are still quite high potential savings according to Figure 58. Notice that the relative change between the saving of CO_2 and NO_x has decreased compared with the embedded system. Apparently NO_x emissions are more correlated with the level of desired speed compared with CO_2 which seems to be more correlated with anticipation of upcoming speed limits and gear shifting points.

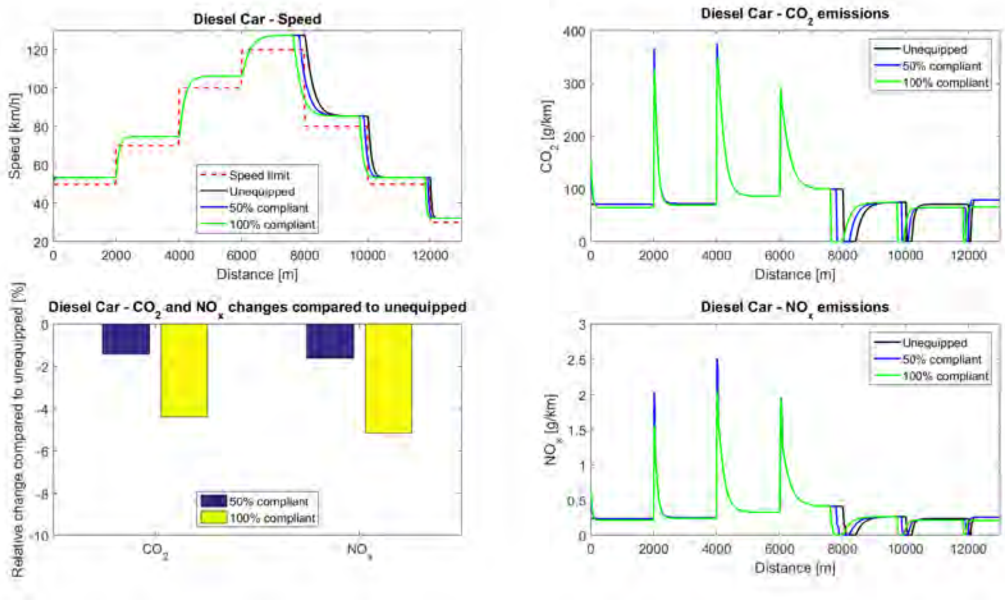


Figure 58: Estimated savings of using the Nomadic system using RuTSim

12.1.4 Aimsun simulations

The different behaviours using the embedded ecoDriver system are presented in Figure 59 containing speed profiles for an unequipped vehicle, 50% compliance and 100% compliance. The results are as expected with the fully compliant driver never exceeding the speed limit. The level of compliance also affects the start of deceleration and the minimum deceleration value.

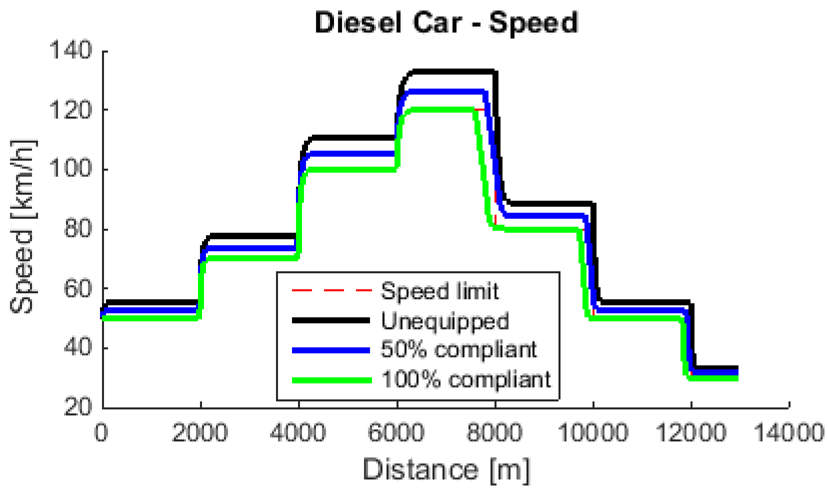


Figure 59: Aimsun Simulations of a 0, 50, and 100% compliant driver equipped with the embedded ecoDriver system

Figure 60 presents the saving that can be made using the embedded ecoDriver system within simulations using the Aimsun. Savings are a little bit larger for CO_2 than compared wtih NO_x for this specific case.

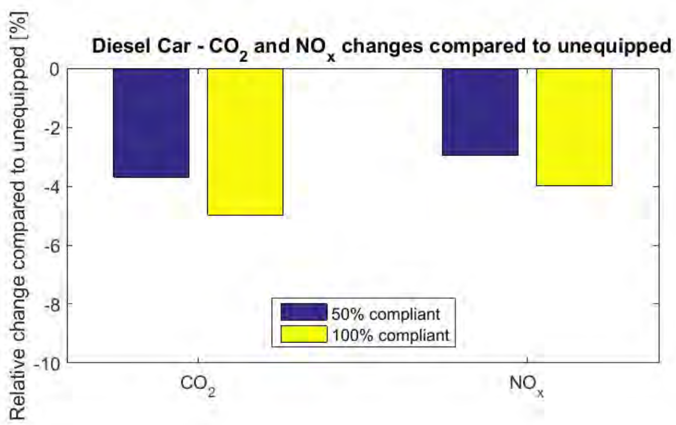


Figure 60: Estimated savings of using the embedded system using Aimsun simulating a 0, 50, and 100% compliant driver

In comparison to the advanced embedded system, the nomadic ecoDriver system only provides the driver with shifting points and when to start anticipation to upcoming lower speed limits. Therefore, as seen in Figure 61, the compliance level have no effect on the desired speed and even the 100% compliant driver in this particular case has a desired speed above the speed limit.

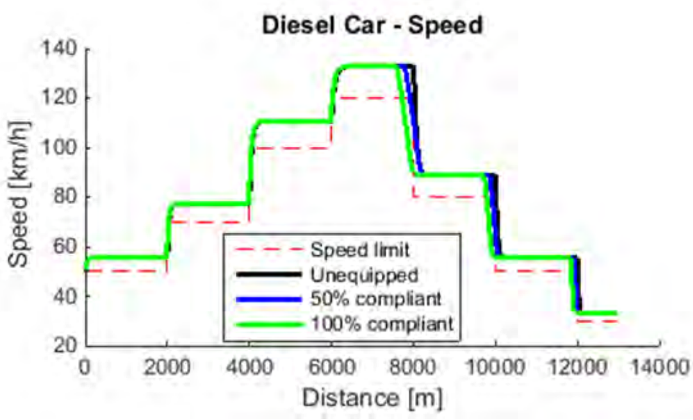


Figure 61: Aimsun Simulations of a 0, 50, and 100% compliant driver equipped with the Nomadic ecoDriver system

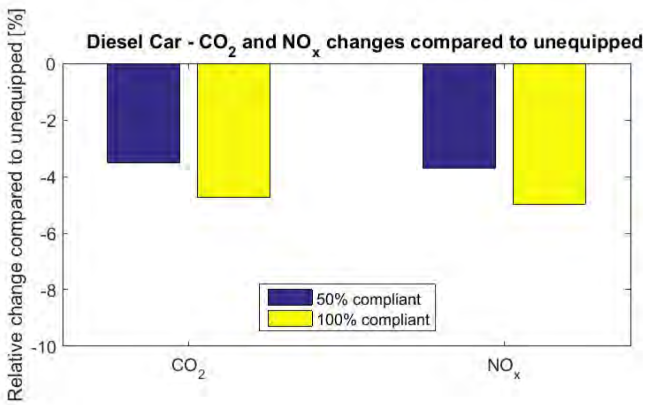


Figure 62: Estimated savings of using the nomadic system using Aimsun simulating a 0, 50, and 100% compliant driver

The nomadic system does not affect the desired speed but there are still substantial potential savings for CO_2 according to Figure 62. The relative change of the CO_2 savings has decreased compared with the embedded system and are almost equal to the NO_x changes.

The verification simulation results show the same trend for all simulators, but differences can be observed. These difference depend on that the simulators have been calibrated for different road environments with totally different speed levels and driving behaviour.

12.2 Verification simulations of the scaling up networks

This section presents results for simulations of all the 10 networks (the 2 motorways, 4 rural roads, and the 4 urban roads) for the common starting point in 2015. The 2015 simulations were used for verification of the simulations and the performance indicators. The network had already been calibrated for the local conditions. However, since adjustments of the traffic mix was required to fit the ecoDriver scenarios an additional verification of the results were needed. For the emission and fuel consumption PIs there were no measurements at the specific modeller road networks available so a verification that the values are within a reasonable range for the different vehicle types and road environments were needed.

12.2.1 Motorway simulations

In Table 24 and Table 25 below, the results for the motorway simulations are given for the 2015 traffic situation with low demand. The mean speeds are in line with the speed limits of the networks (maximum 100 km/h for the urban network and partly 100, partly 130 for the interurban network) and the maximum speeds of the vehicle types. The mean travel times are consistent with the mean speeds. The mean travel time without speeding is a little bit higher, as expected. The standard deviation of the travel time is rather low, as expected for a low demand scenario. For the trucks the standard deviation is much lower than for the other vehicle types, which can be explained because all trucks drive at about the same speed.

Table 24: Travel time (average and standard deviation) and average speed from simulations of the 2015 traffic situation on the simulated motorways with low demand.

Network	Vehicle class	Mean travel time (s/km)	Mean travel time no speeding (s/km)	Stdev travel time (s/km)	Stdev travel time no speeding (s/km)	Mean speed (km/h)
Urban motorway	Car	39.4	39.8	7.9	8.7	91.3
Urban motorway	Van	39.5	39.8	7.7	8.4	91.1
Urban motorway	Truck	42.3	42.4	6.7	7.5	85.1
Interurban motorway	Car	31.7	32.2	7.46	7.88	113.4
Interurban motorway	Van	33.0	33.2	7.15	7.85	109.2
Interurban motorway	Truck	40.9	41.0	3.87	4.35	87.9

In Table 25 below, the results of the emissions, fuel and energy consumption are given. CO_2 emissions are in the range of what can be expected. For Diesel cars, CO_2 emissions, fuel and energy are lower than for petrol cars, as expected. Fuel usage seems rather low compared to average consumption in practice, but for motorways with low demands these are realistic values. The values for the interurban scenarios are a little bit higher than for the urban scenario, which can be explained by the higher speeds and higher speed variations in the interurban scenario. NO_x emissions are in the range of normal values for NO_x for the different vehicle types. For the trucks, they are lower than for the rural road simulations, due to the more constant speeds and more optimal speeds. For the cars and vans, they are a little bit higher than for the rural road simulations, due to the higher average speeds.

Table 25: CO_2 and NO_x emissions and fuel and energy consumption from simulations of the 2015 traffic situation on the simulated motorways.

Network	Vehicle class	Powertrain	CO_2 (g/km)	NO_x (g/km)	Fuel (l/km)	Energy (kJ/km)
Urban motorway	Car	ICE (Diesel)	95.3	0.508	0.036	1.300
Urban motorway	Car	ICE (Petrol)	115.2	0.022	0.049	1.571
Urban motorway	Car	Electric	0.0	0.0	0.0	0.651
Interurban motorway	Car	ICE (Diesel)	102.5	0.513	0.039	1.398
Interurban motorway	Car	ICE (Petrol)	123.2	0.022	0.052	1.680
Interurban motorway	Car	Electric	0.0	0.0	0.0	0.915
Urban motorway	Van	ICE (Diesel)	217.0	1.52	0.082	2.960
Interurban motorway	Van	ICE (Diesel)	240.9	1.91	0.091	3.287
Interurban motorway	Truck	ICE (Diesel)	687.5	3.04	0.260	9.379
Urban motorway	Truck	ICE (Diesel)	690.2	3.19	0.260	9.416

12.2.2 Rural road simulations

Table 26 presents the average travel time (actual and corrected for speeding) and the corresponding standard deviation for the rural roads. The table also presents the average speed used as input to the safety assessment. The main part of the simulated rural network has a speed limit of 90 km/h with some local speed limits at 70 km/h. A travel speed of 90 km/h correspond to a travel time of 40 s/km.

Table 26: Travel time and average speed from simulations of the 2015 traffic situation with low demand on the simulated rural roads.

Network	**Vehicle class**	**Mean travel time (s/km)**	**Mean travel time no speeding (s/km)**	**Stdev travel time (s/km)**	**Stdev travel time no speeding (s/km)**	**Mean speed (km/h)**
Flat high intersection	Car	37.4	41.0	0.94	0.60	96.2
Flat high intersection	Van	37.7	41.1	0.29	0.06	95.4
Flat high intersection	Truck	43.7	45.9	0.46	0.10	82.3
Flat low intersection	Car	36.9	40.4	0.93	0.61	97.5
Flat low intersection	Van	37.3	40.4	0.30	0.06	96.4
Flat low intersection	Truck	43.4	45.5	0.43	0.09	82.9
Hilly high intersection	Car	37.4	41.0	0.90	0.59	96.3
Hilly high intersection	Van	37.6	41.0	0.33	0.09	95.7
Hilly high intersection	Truck	43.9	46.0	0.41	0.10	82.0
Hilly low intersection	Car	36.9	40.4	0.90	0.60	97.5
Hilly low intersection	Van	37.2	40.4	0.34	0.09	96.8
Hilly low intersection	Truck	43.6	45.6	0.45	0.10	82.5

Table 27 presents emissions, fuel and energy consumption for the rural roads. The average emissions are quite low compared with motorway and urban estimations which is natural since the majority of rural road driving consists of cruising. The potential number of overtakings is also decreased compared with motorway driving and the average engine speeds are assumed to be lower at rural roads compared with both motorway and urban driving. The average fuel consumption is way below the current numbers and may be explained by the future projections requiring more effective combustion and energy extraction. Since the emission model needs to be representative also for future years, it has been adapted for Euro VI vehicles.

Table 27: CO_2 and NO_x emissions and fuel and energy consumption from simulations of the 2015 traffic situation with low demand on the simulated rural roads.

Network	Vehicle class	Powertrain	CO_2 (g/km)	NO_x (g/km)	Fuel (l/km)	Energy (kJ/km)
Flat high intersection	Car	ICE (Diesel)	82.5	324.4	0.031	1.13
Flat high intersection	Car	ICE (Petrol)	103.4	14.8	0.044	1.41
Flat high intersection	Car	Electric	0.0	0.0	0.000	0.72
Flat low intersection	Car	ICE (Diesel)	81.6	314.7	0.031	1.11
Flat low intersection	Car	ICE (Petrol)	106.4	16.3	0.045	1.45
Flat low intersection	Car	Electric	0.0	0.0	0.000	0.73
Hilly high intersection	Car	ICE (Diesel)	87.6	376.3	0.033	1.19
Hilly high intersection	Car	ICE (Petrol)	105.5	15.8	0.044	1.44
Hilly high intersection	Car	Electric	0.0	0.0	0.000	0.72
Hilly low intersection	Car	ICE (Diesel)	86.3	363.7	0.033	1.18
Hilly low intersection	Car	ICE (Petrol)	105.5	15.8	0.044	1.44
Hilly low intersection	Car	Electric	0.0	0.0	0.000	0.73
Flat high intersection	Van	ICE (Diesel)	213.7	1473.6	0.081	2.92
Flat low intersection	Van	ICE (Diesel)	214.2	1471.2	0.081	2.92
Hilly high intersection	Van	ICE (Diesel)	216.1	1553.0	0.082	2.95
Hilly low intersection	Van	ICE (Diesel)	216.7	1549.4	0.082	2.96
Flat high intersection	Truck	ICE (Diesel)	948.5	4811.6	0.358	12.94
Flat low intersection	Truck	ICE (Diesel)	945,1	4764,2	0,357	12,89
Hilly high intersection	Truck	ICE (Diesel)	983,7	4462,6	0,371	13,42
Hilly low intersection	Truck	ICE (Diesel)	979,2	4436,6	0,370	13,36

12.2.3 Urban road simulations

Table 28 presents the average travel time (actual and corrected for speeding) and the corresponding standard deviation for the urban spacious roads (flat). The table also presents the average speed used as input to the safety assessment. The main part of the simulated rural network has a speed limit of 60 km/h with some local speed limits (in the side roads) at 48 km/h. A travel speed of 60 km/h corresponds to a travel time of 60 s/km. It may be noted that in the urban scenarios, the signalised intersections have a significant impact on the total travel time. For this reason, though the mean speed (measured within the sections) is quite close to the speed limit, the mean travel times are much higher compared to the travel times corresponding to the speed limit. It may be also noted that the signalised intersections also result very high standard deviations in travel time. The results for the Flat and Hilly networks are found to be quite similar.

Table 28: Travel time and average speed from simulations of the 2015 traffic situation with low demand on the simulated urban roads.

Network	Vehicle class	Mean travel time (s/km)	Mean travel time no speeding (s/km)	Stdev travel time (s/km)	Stdev travel time no speeding (s/km)	Mean speed (km/h)
Flat and spacious	Car	117.7641	124.6817	1.643618	1.698707	59.47317
Flat and spacious	Van	126.3166	128.7853	5.042917	4.996551	56.27315
Flat and spacious	Truck	142.4731	142.6329	23.75974	23.80665	51.76796
Hilly and spacious	Car	117.9753	124.836	1.591986	1.656589	59.41232
Hilly and spacious	Van	126.7893	129.163	5.186663	5.139365	56.0891
Hilly and spacious	Truck	142.9753	143.1279	23.53157	23.57183	51.66941

Table 29 presents emissions, fuel and energy consumption for the urban roads. The average emissions are much higher compared with motorway and rural estimations which is natural given the larger occurrences of acceleration-decelerations at the intersections. This results in very high levels of NO_x in particular. Since the emission model needs to be representative also for future years, it has been adapted for Euro VI vehicles.

Table 29: CO_2 and NO_x emissions and fuel and energy consumption from simulations of the 2015 traffic situation with low demand on the simulated urban roads.

Network	Vehicle class	Powertrain	CO_2 (g/km)	NO_x (g/km)	Fuel (l/km)	Energy (kJ/km)
Flat and spacious	Car	ICE (Diesel)	131.5233	2.777026	0.049633	1794.315
Flat and spacious	Car	ICE (Petrol)	144.5112	0.101186	0.060974	1971.504
Flat and spacious	Van	ICE (Diesel)	221.6417	2.329173	0.083641	3023.762
Flat and spacious	Truck	ICE (Diesel)	779.7421	7.829103	0.29424	10637.68
Hilly and spacious	Car	ICE (Diesel)	127.6342	2.663207	0.048165	1741.258
Hilly and spacious	Car	ICE (Petrol)	139.6294	0.097073	0.058914	1904.903
Hilly and spacious	Van	ICE (Diesel)	207.74	2.218777	0.078395	2834.106
Hilly and spacious	Truck	ICE (Diesel)	853.947	7.290488	0.32224	11650.03

It may be noted that the final simulations include 2 additional case studies (Flat and compact, Hilly and compact), but formal verification runs have not been done on these networks.

13. Statistical considerations

This chapter describes the statistical considerations that need to be taken into account when setting-up, running and analysing results using a stochastic traffic simulation model. The first aspect is the need for a warming-up and cooling down period, the second is the number of replications required to achieve a desirable level of confidence, and the third is the need for hypothesis testing of the differences in the PIs between the 'with ecoDriver' and 'without ecoDriver' cases.

13.1 Warming up and cooling down period

At the start of a simulation, the network is empty. This means that the first vehicles to enter the network are driving on an empty road. This situation is not representative for the scenario. Hence, a warming-up period at the start of the simulation is excluded from the output. The length of the warming up period can be calculated as the longest distance in the network divided by the average speed of the slowest vehicle. The latter can be set to the lowest desired speed, or it can be measured from a test run. Alternatively, the warming up period can be measured directly from a test run, for example from the latest arrival time of all vehicles departing in the first N minutes, where N is for example equal to 5.

For travel time and delay calculations, one also needs to consider a "cooling down" period at the end of the simulation. Indeed, at the end of the simulation there are still vehicles present in the network. Their travel time is not known because they have not finished their journey. Simply excluding those vehicles from the travel time and delay estimates may lead to a wrong impact estimate. This is illustrated for a hypothetical example in Figure 63. Without a cooling down period, all trajectories except that indicated with a cross will be taken into account for calculating travel times and delays. This means that slower vehicles will not be taken into account. In this particular example, the effect of the system is to increase the spread in travel times, but without considering a cooling down period it may seem that the effect is to decrease travel time. With a cooling down period, only the solid trajectories will be considered and the correct effect is estimated.

The length of the cooling down period can be calculated as the longest distance in the network divided by the average speed of the slowest vehicle, so according to the same principle as the length of the warming up period. As the network is now filled, the average speed of slowest vehicle might be lower than the lowest desired speed. Alternatively, the cooling down period can be measured directly from a test run, for example from the earliest departure time of all vehicles arriving in the last N minutes, where N is for example equal to 5. In case of (heavy) congestion the length of the cooling down period may be hard to determine because the average speed of the slowest vehicle will depend on the traffic state it encounters, and this traffic state may be changing significantly over time.

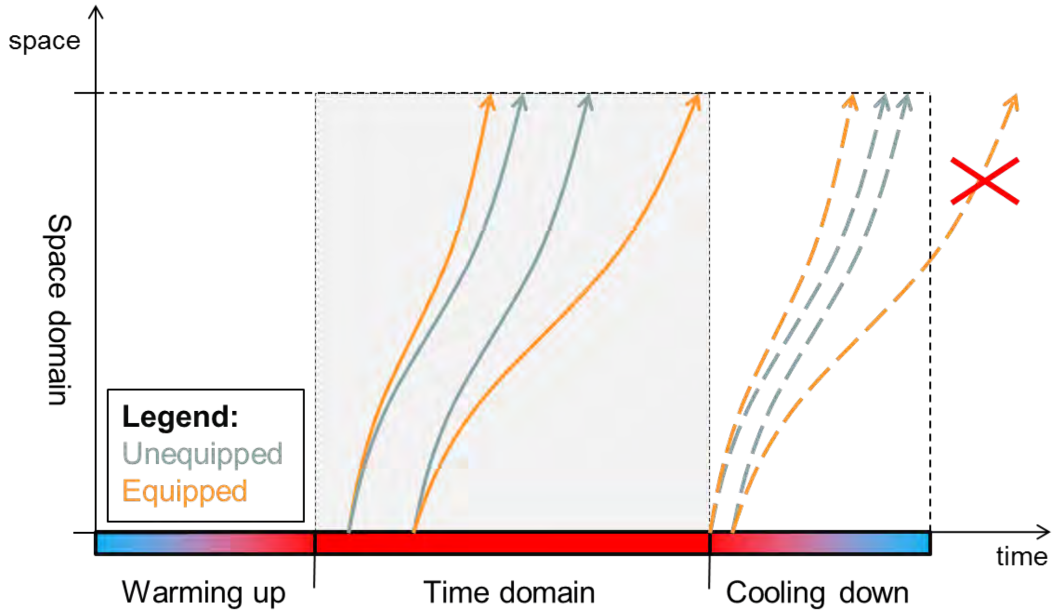


Figure 63: Illustration of warming up and cooling down period

13.2 Number of replications

Estimation of required number of replications n has been calculated as (see e.g. Burghout (2004))

$$n = \left(\frac{s \cdot t_{n-1}(\alpha/2)}{\bar{x} \cdot \epsilon}\right)^2$$

where s is the standard deviation for the investigated performance indicator (PI), $\bar{x}$ is the mean for the investigated PI, ϵ is accepted error rate in terms of percent of the mean value and $t_{n-1}(\alpha/2)$ is the value from a student t-distribution for the confidence level $\alpha/2$. The standard deviation s and the mean $\bar{x}$ are unknown but can be estimated by running a set of simulations (e.g. 4-6). The number of replications required and the actual number of replications conducted for each network is presented in Table 30.

Table 30: Number of replications conducted and minimum number of replications required for the 10 different networks

Network	Demand level	Number of replications conducted for each simulation case	Minimum required number of replications for each simulation case
Urban motorway	Low	5	1
Urban motorway	Moderate	5	1
Interurban motorway	Low	5	1
Interurban motorway	Moderate	5	1
Flat rural road with low intersection density	Low	10	2
Flat rural road with low intersection density	Moderate	10	1
Flat rural road with high intersection density	Low	10	2
Flat rural road with high intersection density	Moderate	10	1
Hilly rural road with low intersection density	Low	10	2
Hilly rural road with low intersection density	Moderate	10	1
Hilly rural road with high intersection density	Low	10	2
Hilly rural road with high intersection density	Moderate	10	1
Flat urban roads in a spacious city	Low	10	4
Flat urban roads in a spacious city	Moderate	10	4
Flat urban roads in a compact city	Low	10	4
Flat urban roads in a compact city	Moderate	10	4
Hilly urban roads in a spacious city	Low	10	4
Hilly urban roads in a spacious city	Moderate	10	4
Hilly urban roads in a compact city	Low	10	4
Hilly urban roads in a compact city	Moderate	10	4

13.3 Statistical hypothesis testing

Statistical hypothesis testing were applied to test if there is a statistical significant difference in the PI between the with-ecoDriver and without-ecoDriver cases. The PIs (which are aggregated measures as average travel time, average CO_2, etc.) were approximately normal distributed and a between subject two sided t-test were conducted for each with and without comparison. The null-hypothesis were that there are no difference and the alternative hypothesis there is a difference, i.e.:

$$H_0: \mu_{with} - \mu_{without} = 0$$
$$H_a: \mu_{with} - \mu_{without} \neq 0$$

where μ_{with} and $\mu_{without}$ is the average PI values over all replications in the with and without ecoDriver cases , respectively. For example, μ_{with} could be the average CO_2 for cars on an urban motorway with low demand in the Green future scenario in 2035 if the ecoDriver system(s) where introduced and $\mu_{without}$ would then be the average CO_2 for cars on an urban motorway with low demand in the Green future scenario in 2035 in the case that the ecoDriver system(s) where not introduced. The null hypothesis is rejected if

$$t^* > t_{n_x+n_y-2}(\alpha/2)$$

where $t_{n_{with}+n_{without}-2}(\alpha/2)$ is the value from the student t-distribution for the confidence level α with $n_{with} + n_{without} - 2$ degrees of freedom and where t^* is calculated as

$$t^* = \frac{(\bar{x} - \bar{y}) - \Delta\mu}{\sqrt{\frac{s_p^2}{n_{with}} + \frac{s_p^2}{n_{without}}}}, \tag{30}$$

where s_p^2 is the pooled variance calculated as

$$s_p^2 = \frac{(n_{with} - 1) \cdot s_{with}^2 + (n_{without} - 1) \cdot s_{without}^2}{n_{with} + n_{wihtout} - 2}, \tag{31}$$

where s_{with}^2 and $s_{without}^2$ is the variance for the with and without ecoDriver case respectively.

14. Simulations results and analysis

This chapter covers results from the traffic simulation performed at motorways, rural and urban roads. Due to the main focus of the project, CO_2 is presented for each combination simulation. Other performance indicators are only presented for the year 2035 since that is the year with most comprehensive impact.

Output indicators for the different vehicle types (with and without ecoDriver, nomadic/embedded, diesel/petrol/electric) were aggregated into three basic types of different size: car, van and truck. This was done by using the original shares of the vehicle mix as presented in Annex A. The absolute values of the indicators were calculated as the average of the simulation runs for different random seeds (for the motorway simulations, 5 different seeds were used, as presented in Table 30). Next, for each scenario, the percentage change of the average output indicators of the scenario with ecoDriver compared to the scenario without ecoDriver, was calculated. Furthermore, the safety indicators were derived based on the change in average speeds for each vehicle type. Finally, the t-test (two-sided, 5%) was performed to test if results were significant. If not, the effect was considered non-significant and hence put to zero. The average percentage of significant results of the motorway simulations is 75%.

14.1 Expected results from the simulation

This chapter contains all results from the simulations performed using the different ecoDriver system within the project. The results are evaluated based on the performance indicators stated below. A short description of expected results according to the functionality of the ecoDriver system and how it affects driving behaviour is given for each indicator.

- **CO_2 emissions**
  Are assumed to be correlated with speed. The ecoDriver systems aim to reduce the cruising speed towards the speed limit which should imply a decrease in CO_2. The use of lower shifting points should also induce decreased CO_2 emissions together with earlier anticipation towards upcoming lower speed limits. Electric vehicles are assumed to have no CO_2 emissions. Diesel cars are assumed to have significantly lower CO_2 emissions compared with petrol cars. Vans are expected to have higher emissions than cars, and trucks are expected to have the highest emissions of all vehicle classes. The Embedded system is expected to have more comprehensive savings than the Nomadic system and increased compliance and penetration rates should result in major savings. Trucks and vans may have higher savings due to higher compliance for professional drivers. The degree of saturation will also affect the emissions and higher traffic demand is expected to give more interactions causing less time in free driving mode. Potential savings of the ecoDriver systems is assumed to be lower at low traffic demand levels since most of the advice is related to free driving mode.

- **Fuel consumption**

Fuel consumption is derived from CO_2 which implies almost full correlation. Some deviations in savings between CO_2 and fuel consumption may occur since different powertrains pollutes different volumes of CO_2. Electric vehicles are assumed to have no fuel consumption.

- **Energy consumption**

Is derived from CO_2 for vehicles using fossil fuel, implying almost full correlation between CO_2 and energy consumption. Energy consumption is estimated for electric vehicles and is expected to be significantly lower compared with other powertrains. This may cause some deviations in total savings compared with CO_2.

- **NO_x emissions**

The NO_x emissions are assumed to be correlated with speed to some extent even if the relation is further more complex than for CO_2, especially for trucks. Lower speeds should imply lower pollutions of NO_x and diesel cars are expected to have significantly higher pollution levels than petrol cars. Vans are expected to have larger emissions than cars, and trucks are expected to be the most polluting vehicle class. The Embedded system is expected to have more comprehensive savings than the Nomadic system and increased compliance and penetration rates should result in major savings. Trucks and vans may have higher savings due to the higher expected higher compliance for professional drivers. Increased traffic demand is expected to decrease the potential savings.

- **Travel time**

Increased travel time is expected for all vehicle classes due to decreased average speed. The relative change should be less for trucks due to a generally lower travelling speed in comparison to other vehicle classes. The Embedded system is expected to cause longer travel times than the Nomadic system, especially for the cases with increased compliance and penetration. Trucks and vans may have most comprehensive increases due to the higher expected compliance for professional drivers.

- **Travel time corrected for speeding**

Recalculating travel time excluding speeding will cause less increase in travel time for all vehicles. The overall effect is assumed to be similar as for travel time, but the effect is expected to be significantly lower when excluding speeding. Increased traffic demand is expected to decrease the potential savings.

- **Fatal crashes/fatal injuries**

Is derived from average speed which is assumed to decrease when compliance and penetration rates increases. Trucks and vans may have larger savings due to the expectation of higher compliance for professional drivers. Increased traffic demand is expected to decrease the potential savings.

The anticipated benefits can also be expected to vary across the road types depending on the traffic conditions, driving behaviour, speed levels, speed limit variations, traffic mix, etc. For instance, in the urban scenarios, the possibility to freely choose the speed is limited and variations and acceleration and decelerations may be caused primarily by intersections and traffic signals. Furthermore, gear shifting and effects on gear advice can be expected to be smallest in the motorway scenarios since motorway driving is commonly done using the highest gear. The limited overtaking possibilities on rural roads often create platoons which may on one hand limit the possibility for vehicles constrained in the platoon to follow eco-driving advice, on the other hand an eco driving platoon leader may inforce eco-driving behaviour on the followers.

14.2 Motorway results

In Table 31, the percentage of significant results per network type per indicator is given. The full results are presented in Annex I, where a zero either indicates an effect of 0% or a non-significant effect.

Table 31: Percentage of statistically significant results (two-sided t-test at 5%) per motorway network type and per performance indicator

	CO_2	NO_x	fuel	energy	Travel time	Travel time no speeding	speed	All
Urban motorway Low demand	92%	89%	92%	92%	72%	67%	72%	82%
Urban motorway Moderate demand	83%	83%	83%	83%	75%	81%	75%	81%
Interurban motorway Low demand	58%	58%	67%	56%	75%	67%	75%	65%
Interurban motorway Moderate demand	83%	92%	89%	81%	58%	53%	58%	73%

The results of the changes for all indicators for the different motorway scenarios is shown in Table 67 - Table 70 in Annex I. For CO_2, the results are also graphically shown in Figure 64 - Figure 66.

Expected CO_2 effects from the network characteristics would be small savings in the CF scenario for the cars and vans due to the speed reduction for speeding vehicles, depending on compliance and penetration rate, which become larger for later years and for the PF and GF scenario successively. Larger savings are expected for trucks, since speed reduction for trucks (on motorways) will have a larger effect on fuel consumption and emissions than for cars generally. Additional savings are expected in the interurban scenario, where the speed limit is higher and where there is a speed limit change from 120 km/h to 80 km/h, which will be anticipated by the ecoDriver system.

Most of these effects are observed in the simulation results. The effects are largest for the GF scenarios, for the year 2035 and for trucks, as expected. In some cases, for the year 2030 there are larger effects than for the year 2035, especially for the cars. However, the interurban scenario shows smaller positive effects than the urban scenario, which was not directly foreseen. CO_2 is decreasing for almost all cases, except for some cases of the interurban scenario. The explanation for this increase and for the smaller effects of the interurban scenarios and the year 2035 is that the ecoDriver system may disturb the normal driving behaviour of the vehicles without ecoDriver, especially for higher speed limits and moderate traffic demand levels. When the ecoDriver vehicles have a lower speed than the desired speed of the normal driver, this may lead into more dynamic driving behaviour of the drivers without an ecoDriver system, such as decelerating for the ecoDriver equipped vehicles with lower speed and accelerating for overtaking manoeuvres (to overtake e.g. the ecoDriver equipped vehicles). This effect was investigated by looking at the (average) deceleration and acceleration of the vehicles and indeed it was found that in the mixed scenarios (with ecoDriver) the normal vehicles showed more dynamic driving behaviour than in the scenarios without ecoDriver.

The CO_2 decrease might seem smaller than expected generally, but this is expected from the way the systems were modelled: for passenger cars, there is only a small effect since only drivers that have an intended speed larger than the speed limit and who have the embedded system, will have an effect on their chosen speed. This considers only a small part of all drivers in the simulation. Further, anticipating on a lower speed limit by decreasing earlier, has only a very small effect on emissions, since the duration travelling with high speed is diminished with a very short time compared to the total travel time. In the motorway simulations, this only happens on the A67 driving from east to west when the speed limit is changed from 130 to 100.

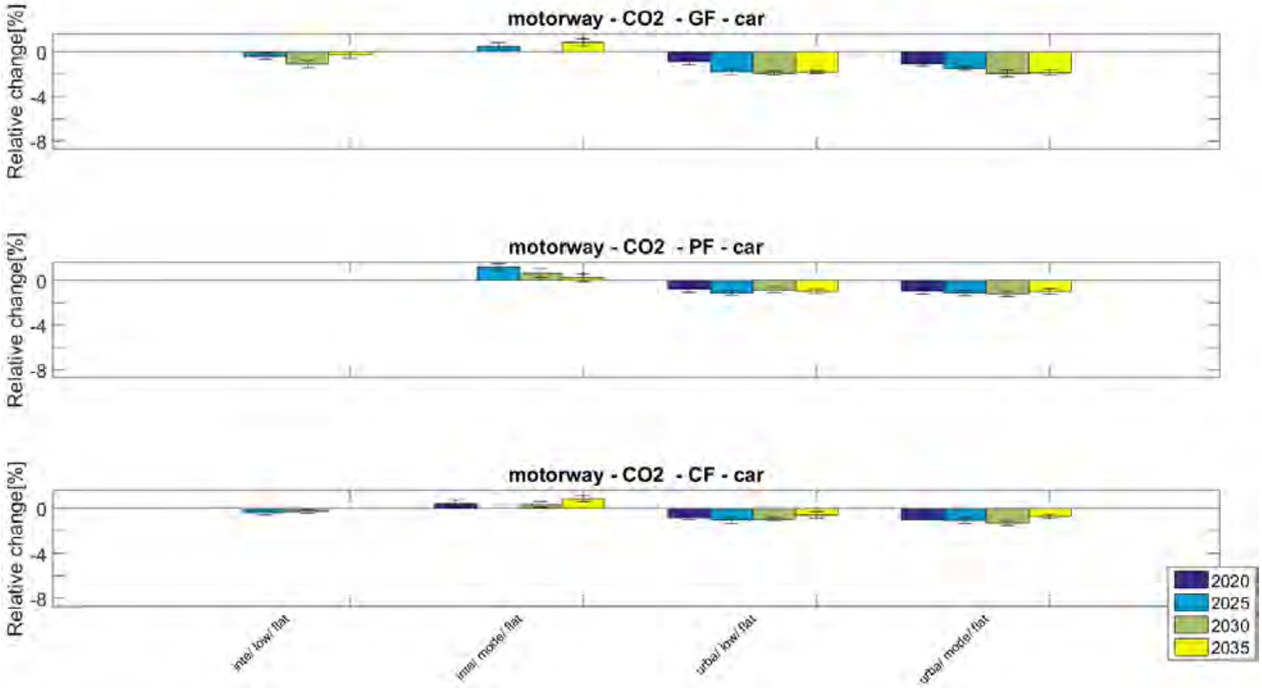


Figure 64: Relative change of CO_2 for cars simulated in different scenarios, motorways, years and traffic demands.

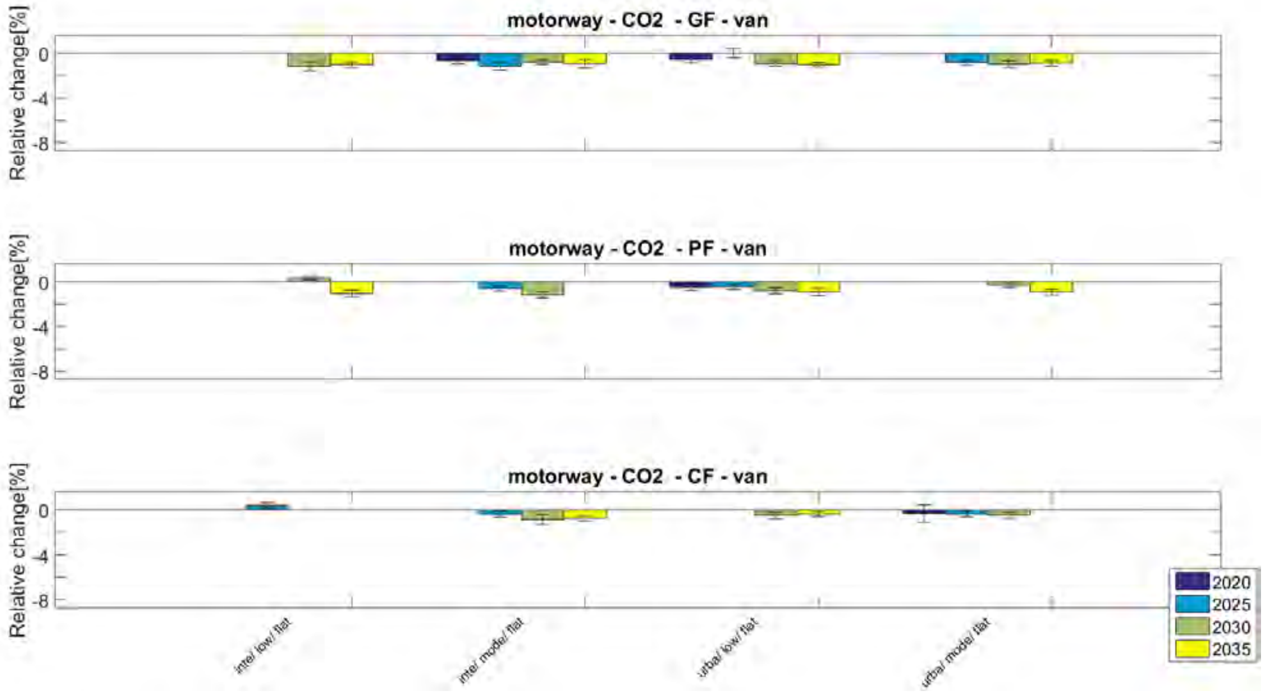


Figure 65: Relative change of CO_2 for vans simulated in different scenarios, motorways, years and traffic demands.

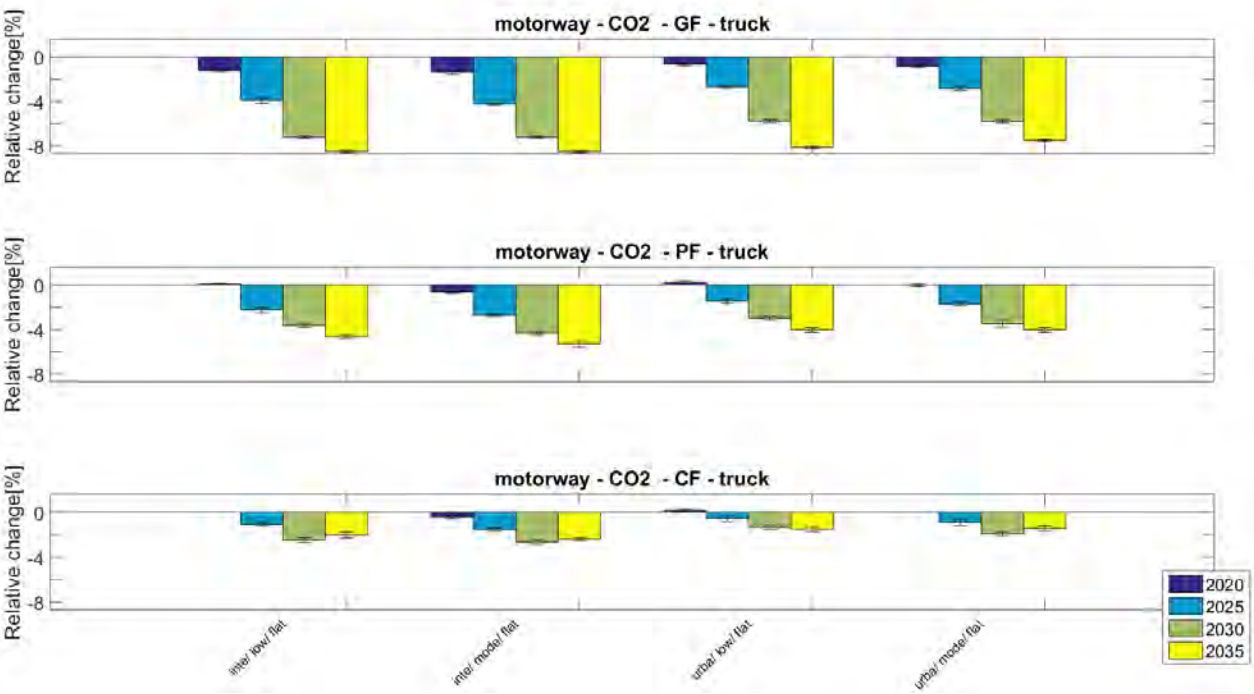


Figure 66: Relative change of CO_2 for trucks simulated in different scenarios, motorways, years and traffic demands.

For trucks, the effects are more consistent and larger, as can be seen in Figure 66. The CO_2 decrease for cars is in the range of 0.6% to 1.9%, as can be seen in the appendix (Table 67 - Table 70). For trucks, the savings are larger, up to 8.1%. Savings for fuel and energy are comparable. The largest effects are the NO_x emissions of trucks; these go up to an increase of 33.6%. This can be explained because NO_x emissions are less dependent of speed dynamics and more on the speed level. The engine of trucks is optimised for a certain speed, which is probably more around 90 km/h than around 80 km/h. Furthermore, the reliability of the NO_x model for high, rather constant speeds as in the motorway simulations, is low, since there were few measurements from real world data available to validate the model. This is a point for improvement for future research.

Travel times are mostly increasing, especially for trucks, however, sometimes there is a very small decrease in the travel times for cars and vans. This can probably be attributed to stochastic variations.

Looking at an overview of the effects for all indicators in Figure 67-Figure 69, it is striking that (besides the effect of NO_x) there is especially a large substantial reduction of fatalities in the GF scenario. This is due to the speed reduction. Besides reducing CO_2, the system hence has a positive safety effect (when the compliance rate of the system is high as in the GF scenario). In the PF scenario, this effect is not apparent, and in the CF scenario there is even an increase of fatalities on the urban motorway.

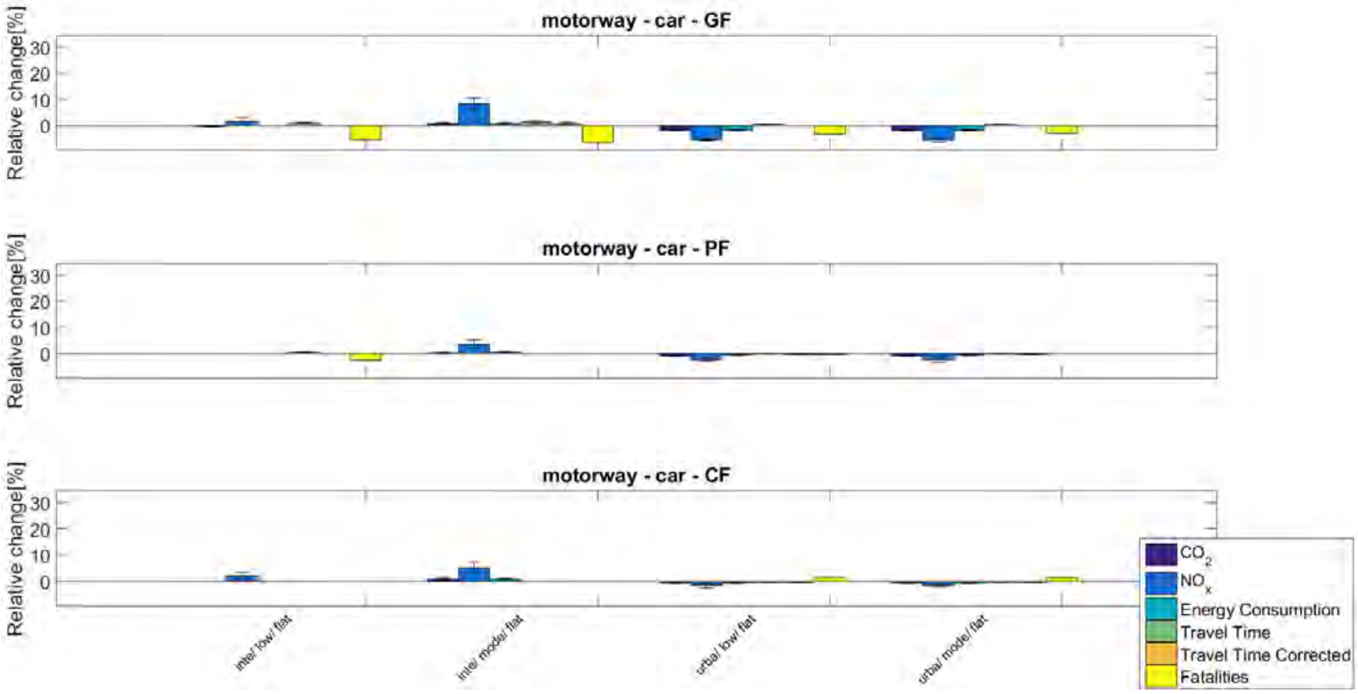


Figure 67: Relative changes of CO_2, NO_x, Energy consumption, Travel time, travel time corrected for speeding and Fatalities for cars simulated at 2035 using different scenarios, motorways and traffic demand

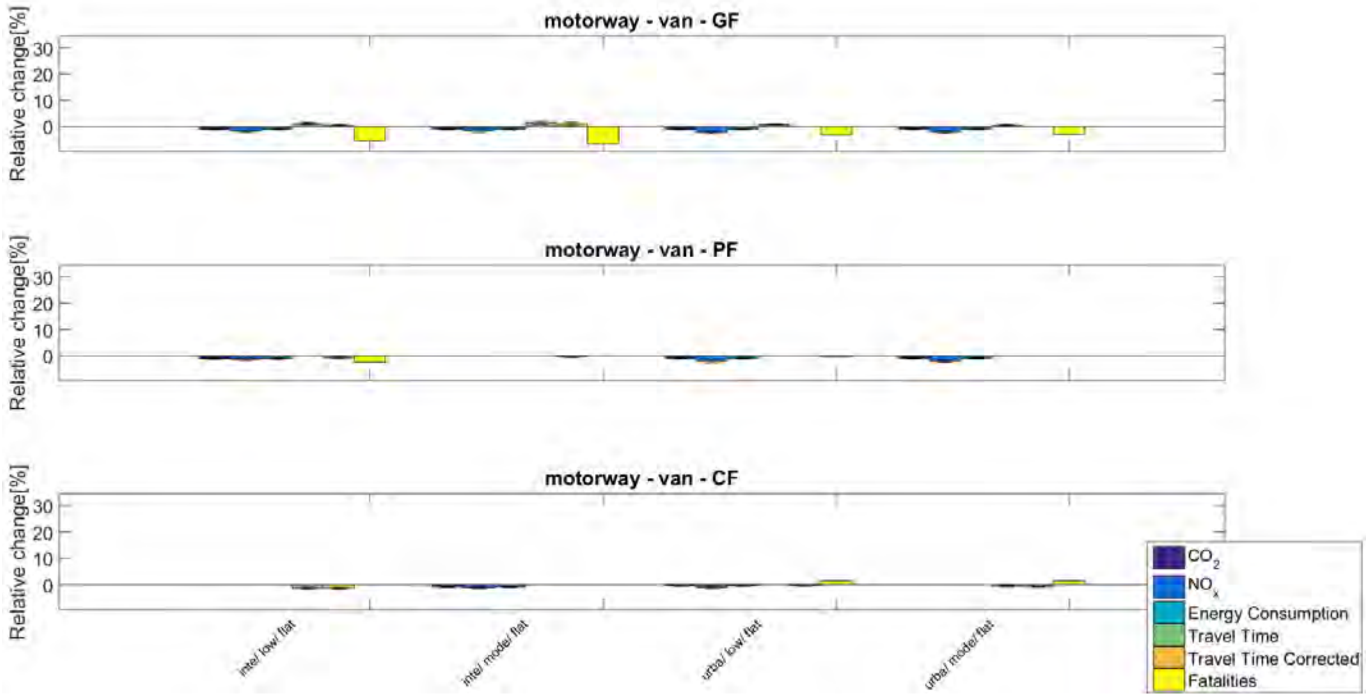


Figure 68: Relative changes and error bars of CO_2, NO_x, Energy consumption, Travel time, travel time corrected for speeding and Fatalities for vans simulated at 2035 using different scenarios, motorways and traffic demand.

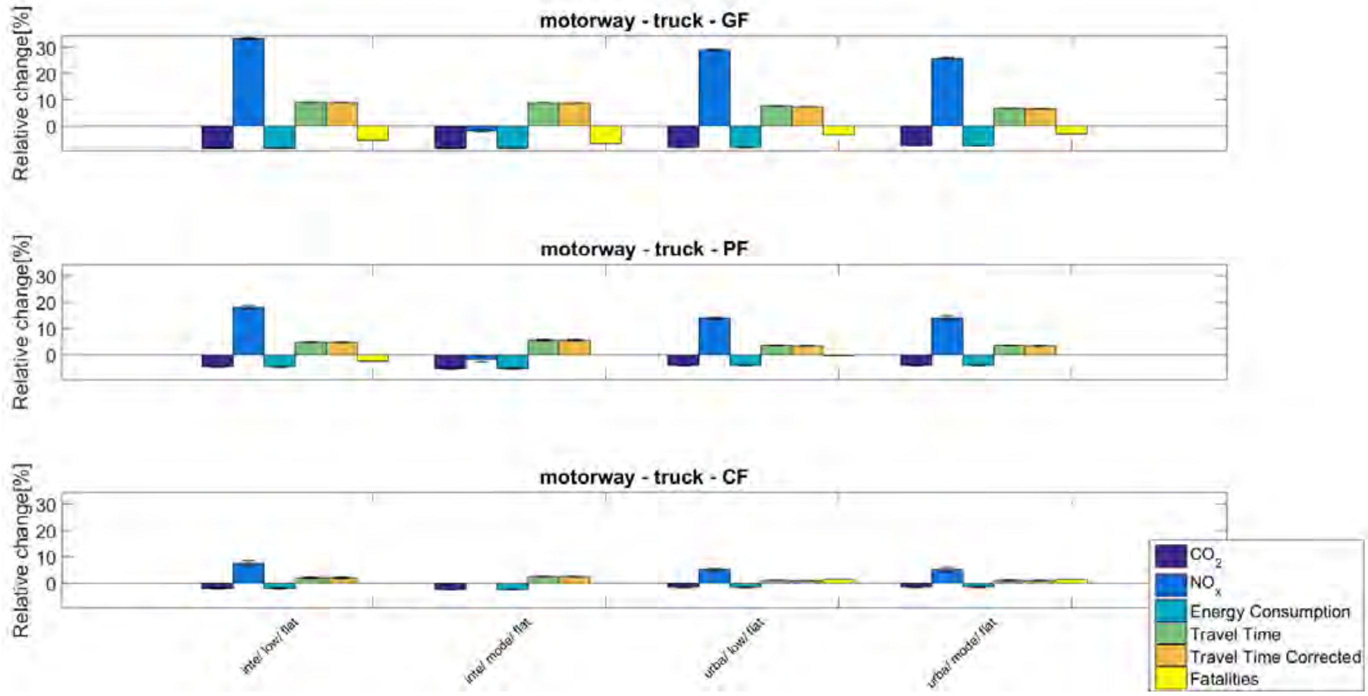


Figure 69: Relative changes of CO_2, NO_x, Energy consumption, Travel time, travel time corrected for speeding and Fatalities for trucks simulated at 2035 using different scenarios, motorways and traffic demand.

14.3 Rural results

This section includes an overview of the most important results from the rural road simulations performed using RuTSim, shown in Table 32.

Table 32: Percentage of statistically significant (two-sided t-test at 5%) results per rural network type and per performance indicator

	CO_2	NOx	fuel	energy	Travel time	Travel time no speeding	All
Rural Flat High intersection density Low demand	61%	67%	61%	64%	72%	50%	63%
Rural Flat High intersection density Moderate demand	75%	64%	75%	75%	72%	17%	63%
Rural Flat Low intersection density Low demand	58%	56%	58%	56%	67%	28%	54%
Rural Flat Low intersection density Moderate demand	72%	64%	72%	72%	67%	6%	59%
Rural Hilly High intersection density Low demand	44%	58%	44%	44%	69%	56%	53%
Rural Hilly High intersection density Moderate demand	61%	69%	61%	61%	69%	17%	56%
Rural Hilly Low intersection density Low demand	50%	56%	50%	50%	64%	17%	48%
Rural Hilly Low intersection density Moderate demand	72%	64%	72%	69%	64%	3%	57%

Expected CO_2 effects from the network characteristics were increased savings of hilly networks and networks with high intersections intensity. This assumption is based on the fact that speed compliance is higher on uphill segments and that higher intersection intensity gives increased number of locations where anticipation due to lower speed limits are useful.

Figure 70 presents the CO_2 results for cars. The CO_2 savings are consistently increasing over time for the Green Future and Policy Freeze scenarios, meaning that increased penetration rates and compliance result in less emissions of CO_2. The same pattern is not observed for Challenging Future scenario which may be explained by the fact that compliance is decreasing from year 2030 to 2035 even if the penetration rate increases (This decrease in compliance is due to the assumption of lack of system and map updates in the ecoDriver systems in the Challenging Future scenario, see the scenario descriptions in Deliverable D52.1 (Jopson et al., 2015)).

Similar patterns as for cars are also observed for vans. Savings are increasing over time for the Policy Freeze and Green Future scenarios, mainly due to the increased penetration rate and compliance level. The higher compliance among professional drivers gives even higher savings for vans compared to cars, cf. Figure 71 (vans) and Figure 70 (cars).

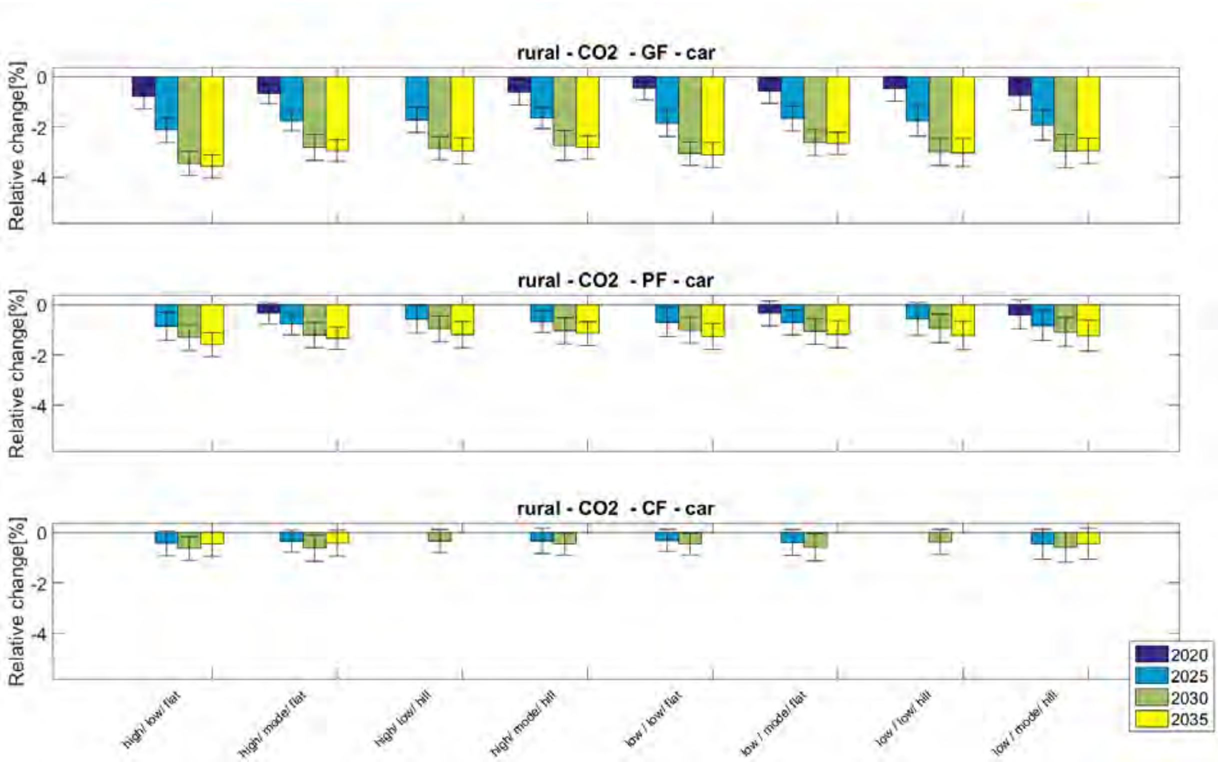


Figure 70: Relative change of CO_2 for cars simulated in different scenarios, rural road networks, years and traffic demands.

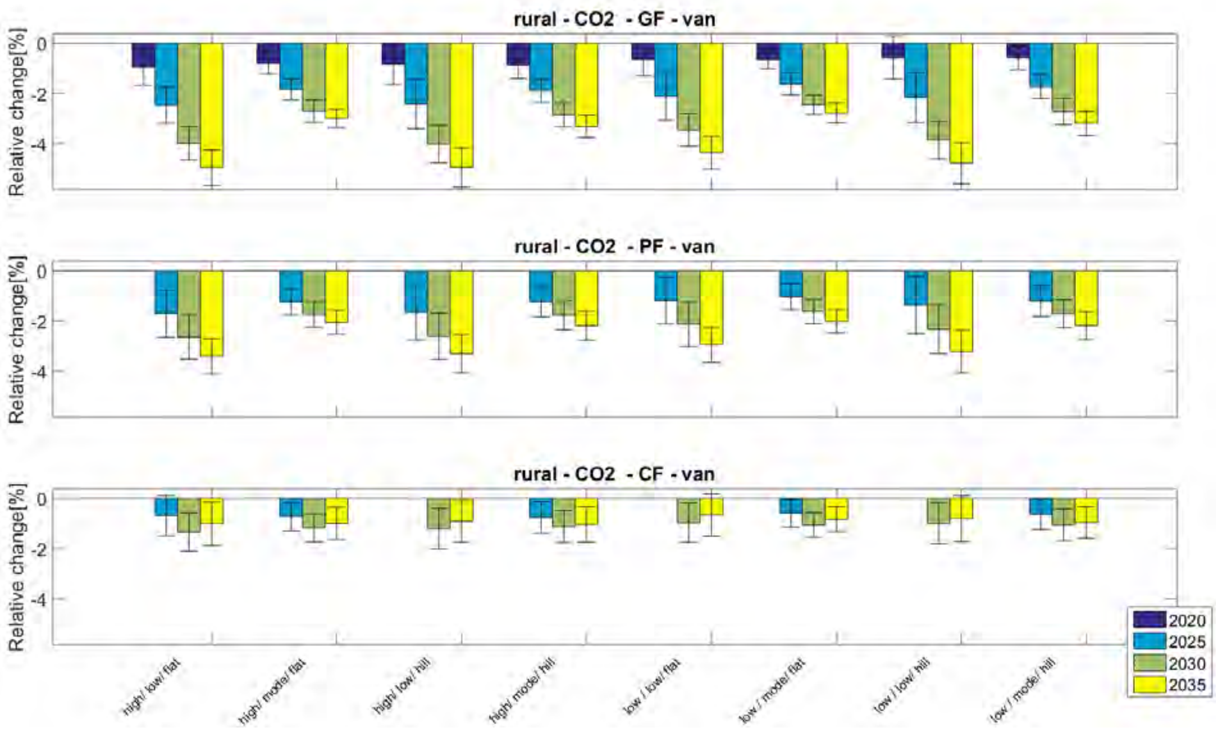


Figure 71: Relative change of CO_2 for vans simulated in different scenarios, rural road networks, years and traffic demands.

The CO_2 savings for trucks (Figure 72) are significantly lower compared to the other vehicle classes. A majority of the results are not significant and there are not significant difference at all for trucks in the Challenging Future scenario. The lack of improvement is explained by the complexity of truck engines and emissions from trucks, which also make it difficult to develop emission models for trucks. Most trucks are optimised for specific speeds and/or engine loads and a decrease in cruising speed do not necessary even result in a decrease in CO_2 per kilometre driven for all combinations of engine size, payload and speed level.

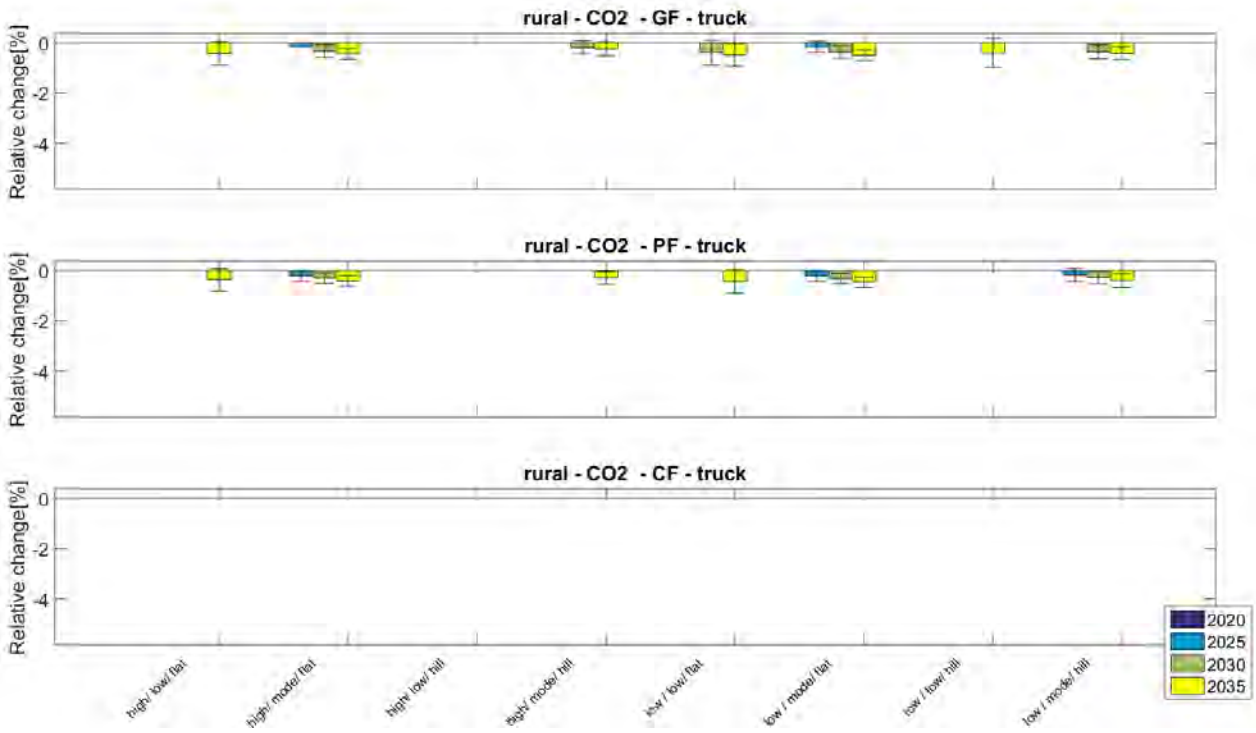


Figure 72. Relative change of CO_2 for trucks simulated in different scenarios, rural road networks, years and traffic demands.

A sub set of the most interesting performance indicators for cars are presented in Figure 73. It is clear that the most improvements related to the ecoDriver system is related to the safety measures. The significant decrease in number of fatalities is a consequence of the decreased average speed, but since the decrease in speed mainly affects speeding vehicles, this may not be considered as a loss of welfare. It is further interesting to compare travel times corrected for speeding with the improvements in safety and emissions since these performance indicators are directly affecting the total benefit of the support system in a social welfare perspective.

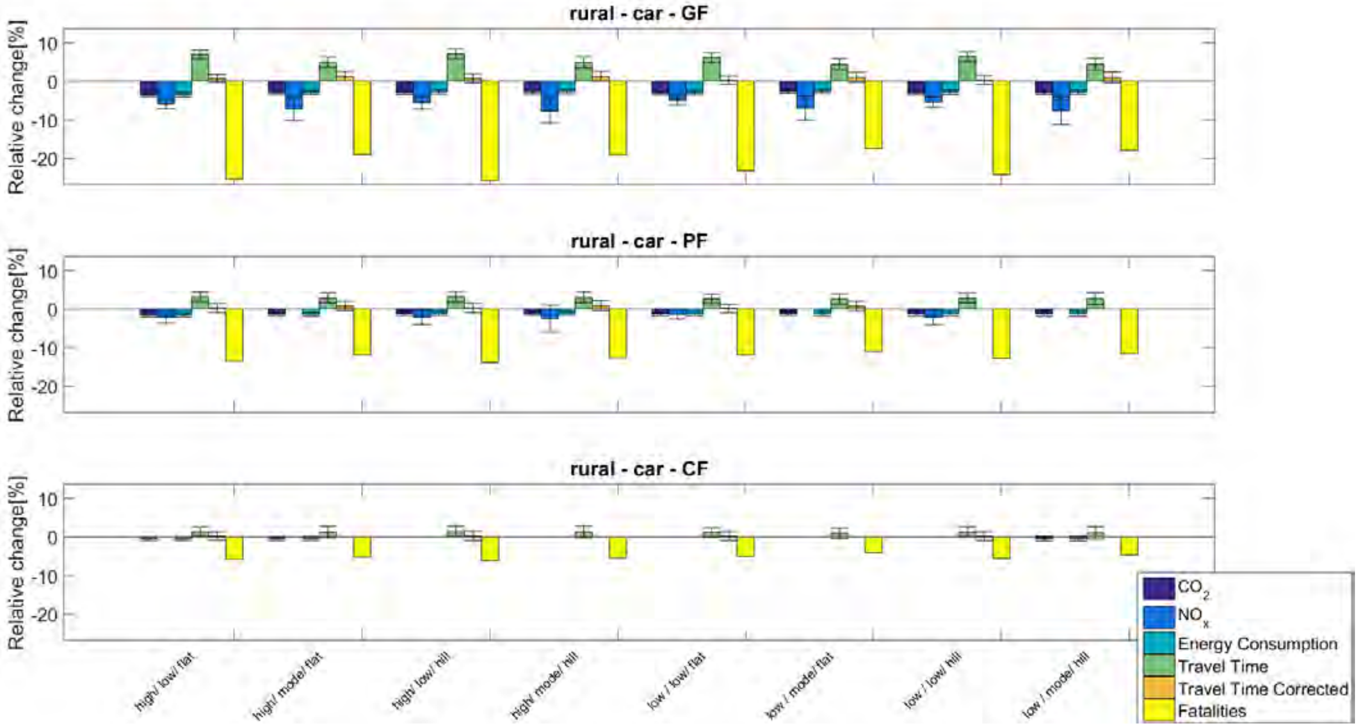


Figure 73: Relative changes of CO_2, NO_x, Energy consumption, Travel time, travel time corrected for speeding and Fatalities for cars simulated at 2035 using different scenarios, rural roads and traffic demand.

As can be observed in Figure 74, the total benefit is more comprehensive for vans than for cars. Travel times are significantly increasing compared to cars, but the potential of emissions related savings are significantly higher compared to cars.

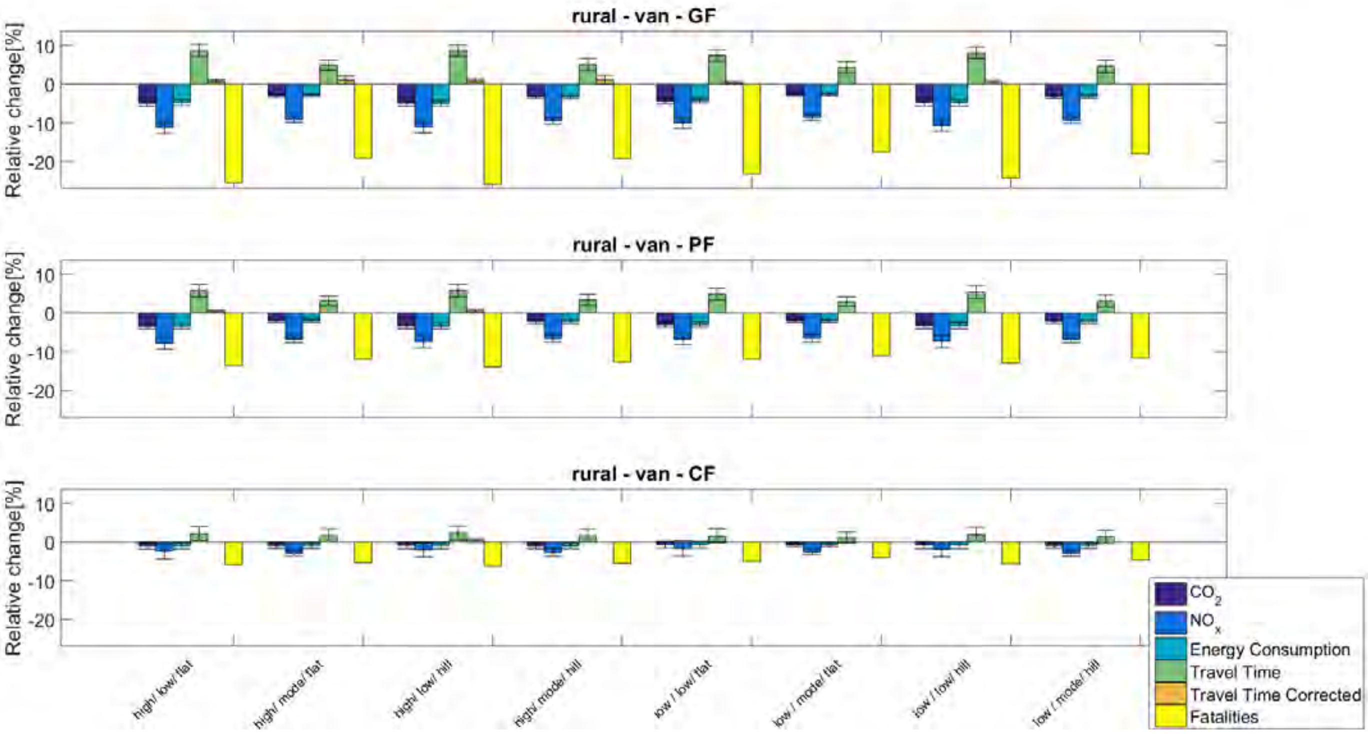


Figure 74: Relative changes of CO_2, NO_x, Energy consumption, Travel time, travel time corrected for speeding and Fatalities for vans simulated at 2035 using different scenarios, rural roads and traffic demand.

Smallest savings in general are observed for the trucks. As can be observed in Figure 75 there are significant increases in NO_x and travel times, mainly an effect of the decrease in average speed. Minor savings in CO_2 and energy are observed, but the overall effect is quite small or even negative (due to the complexity of truck engines and emissions discussed above). The minor savings of fuel may still correspond to a comprehensive amount of litres since the fuel consumption for trucks are significantly higher compared to vans and cars.

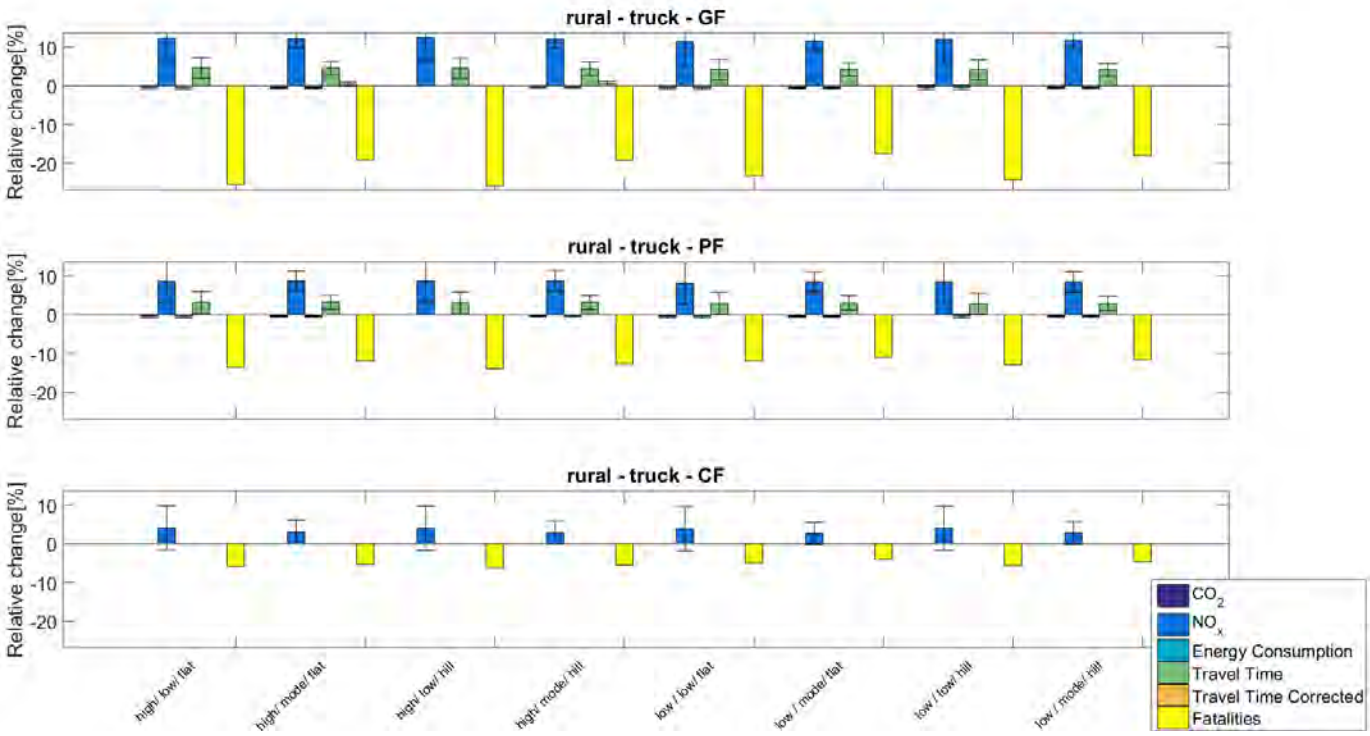


Figure 75: Relative changes of CO_2, NO_x, Energy consumption, Travel time, travel time corrected for speeding and Fatalities for trucks simulated at 2035 using different scenarios, rural roads and traffic demand.

14.4 Urban results

A common trend of all urban simulation results has been very high standard deviations of the performance indicators. With exception of NO_x and the safety PIs, the other PIs are mostly found to be insignificant due to this issue, see Table 33 for an overview of percentage of significant results for the different urban traffic simulation cases.

This is not fully unexpected and may have been due to the following reasons:

- The speed limit variations are quite small in the urban network and applicable mostly to vehicles turning to side streets. It may be noted that this is typical in real urban scenarios as well.
- The urban networks used in the study have a large number of traffic lights in a short distance (again typical for city cores). It may be noted that the Urban Spacious network has 13 signalized intersections (of which 5 are pedestrian crossings) and the Urban Compact network has 19 signalized intersections (of which 11 are pedestrian crossings). These traffic lights are the main sources of acceleration deceleration in an urban environment. But the current ecoDriver system does not have any signal status related advice.

- The high numbers of traffic signals caused high standard deviations in travel times as well as the other PIs across the urban simulations which contributed to statistical insignificance.

Table 33: Percentage of statistically significant results (two-sided t-test at 5%) per urban network type and per performance indicator

	CO2	NOx	fuel	energy	Travel time	Travel time no speeding	All
Urban Flat Compact Low demand	0%	0%	0%	0%	0%	0%	0%
Urban Flat Compact Moderate demand	0%	0%	0%	0%	0%	0%	0%
Urban Flat Spacious Low demand	0%	2%	0%	0%	0%	0%	2%
Urban Flat Spacious Moderate demand	2%	12%	3%	2%	0%	0%	19%
Urban Hilly Compact Low demand	0%	0%	0%	0%	0%	0%	0%
Urban Hilly Compact Moderate demand	0%	1%	0%	0%	0%	0%	1%
Urban Hilly Spacious Low demand	0%	4%	0%	0%	0%	0%	4%
Urban Hilly Spacious Moderate demand	0%	17%	0%	0%	0%	0%	17%

As seen in Table 33, apart from a few cases, the with-ecoDriver and without eco-Driver does not make any significant differences in terms on emissions (as opposed to Rural and Motorway scenarios). The exception is NO_x results, where in case of Car and Vans small improvements are observed (Figure 76 and Figure 77). Significant improvements are also observed in terms of safety PIs, which are presented in Figure 78.

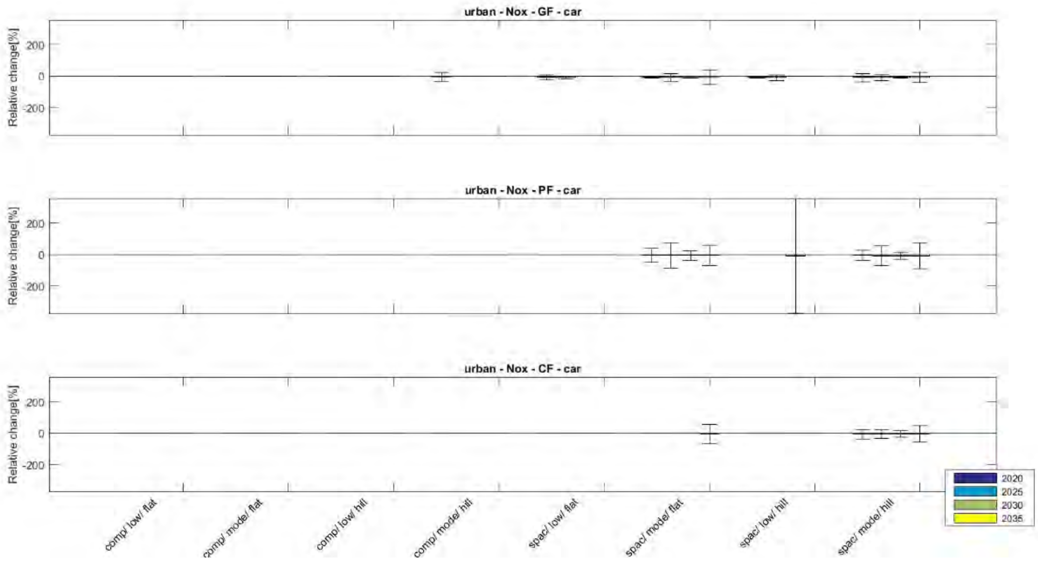


Figure 76: Relative change and error bars of NO_x for cars simulated at different scenarios, urban road networks, years and traffic demands.

As seen in Figure 76, the relative NO_x changes are more in Green Future Scenarios and mostly in case of the low/moderate flow conditions in the urban spacious scenario. The same trend is observed for vans in Figure 74, where the Challenging Future and Policy Freeze scenarios mostly have insignificant results.

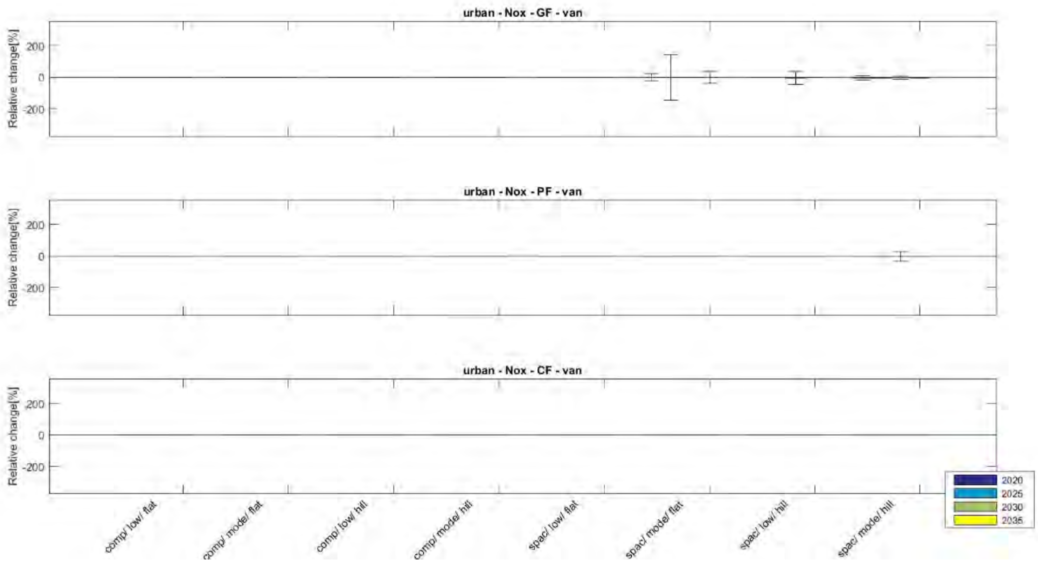


Figure 77: Relative change and error bars of NO_x for vans simulated at different scenarios, rural road networks, years and traffic demands.

The results regarding the changes in fatalities (which have the highest magnitudes of significant changes among all PIs) are presented in Figure 78. It can be seen that the changes are larger in magnitude for the Green Future scenarios and least for the Challenging Future scenarios as expected. The effects are larger in magnitude for the Urban Spacious network, both hilly and flat and low and moderate flow levels.

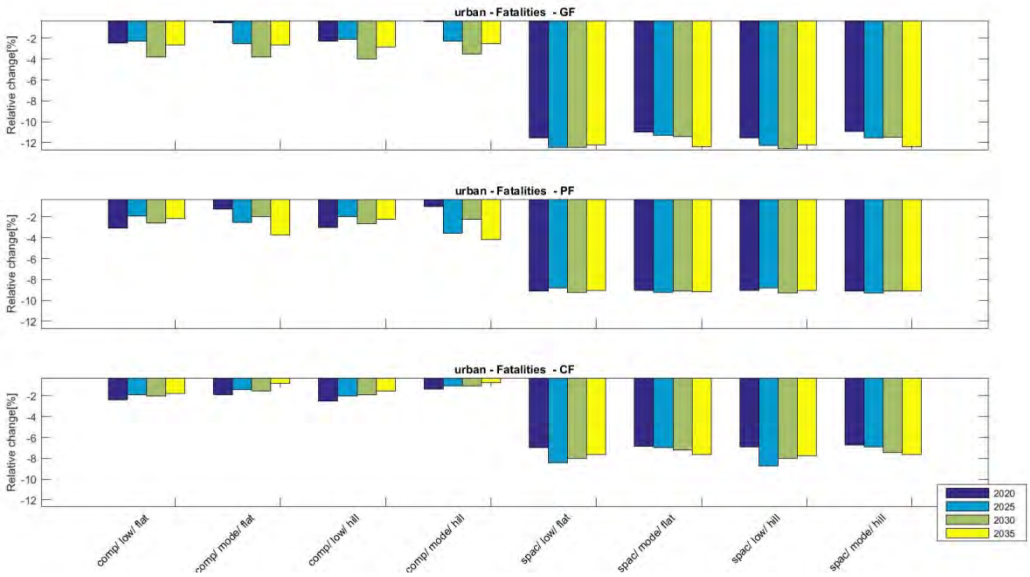


Figure 78: Relative change of fatalities (across all vehicle types) simulated at different scenarios, urban networks, years and traffic demands.

A cross comparison of the magnitude of changes of the performance indicators for cars are presented in Figure 79. As mentioned earlier in this section, it is clear that the most improvements related to the ecoDriver system in the urban scenarios is related to the safety measures and minor improvements are observed for NO_x. The changes in CO_2, Energy Consumption and Travel Time are largely insignificant. As discussed earlier, the significant decrease in number of fatalities is a consequence of the decreased average speed, but since the decrease in speed mainly affects speeding vehicles, this may not be considered as a loss of welfare.

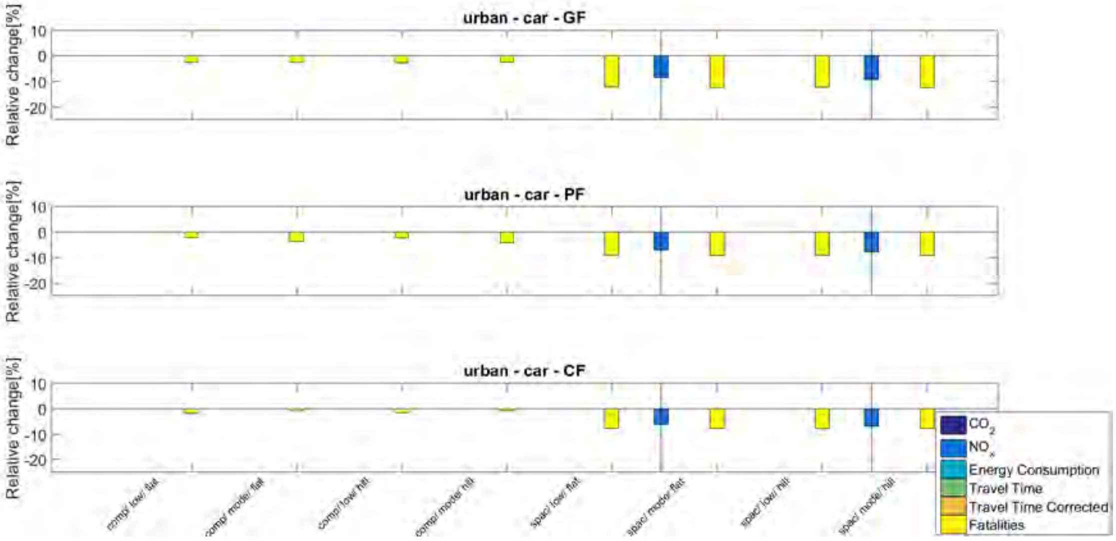


Figure 79: Relative changes and error bars of CO_2, NO_x, Energy consumption, Travel time, travel time corrected for speeding and fatalities for cars simulated at 2035 using different scenarios, urban networks and traffic demand.

On the other hand, for the vans, as can be observed in Figure 80 , the only significant improvements are observed for NO_x (only in Green Future scenario). For trucks and buses, which are less than 2% of the total traffic in the urban scenarios, no significant changes have been observed.

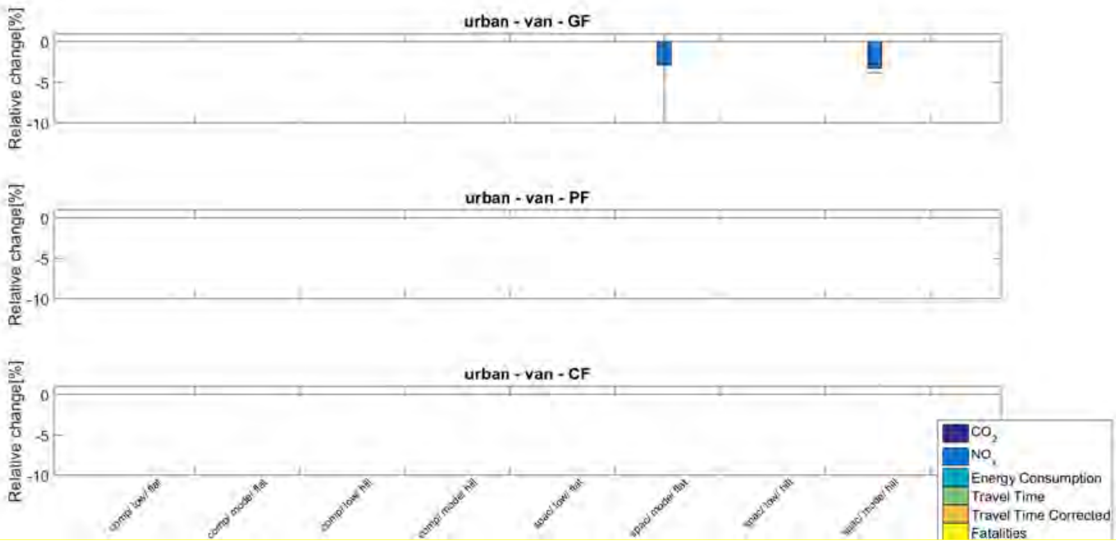


Figure 80: Relative changes and error bars of CO_2, NO_x, Energy consumption, Travel time, travel time corrected for speeding and fatalities for vans simulated at 2035 using different scenarios, urban networks and traffic demand.

14.5 Discussion

In general the effects of the ecoDriver systems are smaller than expected, especially for CO_2 and NO_x. Largest savings of CO_2 are achieved on the rural roads, moderate savings at the motorways and no significant savings in the urban networks. For the rural roads the CO_2 pollutions from vans and cars decrease the most while the CO_2 savings on motorways mainly come from the trucks (which also show the highest decrease in speed and increase in travel time).

The relative change in NO_x emissions are ambiguous. On motorways there is some effect for vans while there is relatively large savings on rural roads (with exception for the Challenging Future scenarios) and limited savings for the urban roads. For cars there are savings on rural roads in the Green Future scenario, but limited effects for the other scenarios. On the motorways, the NO_x from cars sometimes even increases on the interurban motorway. For the urban setting there are a few cases in which the NO_x savings from cars are found to be significant. There are large increases in NO_x from trucks both on motorways and rural roads, while no changes are observed for the urban scenarios where truck proportions are very small. This can be explained because NO_x emissions from trucks are less dependent of speed dynamics and more on the speed level. The engine of trucks is optimised for a certain speed, which is probably more around 90 km/h than around 80 km/h. Truck emissions are also quite sensitive to the relation between engine size and pay load. It might be that the two truck types in the simulation is having less suitable combination of engine size and pay load (EURO V 15t rigid truck with an engine power of 270 kW for the urban and motorway environments and a EURO V 30t semi-trailer truck with an engine power of 340kW for the rural roads).

The relative change in energy consumption follows the result for CO_2 but the effect sizes are smaller. Fuel consumption for ICE vehicle follows the trend for CO_2 but since some cars are electric the average change in fuel consumption for all cars is smaller than the CO_2 change.

There are, in general, substantial increases in travel time, especially for the Green Future scenario for which the penetration and compliance rates are higher and increasing faster over the years. The size of the increase varies and are in general high for the rural cases, while more moderate changes in some rare cases for the motorway and urban cases. The travel time corrected for speeding follow the same trend as the travel time but with lower effect sizes. The safety effects are in general high. The savings are in general largest for the Green Future scenario but there are substantial savings for most combinations of scenario, year and road type.

15. Implications for the ecoDriver project

The traffic simulation results have a direct impact on the ecoDriver project since they constitute one of the major inputs to the scaling up and the cost benefit analysis. The results indicate relatively moderate savings in CO_2, NO_x and energy consumption, large safety savings but also rather large increases in travel time. The CO_2 savings are smaller than the average savings found in the field trials, which is natural since the field trial results only include savings from equipped vehicles while the traffic simulations present the average saving for a mix of equipped (Embedded and Nomadic) and non-equipped vehicles.

The savings are in general largest on the rural roads, somewhat lower on motorways and there is in principle only safety effects in the urban setting. This is quite natural since all the types of advice (speed, gear and upcoming lower speed limit) appears and may influence the drivers on the rural roads. Motorway driving commonly implies driving at the highest gear, thus gear advice is not frequent. The number of speed limit changes are also less frequent on motorways. Thus, the main contributing part on motorways is the speed advice. Urban road driving implies more frequent gear changes while the possibility to freely choose the speed and for speeding is more limited. The main contributing part on urban roads is therefore the gear advice. Another reason for the larger effects on rural roads is the limited overtaking possibilities which implies that equipped and highly compliant drivers tend to become platoon leaders more frequently than on motorways. As platoon leaders they do not only decrease their own speed but also the speed of the vehicles in the platoon. On motorways the effect on surrounding non equipped vehicles seems to be the opposite with a more dynamic driving behaviour of the drivers without ecoDriver system, such as decelerating for the ecoDriver equipped vehicles with lower speed and accelerating for overtaking manoeuvres (to overtake e.g. the ecoDriver equipped vehicles).

15.1 Uncertainties and lessons learnt

The simulated vehicles have been equipped with versions of the Full ecoDriver System (FeDS) and the ecoDriver App. The representations of these two systems in the simulations differ to some extent from the real FeDS and ecoDriver App. The real world system includes some additional “pop ups” and feedback that were not included directly in the simulations. The feedback was instead indirectly included in the compliance to the advice with respect to which speed to drive at, which gear to use and when to switch and when to start decelerate for an upcoming lower speed limit. The initial plan was to integrate the real world FeDS and ecoDriver App system into the simulations. The Vehicle Energy and Environment estimator part of the FeDS was integrated with the traffic simulation models but verification simulations indicated strange behaviour of the speed and gear advice given by the FeDS connected to the traffic simulators. Furthermore, it turned out that the execution time of the simulations increased extensively and running several simulations replications of scenarios and future years involving substantial penetration rates would take weeks to run. In the end, an alternative approach had to be selected due to project time constraints. This implied some simplifications of the FeDS. On the other hand the implemented version did not include the artefacts in the FeDS that were found during the extensive verification simulations.

It would have been desirable if the real world implementation of the ecoDriver systems had been done in such a way that integrating them into the traffic simulators had been more straightforward. This would have made it possible to run verification simulations already in the development process of the ecoDriver systems since the traffic simulators could have offered test in several traffic conditions without the need to first integrate the system into a real vehicle. The idea of integrating the real world FeDS into the traffic simulators arise during the project and was not planned initially. Future projects involving traffic simulation of driver support systems, especially such systems that include modelling of the powertrain, should plan to run activities on integration of the driver support system and the traffic simulators as a part of the development work packages.

The results indicate large increases in NO_x for trucks, especially at typical motorway and rural road speeds (80-90 km/h). According to the utilised emission model the NO_x emissions in g/km increase when cruising at 80 km/h compared to cruising at 90 km/h. The large increases in emissions were for trucks could not be explained in a satisfactory way, but could be caused by the nature of the emission model used (a regression model). The aim in ecoDriver was to apply a model that reflects reality as much as possible, i.e. based on real-world measurements (as opposed to chassis dynamometer measurements). However, there aren't enough real world measurements yet to answer this discussion. We've tried to use the best possible data (based on raw measurements), but they're just now started to be collected. It has become clear that models based on chassis dynamometer measurements also have weaknesses. Thus, there is a need for further research and development of real world driving based energy and emission models. One also have to bear in mind that emissions from trucks is complex and depend on for which payload in relation to engine power and speed level that the engine is optimised for. Furthermore, the performance indicator used in ecoDriver is NO_x in g/km. Cruising at a higher speed means that the vehicle needs a shorter time to travel each kilometre. So even if the emissions per second is lower at a lower speed this does not always imply that the emissions per kilometre is lower. The NO_x results have been included in the scaling up and CBA (and the uncertainties about the NO_x results have been accounted for in a sensitivity analysis).

On rural roads the ecoDriver equipped vehicles tend to become platoon leaders more often than non-equipped vehicles. This implies that the platoons will drive somewhat slower when ecoDriver is introduced. This makes it, to some extent, easier for the followers to overtake the platoon leader since the overtaking can be conducted faster (cf. if the leader vehicle was driving faster and the follower overtake at the same speed in both conditions). This is captured in the simulations but any eventual increase of risky overtakings (i.e. overtakings with small safety margins) due to longer time "waiting" in the platoon is not captured.

There are other situational variables that could possibly have an effect on the potential impacts of the ecoDriver systems. An (obvious) example is weather; during bad weather (e.g. heavy rain, snow, slippery roads) people generally drive with lower speeds, so the impacts of ecoDriver could be smaller. Recent investigations in UK show that although driver behaviour varies with weather, the mean, standard deviation, and 5th and 95th percentile of speed and acceleration are mainly affected during more extreme weather conditions such as heavy rain (Pellecuer et al., 2016). In the simulations generic European circumstances were used.

A major reason for the small effects in the urban scenarios is the absence of traffic signal related advice in the current ecoDriver system. It is anticipated that the expected improvements in the urban scenarios are thus an underestimation of the true potential and follow up research should be done to capture the improvements arising from providing ecoDriving advice related to the status of the upcoming signal so that drivers have smoother acceleration decelerations in urban scenarios leading to further air quality benefits.

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Annex

Annex A. Future projections of traffic mix and penetration rates

Motorway

The share of vehicle kilometres per vehicle type for the motorway simulations was determined in WP52 and shown in Table 34 - Table 36 below.

Table 34: Share of vehicle kilometres per vehicle class on motorways - Green Future scenario

		Year				
Vehicle class	**Fuel type**	**2015**	**2020**	**2025**	**2030**	**2035**
Car	Petrol	43.1%	38.9%	36.5%	35.3%	34.9%
Car	Diesel	56.8%	60.9%	63.2%	64.2%	64.5%
Car	Electricity	0.1%	0.2%	0.3%	0.5%	0.6%
Car	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%
Van	Diesel	100%	100%	100%	100%	100%
Truck	Diesel	100%	100%	100%	100%	100%

Table 35: Share of vehicle kilometres per vehicle class on motorways - Policy Freeze scenario

		Year					
Vehicle class	**Fuel type**	**2013**	**2015**	**2020**	**2025**	**2030**	**2035**
Car	Petrol	45.8%	43.1%	38.9%	36.5%	35.3%	34.9%
Car	Diesel	54.1%	56.8%	60.9%	63.2%	64.2%	64.5%
Car	Electricity	0.1%	0.1%	0.2%	0.3%	0.5%	0.6%
Car	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Van	Diesel	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Truck	Diesel	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 36: Share of vehicle kilometres per vehicle class on motorways -Challenging Future scenario

		Year				
Vehicle class	**Fuel type**	**2015**	**2020**	**2025**	**2030**	**2035**
Car	Petrol	43.2%	38.9%	36.4%	34.7%	33.7%
Car	Diesel	56.7%	60.9%	63.5%	65.1%	66.1%
Car	Electricity	0.1%	0.2%	0.2%	0.2%	0.2%
Car	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%
Van	Diesel	100.0%	100.0%	100.0%	100.0%	100.0%
Truck	Diesel	100.0%	100.0%	100.0%	100.0%	100.0%

The shares in vehicle kilometres were translated into input percentages for the motorway simulations, divided into vehicles without ecoDriver system, with the Full Embedded ecoDriver System (FeDS) and the nomadic ecoDriver system (the ecoDriver App) as given in Table 37 - Table 39 below.

Table 37: Fractions of vehicle types for the motorway simulations - Green Future scenario

			2020	**2025**	**2030**	**2035**	**2020**	**2025**	**2030**	**2035**
Class	**Fuel type**	**ecoDriver system**	**yes**	**yes**	**yes**	**yes**	**no**	**no**	**no**	**no**
Car	Petrol	Unequipped	0.109	0.095	0.088	0.090	0.386	0.367	0.373	0.420
Car		Embedded	0.046	0.154	0.216	0.252	-	-	-	-
Car		Nomadic	0.231	0.118	0.069	0.078	-	-	-	-
Car	Diesel	Unequipped	0.172	0.162	0.144	0.116	0.611	0.626	0.611	0.543
Car		Embedded	0.073	0.263	0.354	0.326	-	-	-	-
Car		Nomadic	0.365	0.201	0.113	0.101	-	-	-	-
Car	Electricity	Unequipped	0.001	0.002	0.004	0.008	0.003	0.007	0.016	0.038
Car		Embedded	0.000	0.003	0.009	0.023	-	-	-	-
Car		Nomadic	0.002	0.002	0.003	0.007	-	-	-	-
Van	Diesel	Unequipped	0.089	0.076	0.063	0.050	1.000	1.000	1.000	1.000
Van		Embedded	0.112	0.391	0.678	0.855	-	-	-	-
Van		Nomadic	0.798	0.533	0.259	0.095	-	-	-	-
Truck	Diesel	Unequipped	0.089	0.076	0.063	0.050	1.000	1.000	1.000	1.000
Truck		Embedded	0.112	0.391	0.678	0.855	-	-	-	-
Truck		Nomadic	0.109	0.095	0.088	0.090	0.386	0.367	0.373	0.420

Table 38: Fractions of vehicle types for the motorway simulations - Policy Freeze scenario

			2020	**2025**	**2030**	**2035**	**2020**	**2025**	**2030**	**2035**
Class	**Fuel type**	**ecoDriver system**	**yes**	**yes**	**yes**	**yes**	**no**	**no**	**no**	**no**
Car	Petrol	Unequipped	0.184	0.166	0.155	0.147	0.389	0.365	0.353	0.349
Car		Embedded	0.020	0.065	0.107	0.125	-	-	-	-
Car		Nomadic	0.185	0.134	0.091	0.077	-	-	-	-
Car	Diesel	Unequipped	0.288	0.288	0.281	0.271	0.609	0.632	0.642	0.645
Car		Embedded	0.032	0.113	0.195	0.232	-	-	-	-
Car		Nomadic	0.289	0.231	0.166	0.142	-	-	-	-
Car	Electricity	Unequipped	0.001	0.001	0.002	0.003	0.002	0.003	0.005	0.006
Car		Embedded	0.000	0.001	0.001	0.002	-	-	-	-
Car		Nomadic	0.001	0.001	0.001	0.001	-	-	-	-
Van	Diesel	Unequipped	0.139	0.126	0.113	0.100	1.000	1.000	1.000	1.000
Van		Embedded	0.067	0.296	0.537	0.715	-	-	-	-
Van		Nomadic	0.793	0.577	0.349	0.185	-	-	-	-
Truck	Diesel	Unequipped	0.139	0.126	0.113	0.100	1.000	1.000	1.000	1.000
Truck		Embedded	0.067	0.296	0.537	0.715	-	-	-	-
Truck		Nomadic	0.793	0.577	0.349	0.185	-	-	-	-

Table 39: Fractions of vehicle types for the motorway simulations - Challenging Future scenario

			2020	2025	2030	2035	2020	2025	2030	2035
Class	**Fuel type**	**ecoDriver system**	**yes**	**yes**	**yes**	**yes**	**no**	**no**	**no**	**no**
Car	Petrol	Unequipped	0.211	0.198	0.189	0.183	0.389	0.364	0.347	0.337
Car		Embedded	0.010	0.033	0.056	0.068	-	-	-	-
Car		Nomadic	0.168	0.133	0.103	0.085	-	-	-	-
Car	Diesel	Unequipped	0.331	0.345	0.354	0.359	0.609	0.635	0.651	0.661
Car		Embedded	0.015	0.057	0.104	0.134	-	-	-	-
Car		Nomadic	0.263	0.232	0.193	0.167	-	-	-	-
Car	Electricity	Unequipped	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002
Car		Embedded	0.000	0.000	0.000	0.000	-	-	-	-
Car		Nomadic	0.001	0.001	0.001	0.001	-	-	-	-
Van	Diesel	Unequipped	0.200	0.200	0.200	0.200	1.000	1.000	1.000	1.000
Van		Embedded	0.046	0.212	0.399	0.539	-	-	-	-
Van		Nomadic	0.754	0.588	0.401	0.261	-	-	-	-
Truck	Diesel	Unequipped	0.200	0.200	0.200	0.200	1.000	1.000	1.000	1.000
Truck		Embedded	0.046	0.212	0.399	0.539	-	-	-	-
Truck		Nomadic	0.211	0.198	0.189	0.183	-	-	-	-

Rural roads

The share of vehicle kilometres per vehicle type for the rural road simulations was determined in WP52 and shown in Table 40 - Table 42 below.

Table 40: Share of vehicle kilometres per vehicle class on rural roads - Green Future scenario

		Year				
Vehicle class	**Fuel type**	**2015**	**2020**	**2025**	**2030**	**2035**
Car	Petrol	52.8%	47.9%	45.6%	45.8%	49.7%
Car	Diesel	47.1%	51.9%	53.7%	52.7%	46.9%
Car	Electricity	0.1%	0.3%	0.6%	1.4%	3.4%
Car	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%
Van	Diesel	100.0%	100.0%	100.0%	100.0%	100.0%
Truck	Diesel	100.0%	100.0%	100.0%	100.0%	100.0%

Table 41: Share of vehicle kilometres per vehicle class on rural roads - Policy Freeze scenario

		Year					
Vehicle class	**Fuel type**	**2013**	**2015**	**2020**	**2025**	**2030**	**2035**
Car	Petrol	55.3%	52.6%	48.2%	45.6%	44.2%	43.5%
Car	Diesel	44.6%	47.3%	51.6%	54.1%	55.4%	55.8%
Car	Electricity	0.1%	0.1%	0.2%	0.3%	0.4%	0.6%
Car	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Van	Diesel	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Truck	Diesel	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 42: Share of vehicle kilometres per vehicle class on rural roads - Challenging Future scenario

		Year				
Vehicle class	**Fuel type**	**2015**	**2020**	**2025**	**2030**	**2035**
Car	Petrol	52.7%	48.2%	45.5%	43.7%	42.6%
Car	Diesel	47.2%	51.6%	54.3%	56.1%	57.2%
Car	Electricity	0.1%	0.2%	0.2%	0.2%	0.2%
Car	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%
Van	Diesel	100.0%	100.0%	100.0%	100.0%	100.0%
Truck	Diesel	100.0%	100.0%	100.0%	100.0%	100.0%

The shares in vehicle kilometres were translated into input percentages for the rural road simulations, divided into vehicles without ecoDriver system, with the Full Embedded ecoDriver System (FeDS) and the nomadic ecoDriver system (the ecoDriver App) as given in Table 43 - Table 45 below.

Table 43: Fractions of vehicle types for the rural road simulations - Green Future scenario

			2020	2025	2030	2035	2020	2025	2030	2035
Class	**Fuel type**	**ecoDriver system**	**yes**	**yes**	**yes**	**yes**	**no**	**no**	**no**	**no**
Car	Petrol	Unequipped	0.135	0.118	0.108	0.106	0.479	0.456	0.458	0.497
Car		Embedded	0.057	0.192	0.265	0.298	-	-	-	-
Car		Nomadic	0.286	0.147	0.085	0.093	-	-	-	-
Car	Diesel	Unequipped	0.146	0.139	0.124	0.100	0.519	0.537	0.527	0.469
Car		Embedded	0.062	0.226	0.305	0.282	-	-	-	-
Car		Nomadic	0.310	0.173	0.098	0.088	-	-	-	-
Car	Electricity	Unequipped	0.001	0.002	0.003	0.007	0.003	0.006	0.014	0.034
Car		Embedded	0.000	0.003	0.008	0.020	-	-	-	-
Car		Nomadic	0.002	0.002	0.003	0.006	-	-	-	-
Van	Diesel	Unequipped	0.089	0.076	0.063	0.050	1.000	1.000	1.000	1.000
Van		Embedded	0.113	0.391	0.678	0.855	-	-	-	-
Van		Nomadic	0.798	0.533	0.259	0.095	-	-	-	-
Truck	Diesel	Unequipped	0.089	0.076	0.063	0.050	1.000	1.000	1.000	1.000
Truck		Embedded	0.113	0.391	0.678	0.855	-	-	-	-
Truck		Nomadic	0.798	0.533	0.259	0.095	-	-	-	-

Table 44: Fractions of vehicle types for the rural road simulations - Policy Freeze scenario

			2020	2025	2030	2035	2020	2025	2030	2035
Class	**Fuel type**	**ecoDriver system**	**yes**	**yes**	**yes**	**yes**	**no**	**no**	**no**	**no**
Car	Petrol	Unequipped	0.228	0.207	0.193	0.183	0.482	0.456	0.442	0.435
Car		Embedded	0.026	0.082	0.134	0.157	-	-	-	-
Car		Nomadic	0.228	0.167	0.114	0.096	-	-	-	-
Car	Diesel	Unequipped	0.244	0.246	0.243	0.235	0.516	0.541	0.554	0.558
Car		Embedded	0.027	0.097	0.168	0.201	-	-	-	-
Car		Nomadic	0.245	0.198	0.143	0.123	-	-	-	-
Car	Electricity	Unequipped	0.001	0.001	0.002	0.003	0.002	0.003	0.004	0.006
Car		Embedded	0.000	0.001	0.001	0.002	-	-	-	-
Car		Nomadic	0.001	0.001	0.001	0.001	-	-	-	-
Van	Diesel	Unequipped	0.14	0.126	0.113	0.1	1.000	1.000	1.000	1.000
Van		Embedded	0.067	0.297	0.537	0.715	-	-	-	-
Van		Nomadic	0.793	0.577	0.35	0.185	-	-	-	-
Truck	Diesel	Unequipped	0.14	0.126	0.113	0.1	1.000	1.000	1.000	1.000
Truck		Embedded	0.067	0.297	0.537	0.715	-	-	-	-
Truck		Nomadic	0.793	0.577	0.35	0.185	-	-	-	-

Table 45: Fractions of vehicle types for the rural road simulations - Challenging Future scenario

			2020	2025	2030	2035	2020	2025	2030	2035
Class	**Fuel type**	**ecoDriver system**	**yes**	**yes**	**yes**	**yes**	**no**	**no**	**no**	**no**
Car	Petrol	Unequipped	0.287	0.262	0.247	0.238	0.527	0.482	0.455	0.437
Car		Embedded	0.013	0.043	0.073	0.089	-	-	-	-
Car		Nomadic	0.227	0.176	0.135	0.111	-	-	-	-
Car	Diesel	Unequipped	0.257	0.281	0.296	0.305	0.472	0.516	0.543	0.561
Car		Embedded	0.012	0.046	0.087	0.114	-	-	-	-
Car		Nomadic	0.203	0.189	0.161	0.142	-	-	-	-
Car	Electricity	Unequipped	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002
Car		Embedded	0.000	0.000	0.000	0.000	-	-	-	-
Car		Nomadic	0.000	0.001	0.001	0.000	-	-	-	-
Van	Diesel	Unequipped	0.2	0.2	0.2	0.2	1.000	1.000	1.000	1.000
Van		Embedded	0.046	0.212	0.399	0.539	-	-	-	-
Van		Nomadic	0.754	0.588	0.401	0.261	-	-	-	-
Truck	Diesel	Unequipped	0.2	0.2	0.2	0.2	1.000	1.000	1.000	1.000
Truck		Embedded	0.046	0.212	0.399	0.539	-	-	-	-
Truck		Nomadic	0.754	0.588	0.401	0.261	-	-	-	-

Urban

The share of vehicle kilometres per vehicle type for the urban simulations was determined in WP52 and shown in Table 46 - Table 48 below.

Table 46: Share of vehicle kilometres per vehicle class on urban roads - Green Future scenario

		Year				
Vehicle class	**Fuel type**	**2015**	**2020**	**2025**	**2030**	**2035**
Car	Petrol	55.545%	51.411%	48.789%	47.360%	46.720%
Car	Diesel	44.355%	48.148%	50.651%	51.900%	52.200%
Car	Electricity	0.100%	0.440%	0.561%	0.740%	1.080%
Car	SUBTOTAL	100,0%	100,0%	100,0%	100,0%	100,0%
Van	Diesel	13.40%	14.28%	14.28%	14.28%	15.30%
Truck	Diesel	2.06%	2.04%	2.04%	2.04%	2.04%
Bus	Diesel	2.00%	1.00%	1.00%	1.00%	1.00%

Table 47: Share of vehicle kilometres per vehicle class on urban roads - Policy Freeze scenario

Vehicle class	**Fuel type**		**2015**	**2020**	**2025**	**2030**	**2035**
Car	Petrol	55.545%	50.996%	48.600%	48.150%	50.750%	
Car	Diesel	44.355%	48.448%	50.000%	48.600%	42.000%	
Car	Electricity	0.100%	0.556%	1.400%	3.250%	7.250%	
Car	SUBTOTAL	100,0%	100,0%	100,0%	100,0%	100,0%	
Van	Diesel	13.40%	13.26%	13.26%	13.26%	13.26%	
Truck	Diesel	2.06%	2.04%	2.04%	2.04%	2.04%	
Bus	Diesel	2.00%	1.00%	1.00%	1.00%	1.00%	

Table 48: Share of vehicle kilometres per vehicle class on urban roads - Challenging Future scenario

		Year				
Vehicle class	**Fuel type**	**2015**	**2020**	**2025**	**2030**	**2035**
Car	Petrol	55.545%	51.456%	48.624%	46.890%	45.875%
Car	Diesel	44.355%	48.248%	51.051%	52.800%	53.900%
Car	Electricity	0.100%	0.295%	0.325%	0.310%	0.225%
Car	SUBTOTAL	100,0%	100,0%	100,0%	100,0%	100,0%
Van	Diesel	13.40%	13.26%	13.26%	13.26%	13.26%
Truck	Diesel	2.06%	2.04%	2.04%	2.04%	2.04%
Bus	Diesel	2.00%	1.00%	1.00%	1.00%	1.00%

The shares in vehicle kilometres were translated into input percentages for the urban road simulations, divided into vehicles without ecoDriver system, with the Full Embedded ecoDriver System (FeDS) and the nomadic ecoDriver system (the ecoDriver App) as given in Table 49 - Table 51 below.

Table 49: Fractions of vehicle types for the urban road simulations - Green Future scenario

			2020	2025	2030	2035	2020	2025	2030	2035
Class	**Fuel type**	**ecoDriver system**	**yes**	**yes**	**yes**	**yes**	**no**	**no**	**no**	**no**
Car	Petrol	Unequipped	0.145	0.127	0.112	0.100				
Car		Embedded	0.062	0.205	0.274	0.280	-	-	-	-
Car		Nomadic	0.307	0.156	0.087	0.087	-	-	-	-
Car	Diesel	Unequipped	0.136	0.131	0.123	0.111				
Car		Embedded	0.058	0.213	0.300	0.313	-	-	-	-
Car		Nomadic	0.288	0.162	0.096	0.097	-	-	-	-
Car	Electricity	Unequipped	0.001	0.001	0.002	0.002				
Car		Embedded	0.001	0.002	0.004	0.006	-	-	-	-
Car		Nomadic	0.003	0.002	0.001	0.002	-	-	-	-
Van	Diesel	Unequipped	0.040	0.037	0.034	0.033				
Van		Embedded	0.017	0.060	0.083	0.092	-	-	-	-
Van		Nomadic	0.085	0.046	0.026	0.029	-	-	-	-
Truck	Diesel	Unequipped	0.002	0.002	0.001	0.001				
Truck		Embedded	0.002	0.008	0.014	0.017	-	-	-	-
Truck		Nomadic	0.016	0.011	0.005	0.002				
Bus	Diesel	Unequipped	0.001	0.001	0.001	0.001				
Bus		Embedded	0.001	0.004	0.007	0.009	-	-	-	-
Bus		Nomadic	0.008	0.005	0.003	0.001				

Table 50: Fractions of vehicle types for the urban road simulations - Policy Freeze scenario

			2020	2025	2030	2035	2020	2025	2030	2035
Class	**Fuel type**	**ecoDriver system**	**yes**	**yes**	**yes**	**yes**	**no**	**no**	**no**	**no**
Car	Petrol	Unequipped	0.241	0.221	0.211	0.213				
Car		Embedded	0.027	0.087	0.146	0.183	-	-	-	-
Car		Nomadic	0.242	0.178	0.124	0.111	-	-	-	-
Car	Diesel	Unequipped	0.229	0.228	0.213	0.177				
Car		Embedded	0.026	0.089	0.148	0.151	-	-	-	-
Car		Nomadic	0.230	0.183	0.125	0.092	-	-	-	-
Car	Electricity	Unequipped	0.003	0.006	0.014	0.030				
Car		Embedded	0.000	0.003	0.010	0.026	-	-	-	-
Car		Nomadic	0.003	0.005	0.008	0.016	-	-	-	-
Van	Diesel	Unequipped	0.063	0.060	0.058	0.056				
Van		Embedded	0.007	0.024	0.040	0.048	-	-	-	-
Van		Nomadic	0.063	0.049	0.034	0.029	-	-	-	-
Truck	Diesel	Unequipped	0.003	0.003	0.002	0.002				
Truck		Embedded	0.001	0.006	0.011	0.015	-	-	-	-
Truck		Nomadic	0.016	0.012	0.007	0.004	-	-	-	-
Bus	Diesel	Unequipped	0.001	0.001	0.001	0.001				
Bus		Embedded	0.001	0.003	0.005	0.007	-	-	-	-
Bus		Nomadic	0.008	0.006	0.003	0.002				

Table 51: Fractions of vehicle types for the urban road simulations - Challenging Future scenario

			2020	2025	2030	2035	2020	2025	2030	2035
Class	**Fuel type**	**ecoDriver system**	**yes**	**yes**	**yes**	**yes**	**no**	**no**	**no**	**no**
Car	Petrol	Unequipped	0.280	0.264	0.255	0.249				
Car		Embedded	0.013	0.044	0.075	0.093	-	-	-	-
Car		Nomadic	0.222	0.178	0.139	0.116	-	-	-	-
Car	Diesel	Unequipped	0.262	0.278	0.287	0.293				
Car		Embedded	0.012	0.046	0.085	0.109	-	-	-	-
Car		Nomadic	0.208	0.187	0.156	0.137	-	-	-	-
Car	Electricity	Unequipped	0.002	0.002	0.002	0.001				
Car		Embedded	0.000	0.000	0.000	0.000	-	-	-	-
Car		Nomadic	0.001	0.001	0.001	0.001	-	-	-	-
Van	Diesel	Unequipped	0.072	0.072	0.072	0.072				
Van		Embedded	0.003	0.012	0.021	0.027	-	-	-	-
Van		Nomadic	0.057	0.049	0.039	0.034	-	-	-	-
Truck	Diesel	Unequipped	0.004	0.004	0.004	0.004				
Truck		Embedded	0.001	0.004	0.008	0.011	-	-	-	-
Truck		Nomadic	0.015	0.012	0.008	0.005				
Bus	Diesel	Unequipped	0.002	0.002	0.002	0.002				
Bus		Embedded	0.000	0.002	0.004	0.005	-	-	-	-
Bus		Nomadic	0.008	0.006	0.004	0.003				

Annex B. Advised gear shift thresholds

A * means that the vehicle is an automatic, % means that it has a variable transmission

Table 52: Gear advice engine speed thresholds for upshifts, embedded and Nomadic system.

Gear	Nissan Leaf	Renault Clio	Renault Scenic	VW Transporter T5 (van)	DAF LF (truck 15t)	DAF XF (truck 30t)
Number of gears	1*%	5	6	5	10*	10*
1	-	1900	1900	1350	-	-
2	-	1500	1500	1350	-	-
3	-	1450	1450	1350	-	-
4	-	1800	1800	1350	-	-
5	-	-	1900	-	-	-
6	-	-	-	-	-	

Table 53: Gear advice engine speed thresholds for downshifts, embedded and Nomadic system.

Gear	Nissan Leaf	Renault Clio	Renault Scenic	VW Transporter T5 (van)	DAF LF (truck 15t)	DAF XF (truck 30t)
Number of gears	1*%	5	6	5	10*	10*
1	-	-	-	-	-	-
2	-	1000	1000	700	-	-
3	-	1000	1000	800	-	-
4	-	1000	1100	800	-	-
5	-	1200	1150	900	-	-
6	-	-	1150	-	-	-

Annex C. Speed advice compliance parameter values

Distributions are provided with locations of the points in the piecewise distribution $[x_1, y_1, x_2, y_2, x_3, y_3 \dots]$ where x is speed compliance and y denotes the percentage cumulative distribution

Table 54: Speed advice compliance piecewise distributions for flat and downhill segments.

	Ordinary drivers		Professional drivers	
Scenario - Year	Embedded	Nomadic	Embedded	Nomadic
GF - 2015	[0.0,19,0.83,40,1.0,83]	[0,0]	[0.0,4,0.83,25,1.0,68]	[0,0]
GF - 2020	[0.0,10.45,0.83,22,1.0,45.65]	[0,0]	[0.0,2.2,0.83,13.75,1.0,37.4]	[0,0]
GF - 2025	[0.0,10.45,0.83,22,1.0,45.65]	[0,0]	[0.0,2.2,0.83,13.75,1.0,37.4]	[0,0]
GF - 2030	[0.0,1.9,0.83,4,1.0,8.3]	[0,0]	[0.0,0.4,0.83,2.5,1.0,6.8]	[0,0]
GF - 2035	[0.0,1.9,0.83,4,1.0,8.3]	[0,0]	[0.0,0.4,0.83,2.5,1.0,6.8]	[0,0]
PF - 2015	[0.0,19,0.83,40,1.0,83]	[0,0]	[0.0,4,0.83,25,1.0,68]	[0,0]
PF - 2020	[0.0,19,0.83,40,1.0,83]	[0,0]	[0.0,4,0.83,25,1.0,68]	[0,0]
PF - 2025	[0.0,19,0.83,40,1.0,83]	[0,0]	[0.0,4,0.83,25,1.0,68]	[0,0]
PF - 2030	[0.0,19,0.83,40,1.0,83]	[0,0]	[0.0,4,0.83,25,1.0,68]	[0,0]
PF - 2035	[0.0,19,0.83,40,1.0,83]	[0,0]	[0.0,4,0.83,25,1.0,68]	[0,0]
CF - 2015	[0.0,19,0.83,40,1.0,83]	[0,0]	[0.0,4,0.83,25,1.0,68]	[0,0]
CF - 2020	[0.0,19,0.83,40,1.0,83]	[0,0]	[0.0,4,0.83,25,1.0,68]	[0,0]
CF - 2025	[0.0,39.25,0.83,55,1.0,87.25]	[0,0]	[0.0,28,0.83,43.75,1.0,76]	[0,0]
CF - 2030	[0.0,39.25,0.83,55,1.0,87.25]	[0,0]	[0.0,28,0.83,43.75,1.0,76]	[0,0]
CF - 2035	[0.0,59.5,0.83,70,1.0,91.5]	[0,0]	[0.0,52.2,0.83,62.5,1.0,84]	[0,0]

Table 55: Speed advice compliance piecewise distributions for uphill segments.

	Ordinary drivers		Professional drivers	
Scenario - Year	Embedded	Nomadic	Embedded	Nomadic
GF - 2015	[0.39,9,0.80,33,1.0,95]	[0,0]	[0.39,0,0.80,18,1.0,80]	[0,0]
GF - 2020	[0.39,4.95,0.80,18.15,1.0,52.25]	[0,0]	[0.39,0,0.80,9.9,1.0,44]	[0,0]
GF - 2025	[0.39,4.95,0.80,18.15,1.0,52.25]	[0,0]	[0.39,0,0.80,9.9,1.0,44]	[0,0]
GF - 2030	[0.39,0.9,0.80,3,3,1.0,9,5]	[0,0]	[0.39,0,0.80,1.8,1.0,8.0]	[0,0]
GF - 2035	[0.39,0.9,0.80,3,3,1.0,9,5]	[0,0]	[0.39,0,0.80,1.8,1.0,8.0]	[0,0]
PF - 2015	[0.39,9,0.80,33,1.0,95]	[0,0]	[0.39,0,0.80,18,1.0,80]	[0,0]
PF - 2020	[0.39,9,0.80,33,1.0,95]	[0,0]	[0.39,0,0.80,18,1.0,80]	[0,0]
PF - 2025	[0.39,9,0.80,33,1.0,95]	[0,0]	[0.39,0,0.80,18,1.0,80]	[0,0]
PF - 2030	[0.39,9,0.80,33,1.0,95]	[0,0]	[0.39,0,0.80,18,1.0,80]	[0,0]
PF - 2035	[0.39,9,0.80,33,1.0,95]	[0,0]	[0.39,0,0.80,18,1.0,80]	[0,0]
CF - 2015	[0.39,9,0.80,33,1.0,95]	[0,0]	[0.39,0,0.80,18,1.0,80]	[0,0]
CF - 2020	[0.39,9,0.80,33,1.0,95]	[0,0]	[0.39,0,0.80,18,1.0,80]	[0,0]
CF - 2025	[0.39,31.75,0.80,49.75,1.0,96.25]	[0,0]	[0.39,25,0.80,38.5,1.0,85]	[0,0]
CF - 2030	[0.39,31.75,0.80,49.75,1.0,96.25]	[0,0]	[0.39,25,0.80,38.5,1.0,85]	[0,0]
CF - 2035	[0.39,54.5,0.80,66.5,1.0,97.5]	[0,0]	[0.39,50,0.80,59,1.0,90]	[0,0]

Annex D. Gear shift thresholds

A * means that the vehicle is an automatic, % means that it has a variable transmission.

Table 56: Gear shift thresholds RPM for upshift, calibrated based on initial field trial analysis.

Gear	Nissan Leaf	Renault Clio	Renault Scenic	VW Transporter T5 (van)	DAF LF (truck 15t)	DAF XF (truck 30t)
Number of gears	1*%	5	6	5	10*	10*
1	-	2200	2200	2200	-	-
2	-	2200	2100	2100	-	-
3	-	2200	2000	2000	-	-
4	-	2550	1900	1900	-	-
5	-	-	1900	-	-	-

Table 57: Gear shift delays RPM for upshifts, calibrated based on initial field trial analysis.

Gear	Nissan Leaf	Renault Clio	Renault Scenic	VW Transporter T5 (van)	DAF LF (truck 15t)	DAF XF (truck 30t)
Number of gears	1*%	5	6	5	10*	10*
1	-	350	200	200	-	-
2	-	350	200	200	-	-
3	-	350	200	200	-	-
4	-	350	0	0	-	-
5	-	-	0	-	-	-

Table 58: Gear shift thresholds RPM for downshift, calibrated based on initial field trial analysis.

Gear	Nissan Leaf	Renault Clio	Renault Scenic	VW Transporter T5 (van)	Daf LF (truck 15t)	Daf XF (truck 30t)
Number of gears	1	5	6	5	10*	10*
2	-	1050	1150	1150	-	-
3	-	1200	1200	1200	-	-
4	-	1250	1250	1200	-	-
5	-	1600	1200	1200	-	-
6	-	-	1200	-	-	-

Annex E. Gear advice compliance parameter values

Table 59: Scenario projections of gear compliance for ordinary drivers using the embedded system

	Upshift from gear					Downshift from gear				
Scenario - Year	**1**	**2**	**3**	**4**	**5**	**2**	**3**	**4**	**5**	**6**
GF - 2015	50%	50%	71%	64%	83%	0%	50%	44%	33%	100%
GF - 2020	73%	73%	84%	80%	91%	45%	73%	69%	63%	100%
GF - 2025	73%	73%	84%	80%	91%	45%	73%	69%	63%	100%
GF - 2030	95%	95%	97%	96%	98%	90%	95%	94%	93%	100%
GF - 2035	95%	95%	97%	96%	98%	90%	95%	94%	93%	100%
PF - 2015	50%	50%	71%	64%	83%	0%	50%	44%	33%	100%
PF - 2020	50%	50%	71%	64%	83%	0%	50%	44%	33%	100%
PF - 2025	50%	50%	71%	64%	83%	0%	50%	44%	33%	100%
PF - 2030	50%	50%	71%	64%	83%	0%	50%	44%	33%	100%
PF - 2035	50%	50%	71%	64%	83%	0%	50%	44%	33%	100%
CF - 2015	50%	50%	71%	64%	83%	0%	50%	44%	33%	100%
CF - 2020	50%	50%	71%	64%	83%	0%	50%	44%	33%	100%
CF - 2025	38%	38%	54%	48%	63%	0%	38%	33%	25%	75%
CF - 2030	38%	38%	54%	48%	63%	0%	38%	33%	25%	75%
CF - 2035	25%	25%	36%	32%	42%	0%	25%	22%	17%	50%

Table 60: Scenario projections of gear compliance for professional drivers using the embedded system

	Upshift from gear					Downshift from gear				
Scenario - Year	**1**	**2**	**3**	**4**	**5**	**2**	**3**	**4**	**5**	**6**
GF - 2015	65%	65%	86%	79%	98%	15%	65%	59%	48%	100%
GF - 2020	81%	81%	93%	88%	99%	53%	81%	78%	72%	100%
GF - 2025	81%	81%	93%	88%	99%	53%	81%	78%	72%	100%
GF - 2030	97%	97%	99%	98%	100%	92%	97%	96%	95%	100%
GF - 2035	97%	97%	99%	98%	100%	92%	97%	96%	95%	100%
PF - 2015	65%	65%	86%	79%	98%	15%	65%	59%	48%	100%
PF - 2020	65%	65%	86%	79%	98%	15%	65%	59%	48%	100%
PF - 2025	65%	65%	86%	79%	98%	15%	65%	59%	48%	100%
PF - 2030	65%	65%	86%	79%	98%	15%	65%	59%	48%	100%
PF - 2035	65%	65%	86%	79%	98%	15%	65%	59%	48%	100%
CF - 2015	65%	65%	86%	79%	98%	15%	65%	59%	48%	100%
CF - 2020	65%	65%	86%	79%	98%	15%	65%	59%	48%	100%
CF - 2025	49%	49%	65%	59%	74%	11%	49%	45%	36%	75%
CF - 2030	49%	49%	65%	59%	74%	11%	49%	45%	36%	75%
CF - 2035	33%	33%	43%	39%	49%	8%	33%	30%	24%	50%

Table 61: Scenario projections of gear compliance for ordinary drivers using the nomadic system

	Upshift from gear					Downshift from gear				
Scenario - Year	**1**	**2**	**3**	**4**	**5**	**2**	**3**	**4**	**5**	**6**
GF - 2015	83%	36%	40%	47%	47%	0%	25%	0%	13%	13%
GF - 2020	91%	65%	67%	71%	71%	45%	59%	45%	52%	52%
GF - 2025	91%	65%	67%	71%	71%	45%	59%	45%	52%	52%
GF - 2030	98%	94%	94%	95%	95%	90%	93%	90%	91%	91%
GF - 2035	98%	94%	94%	95%	95%	90%	93%	90%	91%	91%
PF - 2015	83%	36%	40%	47%	47%	0%	25%	0%	13%	13%
PF - 2020	83%	36%	40%	47%	47%	0%	25%	0%	13%	13%
PF - 2025	83%	36%	40%	47%	47%	0%	25%	0%	13%	13%
PF - 2030	83%	36%	40%	47%	47%	0%	25%	0%	13%	13%
PF - 2035	83%	36%	40%	47%	47%	0%	25%	0%	13%	13%
CF - 2015	83%	36%	40%	47%	47%	0%	25%	0%	13%	13%
CF - 2020	83%	36%	40%	47%	47%	0%	25%	0%	13%	13%
CF - 2025	63%	27%	30%	35%	35%	0%	19%	0%	9%	9%
CF - 2030	63%	27%	30%	35%	35%	0%	19%	0%	9%	9%
CF - 2035	42%	18%	20%	23%	23%	0%	13%	0%	6%	6%

Table 62: Scenario projections of gear compliance for professional drivers using the nomadic system

	Upshift from gear					Downshift from gear				
Scenario - Year	1	2	3	4	5	2	3	4	5	6
GF - 2015	98%	51%	55%	62%	62%	15%	40%	15%	28%	13%
GF - 2020	99%	73%	75%	79%	79%	53%	67%	53%	60%	52%
GF - 2025	99%	73%	75%	79%	79%	53%	67%	53%	60%	52%
GF - 2030	100%	95%	96%	96%	96%	92%	94%	92%	93%	91%
GF - 2035	100%	95%	96%	96%	96%	92%	94%	92%	93%	91%
PF - 2015	98%	51%	55%	62%	62%	15%	40%	15%	28%	13%
PF - 2020	98%	51%	55%	62%	62%	15%	40%	15%	28%	13%
PF - 2025	98%	51%	55%	62%	62%	15%	40%	15%	28%	13%
PF - 2030	98%	51%	55%	62%	62%	15%	40%	15%	28%	13%
PF – 2035	98%	51%	55%	62%	62%	15%	40%	15%	28%	13%
CF – 2015	98%	51%	55%	62%	62%	15%	40%	15%	28%	13%
CF – 2020	98%	51%	55%	62%	62%	15%	40%	15%	28%	13%
CF – 2025	74%	38%	41%	46%	46%	11%	30%	11%	21%	9%
CF – 2030	74%	38%	41%	46%	46%	11%	30%	11%	21%	9%
CF – 2035	49%	25%	28%	31%	31%	8%	20%	8%	14%	6%

Annex F. Maximum acceleration figures

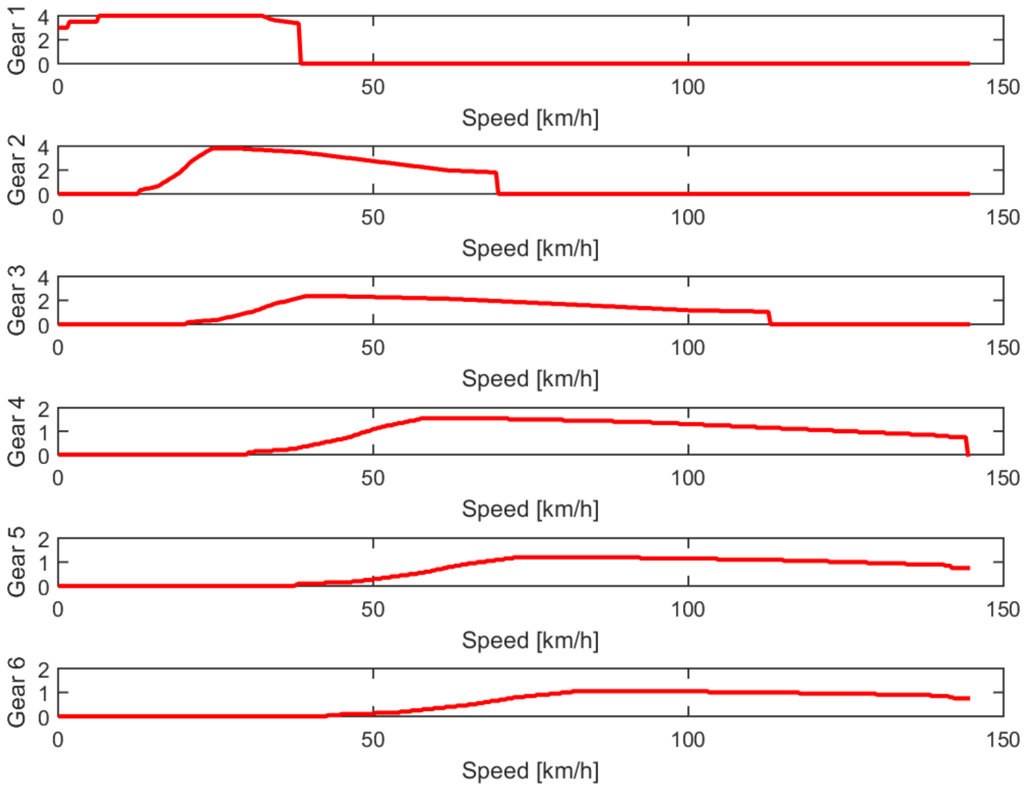

Figure 81: Maximum acceleration available [m/s^2] for Renault Scenic (diesel) for all possible combinations of speed and gears.

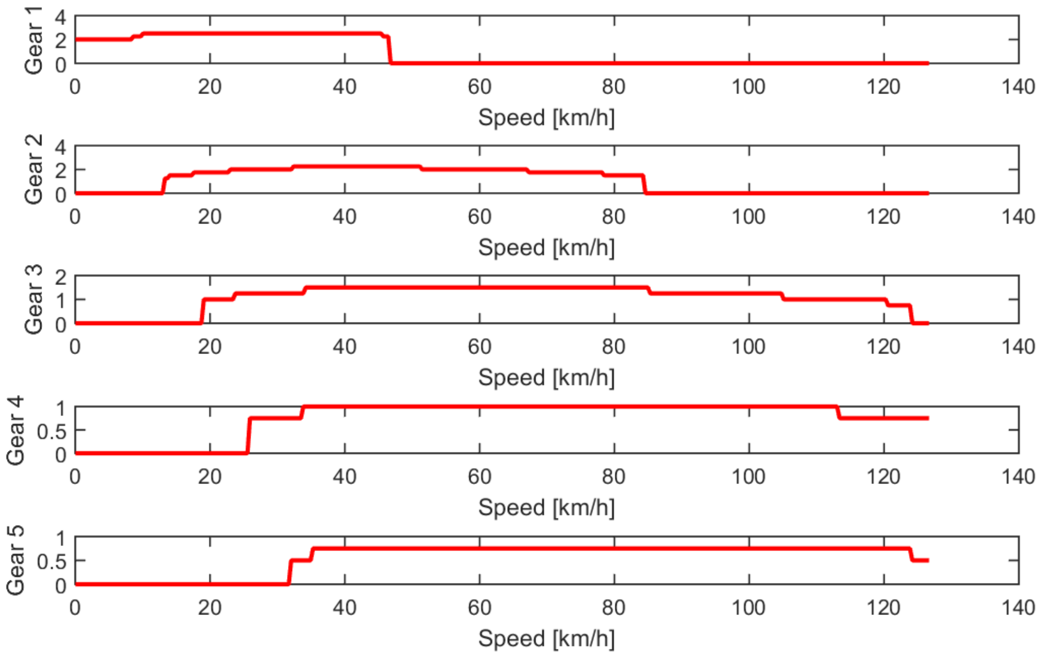

Figure 82: Maximum acceleration available [m/s^2] for Renault Clio (petrol) for all possible combinations of speed and gears.

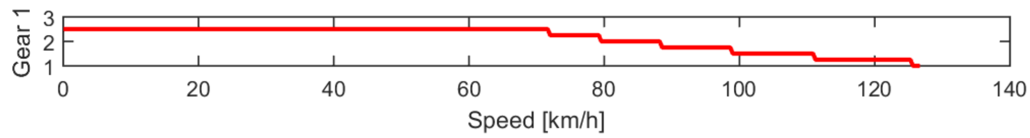

Figure 83: Maximum acceleration available [m/s^2] for Nissan Leaf (electric) for all possible combinations of speed and gears.

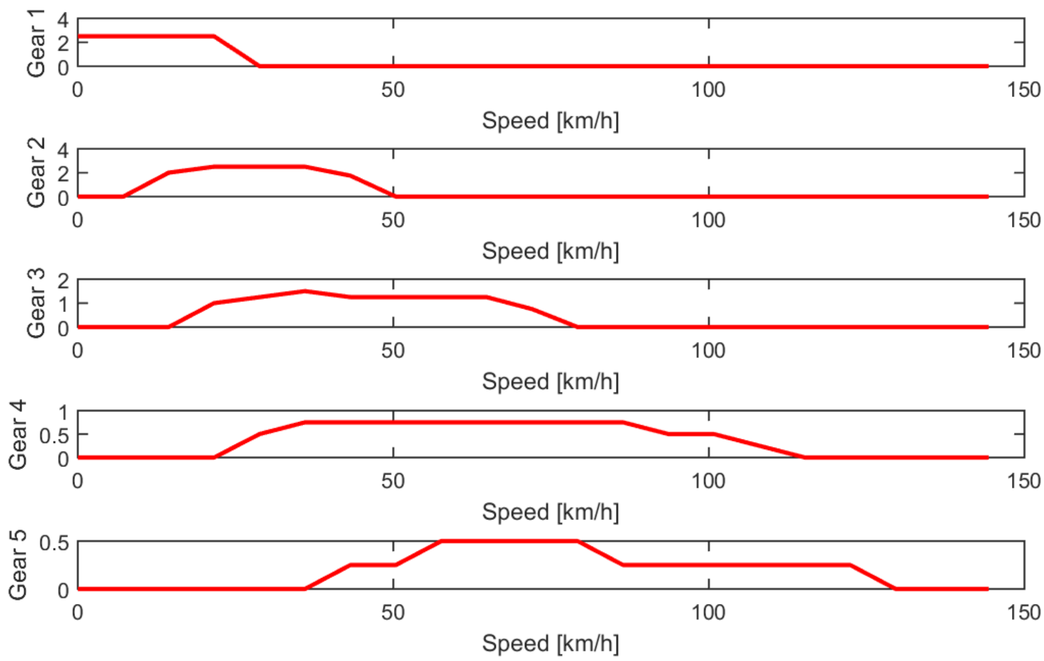

Figure 84: Maximum acceleration available [m/s^2] for VW Transporter (diesel) for all possible combinations of speed and gears.

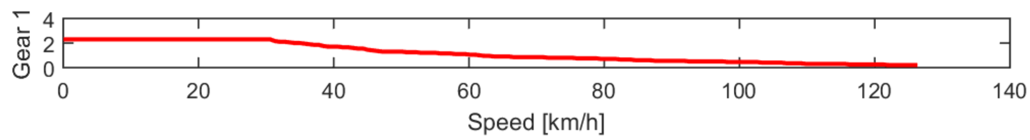

Figure 85: Maximum acceleration available [m/s^2] for DAF XF 15 tonnes (diesel) for all possible combinations of speed and gears.

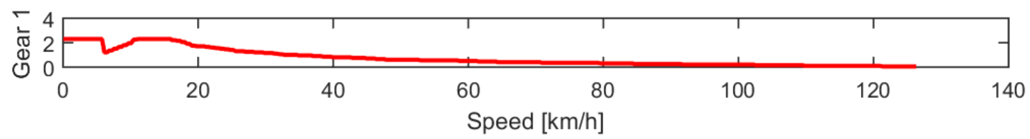

Figure 86: Maximum acceleration available [m/s^2] for DAF XF 30 tonnes (diesel) for all possible combinations of speed and gears.

Annex G. Gear ratios

Gear ratios are given in $\left[\frac{RPM}{\frac{km}{h}}\right]$. A * means that the vehicle is an automatic, % means that it has a variable transmission.

Table 63: Number of gears and gear ratios for each vehicle type.

Gear	Nissan Leaf	Renault Clio	Renault Scenic	VW Transporter T5 (van)	DAF LF (truck 15t)	DAF XF (truck 30t)
Number of gears	1*%	5	6	5	10*	10*
1	-	136.22	118.00	136.10	96.50	96.50
2	-	74.83	64.85	82.57	70.71	70.71
3	-	50.92	40.00	49.92	55.20	55.20
4	-	37.61	27.03	33.86	44.62	44.62
5	-	30.00	21.37	23.63	38.21	38.21
6	-	-	18.90	-	28.06	28.06
7	-	-	-	-	20.60	20.60
8	-	-	-	-	16.05	16.05
9	-	-	-	-	12.99	12.99
10	-	-	-	-	11.11	11.11

Annex H. Emission model details

The variables that are used are listed in Table 64.

Table 64: Overview of the IEM variables. The role is: P = input parameter, O = output, I = intermediate result. Input parameters can be fixed or varying during a simulation (but are assumed fixed in each application of the model). The default column shows the default value of a parameter, if applicable.

Variable	Role	Notation	Unit	Range	Default
Vehicle type	P	V	-	{EC,PC,DC,DV, DT}[1]	
ITS variant	P	I	-	{O,E,N}[2]	
Slope of the road (vertical displacement / road length, i.e., the sine of the slope angle)	P	H	-	$\mathbb{R}$	
Current vehicle speed	P	v	m/s	≥ 0	
Current vehicle speed	I	v_{kmh}	km/h	≥ 0	
Maximum valid deceleration	P	$a_{\min}$	m/s²	≤ 0	-5
Maximum valid acceleration	P	$a_{\max}$	m/s²	≥ 0	4
Current acceleration	P	a	m/s²	$\mathbb{R}$	
Bounded acceleration	I	a_{bound}	m/s²	$\mathbb{R}$	
Current engine speed	I	r	rpm	≥ 0	
Bounded engine speed	I	r_{bound}	rpm	≥ 0	
Contribution to CO_2 emission of engine	P	c_{engine}	60 g	≥ 0	Table 65
Contribution to CO_2 emission of inertia	P	c_{inertia}	3.6 g s^2 / m^2	≥ 0	Table 65
Acceleration gain due to slope	P	c_{slope}	m/s²	≥ 0	11
Contribution to CO_2 emission of rolling resistance	P	c_{roll}	3.6 g/m	≥ 0	Table 65
Contribution to CO_2 emission of aerodynamic resistance	P	c_{aero}	3.6^3 g s^2/m^3	≥ 0	Table 65
Coefficient of linear dependence of NO_x emission on CO_2 emission	P	n_{linear}	1/1000	≥ 0	Table 66

[1] These abbreviations stand for Electric Car, Petrol Car, Diesel Car, Diesel Van and Diesel Truck, respectively.
[2] These abbreviations stand for None, Embedded (FeDS) and Nomadic (android), respectively.

Variable	Role	Notation	Unit	Range	Default
Coefficient of quadratic dependence of NO_x emission on CO_2 emission	P	$n_{\text{quadratic}}$	s/(1000 g)	≥ 0	Table 66
Coefficient of dependence of NO_x emission on change in CO_2 emission		$n_{\text{transient}}$	s^5/(1000 g)	≥ 0	Table 66
Coefficient of dependence of NO_x emission on average CO_2 emission		n_{stable}	s/(1000 g)	≥ 0	Table 66
Ratio between fuel consumption and CO_2 emission	P	c_{fuel}	g/l	≥ 0	2370 for petrol, 2650 for diesel
Ratio between energy consumption and CO_2 emission	P	c_{energy}	g/J	≥ 0	$73.3 \cdot 10^{-6}$
Energy loss in engine and driveline	P	e_{engine}	-	≥ 0	25%
Energy recovery from braking	P	e_{brake}	-	≥ 0	70%
Gravitational acceleration	P	G	m/s^2	= 9.81	9.81
CO_2 emission	O	C	g/s	≥ 0	
NO_x emission	O	N	mg/s	≥ 0	
Fuel consumption per time unit	O	U	l/s	≥ 0	
Energy consumption per time unit	O	P	J/s	≥ 0	
Total external force	O	F_{ext}	N	$\mathbb{R}$	
Constant rolling resistance coefficient	O	$f_{\text{roll},0}$	m/s^2	≥ 0	
Linear rolling resistance coefficient	O	$f_{\text{roll},1}$	1/s	≥ 0	
Aerodynamic resistance coefficient	O	f_{aero}	1/m	≥ 0	
CO_2 emission on previous time step	I	C_p	g/s	≥ 0	
CO_2 emission on pre-previous time step	I	C_{pp}	g/s	≥ 0	
Time step	P	Δt	s	≥ 0	

Variable	Role	Notation	Unit	Range	Default
Second derivative of CO_2 emission with respect to time	I	C''	g/s^3	$\mathbb{R}$	
Average CO_2 emission over time	I	C_{av}	g/s	≥ 0	
Average CO_2 emission over time, on previous time step	I	$C_{\text{av,p}}$	g/s	≥ 0	

CO_2 emission

First the bounded acceleration is calculated as the acceleration bounded between a_{min} and a_{max}:

$$a_{\text{bound}} = \min\{a_{\text{max}}, \max\{a_{\text{min}}, a\}\} \tag{32}$$

In the traffic simulations we use the estimated engine speeds for all car types and the Van. If the engine speed is not available in the simulations the engine speeds r and r_{bound} are calculated as

$$r = \begin{cases} 1000 + \dfrac{1800 - 1000}{90} v_{\text{kmh}}, & V = DT \\ 30 \cdot v_{\text{kmh}}, & \text{otherwise} \end{cases} \tag{33}$$

$$r_{\text{bound}} = \begin{cases} \min\{r, 1800\}, & V = DT \\ \max\{r, 1800\}, & V \neq DT \end{cases} \tag{34}$$

Here $v_{\text{kmh}} = 3.6\, v$. The CO_2 emission is calculated as

$$C = \max\{0, c_{\text{engine}}\, r_{\text{bound}} + c_{\text{inertia}} v_{\text{kmh}} \left(a_{\text{bound}} + c_{\text{slope}}\, H\right) + c_{\text{roll}}\, v_{\text{kmh}} + c_{\text{aero}} v_{\text{kmh}}^3\} \tag{35}$$

NO_x emission

This is calculated as a function of the CO_2 emission:

$$N = n_{\text{linear}}\, C + n_{\text{quadratic}}\, C^2 + n_{\text{transient}}\, (C'')^2 + n_{\text{stable}}\, C\, (C_{\text{av}} - C) \tag{36}$$

Here the second derivative C'' is calculated by numerical approximation as

$$C'' = \frac{C - 2 * C_p + C_{pp}}{(\Delta t)^2} \tag{37}$$

The average C_{av} is calculated as a running average:

$$C_{\text{av}} = (1 - w\, \Delta t)\, C_{\text{av,p}} + w\, \Delta t\, C \tag{38}$$

Fuel consumption

The fuel consumption is calculated from the CO_2 emission as

$$U = C/c_{\mathrm{fuel}} \tag{39}$$

Energy consumption

If the CO_2 emission is known, then the energy consumption per time unit is calculated from the CO_2 emission as

$$P = C/c_{\mathrm{energy}} \tag{40}$$

Otherwise, first the bounded acceleration is calculated as follows:

$$a_{\mathrm{bound}} = \min\{a_{\max}, \max\{0, a\}\} \tag{41}$$

(Similar to (32), except that only positive accelerations are used).

Then the energy consumption per time unit is determined by

$$P = \begin{cases} (1 + e_{\mathrm{engine}}) \left(0.012\, m\, G + 0.04\, v_{\mathrm{kmh}}^2 + (1 - e_{\mathrm{brake}})\, m \left(a_{\mathrm{bound}} + c_{\mathrm{slope}}\, H\right)\right) \dfrac{v_{\mathrm{kmh}}}{3.6}, & v > 0 \\ 0, & v = 0 \end{cases} \tag{42}$$

External force

The energy consumption models incorporate the external forces due to rolling resistance, aerodynamic resistance and slope. Dividing by the vehicle speed, ignoring the energy and brake efficiency terms, selecting the components with correct dependencies on speed and slope yields:

$$F_{\mathrm{ext}} = 0.012\, m\, G + 0.04\, v_{\mathrm{kmh}}^2 + m\, c_{\mathrm{slope}}\, H \tag{43}$$

The external force model (see emulator doc) is of the form:

$$F_{\mathrm{ext}} = f_{\mathrm{roll}}\, m\, G \sqrt{1 - H^2} \, + \, f_{\mathrm{aero}} v^2 + m\, G\, H \tag{44}$$

Assuming H is close to 0, the term $\sqrt{1 - H^2}$ is close to 1 and hence is ignored. By comparing (43) and (44) the parameters f_{roll} and f_{aero} can be expressed in terms of the parameters used in (43):

$$f_{\mathrm{roll}} = 0.012, \qquad f_{\mathrm{aero}} = 3.6^2 \cdot 0.04 \approx 0.52 \tag{45}$$

Here the mass of the electric car is set to 1500kg. These are reasonable values, and quite similar to the ones used in the external forces model of the Leaf, namely:

$$f_{\text{roll}} = 0.01, \quad f_{\text{aero}} = 0.41 \tag{46}$$

The slope components of (43) and (44) are not quite the same, because $c_{\text{slope}} = 11$ is not equal to G. In all cases, the values used in the emission model are 10-20% higher than those used in the vehicle model, perhaps because they include some efficiency losses.

Table 65: Parameter values for the CO_2 model.

Vehicle category	c_{engine}	c_{inertia}	c_{roll}	c_{aero}
Passenger Diesel car (Scenic)	0.0003	0.08	0.009	0.0000008
Passenger Petrol car (Clio)	0.00039	0.08	0.009	0.0000008
Light Commercial Vehicle (VW Transporter T5)	0.000422	0.073564	0.02972	0.0000021
Truck Urban 15t Rigid Truck (DAF LF)	0.001412	0.269618	0.061899	1.326E-05
Truck Motorway/Rural 30t Rigid Truck (DAF XF)	0.002156	0.527691	0.123798	1.326E-05

Table 66: Parameter values for the NO_x model.

Vehicle category	n_{linear}	$n_{\text{quadratic}}$	$n_{\text{transient}}$	n_{stable}
Passenger Diesel car (Scenic)	3	0.3	0.35	0.1
Passenger Petrol car (Clio)	0.1165	0.00689	0.0125	-0.00125
Light Commercial Vehicle (VW Transporter T5)	3.495099	0.563841	0.194716	0.159257
Truck Urban 15t Rigid Truck (DAF LF)	10.66094	-0.64963	0.103212	-0.72621
Truck Motorway/Rural 30t Rigid Truck (DAF XF)	8.44858	-0.26991	0.070667	-0.31033

Annex I. Simulation results

Simulation results for the motorway networks

Table 67: Change in the performance indicators for the urban motorway simulations with moderate demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF20	car	-1.0%	-1.9%	-1.0%	-1.0%	-0.2%	-0.2%	0.6%	0.8%
CF25	car	-1.1%	-2.5%	-1.1%	-1.1%	-0.4%	-0.4%	0.9%	1.1%
CF30	car	-1.3%	-3.5%	-1.3%	-1.3%	-0.5%	-0.5%	1.1%	1.4%
CF35	car	-0.7%	-1.7%	-0.7%	-0.7%	-0.3%	-0.4%	1.2%	1.5%
PF20	car	-1.0%	-1.6%	-1.0%	-1.0%	-0.1%	-0.2%	0.6%	0.7%
PF25	car	-1.1%	-2.6%	-1.1%	-1.1%	(N.S.)	-0.3%	(N.S.)	(N.S.)
PF30	car	-1.2%	-3.1%	-1.2%	-1.2%	-0.3%	-0.4%	0.5%	0.7%
PF35	car	-1.2%	-3.0%	-1.1%	-0.8%	-0.2%	-0.4%	(N.S.)	(N.S.)
GF20	car	-1.1%	-2.1%	-1.1%	-1.1%	(N.S.)	-0.1%	(N.S.)	(N.S.)
GF25	car	-1.5%	-4.0%	-1.5%	-1.1%	(N.S.)	(N.S.)	-0.8%	-1.0%
GF30	car	-1.9%	-5.2%	-1.9%	-1.6%	0.6%	(N.S.)	-2.6%	-3.2%
GF35	car	-1.9%	-5.5%	-1.8%	-1.8%	0.4%	(N.S.)	-2.4%	-3.0%
CF20	van	-0.3%	-0.6%	-0.3%	-0.3%	-0.4%	-0.4%	0.6%	0.8%
CF25	van	-0.4%	-1.0%	-0.4%	-0.4%	-0.6%	-0.7%	0.9%	1.1%
CF30	van	-0.5%	-1.1%	-0.5%	-0.5%	-0.5%	-0.5%	1.1%	1.4%
CF35	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.5%	-0.6%	1.2%	1.5%
PF20	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	0.6%	0.7%
PF25	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.7%	(N.S.)	(N.S.)
PF30	van	-0.3%	-0.7%	-0.2%	-0.3%	(N.S.)	-0.6%	0.5%	0.7%
PF35	van	-0.6%	-1.3%	-0.5%	-0.6%	(N.S.)	-0.5%	(N.S.)	(N.S.)
GF20	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)
GF25	van	-0.8%	-1.7%	-0.8%	-0.8%	(N.S.)	(N.S.)	-0.8%	-1.0%
GF30	van	-1.0%	-2.2%	-0.9%	-1.0%	0.2%	-0.2%	-2.6%	-3.2%
GF35	van	-0.9%	-2.1%	-0.8%	-0.9%	0.4%	(N.S.)	-2.4%	-3.0%
CF20	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.4%	-0.5%	0.6%	0.8%
CF25	truck	-0.9%	3.2%	-0.9%	-0.9%	0.5%	0.4%	0.9%	1.1%
CF30	truck	-2.0%	6.7%	-1.9%	-2.0%	1.6%	1.5%	1.1%	1.4%
CF35	truck	-1.4%	5.1%	-1.4%	-1.4%	1.0%	1.0%	1.2%	1.5%
PF20	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.3%	-0.4%	0.6%	0.7%
PF25	truck	-1.7%	6.1%	-1.7%	-1.7%	1.3%	1.2%	(N.S.)	(N.S.)
PF30	truck	-3.5%	11.4%	-3.5%	-3.5%	2.8%	2.7%	0.5%	0.7%
PF35	truck	-4.2%	14.3%	-4.2%	-4.2%	3.6%	3.4%	(N.S.)	(N.S.)
GF20	truck	-0.8%	3.0%	-0.8%	-0.8%	0.4%	0.3%	(N.S.)	(N.S.)
GF25	truck	-2.9%	1(N.S.)	-2.8%	-2.9%	2.5%	2.4%	-0.8%	-1.0%
GF30	truck	-5.8%	20.6%	-5.8%	-5.8%	5.3%	5.1%	-2.6%	-3.2%
GF35	truck	-7.5%	25.8%	-7.5%	-7.5%	6.8%	6.6%	-2.4%	-3.0%

Table 68: Change in the performance indicators for the urban motorway simulations with low demand

Scenario	Vehicle type	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF20	car	-0.8%	-1.5%	-0.8%	-0.8%	-0.2%	-0.2%	0.6%	0.7%
CF25	car	-1.1%	-2.2%	-1.1%	-1.1%	-0.2%	-0.2%	1.0%	1.2%
CF30	car	-1.0%	-2.7%	-1.0%	-1.0%	-0.4%	-0.5%	0.9%	1.2%
CF35	car	-0.6%	-1.6%	-0.6%	-0.6%	-0.4%	-0.4%	1.2%	1.5%
PF20	car	-0.7%	-1.3%	-0.8%	-0.7%	-0.1%	-0.1%	0.3%	0.3%
PF25	car	-1.1%	-2.2%	-1.1%	-1.1%	(N.S.)	-0.2%	(N.S.)	(N.S.)
PF30	car	-0.9%	-2.2%	-0.8%	-0.9%	(N.S.)	-0.2%	(N.S.)	(N.S.)
PF35	car	-1.0%	-2.4%	-1.0%	-0.6%	-0.1%	-0.3%	-0.4%	-0.4%
GF20	car	-0.9%	-1.4%	-0.9%	-0.9%	(N.S.)	(N.S.)	-0.4%	-0.5%
GF25	car	-1.8%	-4.7%	-1.8%	-1.4%	0.3%	(N.S.)	-1.2%	-1.5%
GF30	car	-1.9%	-5.3%	-1.9%	-1.6%	0.5%	0.0%	-2.6%	-3.2%
GF35	car	-1.8%	-5.5%	-1.8%	-1.8%	0.5%	(N.S.)	-2.7%	-3.3%
CF20	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	0.6%	0.7%
CF25	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.6%	-0.6%	1.0%	1.2%
CF30	van	-0.5%	-1.2%	-0.5%	-0.5%	(N.S.)	-0.5%	0.9%	1.2%
CF35	van	-0.4%	-1.0%	-0.4%	-0.4%	(N.S.)	-0.3%	1.2%	1.5%
PF20	van	-0.5%	-0.9%	-0.5%	-0.5%	(N.S.)	(N.S.)	0.3%	0.3%
PF25	van	-0.4%	-1.1%	-0.4%	-0.5%	-0.4%	-0.6%	(N.S.)	(N.S.)
PF30	van	-0.8%	-1.6%	-0.8%	-0.8%	0.4%	(N.S.)	(N.S.)	(N.S.)
PF35	van	-0.9%	-2.1%	-0.9%	-0.9%	(N.S.)	(N.S.)	-0.4%	-0.4%
GF20	van	-0.6%	-1.2%	-0.5%	-0.6%	(N.S.)	0.0%	-0.4%	-0.5%
GF25	van	(N.S.)	-1.2%	(N.S.)	(N.S.)	0.0%	(N.S.)	-1.2%	-1.5%
GF30	van	-0.9%	-2.1%	-0.9%	-0.9%	0.6%	0.0%	-2.6%	-3.2%
GF35	van	-1.0%	-2.3%	-1.0%	-1.0%	0.8%	(N.S.)	-2.7%	-3.3%
CF20	truck	0.2%	(N.S.)	0.2%	0.2%	-0.3%	-0.4%	0.6%	0.7%
CF25	truck	-0.6%	2.5%	-0.6%	-0.6%	0.3%	0.2%	1.0%	1.2%
CF30	truck	-1.3%	5.1%	-1.3%	-1.3%	0.9%	0.8%	0.9%	1.2%
CF35	truck	-1.5%	5.2%	-1.5%	-1.5%	1.0%	0.9%	1.2%	1.5%
PF20	truck	0.2%	(N.S.)	0.2%	0.2%	-0.4%	-0.4%	0.3%	0.3%
PF25	truck	-1.4%	5.4%	-1.4%	-1.4%	1.1%	1.0%	(N.S.)	(N.S.)
PF30	truck	-3.0%	10.5%	-3.0%	-3.0%	2.6%	2.4%	(N.S.)	(N.S.)
PF35	truck	-4.0%	14.0%	-4.0%	-4.0%	3.5%	3.3%	-0.4%	-0.4%
GF20	truck	-0.7%	3.0%	-0.7%	-0.7%	0.6%	0.5%	-0.4%	-0.5%
GF25	truck	-2.7%	10.2%	-2.7%	-2.7%	2.6%	2.4%	-1.2%	-1.5%
GF30	truck	-5.8%	20.8%	-5.7%	-5.8%	5.3%	5.1%	-2.6%	-3.2%
GF35	truck	-8.1%	29.0%	-8.1%	-8.1%	7.6%	7.4%	-2.7%	-3.3%

Table 69: Change in the performance indicators for the interurban motorway simulations with low demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF20	car	(N.S.)	2.3%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)
CF25	car	-0.4%	(N.S.)	-0.4%	-0.4%	0.1%	(N.S.)	-0.4%	-0.4%
CF30	car	-0.3%	(N.S.)	-0.2%	-0.3%	0.3%	(N.S.)	-0.9%	-1.1%
CF35	car	(N.S.)	2.2%	0.3%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)
PF20	car	(N.S.)	1.6%	(N.S.)	(N.S.)	0.2%	0.1%	-0.5%	-0.6%
PF25	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)
PF30	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	0.5%	(N.S.)	-2.0%	-2.4%
PF35	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	0.5%	(N.S.)	-2.0%	-2.5%
GF20	car	(N.S.)	2.4%	(N.S.)	(N.S.)	0.3%	(N.S.)	-1.0%	-1.2%
GF25	car	-0.4%	(N.S.)	-0.3%	-0.4%	0.8%	0.3%	-3.0%	-3.6%
GF30	car	-1.1%	(N.S.)	-0.9%	-0.5%	1.2%	0.4%	-4.8%	-5.9%
GF35	car	-0.3%	1.6%	-0.2%	(N.S.)	1.0%	(N.S.)	-4.4%	-5.4%
CF20	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.9%	-1.0%	(N.S.)	(N.S.)
CF25	van	0.4%	0.9%	0.4%	0.4%	-1.0%	-1.1%	-0.4%	-0.4%
CF30	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.4%	-1.6%	-0.9%	-1.1%
CF35	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.3%	-1.4%	(N.S.)	(N.S.)
PF20	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.4%	-0.5%	-0.6%
PF25	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.8%	-1.1%	(N.S.)	(N.S.)
PF30	van	0.3%	0.7%	0.2%	0.3%	-1.0%	-1.4%	-2.0%	-2.4%
PF35	van	-1.0%	-1.4%	-1.1%	-1.0%	(N.S.)	-0.7%	-2.0%	-2.5%
GF20	van	(N.S.)	(N.S.)	-0.4%	(N.S.)	(N.S.)	(N.S.)	-1.0%	-1.2%
GF25	van	(N.S.)	(N.S.)	-0.5%	(N.S.)	(N.S.)	-0.8%	-3.0%	-3.6%
GF30	van	-1.2%	-1.7%	-1.2%	-1.2%	(N.S.)	(N.S.)	-4.8%	-5.9%
GF35	van	-1.0%	-1.8%	-1.1%	-1.0%	1.2%	0.4%	-4.4%	-5.4%
CF20	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)
CF25	truck	-1.1%	4.1%	-1.1%	-1.1%	1.0%	1.0%	-0.4%	-0.4%
CF30	truck	-2.5%	9.0%	-2.5%	-2.5%	2.3%	2.3%	-0.9%	-1.1%
CF35	truck	-2.0%	7.4%	-2.0%	-2.0%	1.9%	1.9%	(N.S.)	(N.S.)
PF20	truck	0.1%	-0.1%	0.1%	0.1%	0.0%	-0.1%	-0.5%	-0.6%
PF25	truck	-2.3%	8.8%	-2.3%	-2.3%	2.3%	2.2%	(N.S.)	(N.S.)
PF30	truck	-3.6%	14.1%	-3.7%	-3.6%	3.8%	3.7%	-2.0%	-2.4%
PF35	truck	-4.6%	18.0%	-4.7%	-4.6%	4.7%	4.7%	-2.0%	-2.5%
GF20	truck	-1.2%	4.6%	-1.2%	-1.2%	1.2%	1.2%	-1.0%	-1.2%
GF25	truck	-3.9%	15.2%	-3.9%	-3.9%	4.1%	4.1%	-3.0%	-3.6%
GF30	truck	-7.2%	28.1%	-7.2%	-7.2%	7.6%	7.6%	-4.8%	-5.9%
GF35	truck	-8.5%	33.4%	-8.5%	-8.5%	9.0%	9.0%	-4.4%	-5.4%

Table 70: Change in the performance indicators for the interurban motorway simulations with moderate demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF20	car	0.4%	3.1%	0.4%	0.4%	(N.S.)	(N.S.)	(N.S.)	(N.S.)
CF25	car	(N.S.)	2.8%	0.3%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)
CF30	car	0.3%	2.9%	0.4%	0.3%	(N.S.)	0.5%	(N.S.)	(N.S.)
CF35	car	0.8%	5.1%	0.9%	0.8%	(N.S.)	(N.S.)	(N.S.)	(N.S.)
PF20	car	(N.S.)	4.2%	0.6%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)
PF25	car	1.2%	6.5%	1.2%	1.2%	(N.S.)	2.7%	(N.S.)	(N.S.)
PF30	car	0.6%	4.7%	0.7%	0.6%	(N.S.)	(N.S.)	-1.0%	-1.2%
PF35	car	0.2%	3.6%	0.3%	0.5%	(N.S.)	0.8%	(N.S.)	(N.S.)
GF20	car	(N.S.)	3.0%	(N.S.)	(N.S.)	0.4%	4.4%	-1.6%	-2.0%
GF25	car	0.5%	5.3%	0.6%	0.8%	0.3%	(N.S.)	-1.7%	-2.1%
GF30	car	0.0%	3.8%	0.1%	(N.S.)	0.9%	-0.4%	-3.9%	-4.7%
GF35	car	0.8%	8.3%	0.9%	0.8%	1.3%	5.5%	-5.4%	-6.6%
CF20	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)
CF25	van	-0.4%	-0.6%	-0.5%	-0.4%	(N.S.)	0.7%	(N.S.)	(N.S.)
CF30	van	-0.9%	-1.4%	-0.9%	-0.9%	(N.S.)	1.4%	(N.S.)	(N.S.)
CF35	van	-0.8%	-1.1%	-0.8%	-0.8%	(N.S.)	(N.S.)	(N.S.)	(N.S.)
PF20	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	1.0%	(N.S.)	(N.S.)
PF25	van	-0.6%	-0.9%	-0.6%	-0.6%	(N.S.)	4.6%	(N.S.)	(N.S.)
PF30	van	-1.2%	-1.9%	-1.2%	-1.2%	1.0%	(N.S.)	-1.0%	-1.2%
PF35	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	0.7%	(N.S.)	(N.S.)
GF20	van	-0.7%	-1.0%	-0.7%	-0.7%	0.8%	7.8%	-1.6%	-2.0%
GF25	van	-1.2%	-1.9%	-1.2%	-1.2%	1.2%	0.7%	-1.7%	-2.1%
GF30	van	-0.8%	-1.4%	-0.8%	-0.8%	1.1%	1.0%	-3.9%	-4.7%
GF35	van	-0.9%	-1.5%	-1.0%	-0.9%	1.4%	8.9%	-5.4%	-6.6%
CF20	truck	-0.4%	1.3%	-0.4%	-0.4%	0.3%	(N.S.)	(N.S.)	(N.S.)
CF25	truck	-1.5%	5.6%	-1.5%	-1.5%	1.4%	(N.S.)	(N.S.)	(N.S.)
CF30	truck	-2.7%	10.7%	-2.7%	-2.7%	2.9%	0.3%	(N.S.)	(N.S.)
CF35	truck	-2.4%	9.5%	-2.4%	-2.4%	2.5%	(N.S.)	(N.S.)	(N.S.)
PF20	truck	-0.7%	2.3%	-0.7%	-0.7%	0.5%	(N.S.)	(N.S.)	(N.S.)
PF25	truck	-2.7%	10.4%	-2.7%	-2.7%	2.8%	1.4%	(N.S.)	(N.S.)
PF30	truck	-4.3%	17.0%	-4.3%	-4.3%	4.5%	(N.S.)	-1.0%	-1.2%
PF35	truck	-5.3%	20.8%	-5.3%	-5.3%	5.5%	(N.S.)	(N.S.)	(N.S.)
GF20	truck	-1.4%	5.7%	-1.4%	-1.4%	1.5%	2.8%	-1.6%	-2.0%
GF25	truck	-4.2%	17.4%	-4.2%	-4.2%	4.6%	(N.S.)	-1.7%	-2.1%
GF30	truck	-7.2%	29.3%	-7.2%	-7.2%	7.8%	(N.S.)	-3.9%	-4.7%
GF35	truck	-8.5%	33.6%	-8.5%	-8.5%	9.0%	2.5%	-5.4%	-6.6%

Simulation results for the rural road networks

Table 71: Change in the performance indicators for the flat rural road with high intersection density simulated with low demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	0.8%	0.1%	-2.5%	-3.1%
CF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.5%	-3.1%
CF 2020	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.5%	-3.1%
CF 2025	car	-0.4%	(N.S.)	-0.4%	-0.4%	1.2%	0.2%	-4.1%	-5.0%
CF 2025	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-4.1%	-5.0%
CF 2025	van	-0.7%	-1.7%	-0.7%	-0.7%	1.5%	(N.S.)	-4.1%	-5.0%
CF 2030	car	-0.6%	(N.S.)	-0.6%	-0.6%	1.7%	0.2%	-5.9%	-7.2%
CF 2030	truck	(N.S.)	4.5%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-5.9%	-7.2%
CF 2030	van	-1.4%	-3.1%	-1.3%	-1.3%	2.7%	0.3%	-5.9%	-7.2%
CF 2035	car	-0.5%	(N.S.)	-0.5%	-0.4%	1.3%	0.2%	-4.8%	-5.8%
CF 2035	truck	(N.S.)	4.1%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-4.8%	-5.8%
CF 2035	van	-1.0%	-2.4%	-1.0%	-1.0%	2.2%	(N.S.)	-4.8%	-5.8%
GF 2020	car	-0.8%	-1.1%	-0.8%	-0.7%	1.8%	0.2%	-5.3%	-6.4%
GF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-5.3%	-6.4%
GF 2020	van	-1.0%	-2.2%	-1.0%	-0.9%	1.9%	(N.S.)	-5.3%	-6.4%
GF 2025	car	-2.1%	-3.4%	-2.1%	-2.1%	4.3%	0.4%	-12.9%	-15.6%
GF 2025	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-12.9%	-15.6%
GF 2025	van	-2.5%	-5.5%	-2.5%	-2.4%	4.5%	0.4%	-12.9%	-15.6%
GF 2030	car	-3.5%	-5.3%	-3.4%	-3.4%	6.7%	0.7%	-19.8%	-23.8%
GF 2030	truck	(N.S.)	9.8%	(N.S.)	-0.3%	3.5%	(N.S.)	-19.8%	-23.8%
GF 2030	van	-4.0%	-8.9%	-4.0%	-3.8%	7.0%	0.7%	-19.8%	-23.8%
GF 2035	car	-3.6%	-5.9%	-3.5%	-3.5%	6.9%	0.7%	-21.2%	-25.4%
GF 2035	truck	-0.4%	12.3%	-0.4%	-0.4%	4.6%	(N.S.)	-21.2%	-25.4%
GF 2035	van	-5.0%	-11.2%	-5.0%	-4.8%	8.7%	0.8%	-21.2%	-25.4%
PF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	0.8%	0.1%	-2.5%	-3.1%
PF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.5%	-3.1%
PF 2020	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.5%	-3.1%
PF 2025	car	-0.9%	-1.1%	-0.8%	-0.8%	1.9%	0.2%	-6.8%	-8.3%
PF 2025	truck	(N.S.)	5.4%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-6.8%	-8.3%
PF 2025	van	-1.7%	-4.0%	-1.7%	-1.7%	3.1%	(N.S.)	-6.8%	-8.3%
PF 2030	car	-1.3%	-1.6%	-1.3%	-1.3%	2.8%	0.3%	-9.7%	-11.8%
PF 2030	truck	(N.S.)	7.1%	(N.S.)	(N.S.)	2.6%	(N.S.)	-9.7%	-11.8%
PF 2030	van	-2.6%	-5.9%	-2.6%	-2.6%	4.6%	0.4%	-9.7%	-11.8%
PF 2035	car	-1.6%	-2.2%	-1.6%	-1.6%	3.1%	0.3%	-11.2%	-13.6%
PF 2035	truck	-0.4%	8.6%	-0.4%	-0.4%	3.2%	(N.S.)	-11.2%	-13.6%
PF 2035	van	-3.4%	-7.8%	-3.4%	-3.4%	5.8%	0.4%	-11.2%	-13.6%

Table 72: Change in the performance indicators for the flat rural road with high intersection density simulated with moderate demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.5%	-1.9%
CF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.5%	-1.9%
CF 2020	van	(N.S.)	-1.1%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.5%	-1.9%
CF 2025	car	-0.3%	(N.S.)	-0.3%	-0.3%	(N.S.)	(N.S.)	-3.1%	-3.8%
CF 2025	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-3.1%	-3.8%
CF 2025	van	-0.7%	-2.1%	-0.7%	-0.7%	1.2%	(N.S.)	-3.1%	-3.8%
CF 2030	car	-0.6%	(N.S.)	-0.6%	-0.6%	1.4%	(N.S.)	-4.9%	-6.0%
CF 2030	truck	(N.S.)	3.5%	(N.S.)	(N.S.)	1.4%	(N.S.)	-4.9%	-6.0%
CF 2030	van	-1.2%	-3.3%	-1.2%	-1.2%	1.9%	(N.S.)	-4.9%	-6.0%
CF 2035	car	-0.4%	(N.S.)	-0.4%	-0.4%	1.3%	(N.S.)	-4.3%	-5.3%
CF 2035	truck	(N.S.)	3.1%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-4.3%	-5.3%
CF 2035	van	-1.0%	-2.8%	-1.0%	-1.0%	1.7%	(N.S.)	-4.3%	-5.3%
GF 2020	car	-0.7%	(N.S.)	-0.7%	-0.7%	1.4%	(N.S.)	-4.4%	-5.4%
GF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-4.4%	-5.4%
GF 2020	van	-0.8%	-2.6%	-0.8%	-0.8%	1.3%	(N.S.)	-4.4%	-5.4%
GF 2025	car	-1.8%	-4.2%	-1.8%	-1.8%	2.9%	(N.S.)	-9.7%	-11.7%
GF 2025	truck	-0.2%	4.8%	-0.2%	-0.2%	1.8%	(N.S.)	-9.7%	-11.7%
GF 2025	van	-1.8%	-5.0%	-1.8%	-1.8%	2.9%	(N.S.)	-9.7%	-11.7%
GF 2030	car	-2.8%	-7.2%	-2.8%	-2.8%	4.5%	1.0%	-14.6%	-17.6%
GF 2030	truck	-0.3%	9.7%	-0.3%	-0.3%	3.7%	(N.S.)	-14.6%	-17.6%
GF 2030	van	-2.7%	-7.8%	-2.7%	-2.6%	4.4%	0.8%	-14.6%	-17.6%
GF 2035	car	-2.9%	-7.2%	-2.9%	-3.0%	4.9%	1.2%	-15.8%	-19.1%
GF 2035	truck	-0.4%	12.2%	-0.5%	-0.5%	4.6%	0.5%	-15.8%	-19.1%
GF 2035	van	-3.0%	-9.1%	-3.0%	-2.8%	4.9%	1.1%	-15.8%	-19.1%
PF 2020	car	-0.3%	(N.S.)	-0.3%	-0.3%	(N.S.)	(N.S.)	-2.1%	-2.6%
PF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.1%	-2.6%
PF 2020	van	(N.S.)	-1.4%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.1%	-2.6%
PF 2025	car	-0.8%	(N.S.)	-0.8%	-0.8%	1.7%	(N.S.)	-5.9%	-7.2%
PF 2025	truck	-0.2%	4.6%	-0.2%	-0.2%	1.7%	(N.S.)	-5.9%	-7.2%
PF 2025	van	-1.2%	-3.5%	-1.2%	-1.2%	2.0%	(N.S.)	-5.9%	-7.2%
PF 2030	car	-1.2%	(N.S.)	-1.2%	-1.2%	2.4%	(N.S.)	-8.3%	-10.0%
PF 2030	truck	-0.3%	6.7%	-0.3%	-0.3%	2.5%	(N.S.)	-8.3%	-10.0%
PF 2030	van	-1.7%	-5.3%	-1.7%	-1.7%	2.8%	(N.S.)	-8.3%	-10.0%
PF 2035	car	-1.3%	(N.S.)	-1.3%	-1.4%	2.9%	0.8%	-9.8%	-12.0%
PF 2035	truck	-0.4%	8.8%	-0.4%	-0.4%	3.3%	(N.S.)	-9.8%	-12.0%
PF 2035	van	-2.1%	-6.7%	-2.1%	-2.0%	3.2%	(N.S.)	-9.8%	-12.0%

Table 73: Change in the performance indicators for the flat rural road with low intersection density simulated with low demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.5%	-1.8%
CF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.5%	-1.8%
CF 2020	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.5%	-1.8%
CF 2025	car	-0.3%	(N.S.)	-0.3%	(N.S.)	1.0%	0.2%	-3.6%	-4.4%
CF 2025	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-3.6%	-4.4%
CF 2025	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	1.3%	(N.S.)	-3.6%	-4.4%
CF 2030	car	-0.5%	(N.S.)	-0.4%	-0.4%	1.4%	0.2%	-5.0%	-6.1%
CF 2030	truck	(N.S.)	4.1%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-5.0%	-6.1%
CF 2030	van	-1.0%	-2.3%	-1.0%	-1.0%	2.1%	(N.S.)	-5.0%	-6.1%
CF 2035	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	1.2%	0.2%	-4.1%	-5.0%
CF 2035	truck	(N.S.)	3.8%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-4.1%	-5.0%
CF 2035	van	-0.7%	-1.6%	-0.7%	-0.7%	1.6%	(N.S.)	-4.1%	-5.0%
GF 2020	car	-0.4%	(N.S.)	-0.4%	-0.4%	1.3%	(N.S.)	-3.8%	-4.6%
GF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-3.8%	-4.6%
GF 2020	van	-0.7%	-1.4%	-0.7%	-0.7%	1.4%	(N.S.)	-3.8%	-4.6%
GF 2025	car	-1.8%	-2.9%	-1.8%	-1.8%	3.8%	0.2%	-11.4%	-13.8%
GF 2025	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-11.4%	-13.8%
GF 2025	van	-2.1%	-4.6%	-2.1%	-2.1%	3.7%	(N.S.)	-11.4%	-13.8%
GF 2030	car	-3.1%	-4.6%	-3.0%	-3.1%	5.9%	0.3%	-17.9%	-21.6%
GF 2030	truck	-0.4%	9.1%	-0.4%	-0.4%	3.1%	(N.S.)	-17.9%	-21.6%
GF 2030	van	-3.5%	-7.7%	-3.5%	-3.4%	5.9%	0.3%	-17.9%	-21.6%
GF 2035	car	-3.1%	-5.0%	-3.1%	-3.1%	6.1%	0.3%	-19.3%	-23.2%
GF 2035	truck	-0.5%	11.4%	-0.5%	-0.5%	4.2%	(N.S.)	-19.3%	-23.2%
GF 2035	van	-4.4%	-10.0%	-4.4%	-4.2%	7.4%	0.3%	-19.3%	-23.2%
PF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.7%	-2.1%
PF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.7%	-2.1%
PF 2020	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.7%	-2.1%
PF 2025	car	-0.7%	(N.S.)	-0.7%	-0.7%	1.6%	(N.S.)	-5.6%	-6.9%
PF 2025	truck	(N.S.)	4.7%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-5.6%	-6.9%
PF 2025	van	-1.2%	-2.8%	-1.2%	-1.2%	2.2%	(N.S.)	-5.6%	-6.9%
PF 2030	car	-1.0%	(N.S.)	-1.0%	-1.0%	2.3%	0.2%	-8.3%	-10.1%
PF 2030	truck	(N.S.)	6.3%	(N.S.)	(N.S.)	2.3%	(N.S.)	-8.3%	-10.1%
PF 2030	van	-2.1%	-4.9%	-2.1%	-2.2%	3.7%	(N.S.)	-8.3%	-10.1%
PF 2035	car	-1.3%	-1.3%	-1.3%	-1.3%	2.7%	0.2%	-9.8%	-11.9%
PF 2035	truck	-0.4%	8.2%	-0.4%	-0.4%	2.9%	(N.S.)	-9.8%	-11.9%
PF 2035	van	-2.9%	-6.7%	-2.9%	-3.0%	4.9%	(N.S.)	-9.8%	-11.9%

Table 74: Change in the performance indicators for the flat rural road with low intersection density simulated with moderate demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.9%	-1.1%
CF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.9%	-1.1%
CF 2020	van	(N.S.)	-0.9%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.9%	-1.1%
CF 2025	car	-0.4%	(N.S.)	-0.4%	-0.4%	(N.S.)	(N.S.)	-2.4%	-3.0%
CF 2025	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.4%	-3.0%
CF 2025	van	-0.6%	-1.8%	-0.6%	-0.6%	(N.S.)	(N.S.)	-2.4%	-3.0%
CF 2030	car	-0.6%	(N.S.)	-0.6%	-0.6%	1.2%	(N.S.)	-4.1%	-5.0%
CF 2030	truck	(N.S.)	2.9%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-4.1%	-5.0%
CF 2030	van	-1.1%	-3.0%	-1.1%	-1.1%	1.6%	(N.S.)	-4.1%	-5.0%
CF 2035	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	0.9%	(N.S.)	-3.3%	-4.1%
CF 2035	truck	(N.S.)	2.7%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-3.3%	-4.1%
CF 2035	van	-0.8%	-2.7%	-0.8%	-0.8%	1.2%	(N.S.)	-3.3%	-4.1%
GF 2020	car	-0.6%	(N.S.)	-0.6%	-0.6%	0.9%	(N.S.)	-2.9%	-3.6%
GF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.9%	-3.6%
GF 2020	van	-0.7%	-2.2%	-0.7%	-0.7%	0.8%	(N.S.)	-2.9%	-3.6%
GF 2025	car	-1.7%	-4.4%	-1.7%	-1.7%	2.4%	(N.S.)	-8.3%	-10.1%
GF 2025	truck	-0.2%	4.1%	-0.2%	-0.2%	1.5%	(N.S.)	-8.3%	-10.1%
GF 2025	van	-1.6%	-4.6%	-1.6%	-1.6%	2.4%	(N.S.)	-8.3%	-10.1%
GF 2030	car	-2.6%	-7.1%	-2.6%	-2.7%	3.9%	(N.S.)	-13.1%	-15.8%
GF 2030	truck	-0.4%	8.8%	-0.4%	-0.4%	3.3%	(N.S.)	-13.1%	-15.8%
GF 2030	van	-2.5%	-7.3%	-2.5%	-2.4%	3.8%	(N.S.)	-13.1%	-15.8%
GF 2035	car	-2.6%	-6.9%	-2.6%	-2.7%	4.4%	1.0%	-14.5%	-17.5%
GF 2035	truck	-0.5%	11.6%	-0.5%	-0.5%	4.3%	(N.S.)	-14.5%	-17.5%
GF 2035	van	-2.8%	-8.6%	-2.8%	-2.7%	4.3%	(N.S.)	-14.5%	-17.5%
PF 2020	car	-0.3%	(N.S.)	-0.3%	-0.4%	(N.S.)	(N.S.)	-1.2%	-1.5%
PF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.2%	-1.5%
PF 2020	van	(N.S.)	-1.1%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.2%	-1.5%
PF 2025	car	-0.7%	(N.S.)	-0.7%	-0.7%	1.4%	(N.S.)	-4.9%	-6.0%
PF 2025	truck	-0.2%	4.3%	-0.2%	-0.2%	1.6%	(N.S.)	-4.9%	-6.0%
PF 2025	van	-1.0%	-3.1%	-1.0%	-1.0%	1.5%	(N.S.)	-4.9%	-6.0%
PF 2030	car	-1.1%	(N.S.)	-1.1%	-1.1%	2.1%	(N.S.)	-7.5%	-9.1%
PF 2030	truck	-0.3%	6.2%	-0.3%	-0.3%	2.3%	(N.S.)	-7.5%	-9.1%
PF 2030	van	-1.6%	-4.9%	-1.6%	-1.6%	2.5%	(N.S.)	-7.5%	-9.1%
PF 2035	car	-1.2%	(N.S.)	-1.2%	-1.2%	2.6%	0.7%	-9.1%	-11.0%
PF 2035	truck	-0.5%	8.4%	-0.5%	-0.5%	3.1%	(N.S.)	-9.1%	-11.0%
PF 2035	van	-2.0%	-6.4%	-2.0%	-2.0%	3.0%	(N.S.)	-9.1%	-11.0%

Table 75: Change in the performance indicators for the hilly rural road with high intersection density simulated with low demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	0.2%	-2.6%	-3.1%
CF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.6%	-3.1%
CF 2020	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.6%	-3.1%
CF 2025	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	1.3%	0.2%	-4.3%	-5.2%
CF 2025	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-4.3%	-5.2%
CF 2025	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	1.6%	(N.S.)	-4.3%	-5.2%
CF 2030	car	-0.3%	(N.S.)	-0.3%	-0.3%	1.7%	0.3%	-6.1%	-7.4%
CF 2030	truck	(N.S.)	4.2%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-6.1%	-7.4%
CF 2030	van	-1.2%	-2.7%	-1.2%	-1.2%	2.7%	0.4%	-6.1%	-7.4%
CF 2035	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	1.4%	0.3%	-5.1%	-6.2%
CF 2035	truck	(N.S.)	4.0%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-5.1%	-6.2%
CF 2035	van	-0.9%	-2.1%	-0.9%	-0.9%	2.3%	0.4%	-5.1%	-6.2%
GF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	1.8%	0.2%	-5.1%	-6.3%
GF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-5.1%	-6.3%
GF 2020	van	-0.8%	-1.7%	-0.8%	-0.8%	1.8%	0.3%	-5.1%	-6.3%
GF 2025	car	-1.7%	-3.5%	-1.7%	-1.7%	4.5%	0.4%	-13.3%	-16.1%
GF 2025	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-13.3%	-16.1%
GF 2025	van	-2.4%	-5.1%	-2.4%	-2.4%	4.6%	0.5%	-13.3%	-16.1%
GF 2030	car	-2.8%	-5.5%	-2.8%	-2.7%	6.9%	0.7%	-20.2%	-24.2%
GF 2030	truck	(N.S.)	9.9%	(N.S.)	(N.S.)	3.4%	(N.S.)	-20.2%	-24.2%
GF 2030	van	-4.0%	-8.6%	-4.0%	-4.1%	7.1%	0.8%	-20.2%	-24.2%
GF 2035	car	-3.0%	-5.7%	-2.9%	-2.8%	7.0%	0.7%	-21.6%	-25.8%
GF 2035	truck	(N.S.)	12.6%	(N.S.)	(N.S.)	4.6%	(N.S.)	-21.6%	-25.8%
GF 2035	van	-5.0%	-11.1%	-4.9%	-5.0%	8.7%	0.9%	-21.6%	-25.8%
PF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	0.8%	(N.S.)	-2.5%	-3.1%
PF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.5%	-3.1%
PF 2020	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.5%	-3.1%
PF 2025	car	-0.6%	(N.S.)	-0.6%	-0.5%	2.1%	0.3%	-7.1%	-8.7%
PF 2025	truck	(N.S.)	5.7%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-7.1%	-8.7%
PF 2025	van	-1.7%	-3.4%	-1.7%	-1.7%	3.2%	0.4%	-7.1%	-8.7%
PF 2030	car	-1.0%	-1.5%	-1.0%	-0.9%	2.9%	0.3%	-10.0%	-12.1%
PF 2030	truck	(N.S.)	7.2%	(N.S.)	(N.S.)	2.6%	(N.S.)	-10.0%	-12.1%
PF 2030	van	-2.6%	-5.6%	-2.6%	-2.7%	4.8%	0.5%	-10.0%	-12.1%
PF 2035	car	-1.2%	-2.1%	-1.2%	-1.2%	3.2%	0.3%	-11.4%	-13.9%
PF 2035	truck	(N.S.)	8.7%	(N.S.)	(N.S.)	3.1%	(N.S.)	-11.4%	-13.9%
PF 2035	van	-3.3%	-7.4%	-3.3%	-3.3%	5.8%	0.5%	-11.4%	-13.9%

Table 76: Change in the performance indicators for the hilly rural road with high intersection density simulated with moderate demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.7%	-2.0%
CF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.7%	-2.0%
CF 2020	van	(N.S.)	-0.8%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.7%	-2.0%
CF 2025	car	-0.3%	(N.S.)	-0.3%	(N.S.)	(N.S.)	(N.S.)	-3.3%	-4.0%
CF 2025	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-3.3%	-4.0%
CF 2025	van	-0.8%	-2.1%	-0.8%	-0.8%	1.1%	(N.S.)	-3.3%	-4.0%
CF 2030	car	-0.5%	(N.S.)	-0.5%	-0.4%	1.5%	(N.S.)	-5.2%	-6.4%
CF 2030	truck	(N.S.)	3.1%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-5.2%	-6.4%
CF 2030	van	-1.1%	-2.9%	-1.1%	-1.1%	1.8%	(N.S.)	-5.2%	-6.4%
CF 2035	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	1.3%	(N.S.)	-4.5%	-5.5%
CF 2035	truck	(N.S.)	2.9%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-4.5%	-5.5%
CF 2035	van	-1.0%	-2.7%	-1.0%	-1.1%	1.6%	(N.S.)	-4.5%	-5.5%
GF 2020	car	-0.6%	(N.S.)	-0.6%	-0.6%	1.2%	(N.S.)	-4.0%	-4.8%
GF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-4.0%	-4.8%
GF 2020	van	-0.9%	-2.3%	-0.9%	-0.9%	1.2%	(N.S.)	-4.0%	-4.8%
GF 2025	car	-1.6%	-5.0%	-1.6%	-1.6%	2.9%	(N.S.)	-9.6%	-11.7%
GF 2025	truck	(N.S.)	4.7%	(N.S.)	(N.S.)	1.8%	(N.S.)	-9.6%	-11.7%
GF 2025	van	-1.9%	-4.9%	-1.9%	-1.9%	2.8%	(N.S.)	-9.6%	-11.7%
GF 2030	car	-2.7%	-7.8%	-2.7%	-2.6%	4.5%	0.9%	-14.6%	-17.6%
GF 2030	truck	-0.2%	9.6%	-0.2%	-0.2%	3.6%	0.5%	-14.6%	-17.6%
GF 2030	van	-2.9%	-7.9%	-2.9%	-2.9%	4.3%	(N.S.)	-14.6%	-17.6%
GF 2035	car	-2.8%	-7.7%	-2.8%	-2.7%	4.9%	1.2%	-15.9%	-19.1%
GF 2035	truck	-0.2%	12.0%	-0.2%	-0.3%	4.5%	0.6%	-15.9%	-19.1%
GF 2035	van	-3.3%	-9.5%	-3.3%	-3.4%	5.0%	1.1%	-15.9%	-19.1%
PF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.0%	-2.5%
PF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.0%	-2.5%
PF 2020	van	(N.S.)	-1.3%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.0%	-2.5%
PF 2025	car	-0.7%	(N.S.)	-0.7%	-0.7%	1.8%	(N.S.)	-6.1%	-7.4%
PF 2025	truck	(N.S.)	4.4%	(N.S.)	(N.S.)	1.7%	(N.S.)	-6.1%	-7.4%
PF 2025	van	-1.2%	-3.3%	-1.2%	-1.3%	1.9%	(N.S.)	-6.1%	-7.4%
PF 2030	car	-1.0%	-2.6%	-1.0%	-1.0%	2.5%	(N.S.)	-8.6%	-10.5%
PF 2030	truck	(N.S.)	6.4%	(N.S.)	-0.2%	2.4%	(N.S.)	-8.6%	-10.5%
PF 2030	van	-1.8%	-5.1%	-1.8%	-1.8%	2.8%	(N.S.)	-8.6%	-10.5%
PF 2035	car	-1.2%	-2.5%	-1.1%	-1.1%	3.1%	0.9%	-10.4%	-12.6%
PF 2035	truck	-0.3%	8.8%	-0.3%	-0.3%	3.2%	(N.S.)	-10.4%	-12.6%
PF 2035	van	-2.2%	-6.6%	-2.2%	-2.2%	3.4%	(N.S.)	-10.4%	-12.6%

Table 77: Change in the performance indicators for the hilly rural road with low intersection density simulated with low demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.8%	-2.3%
CF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.8%	-2.3%
CF 2020	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.8%	-2.3%
CF 2025	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	1.1%	(N.S.)	-3.7%	-4.5%
CF 2025	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-3.7%	-4.5%
CF 2025	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	1.3%	(N.S.)	-3.7%	-4.5%
CF 2030	car	-0.4%	(N.S.)	-0.4%	(N.S.)	1.4%	0.2%	-5.2%	-6.4%
CF 2030	truck	(N.S.)	4.3%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-5.2%	-6.4%
CF 2030	van	-1.0%	-2.4%	-1.0%	-1.0%	2.2%	(N.S.)	-5.2%	-6.4%
CF 2035	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	1.2%	0.2%	-4.6%	-5.6%
CF 2035	truck	(N.S.)	4.0%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-4.6%	-5.6%
CF 2035	van	-0.8%	-1.9%	-0.8%	-0.8%	1.9%	(N.S.)	-4.6%	-5.6%
GF 2020	car	-0.5%	(N.S.)	-0.5%	-0.4%	1.4%	(N.S.)	-3.9%	-4.8%
GF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-3.9%	-4.8%
GF 2020	van	-0.6%	-1.4%	-0.6%	-0.6%	(N.S.)	(N.S.)	-3.9%	-4.8%
GF 2025	car	-1.8%	-3.4%	-1.7%	-1.7%	4.0%	(N.S.)	-12.0%	-14.5%
GF 2025	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-12.0%	-14.5%
GF 2025	van	-2.2%	-4.6%	-2.2%	-2.2%	3.9%	(N.S.)	-12.0%	-14.5%
GF 2030	car	-3.0%	-5.5%	-3.0%	-2.9%	6.2%	0.3%	-18.7%	-22.5%
GF 2030	truck	(N.S.)	9.5%	(N.S.)	(N.S.)	3.1%	(N.S.)	-18.7%	-22.5%
GF 2030	van	-3.9%	-8.4%	-3.9%	-3.9%	6.5%	0.4%	-18.7%	-22.5%
GF 2035	car	-3.0%	-5.4%	-3.0%	-2.9%	6.4%	0.3%	-20.2%	-24.2%
GF 2035	truck	-0.4%	12.0%	-0.4%	-0.4%	4.2%	(N.S.)	-20.2%	-24.2%
GF 2035	van	-4.8%	-10.6%	-4.8%	-4.8%	8.1%	0.5%	-20.2%	-24.2%
PF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.9%	-2.3%
PF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.9%	-2.3%
PF 2020	van	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.9%	-2.3%
PF 2025	car	-0.6%	(N.S.)	-0.6%	-0.5%	1.7%	(N.S.)	-6.1%	-7.4%
PF 2025	truck	(N.S.)	5.2%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-6.1%	-7.4%
PF 2025	van	-1.4%	-3.1%	-1.4%	-1.4%	2.6%	(N.S.)	-6.1%	-7.4%
PF 2030	car	-0.9%	(N.S.)	-0.9%	-0.9%	2.5%	(N.S.)	-8.9%	-10.9%
PF 2030	truck	(N.S.)	6.7%	(N.S.)	(N.S.)	2.3%	(N.S.)	-8.9%	-10.9%
PF 2030	van	-2.3%	-5.2%	-2.3%	-2.4%	4.1%	(N.S.)	-8.9%	-10.9%
PF 2035	car	-1.2%	-2.1%	-1.2%	-1.2%	2.9%	(N.S.)	-10.6%	-12.8%
PF 2035	truck	(N.S.)	8.4%	(N.S.)	-0.4%	2.9%	(N.S.)	-10.6%	-12.8%
PF 2035	van	-3.2%	-7.3%	-3.2%	-3.3%	5.4%	(N.S.)	-10.6%	-12.8%

Table 78: Change in the performance indicators for the hilly rural road with low intersection density simulated with moderate demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.9%	-1.1%
CF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.9%	-1.1%
CF 2020	van	(N.S.)	-0.9%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-0.9%	-1.1%
CF 2025	car	-0.5%	(N.S.)	-0.5%	-0.5%	(N.S.)	(N.S.)	-2.5%	-3.1%
CF 2025	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.5%	-3.1%
CF 2025	van	-0.6%	-1.9%	-0.6%	-0.6%	(N.S.)	(N.S.)	-2.5%	-3.1%
CF 2030	car	-0.6%	(N.S.)	-0.6%	-0.6%	1.3%	(N.S.)	-4.5%	-5.5%
CF 2030	truck	(N.S.)	3.3%	(N.S.)	(N.S.)	1.3%	(N.S.)	-4.5%	-5.5%
CF 2030	van	-1.1%	-3.0%	-1.1%	-1.1%	1.4%	(N.S.)	-4.5%	-5.5%
CF 2035	car	-0.4%	(N.S.)	-0.4%	-0.4%	1.1%	(N.S.)	-3.8%	-4.6%
CF 2035	truck	(N.S.)	2.8%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-3.8%	-4.6%
CF 2035	van	-1.0%	-2.8%	-1.0%	-1.0%	1.4%	(N.S.)	-3.8%	-4.6%
GF 2020	car	-0.7%	(N.S.)	-0.7%	-0.7%	(N.S.)	(N.S.)	-2.7%	-3.3%
GF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-2.7%	-3.3%
GF 2020	van	-0.6%	-1.8%	-0.6%	-0.6%	(N.S.)	(N.S.)	-2.7%	-3.3%
GF 2025	car	-1.9%	-5.6%	-1.9%	-1.9%	2.4%	(N.S.)	-8.4%	-10.3%
GF 2025	truck	(N.S.)	4.3%	(N.S.)	(N.S.)	1.5%	(N.S.)	-8.4%	-10.3%
GF 2025	van	-1.7%	-4.7%	-1.7%	-1.8%	2.4%	(N.S.)	-8.4%	-10.3%
GF 2030	car	-3.0%	-8.2%	-2.9%	-2.9%	4.0%	(N.S.)	-13.5%	-16.3%
GF 2030	truck	-0.4%	9.3%	-0.4%	-0.4%	3.3%	(N.S.)	-13.5%	-16.3%
GF 2030	van	-2.7%	-7.8%	-2.7%	-2.8%	3.8%	(N.S.)	-13.5%	-16.3%
GF 2035	car	-2.9%	-7.6%	-2.9%	-2.9%	4.4%	1.0%	-14.9%	-17.9%
GF 2035	truck	-0.4%	11.8%	-0.4%	-0.4%	4.2%	(N.S.)	-14.9%	-17.9%
GF 2035	van	-3.2%	-9.4%	-3.2%	-3.2%	4.6%	(N.S.)	-14.9%	-17.9%
PF 2020	car	-0.4%	(N.S.)	-0.4%	(N.S.)	(N.S.)	(N.S.)	-1.4%	-1.7%
PF 2020	truck	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.4%	-1.7%
PF 2020	van	(N.S.)	-1.1%	(N.S.)	(N.S.)	(N.S.)	(N.S.)	-1.4%	-1.7%
PF 2025	car	-0.8%	(N.S.)	-0.8%	-0.8%	1.4%	(N.S.)	-5.1%	-6.3%
PF 2025	truck	-0.2%	4.3%	-0.2%	-0.2%	1.5%	(N.S.)	-5.1%	-6.3%
PF 2025	van	-1.2%	-3.3%	-1.2%	-1.2%	1.7%	(N.S.)	-5.1%	-6.3%
PF 2030	car	-1.1%	(N.S.)	-1.1%	-1.1%	2.2%	(N.S.)	-7.7%	-9.3%
PF 2030	truck	-0.3%	6.2%	-0.3%	-0.3%	2.2%	(N.S.)	-7.7%	-9.3%
PF 2030	van	-1.7%	-5.1%	-1.7%	-1.7%	2.5%	(N.S.)	-7.7%	-9.3%
PF 2035	car	-1.2%	(N.S.)	-1.2%	-1.2%	2.7%	(N.S.)	-9.5%	-11.6%
PF 2035	truck	-0.4%	8.4%	-0.4%	-0.4%	2.9%	(N.S.)	-9.5%	-11.6%
PF 2035	van	-2.2%	-6.7%	-2.2%	-2.2%	3.1%	(N.S.)	-9.5%	-11.6%

Simulation results for the urban networks

Table 79: Change in the performance indicators for the spacious flat urban road network with low demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.7%	-3.3%
CF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.7%	-3.3%
CF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.7%	-3.3%
CF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.7%	-3.3%
CF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.9%	-4.0%
CF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.9%	-4.0%
CF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.9%	-4.0%
CF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.9%	-4.0%
CF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.6%	-3.8%
CF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.6%	-3.8%
CF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.6%	-3.8%
CF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.6%	-3.8%
CF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.3%	-3.6%
CF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.3%	-3.6%
CF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.3%	-3.6%
CF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.3%	-3.6%
GF 2020	car	(N.S)	-9.2%	(N.S)	(N.S)	(N.S)	(N.S)	-9.5%	-5.5%
GF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.5%	-5.5%
GF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.5%	-5.5%
GF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.5%	-5.5%
GF 2025	car	(N.S)	-8.9%	(N.S)	(N.S)	(N.S)	(N.S)	-10.3%	-6.0%
GF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.3%	-6.0%
GF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.3%	-6.0%
GF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.3%	-6.0%
GF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.3%	-6.0%
GF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.3%	-6.0%
GF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.3%	-6.0%
GF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.3%	-6.0%
GF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.0%	-5.9%
GF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.0%	-5.9%
GF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.0%	-5.9%
GF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.0%	-5.9%
PF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.5%	-4.3%
PF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.5%	-4.3%
PF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.5%	-4.3%
PF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.5%	-4.3%
PF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.2%	-4.2%
PF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.2%	-4.2%
PF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.2%	-4.2%
PF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.2%	-4.2%

PF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.6%	-4.4%
PF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.6%	-4.4%
PF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.6%	-4.4%
PF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.6%	-4.4%
PF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%

Table 80: Change in the performance indicators for the spacious flat urban road network with moderate demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	-1.0%	(N.S)	-1.0%	-1.0%	(N.S)	(N.S)	-5.6%	-3.2%
CF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.6%	-3.2%
CF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.6%	-3.2%
CF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.6%	-3.2%
CF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.7%	-3.3%
CF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.7%	-3.3%
CF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.7%	-3.3%
CF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.7%	-3.3%
CF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.9%	-3.4%
CF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.9%	-3.4%
CF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.9%	-3.4%
CF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.9%	-3.4%
CF 2035	car	(N.S)	-6.1%	(N.S)	(N.S)	(N.S)	(N.S)	-6.3%	-3.6%
CF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.3%	-3.6%
CF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.3%	-3.6%
CF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.3%	-3.6%
GF 2020	car	(N.S)	-9.9%	(N.S)	(N.S)	(N.S)	(N.S)	-9.0%	-5.3%
GF 2020	van	(N.S)	-2.2%	(N.S)	(N.S)	(N.S)	(N.S)	-9.0%	-5.3%
GF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.0%	-5.3%
GF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.0%	-5.3%
GF 2025	car	(N.S)	-8.6%	-1.6%	(N.S)	(N.S)	(N.S)	-9.3%	-5.4%
GF 2025	van	-0.6%	-2.3%	-0.6%	-0.6%	(N.S)	(N.S)	-9.3%	-5.4%
GF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.3%	-5.4%
GF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.3%	-5.4%
GF 2030	car	(N.S)	-9.6%	(N.S)	(N.S)	(N.S)	(N.S)	-9.4%	-5.5%
GF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.4%	-5.5%
GF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.4%	-5.5%
GF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.4%	-5.5%
GF 2035	car	(N.S)	-8.5%	(N.S)	(N.S)	(N.S)	(N.S)	-10.2%	-6.0%
GF 2035	van	(N.S)	-2.9%	(N.S)	(N.S)	(N.S)	(N.S)	-10.2%	-6.0%
GF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.2%	-6.0%
GF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.2%	-6.0%
PF 2020	car	(N.S)	-5.3%	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2025	car	(N.S)	-6.8%	(N.S)	(N.S)	(N.S)	(N.S)	-7.6%	-4.4%
PF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.6%	-4.4%
PF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.6%	-4.4%
PF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.6%	-4.4%
PF 2030	car	(N.S)	-7.3%	(N.S)	(N.S)	(N.S)	(N.S)	-7.5%	-4.3%

PF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.5%	-4.3%
PF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.5%	-4.3%
PF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.5%	-4.3%
PF 2035	car	(N.S)	-7.0%	(N.S)	(N.S)	(N.S)	(N.S)	-7.5%	-4.4%
PF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.5%	-4.4%
PF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.5%	-4.4%
PF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.5%	-4.4%

Table 81: Change in the performance indicators for the spacious hilly urban road network with low demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.7%	-3.3%
CF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.7%	-3.3%
CF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.7%	-3.3%
CF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.7%	-3.3%
CF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.2%	-4.2%
CF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.2%	-4.2%
CF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.2%	-4.2%
CF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.2%	-4.2%
CF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.6%	-3.8%
CF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.6%	-3.8%
CF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.6%	-3.8%
CF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.6%	-3.8%
CF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.4%	-3.7%
CF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.4%	-3.7%
CF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.4%	-3.7%
CF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.4%	-3.7%
GF 2020	car	(N.S)	-1.0%	(N.S)	(N.S)	(N.S)	(N.S)	-9.5%	-5.6%
GF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.5%	-5.6%
GF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.5%	-5.6%
GF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.5%	-5.6%
GF 2025	car	(N.S)	-10.4%	(N.S)	(N.S)	(N.S)	(N.S)	-10.1%	-5.9%
GF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.1%	-5.9%
GF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.1%	-5.9%
GF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.1%	-5.9%
GF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.4%	-6.1%
GF 2030	van	(N.S)	-5.0%	(N.S)	(N.S)	(N.S)	(N.S)	-10.4%	-6.1%
GF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.4%	-6.1%
GF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.4%	-6.1%
GF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.1%	-5.9%
GF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.1%	-5.9%
GF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.1%	-5.9%
GF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.1%	-5.9%
PF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.2%	-4.2%
PF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.2%	-4.2%
PF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.2%	-4.2%
PF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.2%	-4.2%
PF 2030	car	(N.S)	-9.3%	(N.S)	(N.S)	(N.S)	(N.S)	-7.6%	-4.4%

PF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.6%	-4.4%
PF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.6%	-4.4%
PF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.6%	-4.4%
PF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%
PF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.4%	-4.3%

Table 82: Change in the performance indicators for the spacious hilly urban road network with moderate demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S)	-6.10%	(N.S)	(N.S)	(N.S)	(N.S)	-5.50%	-3.20%
CF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.50%	-3.20%
CF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.50%	-3.20%
CF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.50%	-3.20%
CF 2025	car	(N.S)	-5.70%	(N.S)	(N.S)	(N.S)	(N.S)	-5.70%	-3.30%
CF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.70%	-3.30%
CF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.70%	-3.30%
CF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-5.70%	-3.30%
CF 2030	car	(N.S)	-5.80%	(N.S)	(N.S)	(N.S)	(N.S)	-6.10%	-3.50%
CF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.10%	-3.50%
CF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.10%	-3.50%
CF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.10%	-3.50%
CF 2035	car	(N.S)	-6.80%	(N.S)	(N.S)	(N.S)	(N.S)	-6.30%	-3.60%
CF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.30%	-3.60%
CF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.30%	-3.60%
CF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-6.30%	-3.60%
GF 2020	car	(N.S)	10.40%	(N.S)	(N.S)	(N.S)	(N.S)	-9.00%	-5.30%
GF 2020	van	(N.S)	-3.40%	(N.S)	(N.S)	(N.S)	(N.S)	-9.00%	-5.30%
GF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.00%	-5.30%
GF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.00%	-5.30%
GF 2025	car	(N.S)	-9.40%	(N.S)	(N.S)	(N.S)	(N.S)	-9.50%	-5.50%
GF 2025	van	(N.S)	-3.70%	(N.S)	(N.S)	(N.S)	(N.S)	-9.50%	-5.50%
GF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.50%	-5.50%
GF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.50%	-5.50%
GF 2030	car	(N.S)	- 10.40%	(N.S)	(N.S)	(N.S)	(N.S)	-9.40%	-5.50%
GF 2030	van	(N.S)	-3.20%	(N.S)	(N.S)	(N.S)	(N.S)	-9.40%	-5.50%
GF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.40%	-5.50%
GF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-9.40%	-5.50%
GF 2035	car	(N.S)	-9.40%	(N.S)	(N.S)	(N.S)	(N.S)	-10.20%	-6.00%
GF 2035	van	(N.S)	-3.30%	(N.S)	(N.S)	(N.S)	(N.S)	-10.20%	-6.00%
GF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.20%	-6.00%
GF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-10.20%	-6.00%
PF 2020	car	(N.S)	-6.20%	(N.S)	(N.S)	(N.S)	(N.S)	-7.50%	-4.40%
PF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.50%	-4.40%
PF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.50%	-4.40%
PF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.50%	-4.40%
PF 2025	car	(N.S)	-7.60%	(N.S)	(N.S)	(N.S)	(N.S)	-7.60%	-4.40%
PF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.60%	-4.40%
PF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.60%	-4.40%
PF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.60%	-4.40%

PF 2030	car	(N.S)	-7.80%	(N.S)	(N.S)	(N.S)	(N.S)	-7.50%	-4.40%
PF 2030	van	(N.S)	-2.70%	(N.S)	(N.S)	(N.S)	(N.S)	-7.50%	-4.40%
PF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.50%	-4.40%
PF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.50%	-4.40%
PF 2035	car	(N.S)	-7.70%	(N.S)	(N.S)	(N.S)	(N.S)	-7.50%	-4.30%
PF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.50%	-4.30%
PF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.50%	-4.30%
PF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-7.50%	

Table 83: Change in the performance indicators for compact flat urban road network with low demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.90%	-1.10%
CF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.90%	-1.10%
CF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.90%	-1.10%
CF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.90%	-1.10%
CF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.60%	-0.90%
CF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.60%	-0.90%
CF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.60%	-0.90%
CF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.60%	-0.90%
CF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.70%	-1.00%
CF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.70%	-1.00%
CF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.70%	-1.00%
CF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.70%	-1.00%
CF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.50%	-0.80%
CF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.50%	-0.80%
CF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.50%	-0.80%
CF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.50%	-0.80%
GF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.00%	-1.10%
GF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.00%	-1.10%
GF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.00%	-1.10%
GF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.00%	-1.10%
GF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.10%
GF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.10%
GF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.10%
GF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.10%
GF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-3.10%	-1.80%
GF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-3.10%	-1.80%
GF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-3.10%	-1.80%
GF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-3.10%	-1.80%
GF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.20%	-1.30%
GF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.20%	-1.30%
GF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.20%	-1.30%
GF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.20%	-1.30%
PF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.50%	-1.40%
PF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.50%	-1.40%
PF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.50%	-1.40%
PF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.50%	-1.40%
PF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.50%	-0.90%
PF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.50%	-0.90%
PF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.50%	-0.90%
PF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.50%	-0.90%

PF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.10%	-1.20%
PF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.10%	-1.20%
PF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.10%	-1.20%
PF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.10%	-1.20%
PF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.00%
PF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.00%
PF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.00%
PF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.00%

Table 84: Change in the performance indicators for the for compact flat urban road network with moderate demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.50%	-0.90%
CF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.50%	-0.90%
CF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.50%	-0.90%
CF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.50%	-0.90%
CF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.20%	-0.70%
CF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.20%	-0.70%
CF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.20%	-0.70%
CF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.20%	-0.70%
CF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.20%	-0.70%
CF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.20%	-0.70%
CF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.20%	-0.70%
CF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.20%	-0.70%
CF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.70%	-0.40%
CF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.70%	-0.40%
CF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.70%	-0.40%
CF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.70%	-0.40%
GF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.40%	-0.20%
GF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.40%	-0.20%
GF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.40%	-0.20%
GF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.40%	-0.20%
GF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.00%	-1.20%
GF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.00%	-1.20%
GF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.00%	-1.20%
GF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.00%	-1.20%
GF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-3.10%	-1.80%
GF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-3.10%	-1.80%
GF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-3.10%	-1.80%
GF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-3.10%	-1.80%
GF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.20%	-1.20%
GF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.20%	-1.20%
GF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.20%	-1.20%
GF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.20%	-1.20%
PF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.00%	-0.60%
PF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.00%	-0.60%
PF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.00%	-0.60%
PF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.00%	-0.60%
PF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.10%	-1.20%
PF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.10%	-1.20%
PF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.10%	-1.20%

PF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.10%	-1.20%
PF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.60%	-0.90%
PF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.60%	-0.90%
PF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.60%	-0.90%
PF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.60%	-0.90%
PF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-3.00%	-1.70%
PF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-3.00%	-1.70%
PF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-3.00%	-1.70%
PF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-3.00%	-1.70%

Table 85: Change in the performance indicators for the compact hilly urban road network with low demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.10%	-1.20%
CF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.10%	-1.20%
CF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.10%	-1.20%
CF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.10%	-1.20%
CF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-1.70%**	**-1.00%**
CF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
CF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
CF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
CF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-1.60%**	**-0.90%**
CF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
CF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
CF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
CF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-1.30%**	**-0.70%**
CF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
CF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
CF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
GF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-1.80%**	**-1.10%**
GF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
GF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
GF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
GF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-1.70%**	**-1.00%**
GF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
GF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
GF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
GF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-3.30%**	**-1.90%**
GF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
GF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
GF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
GF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-2.30%**	**-1.30%**
GF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
GF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
GF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**(N.S)**	**(N.S)**
PF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-2.50%**	**-1.40%**
PF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-2.50%**	**-1.40%**
PF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-2.50%**	**-1.40%**
PF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-2.50%**	**-1.40%**
PF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-1.60%**	**-0.90%**
PF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-1.60%**	**-0.90%**
PF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-1.60%**	**-0.90%**
PF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-1.60%**	**-0.90%**

PF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.20%	-1.20%
PF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.20%	-1.20%
PF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.20%	-1.20%
PF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.20%	-1.20%
PF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.10%
PF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.10%
PF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.10%
PF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.10%

Table 86: Change in the performance indicators for the compact hilly urban road network with moderate demand

Scenario	Vehicle class	CO_2	NO_x	Fuel	Energy	Avg TT	Avg TT no speeding	Fatal accidents	Fatalities
CF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.10%	-0.60%
CF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.10%	-0.60%
CF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.10%	-0.60%
CF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.10%	-0.60%
CF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.90%	-0.50%
CF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.90%	-0.50%
CF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.90%	-0.50%
CF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.90%	-0.50%
CF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.90%	-0.50%
CF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.90%	-0.50%
CF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.90%	-0.50%
CF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.90%	-0.50%
CF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.60%	-0.40%
CF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.60%	-0.40%
CF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.60%	-0.40%
CF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.60%	-0.40%
GF 2020	car	(N.S)	**-5.70%**	(N.S)	(N.S)	(N.S)	(N.S)	-0.30%	-0.20%
GF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.30%	-0.20%
GF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.30%	-0.20%
GF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.30%	-0.20%
GF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.90%	-1.10%
GF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.90%	-1.10%
GF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.90%	-1.10%
GF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.90%	-1.10%
GF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.90%	-1.60%
GF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.90%	-1.60%
GF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.90%	-1.60%
GF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.90%	-1.60%
GF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.00%	-1.20%
GF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.00%	-1.20%
GF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.00%	-1.20%
GF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.00%	-1.20%
PF 2020	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.80%	-0.50%
PF 2020	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.80%	-0.50%
PF 2020	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.80%	-0.50%
PF 2020	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-0.80%	-0.50%
PF 2025	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.90%	-1.70%
PF 2025	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.90%	-1.70%
PF 2025	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.90%	-1.70%
PF 2025	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-2.90%	-1.70%

PF 2030	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.00%
PF 2030	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.00%
PF 2030	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.00%
PF 2030	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	-1.80%	-1.00%
PF 2035	car	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-3.40%**	-2.00%
PF 2035	van	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-3.40%**	-2.00%
PF 2035	truck	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-3.40%**	-2.00%
PF 2035	bus	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	(N.S)	**-3.40%**	-2.00%

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