CAN A DRIVING SIMULATOR BE USED TO INVESTIGATE TRAFFIC MANAGEMENT MEASURES FOR HEAVY VEHICLES?

Thomas Engen and Solveig Meland
SINTEF Transport research

1 INTRODUCTION

In many urban areas, freight vehicles represent a modest proportion of the vehicles, but a large proportion of the traffic-related emissions. Heavy freight vehicles waiting to be served at terminals, frequently cause queues inside and outside the terminal areas, making the approach to and operations in the terminal areas difficult and less efficient. Emissions from heavy vehicles increase when the vehicles are forced to keep a low or uneven speed profile (Rexeis et al, 2005), which is typical of queuing situations in urban areas. Thus, reducing the heavy vehicles' exposure to queuing situations, either by giving them priority or restricting their access to parts of the road network under certain conditions – or a combination of these - could be ways to reduce this problem.

The Norwegian Research Council sponsors an on going research project called GOFER (2009-2012), involving the national and local road authorities, municipalities, terminal- and freight operators, technology suppliers as well as R&D-organisations in Norway, targeting these challenges.

The main objective for the GOFER project is to contribute to a reduction in emissions, queues, accidents and operator costs related to heavy freight, by introducing new technical solutions and ways of cooperation. The GOFER project idea is to develop concepts which facilitate control and management of heavy freight vehicles, much the same way as the air control manages airplanes approaching or leaving an airport. This could mean directing vehicles to specific routes in order to avoid queues, or to designated areas for waiting/resting until they are allowed to continue, but then while being given priority by means of for instance green wave through traffic lights or access to public transport lanes. Such a system could contribute to moving heavy vehicles out of rush-hour traffic and terminal-related queues to areas and time periods where the negative environmental impacts would be fewer and smaller. At the same time this could provide more predictability to the drivers and the terminal operator alike, and time spent in queues could be transformed to resting time or be spent on other tasks.

The first phase of the project focussed on user needs and requirements. This formed the basis for the demonstration activities in the project:

- a ten-week long live demonstration of a cooperative information system with heavy vehicles on the 500 km long route from Oslo to Trondheim
- a test in a heavy vehicle driving simulator, to study possible effects of measures prioritizing heavy vehicles in an urban environment
- a study of full scale effects of and necessary requirements for implementation of a GOFER-system, using a micro simulation tool for a terminal area in Oslo

The demonstration activities in GOFER were not primarily tests of technology, but demonstrations of services and functionality. This was an important basis for the prioritizing and delimitations made during the design of the demonstrations. At the same time, the objective was to establish a "win-win"-situation, where all participants could benefit from taking part.

This paper presents main characteristics of and findings from the evaluation of traffic management measures prioritizing freight goods vehicles in an urban traffic environment, using a driving simulator. Meland et al (2012) presents the main findings of the live demo, while the micro simulation is an on going project.

The driving simulator for heavy vehicles was used to study possible effects of prioritizing heavy vehicles by access to public transport lanes and priority by "green waves" in traffic lights. A secondary purpose was to gain experience with using a driving simulator to study this type of measures. The tests were carried out using updated description of road network and traffic conditions for Trondheim.

Logs of vehicle positions, speed and acceleration data from the simulator were recorded, but the main focus of the analysis were to study the heavy vehicle drivers perception of the measures by use of a driving simulator for this kind of study. The study included a four-part questionnaire, where the participants were asked to assess the realism and relevance of various aspects of the test scenarios, and how suited the simulator was to study the measures:

1. About the driver; background and driving experience
2. About the test of access to public transport lanes
3. About the test of "green wave" in traffic lights
4. An overall assessment of the test and comparison of the tested measures

The questions related are closely related to standard questionnaire used at most simulator studies at SINTEF/NTNU. The questionnaire is based on work by Tørnros (1996)

2 THE DRIVING SIMULATOR TEST - AN OUTLINE

Live tests of measures giving priority to heavy freight vehicles in an urban traffic environment proved to be difficult, and in the GOFER project it turned out to be not feasible. Access to public transport lanes was not allowed due to needs for changes in regulation, while prioritizing by use of green waves in traffic lights was too costly and difficult to implement. As a second best option to a live test of prioritizing measures, the project included a study using a driving simulator to investigate effects of traffic management measures giving priority to heavy freight vehicles.

Access to public transport lanes were given were given during the daytime at normal traffic situation. Peak periods are not included in this scenario.

Green waves in traffic lights were to be given during low-traffic periods. This is primarily during night time.

Four different scenarios were created. They are shown in Table 1.

Table 1: Priority measures

	No priority	Priority
Day	Current lane and light signals	Access to public transport lanes
Night	Current lane and light signals	"Green wave" in traffic light signals

The tests were carried out in January 2012.

2.1 The driving simulator

For this experiment, the SINTEF/NTNU driving simulator was used. The simulator consists of both a heavy vehicle cabin and an ordinary car cabin. The physical cabins and the dynamic module for the simulator software can be exchanged within hours. The heavy vehicle cabin was used in this experiment.

The visual representation of the road is presented on three screens in front of the driver and two screens behind the driver, for a total of five projectors. Each screen is 2.4 metres high and 3.1 metres wide. The resolution of all the projectors was 1400 x 1050 pixels.

The visual system is based on PCs that run a Windows operating system. There are three PCs that run the front projection system and two PCs that run the back projection system. The three front screens are rear projected and provide in sum a 180° horizontal field of view and 47° vertical field of view. The two screens behind the vehicle provide in sum a 90° horizontal field of view and 47° vertical field of view.

Sound is provided by a four-channel high fidelity sound system with loudspeakers inside the cabin and a subwoofer in the trunk. In addition, the system provides sound from the driver's vehicle as well as from other vehicles, and lets the driver experience both directional and Doppler effects.

The heavy vehicle simulator does not have a motion base. Some motion is provided by seat vibration, but turning, acceleration and braking motions are not simulated.

2.2 Road design

The simulator tests were carried out on coded parts of the main road network in Trondheim, Norway. This simulator model is based on both existing and planned roads. The network is comprised of the town centre, tunnels, and rural roads. The total length of the simulator network is 55 km.

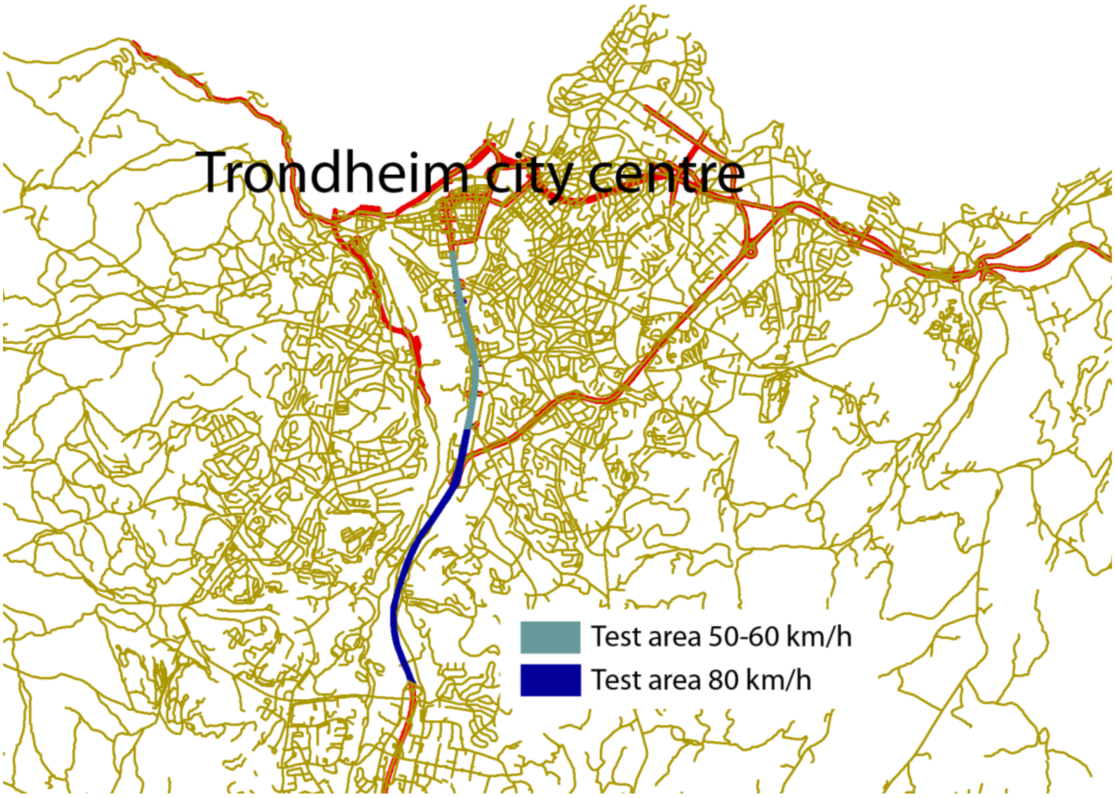

Figure 1: Map of the test area

In this experiment a network of approximately 4 km road with speed limit of 80 km/h and approximately 3 km of road with speed limit between 50 and 60 km/h was used. On the section with speed limit of 80 km/h, the road varies between 4 and 6 lanes with a central reserve, while the section with speed limit between 50 and 60 km/h was 4 lane with and without a central reserve.

The road used in the experiment represents exciting roads in Trondheim which the drivers are likely to use as heavy vehicle drivers.

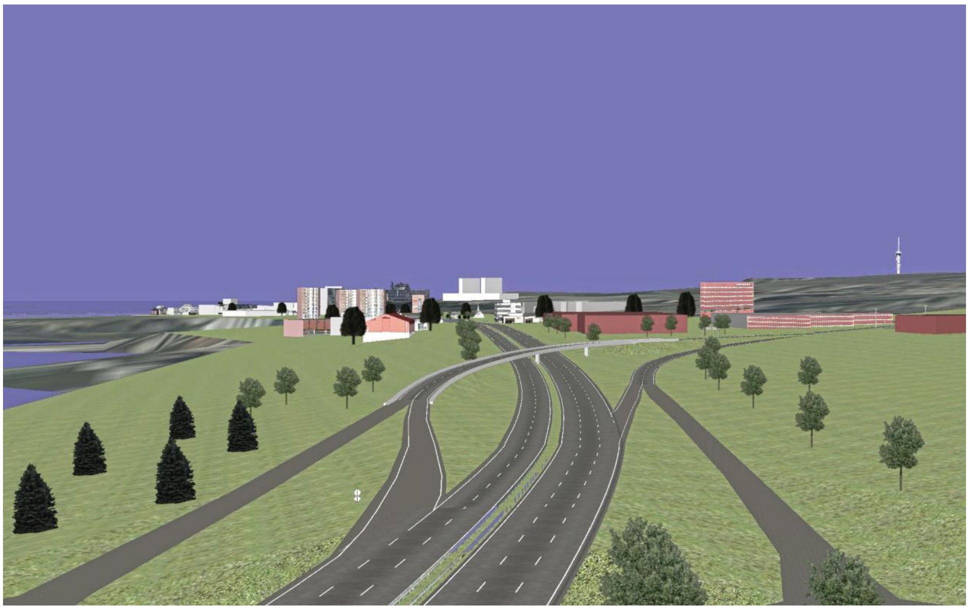

Figure 2: Overview of part of the test area

In the simulator, it is possible to create scenarios based on time of day and different weather categories. This was utilized to create both day- and night-time scenarios. The weather was designed with light clouds. Because of graphic limitations, the night time scenario did not contain overhead lighting, only vehicle lighting.

2.3 Traffic scenario

There are two vehicle types in the driving simulator: The interactive vehicle and autonomous vehicle. The interactive vehicle is controlled by the test driver. The autonomous vehicles represent all other traffic and are controlled by nano and micro traffic simulation. The autonomous traffic can be created and controlled using several methods. The two main methods are:

- All events and all creation and control of the vehicle is done by the simulator.
- Events and other traffic is triggered by events and programmed in advanced

In the first case, traffic is only specified by the traffic volume and both traffic lights and autonomous vehicles behaviour is entirely controlled by the simulator. Using the second methods, events are triggered for example by location of the interactive vehicle or by a timeline. Event might be changes in traffic lights or creation of vehicle coming from the side road. These two methods can be combined. The second method is more time consuming to design, but give much better control of the scenario.

To control the scenario in detail, the second method to create and control traffic was mainly used. To design the scenarios, video recording were used to recreate realistic traffic scenarios. Recordings were done both at night and day to be able to design a before scenario. The amount of traffic and traffic coming from the side roads were based on the video. In addition special focus was on the location of the interactive vehicle at the time of traffic light changes.

Figure 3: Example of daytime and night time traffic scenario

The scenarios designed for the priority of heavy vehicles was also based on the videos, but modified by introducing the priority measures. For the night time scenario, changes were made to when traffic lights were to change, while the daytime scenario allowed the heavy vehicle to use the public transport lane.

2.4 Participation from users

Creating a win-win-situation is particularly important for a demonstration where participation is voluntarily. The possibilities to test a driving simulator and to test possible prioritizing measures were used to attract possible drivers.

It was also important to include the management of involved transport company. At the same time several members of the management has been former drivers. To get them involved in the project, they were included in the pre test of the scenarios. They did not have any direct effect of the changes in the traffic scenarios, but were given the opportunity to comment on the driving experience. This lead to more enthusiasm and involvement from the management and subsequently also made the experiment drivers more eager to participate.

2.5 The Drivers

The experiment involved seven experienced drivers. Eight participants were recruited from the project partner Bring, but only seven were able to conclude all test runs. The eighth person got sick driving in the simulator and was excluded from further analysis. Some of the other driver felt uncomfortable after driving in the simulator, but all seven finished the tests.
Figure 4 show the effect of simulator sickness for each of the seven drivers that did complete the four tests. Each driver is represented on the horizontal axis. It is important to note that all answers to the extent of simulator sickness were in the "low degree" – "very low degree" of the scale.

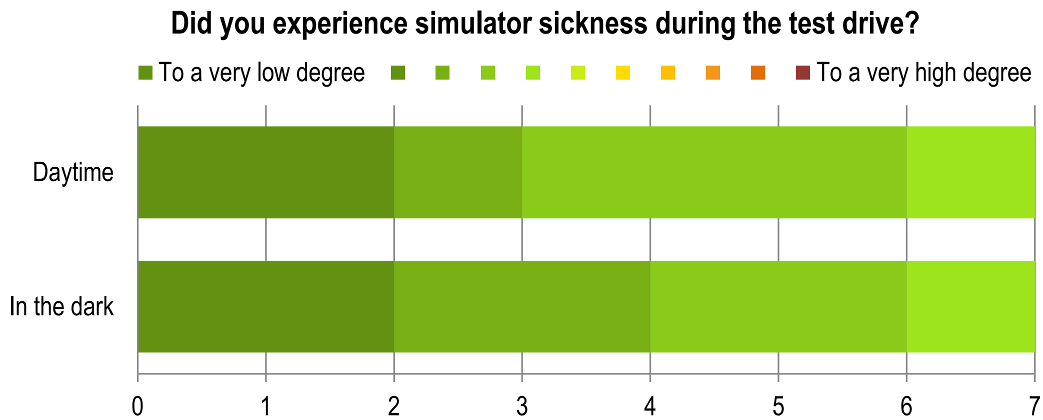

Figure 4: Simulator sickness

The drivers were all male and had an experience as a heavy vehicle driver between 11 and 40 years. 4 of them were daily or weekly driving the route modelled in the driving simulator.

Based on the possibility of driving simulator sickness, only drivers that were not scheduled to drive later in the same day were selected. This lead to the inclusion of drivers that for up to 4 years, had not been driving heavy vehicle as their main occupation.

Each driver completed the four test scenario. After each test round, the driver filled in the appropriate part of the questionnaire. In addition to predefined questions, they were asked to give their impression as free text. The sequence of scenarios was randomized for each driver.

3 THE DRIVING SIMULATOR TEST - DRIVERS' RESPONSES

3.1 The company response

The company employing the drivers, Bring, presented their experiences at a workshop. They see a lot of potential in the driving simulator tests, for example a potential in cost reduction, environmentally friendly transport, and in improved driver working environment. The scenarios tested "would be like a dream" if they could be implemented. Since they were not allowed tested in real life, benefits would be difficult to document in real life.

They feel that the possibilities to measure the stress level of the drivers would be of great benefit. The environment, health and safety of the drivers are important for the employer.

They also see a potential for other tests. One example could be to recreate actual accidents and test driver responses to such extreme situations. One quote to summarize their view is: "There are virtually no limits to the possible scenarios that can be tested".

The manager presenting the company's view of the test had tested the driving simulator at an early phase when calibrating the scenarios. Even though the simulator had not been optimized at the time of his test drive, he had a positive experience and he felt that it had proved to be more challenging than he had expected.

3.2 Driver - response to the simulator

The drivers were overall positive about the driving experience. Several of the drivers expressed that they had a better experience than they expected.
The drivers were asked questions about several factors both for the daytime and night time scenario. They were asked to rate the experience on a scale between 0 and 10, were 0 was very unrealistic 10 was very realistic.

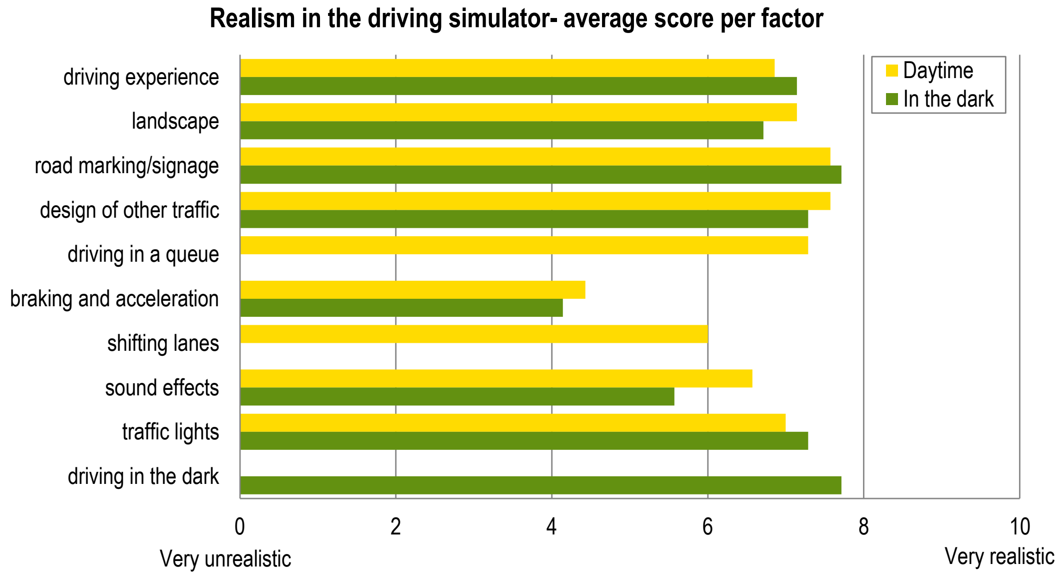

Figure 5: Realism of the driving simulator, per factor

The one factor they were most critical of was breaking and acceleration. Lane shifting had also a low rating in realism. The SINTEF/NTNU simulator lacks a motion base for the heavy vehicle cabin at the present time. It is therefor no surprise that this is a drawback for the simulator experience. When conducting car based experiments at SINTEF/NTNU, a pool of experienced driving simulator test persons are used. In our experience, the lack of motion can to a certain degree be compensated by experience and learning. Since an important part of GOFER was to include test drivers from the participating freight company, this option was not available. Only one driver had experience from a driving simulator before these tests.

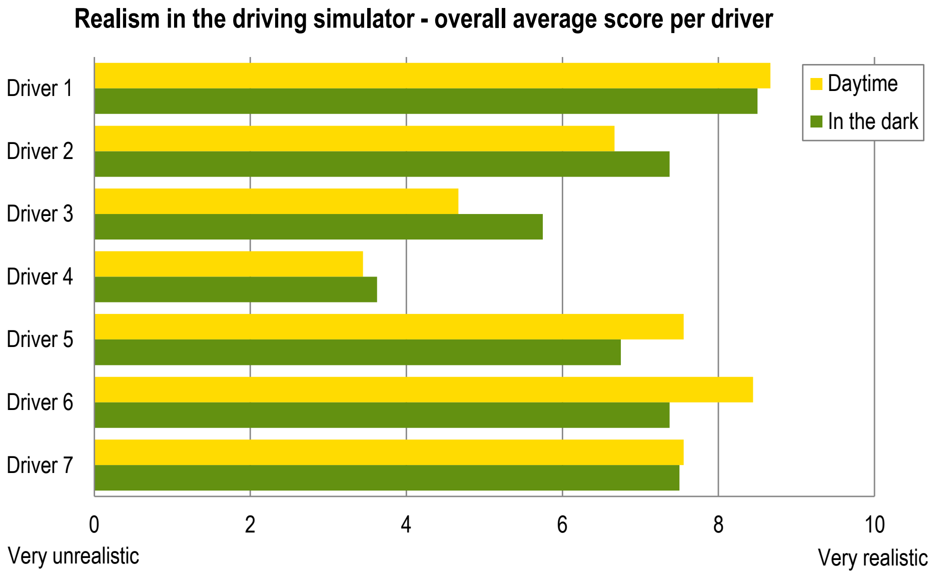

Figure 6: Realism in the driving simulator, per driver

There were quite large differences between the drivers in their perception of realism of the driving simulator. Figure 6 show that especially one person was more sceptical than the rest, but also a second person had a notable lower score. This might be based on experience and expectation for the driving simulator. A lot of games have better visual presentation of the driver environment than is possible to create on a limited budget. In addition, it is more challenging to recreate a familiar environment than a generic environment. Also popular science presentations of driving simulators tend to present simulators with large motion base.

3.3 Driver - response to the measures

In general, the drivers are positive to the measures. For the daytime scenario with access to public transport lanes, only two drivers had any fear of one negative effect. One driver feared some deterioration for traffic safety and one for some deterioration of attention. 73 % of the responses to the measures indicated some or strong improvement when allowed access to Public transport lanes.

The positive effect of access to public transport lane on stress level of the driver is the one factor everyone agreed. The effect on driving performance, comfort and time is also perceived to be positive. The effects on driving safety and attention are the factors the test drivers differ most.

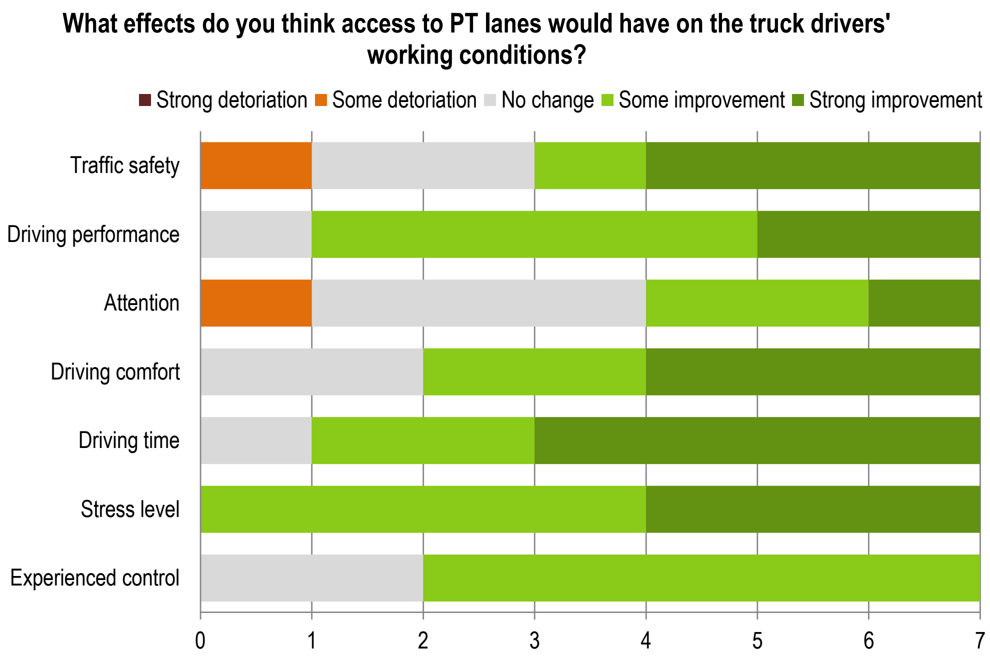

Figure 7: Effects of access to PT lanes

The drivers were even more positive about access to green waves of traffic lights during night time. No one did see any deterioration of this priority measures. 84 % of the responses indicated either some or strong improvement to the different factors in a drivers working condition.

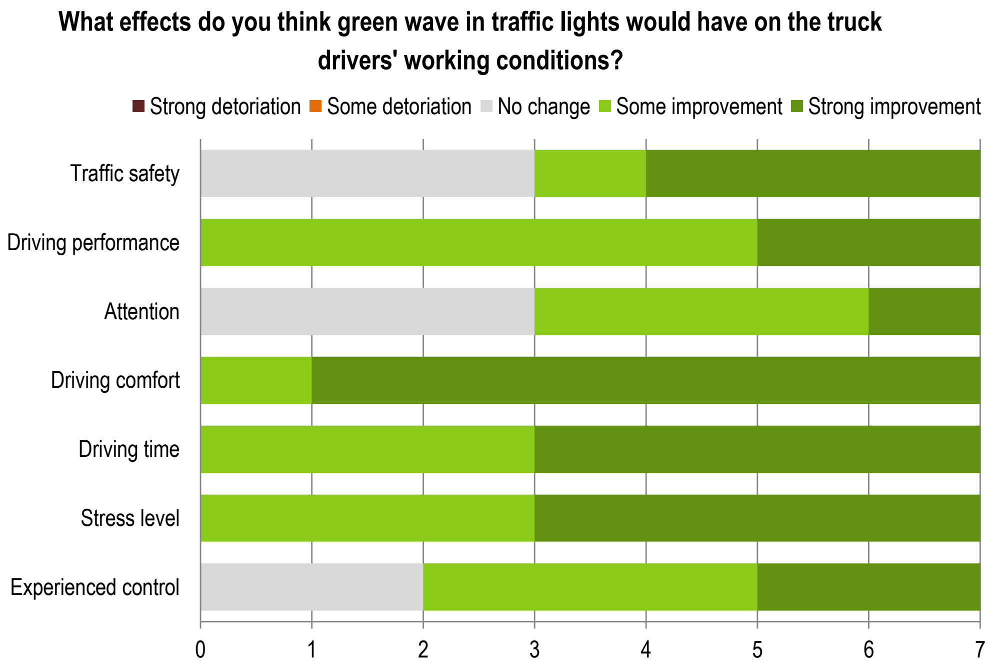

Figure 8: Effects of green waves in traffic lights

There are some differences between the perceived effects of access to public lanes during daytime and green wave during night time. Priority through green waves during night time has the most effect on driving comfort. In addition driving performance, driving time and stress levels are important effects of green waves in traffic lights.

Driving comfort was not an emphasized factor when asked about the two main arguments for the introduction of the prioritizing measures. Just as when asked about effects of the measures, stress was emphasized as an important argument for the prioritizing's. This is true for both green wave in traffic light and access to Public transport lanes.

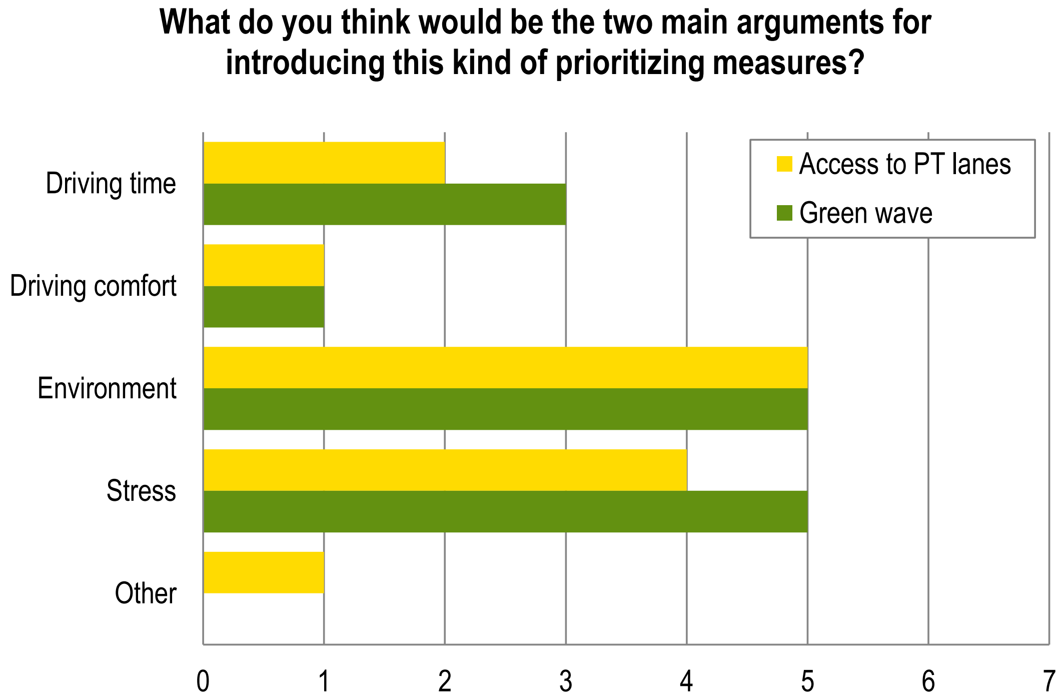

Figure 9: Arguments for prioritizing measures

Environment is also an important argument. For Public transport lane this was viewed as the most important argument. Shorter driving time was viewed by fewer drivers as an important argument.

When the test drivers were asked about the most important measure of the two tested, five out of seven answered accessed to the public transport lanes. This might seem strange since they were more positive to the effects of green waves in the traffic lights during the night. At the same time, some of the drivers emphasized by written text that access to the public transport lanes would bee over a longer time period than access to priority in traffic lights through green waves. The effect of access to public transport lanes is also perceived as most efficient.

The drivers involved in the live demonstration of cooperative information (Melan et.al. 2012) were also asked comparable questions about arguments for introduction of new measures. Their emphasis was on benefits to travel time and traffic safety and least emphasis on environment.

3.4 Drivers – benefits from the tests

We have seen that the drivers are positive to the experience of the driving simulator and to the suggested measures. We did also want to study the relationship between the experience in the driving simulator and the perceived importance of the suggested measures. The drivers were asked how they perceived the driving simulator's ability to convey the experience of getting the priority. Figure 10 and Figure 11 show how each of the seven drivers responded. The effect was perceived as positively by the test drivers, especially for the use of public transport lanes during daytime hours.

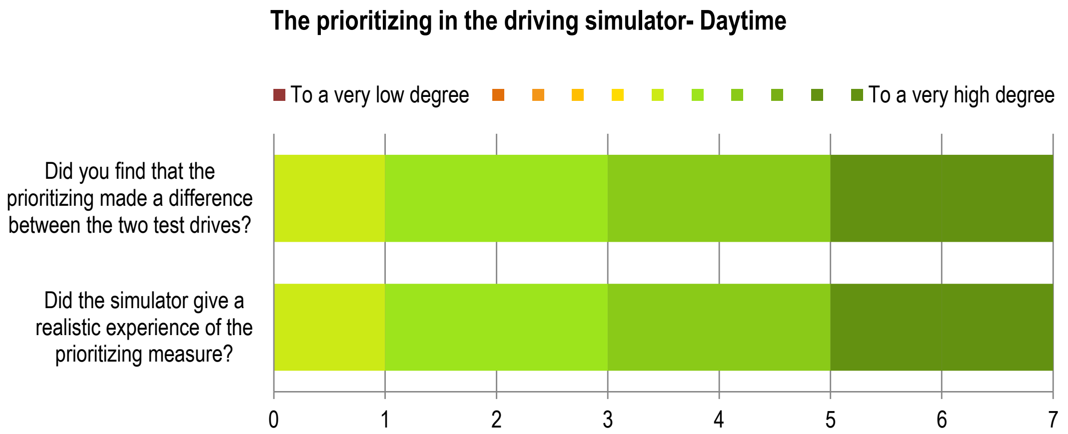

Figure 10: Simulator experience - daytime

The drivers noticed a difference to a much lesser degree in the night time scenario. This was also reflected in the how realistic they perceived the prioritizing.

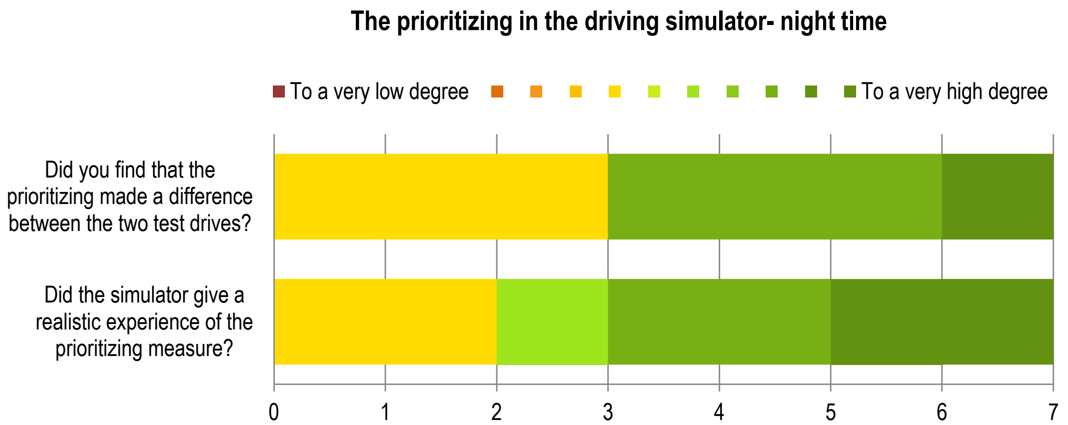

Figure 11: Simulator experience – night time

4 THE DRIVING SIMULATOR TEST – MEASURED BENEFITS

There were a lot of data provided by the tests like vehicle positions, speed, acceleration and lane position. In addition more detailed data about the vehicle was available like engine speed and fuel consumption was available.

Because of budget limitations, the data was not analysed to their full potential. Only basic analysis was conducted.

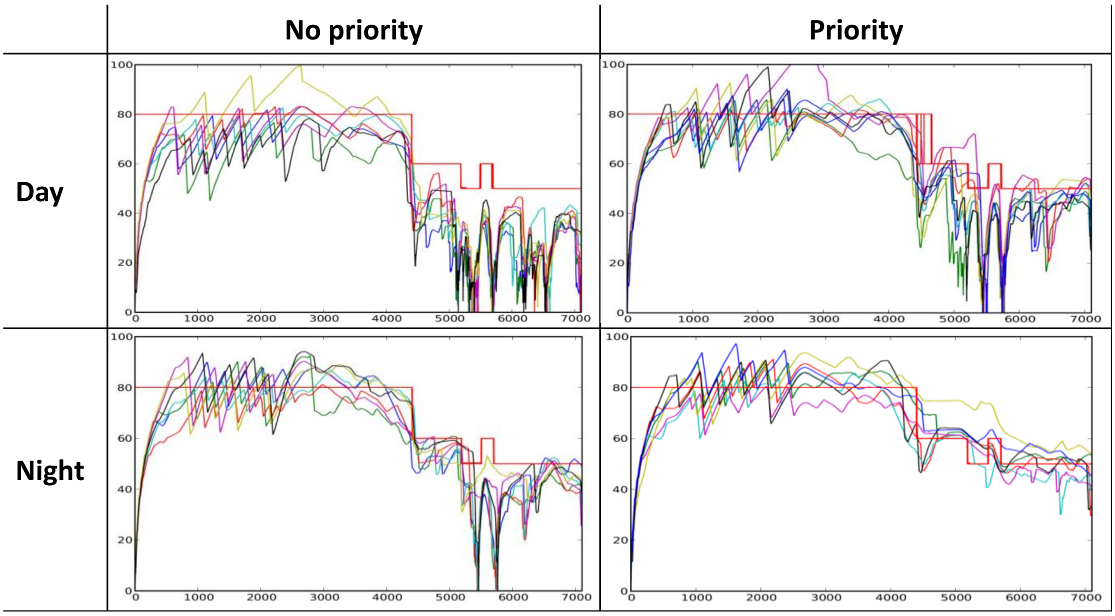

Figure 12: Measured travel behaviour

The priority of vehicle in the public transport lane showed to be most important related to travel time. The average time saved by this priority was 4 minutes. The travel time saved by green wave though priority in traffic signals were 1 minute.

We can observe the largest changes at the second part of the route were speed limits varies between 50 and 60 km/h. This is as intended since there are no differences in the first part of the route regarding prioritizing.

In the daytime the second part of the route had a substantial increase in average speed. The average speed changed from 17 km/h in the normal situation to 30 km/h in the prioritizing environment.

Also during night time there was an increase in average speed in the second part of the route. The average speed changed from 33 km/h to 52 km/h.

5 THE DRIVING SIMULATOR TEST – DISCUSSIONS

The GOFER project involves three different methods to study effects of different measures aimed at the heavy vehicle drivers: Live demo, simulator and micro simulation. The micro simulation study is on-going and results are not available yet. None the less, some experiences can be drawn from this part of the project too.

The most important experiences are:

Live demo – Have to be conducted over a long time period and lot of runs. This is in part due to a lot of uncontrolled factors. It can also be difficult to measure effects on other road-users. During the project we also experienced that it was impossible to introduce some measures like prioritizing of heavy vehicles by green waves in traffic lights and access to public transport lanes.

Micro simulation – The experience so far is that emission models integrated in micro-simulation models have theoretical limitations. The models are not validated for Norwegian situations. We are lacking detailed information about Norwegian driver behaviour and the knowledge about this on the micro simulations. Related to heavy vehicles, we also lack information about the real world situation we are modelling. For example, we do know the percentage of heavy vehicle based on roadside registrations of vehicle length, but these measurements have proven to be inaccurate. In addition we do not know the weight of the vehicles and if they are traveling with cargo. Since no driver is involved in micro simulations it not possible to get information about driver experience through this methodology.

Driving simulator – It is the first time a driving simulator has been used to test the usefulness of different measures related to heavy vehicles. During the test a lot of attention has been at making the driving environment and traffic scenario as realistic as possible. There is a limit to the external validity of the results because the traffic scenario is limited to the one that is designed. This is at the same time one of the advantages since the tests can be conducted during a short period of time, there are few uncontrolled factors, and we can test specific scenarios. An important part of simulator experiment is the possibility to get information about the driver experience.

6 THE DRIVING SIMULATOR TEST - CONCLUSIONS

Based on the tests in the driving simulator, we have conclude that the driving simulator can be used to investigate traffic management measures for heavy vehicles. The simulator gives a realistic driving experience, the measures are represented in a realistic way and the effects of the measures are perceived as realistic. The logged data can also be further analysed and can be used to estimate environmental effects. At the same time, one has to look at alternatives like live demo and micro simulations and consider the advantages and limitations of every method before using the driving simulator.

7 THE ROAD AHEAD

Results from the demonstration will be used to contribute to the development of new tests and analysis aimed at the effects of potential of prioritizing measures. Data from the logging will be available to future projects to improve micro simulation modelling and to make detailed calculations about environmental effects. Based on the results, we can further develop the tool for calculating driving time for heavy vehicles on the Norwegian road network, to seek to further develop tools for calculations of the fuel consumption and emissions from heavy vehicles, and to measure alternative effects on the driver environment.

Both the project partners Bring and the Norwegian Public Roads Administration (NPRA) saw potential in the GOFER simulator demonstration for further development both in conjunction to the two tested measures and in testing other measures. They especially emphasised the useful in testing scenarios that were not allowed to be tested in live traffic.

Acknowledgements

The authors would like to give a special thanks to Bring and their drivers for their enthusiasm, patience and constructive feedback before, during and after the demonstration. Thanks also to The Norwegian Research Council, ITS Norway, NPRA and the rest of the GOFER consortium.

References

Meland S., Mausethagen C. and Rennemo, O.M. (2012) Demonstration of a cooperative information system for heavy vehicles, Proceedings of the 40th European Transport Conference, AET, London

Rexeis, M., Hausberger, S., Riemersma, I., Tartakovsky, L., Zvirin, Y., Van Poppel, M., Cornelis, E. (2005) Heavy duty vehicle emissions, WP 400 Final report under the ARTEMIS project, DGTREN Contract 1999-RD.10429. http://inrets.fr/ur/lte/publi.../ficheartemis/road3/.../Artemis_del4_HDV.pdf

Tørnros, J. (1996) Kørbeteende i verkeleg och simulerad vagtunnel. En valøideringsstudie. VTI meddelande 804, Linkøping