Modelling HGV emissions for GLOSA connected vehicle services

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Abstract

The objective of this study was to demonstrate that accurate vehicle emission modelling could be carried out for Green Light Optimisation Speed Adaption (GLOSA) services both simulated and using real vehicle speed profiles from HGVs. The study successfully combined existing research, techniques and open source software tools to create a platform that would enable both simulated and real-world data to be combined and used successfully to model individual and group vehicle emissions for drivers under the influence of GLOSA advice. This platform can be used to simulate mixed mode vehicle fleets, applied to real world traffic signal junction layouts to support the estimation of benefits associated with GLOSA and specifically, but not limited to, HGVs.

Keywords:

Connected Vehicle Technology and Vehicle Emissions modelling

Introduction

Green Light Optimisation Speed Adaption (GLOSA) offers drivers visual guidance about when a traffic signal is expected to change state, this is combined with speed advice that, if followed, will allow a driver to safely traverse a traffic signal junction without stopping. The anticipated outcome will be improved journey times through routes with heavy traffic signalisation and reduced emissions or fuel consumption dependant on the vehicle age and type.

Problem

Connected vehicle technology is an emerging technology. Identifying potential benefits of connected vehicles services is a developing area. However, without derivation of benefits it will be difficult for road authorities or car manufacturers to make the investment in developing these services. GLOSA offers the potential to improve transition times across traffic signal junctions, reduce stop start conditions that will lead to reductions in vehicle emissions and potentially offer fuel savings. Measuring vehicle emissions in field is possible but requires measurement equipment for individual vehicles and can be costly and time consuming, especially if you wish to measure accumulative effects on vehicle groups. This study examines the novel combination of vehicle emission models, traffic and

C-ITS simulation platforms, for both simulated and speed profile data from real vehicles to estimate emissions, fuel economy and transit time saving of a vehicle influenced by GLOSA. This study specifically examines if emissions can be estimated for HGV type vehicles but can be applied for cars and light commercial vehicles.

Approach

This study combined the use of the open-source software SUMO (Simulation of Urban Mobility) [Eclipse SUMO - Simulation of Urban MObility, 2021] and CMEM (Comprehensive Modal Emission Model) [CMEM Model, 2006]. CMEM was initially developed in the late 1990s with sponsorship from the U.S National Cooperative Highway Research Program (NCHRP) and the U.S. Environmental Protection Agency (EPA) to fulfil the need for microscopic emissions modelling. This type of model is necessary for evaluating emissions benefits of project-level or corridor-specific transportation control measures (e.g. HOV lanes), intelligent transportation systems (ITS) implementations (e.g. electronic toll collection), and traffic flow improvements (e.g. traffic signal coordination).

CMEM is microscopic in the sense that it predicts second-by-second tailpipe emissions and fuel consumption based on different modal operations from in-use vehicle fleet. One of the most important features of CMEM is that it uses a physical, power-demand approach based on a parameterized analytical representation of fuel consumption and emissions production. In this type of model, the entire fuel consumption and emissions process is broken down into components that correspond to physical phenomena associated with vehicle operation and emissions production. Each component is modelled as an analytical representation consisting of various parameters that are characteristic of the process. These parameters vary according to the vehicle type, engine, emission technology, and level of deterioration. One distinct advantage of this physical approach is that it is possible to adjust many of these physical parameters to predict energy consumption and emissions of future vehicle models and applications of new technology (e.g., after-treatment devices).

The required inputs for CMEM include vehicle activity (second-by-second speed trace, at a minimum) and fleet composition of traffic being modelled. The initial version of CMEM contains 23 light-duty gasoline vehicle/technology categories characterized by emission control technology, emission certification standard, mileage, power-to-weight ratio, and high emitting characteristic. With the continued support by the U.S. EPA, CMEM has been maintained and updated by adding new vehicle/technology categories as they emerge. In addition, CMEM has been expanded to include the heavy-duty diesel vehicles. The current version of CMEM (version 3.0, 2005) includes 28 light-duty vehicle/technology categories and 3 heavy-duty vehicle/technology categories.

CMEM is a public-domain model and has several hundred registered users worldwide. At present, it is claimed to be the most detailed and best tested model for estimating hot-stabilized vehicle exhaust emissions at different speeds and accelerations [Dowling et al., 2005]. For further information on the

CMEM efforts, please refer to [Barth et al., 1997; Barth et al., 1999; Barth et al., 2004].

Eclipse SUMO (Simulation of Urban MObility), an open source, highly portable, microscopic and continuous multi-modal traffic simulation package designed to handle large networks. SUMO is a free and open source traffic simulation suite. It is available since 2001 and allows modelling of intermodal traffic systems - including road vehicles, public transport and pedestrians. SUMO was used to model a junction and simulate vehicles driving through it, see figure 1. The TraCI interface within SUMO allowed for tracking individual vehicle velocity profiles and implementing a GLOSA algorithm. This model was used to record the behaviour of a HGV taking the same route with and without the influence of GLOSA. A second-by-second velocity profile of the HGV was extracted from the simulation and used as the input into CMEM.

This study used the command line HDD CMEM model to generate a text file with second-by-second emissions data for a given velocity profile. The emissions data that was generated for this study consisted of: CO2, CO, HC, NOx and fuel use. These values were compared for the GLOSA influenced HGV and one whose behaviour was SUMO generated with no external influence. This comparison is discussed further in the results section.

This study used a model of the English M5 motorway J23 junction, based on the data imported from OpenStreetMap [OpenStreetMap, 2021]. A random simulation of vehicles passing through the two traffic lights (coming onto the roundabout from the left and taking the second exit) was generated. One of these vehicles was chosen to be set to a truck with acceleration set to 0.21 m/s and deceleration set to 0.81m/s, as was inferred would be a realistic representation of a medium-loaded HGV from [Poplin, n.d.]. The two models – with and without the influence of GLOSA, both use the same network model, route and use TraCI (Traffic Control Interface) to track the vehicle speed.

GLOSA was integrated into the SUMO simulation using TraCI (Traffic Control Interface) which allows second by second information about the simulation (e.g. roads, vehicles, traffic light state) to be extracted and allows for the simulation to be changed based on this information. For the incorporation of GLOSA, the model used the command “traci.vehicle.getNextTLS” which tracked information relating to the upcoming traffic lights and their states, for the chosen vehicle. The GLOSA calculation uses information about the distance to the nearest traffic light and its state to calculate the recommended speed for the vehicle. This speed is imposed onto the vehicle- which models compliance to the in-vehicle speed advisory.

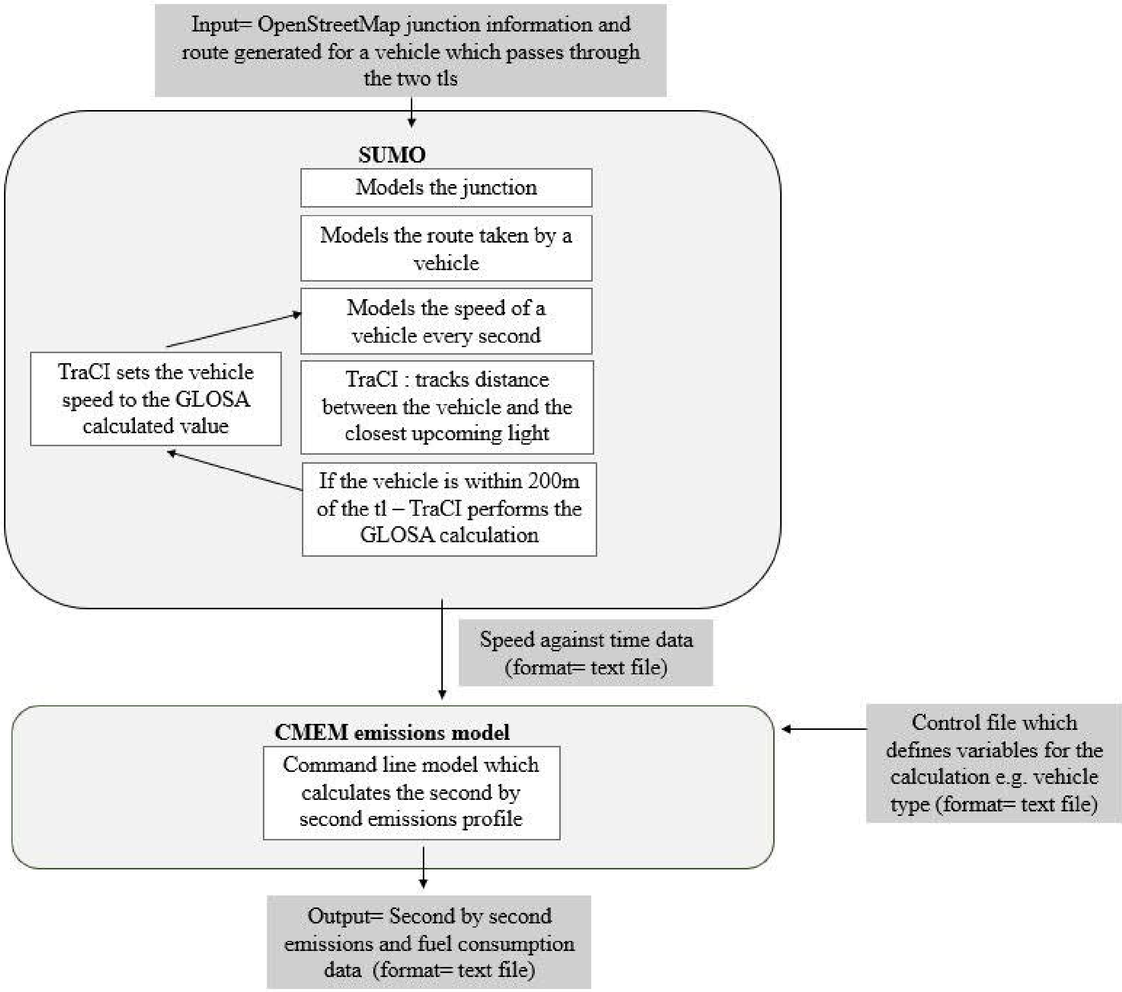


Figure 1 – Flowchart outlining the approach taken in this study where the green indicates the models used and blue indicates the input and output files.

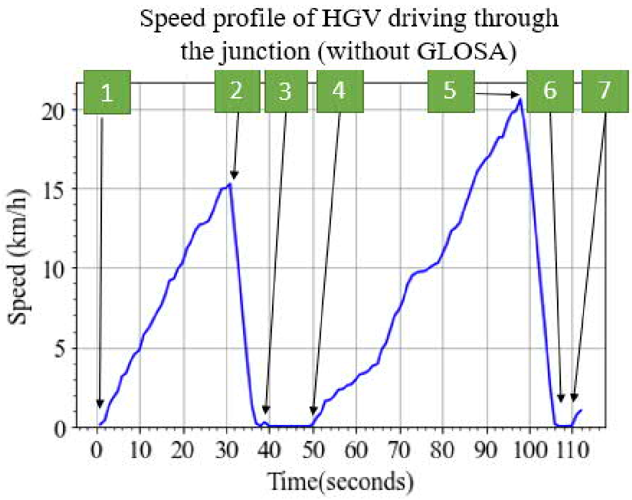
Notably, the network defined rules within SUMO override the TraCI external influence when there is a discrepancy between the two e.g. when a speed is imposed on a vehicle in the simulation, the vehicle will transition to this speed in a way which is compliant with the defined variables such as max acceleration and max deceleration.

The fundamental GLOSA calculation script used was the one outlined in [Krajzewicz, Bieker and Erdmann, 2012] and sourced from [Erdmann, 2021]. As described earlier, the output of the TraCI script was a text file of speed against time in the format required by CMEM. Notably, this required a conversion from m/s to mph. For reference, a separate datafile was created which tracked the distance to the traffic light in order to be able to precisely map the time at which the vehicle passes/stops at the traffic lights.

The script is based upon evaluating if the vehicle will reach a green light if it remains travelling at constant speed. This is the optimum choice as it requires no acceleration or deceleration. If this does not apply, the code imposes maximum acceleration or deceleration depending on the situation. As the GLOSA value is recalculated every second, once the vehicle has accelerated/decelerated sufficiently- the next calculation will show that it should maintain the constant speed it is at.

Results

Figure 2 shows the simulated HGV speed profile as it approaches and travels through traffic signal 1 (TL1) and traffic signal 2 (TL2) and a description of the stages of this journey.



1) (Time: 0 seconds) The simulation begins with the HGV starting from a stationary position and accelerating up to 15.4 km/h/
2) (Time: 31 seconds) The HGV begins to decelerate as it comes up to TL1 which is red.
3) (Time: 37) The HGV is stationary in front of the TL1 which is red.
4) (Time: 49) TL1 changes to green and the HGV accelerates.
5) (Time: 96 seconds) The HGV approaches TL2 which is red and begins to decelerate.
6) (Time: 105 seconds) The HGV is stationary in front of TL2 which is red.
7) (Time: 109 seconds) The HGV passes through TL2 as it turns green.

Figure 2 – Speed profile of the HGV travelling through the junction with annotations describing the stages of this journey (without the influence of GLOSA).

Figure 3 shows the simulated HGV speed profile with the driver under the influence of GLOSA as it approaches and travels through traffic signal 1 (TL1) and traffic signal 2 (TL2).

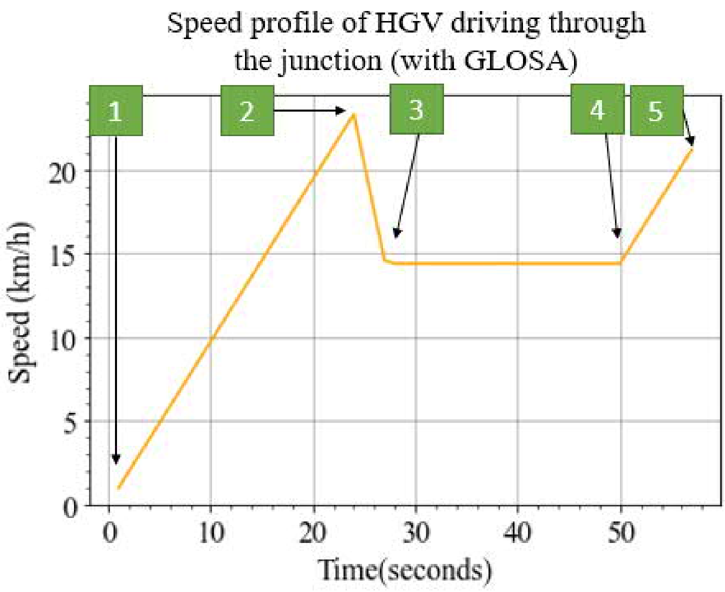


Figure 3 –HGV (with GLOSA) transiting the junction with annotations indicating the stages of the journey.

Figure 4 shows the simulated HGV path as a SUMO visualisation, with layout of the road junction and position of traffic lights (TL1 & TL2). The position of the HGV is shown over the course of the simulation with additional narrative.

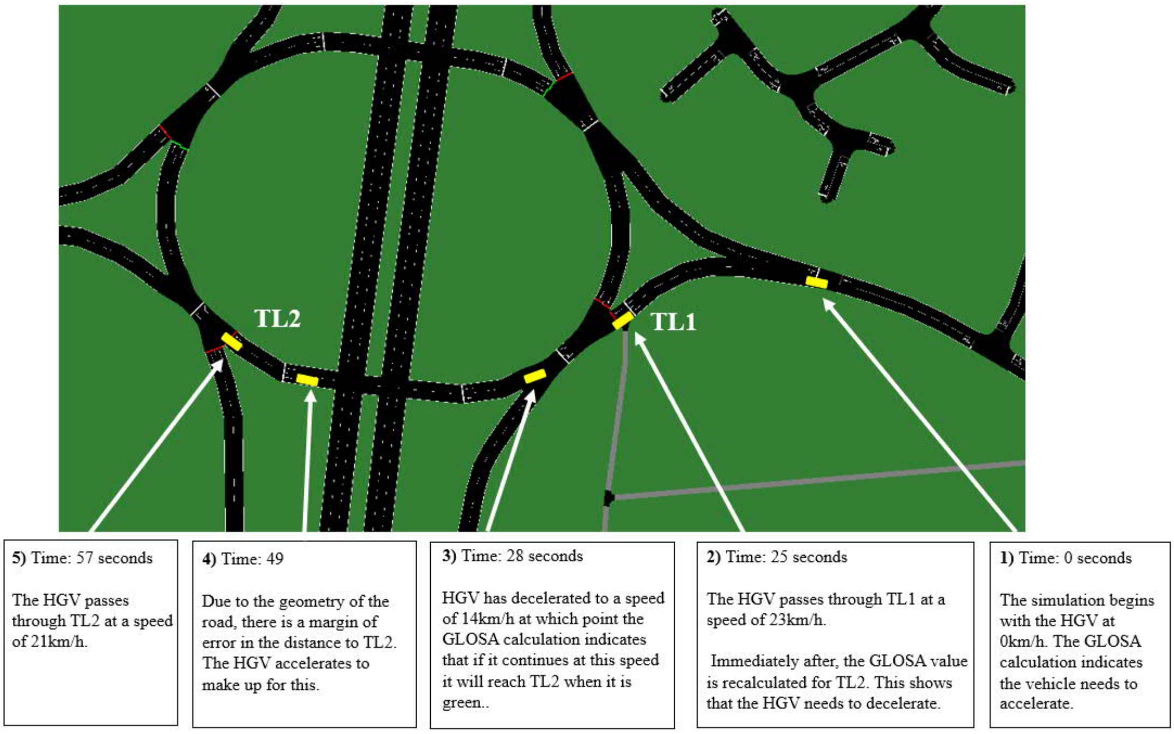


Figure 4 – Diagram of the HGV travelling through the junction with annotations describing the stages of this journey and how GLOSA affects the speed of the vehicle.

Figure 5 shows the cumulative vehicle emissions output (CO, NO_x and HC) data from the CMEM model, based on the SUMO simulated speed profiles for a HGV with and without GLOSA.

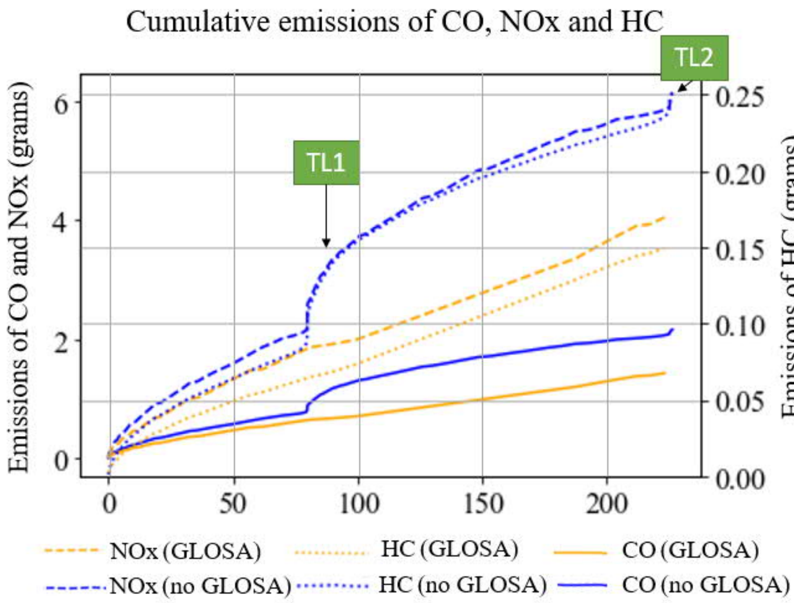


Figure 5 –Cumulative emissions of CO, NOx and HC for HGVs travelling through the junction.

Figure 6 shows the cumulative vehicle emissions output (CO_2 and fuel use) data from the CMEM model, based on the SUMO simulated speed profiles for a HGV with and without GLOSA.

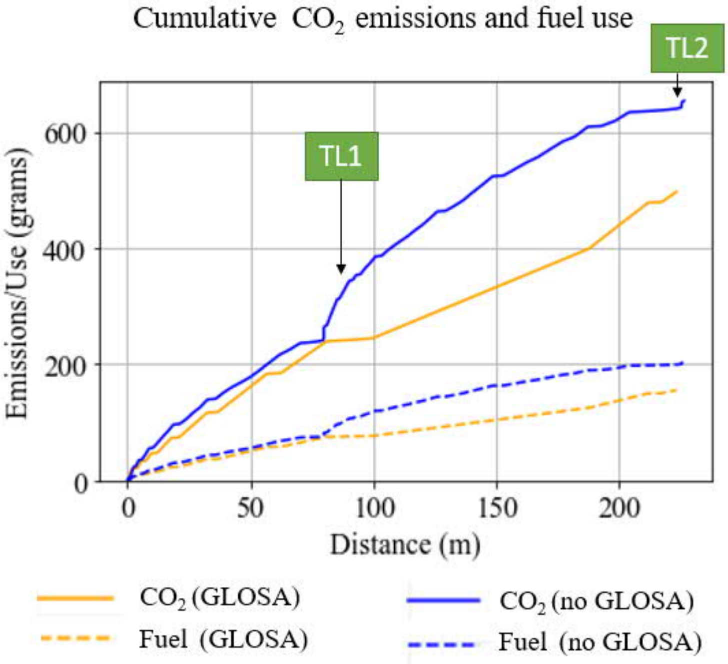


Figure 6 –Cumulative emissions of CO_2 and fuel use for HGVs travelling through the junction.

Table 1 summarises cumulative vehicle emission output from the CMEM model for comparison of HGV runs through the junction with GLOSA influence and without GLOSA influence. The results include the following gas emissions: carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X), as well as estimated fuel consumption and time to transition the junction.

Table 1- Table summarising the emissions data (grams) for the HGVs' journey through TL1 & TL2

	CO_2 (g)	CO (g)	HC (g)	NOx (g)	Fuel (g)	Time(s)
With GLOSA	496.1897	1.426317	0.149348	4.048644	155.3507	57
Without GLOSA	653.0171	2.159071	0.250935	6.149981	203.2002	112
difference	156.8274	0.732754	0.101587	2.101337	47.84952	55

Table 2 summarises cumulative vehicle emission output from the CMEM model for comparison of HGV runs through to traffic signal 1 (TL1) with GLOSA influence and without GLOSA influence. The results include the following gas emissions: carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X), as well as estimated fuel consumption and time to transition the junction.

Table 2- Table summarising the emissions data for the HGVs' journey through TL1

	CO_2 (g)	CO(g)	HC(g)	NOx (g)	Fuel (g)	Time(s)
TL1 with GLOSA	240.6361	0.658976	0.066939	1.895297	75.31831	25
TL1 without GLOSA	266.2492	0.915746	0.110495	2.655123	82.4202	53
difference	25.61309	0.25677	0.043556	0.759826	7.101889	28

Table 3 summarises cumulative vehicle emission output from the CMEM model for comparison of HGV runs through to traffic signal 2 (TL2) with GLOSA influence and without GLOSA influence. The results include the following gas emissions: carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X), as well as estimated fuel consumption and time to transition the junction.

Table 3- Table summarising the emissions data for the HGVs' journey through TL2

	CO_2 (g)	CO(g)	HC(g)	NOx (g)	Fuel (g)	Time(s)
TL2 with GLOSA	255.5536	0.767341	0.082409	2.153347	80.0324	32
TL2 without GLOSA	386.7679	1.243325	0.14044	3.494858	120.78	59
difference	131.2143	0.475984	0.058031	1.341511	40.74763	27

For reference, TL1 is located 83m from where the simulation begins and the distance between TL1 and TL2 is 140m. The total distance travelled by the HGV in the simulation is 223m. Referring to figure 1, it can be seen that the HGV influenced by the GLOSA service transitioned through the junction faster with no instances of deceleration to a stationary position when compared to the HGV not influenced by GLOSA. It can be seen from Table 1, that CO_2 emissions are reduced by 24.01% for HGV influenced by GLOSA, when compared to HGV without GLOSA, transitioning through the junction. It can be seen from Table 1, that NO_x emissions are reduced by 34.17% for HGV influenced by GLOSA, when compared to HGV without GLOSA, transitioning through the junction. It can be seen from Table 1, that fuel consumption is reduced by 23.55% for HGV influenced by GLOSA, when compared to HGV without GLOSA, transitioning through the junction. Similarly, emissions of CO and HC are reduced by 33.94% and 40.48% respectively.

Conclusions

This study examined the combination of Comprehensive Modal Emission Model (CMEM) and the SUMO microscopic traffic simulator to estimate individual vehicle emissions, fuel economy and transit times for vehicles influenced by GLOSA. The study had a specific focus on HGV type vehicles but could be applied for cars and light commercial vehicles. The study confirmed that it was possible to integrate CMEM and SUMO to produce vehicle emissions data and derive fuel consumption estimates for HGV's under the influence of GLOSA.

To validate the emissions data from the CMEM model, values were compared with the EPA SmartWay Carrier Performance Ranking data [SmartWay Carrier Performance Ranking | US EPA, 2021] and the

SUMO built-in emissions modelling. Both sources indicated that the CMEM data was within the expected order of magnitude. This study showed GLOSA has a positive effect reducing vehicle emissions (20 -30%) and reducing fuel consumption (20%+) of HGV's transition across a typical spilt grade junction on the motorway network.

Summary

Heavy goods vehicles (HGVs) are estimated to account for around 17% of UK greenhouse gas (GHG) emissions from road transport and around 21% of road transport NO_x emissions, while making up just 5% of vehicle miles. GLOSA offers driver advice and delivers improved journey times through routes with heavy traffic signalisation and reduced emissions or fuel consumption dependant on the vehicle age and type. This study has shown that vehicle emission models can be successfully combined with traffic simulation models and used to estimate the reduction in vehicle emission and fuel consumption of HGV's under the influence of the GLOSA service. This can be used to generate data that can be used to support business case about future roll out of GLOSA services.

Future Work

Further work would include data validation and exploration of limitations associated with adapting this software, which was built using US vehicle data, to European vehicles.

SUMO was configured that the initial vehicle speed was set at approximately 50km/h (which is likely to be more realistic for an HGV approaching this junction). These simulations showed the same trends as the data presented in this paper, but further analysis will be required. The study could be improved by recording data from simulations with a range of initial speeds and on numerous networks.

Future work should include simulation of mixed fleets (HGV, light commercial, cars) for both connected and connected vehicles. SUMO can support this.

With respect to GLOSA, further work related to how a wider variance of driver influence could be incorporated into configuration of the simulation.

Consideration of how this setup could be used to model other connected vehicle services (IVS, RWW).

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