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EX-ANTE EVALUATION OF LONGER AND HEAVIER VEHICLES IN FLANDERS – A DRIVING SIMULATOR STUDY

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ABSTRACT

Background: The Flemish government is considering the implications of allowing the use of Longer and Heavier Vehicles (LHVs) for road freight transport. These megatrucks can measure up to 25.25m (instead of 18.75m) and weight up to 60 tons (instead of 44 tons). Such trucks are already in circulation in some of the EU Member States (e.g. Sweden, the Netherlands). This driving simulator study is part of a pilot project that's investigating the advantages and disadvantages of introducing LHVs in Flanders (Belgium).
Objectives: To get more insight in the drivers' behavior when drivers are overtaking an LHV or when they are entering/exiting a highway in the presence of an LHV. Getting more insight in the behavior of the LHVs drivers is not the scope of this driving simulator study, but this is investigated in another subproject within the pilot project.
Methodology: The experiment is conducted on a medium-fidelity STISIM driving simulator and the visual virtual environment is presented on a large 180° field of view seamless curved screen, with rear view and side-view mirror images. The driving simulator consists of a mock-up and is equipped with a faceLAB eye tracking system. Fifty participants are exposed to different conditions of entering/exiting the highway and overtaking maneuvers.
Results & conclusions: We can conclude that there is little difference between the regular truck and LHV conditions in case of overtaking maneuvers on a secondary road or entering/exiting a highway. However, some important findings that road authorities should take into consideration are:

- Drivers need a longer distance to perform the overtaking maneuver on a secondary road in the LHV condition;
- Drivers tend to drive closer to the right side of the road after overtaking an LHV. Therefore, only allowing LHVs on roads with physically separated cycle lanes can be an option;
- Drivers need a longer distance to enter the highway safely in the presence of an LHV. Therefore, the merging lanes on highways might be provided with an emergency lane with a minimum length of 250m.

Additionally, a warning sign at the backside of the LHV is very useful to inform the drivers that they are driving behind a truck with a length of up to 25.25 meters.

KEYWORDS

Driving simulator; Longer and Heavier Vehicles; Risky driving behavior; Highway; Overtaking maneuver

INTRODUCTION

Belgium is known as one of the most ideal logistic transits in Europe. Global cities like Amsterdam, London and Paris are accessible within 300km. The foundation is due to a well-established network of roads, rails and water streams. However, the pressure of increasing road transport has raised concerns; especially in large populated urban areas (e.g.: Brussels and Antwerp) where congestion is only getting worse. To avoid growing number of traffic jams, the Flemish government is considering expanding inland shipping and railroad network. However, not all companies can shift their businesses. Therefore, policy makers are considering the implication of allowing the use of Longer and Heavier Vehicles (LHVs; see figure 1) for road freight transport. These megatrucks can measure up to 25.25m (instead of 18.75m) and weight up to 60 tons (instead of 44 tons) *(Brijs, Dreesen, & Daniels, 2007; Debauche & Decock, 2007; Opzoekingscentrum voor de wegenbouw, 2007)*.

Not only in Australia, Canada, New Zealand, Russia and the United States, but also in European countries such as Finland and Sweden LHVs have been among the streets. Next to Finland and Sweden *(Haraldsson et al., 2012; Nykänen & Liimatainen, 2014)*, the attention to such truck combinations grows also in the rest of Europe. In recent years the Netherlands and Germany already launched pilot projects *(Aarts et al., 2010; Aarts & Feddes, 2008; Verkeersnet, 2015).*

Forecasts that freight transport will grow by more than 50% urged the Dutch government to take measures. The Dutch government decided to admit LHVs under certain conditions by means of a trial. The conditions were (and still are): no deterioration of traffic safety, no reverse modal shift, no extra investments in the road network (with the exception of parking areas) and sufficient indication of interest from transport companies *(Schoon, 1999)*. After some preliminary investigations, a first trial was initiated in 2001 to investigate the consequences of LHVs on the roads. A characteristic feature of the process of introducing LHVs in the Netherlands is, in fact, the close cooperation with all stakeholders to ensure broad public support. Calculations show that the use of LHVs can result in a cost saving of 25% per LHV roundtrip *(Aarts et al., 2010; Brijs et al., 2007)*. To be allowed onto the roads in the Netherlands, the LHV must have the required permit. The admittance of LHVs is not expected to cause any deterioration of road safety according to the results of studies so far conducted and the experience gained in the trials. Since 2001 there have been five accidents involving LHVs with damage confined to the vehicle bodywork. To date there have been no serious accidents involving LHVs. In many cases LHVs are not even noticeable among the rest of the traffic. The doubts stem from a possible reverse modal shift, bridges and road safety *(Aarts & Feddes, 2008).*

In the German state of Nedersaksen, a small trial was set up in 2007 with LHVs with a length of up to 25.25m in specific routes. In November 2006, two companies received a license in the state of LHVs driving. Furthermore, the states Noord-Rijnland-Westfalen, Baden-Württemberg and Thüringen allowed companies to launch pilot projects. On the other hand the state of Beieren has forcefully communicated that LHVs were not welcome in their roads before results of traffic engineering feasibility studies are studied. This study by BASt (Bundesanstalt für Strassenwesen) in 2007 examined the impact on road infrastructure and road safety. Finally, in October 2007, the minister decided not to conduct further experiments, but only finishing ongoing projects *(Debauche & Decock, 2007; Opzoekingscentrum voor de wegenbouw, 2007)*.

The infrastructure in Belgium is very different from that of Australia, Canada, Finland and Sweden. LHVs can indeed be quite smoothly deployed on long journeys through scarcely populated areas, on roads where there is no congestion. The use of LHVs in pilot projects in the Netherlands and Germany on the other hand is more comparable with the situation in Belgium, because it has similarities based on highly industrialized Western European areas of high population density and much congestion on the main transport axes.

In studying the effects of a possible introduction of LHVs on road safety of the Flemish roads we encounter a lack of scientific research. We therefore draw upon these pilot projects abroad, but also there prevails some uncertainty about the potential impact of LHVs on road safety.

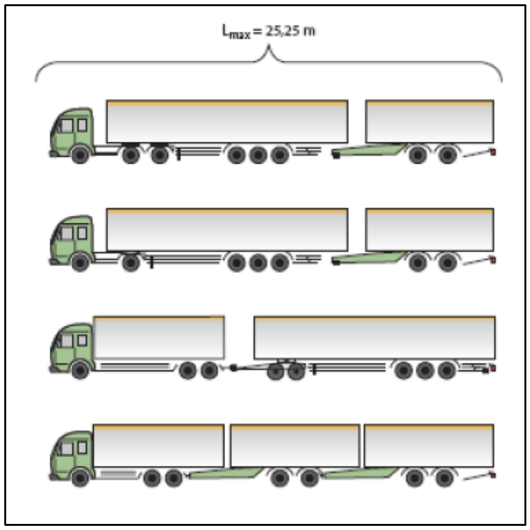

Figure 1: Example of LHV combinations with a maximum length of 25.25m (Debauche & Decock, 2007)

OBJECTIVES

The primary objective of this study is to evaluate the driving (and looking) behavior of drivers in the presence of an LHV vs. a regular truck (RT). For this purpose, different scenarios were built in the driving simulator at the Hasselt University's Transportation Research Institute. The chosen situations are based on the literature, where multiple researches *(Brijs et al., 2007; Hanley & Forkenbrock, 2005; Mazor, Nijhof, de Vlieger, & Verschuur, 2005; Schoon, 1999)* have indicated that these situations are potentially dangerous in the presence of LHVs. Therefore, we address the following research questions within this simulator study:

1. Is there a difference in driving behavior when overtaking an RT vs. LHV?
2. Is there a difference in driving behavior when entering a highway in the presence of an RT vs. LHV?
3. Is there a difference in driving behavior when exiting a highway in the presence of an RT vs. LHV?
4. Do drivers notice the difference between an RT and LHV (i.e. looking behavior)?

Getting more insight in the behavior of the LHVs drivers is not the scope of this driving simulator study, but this is investigated in another subproject within the pilot project.

METHODOLOGY

Participants

Fifty volunteers (all gave informed consent) participated in the study. Two did not finish the experiment due to simulator sickness and no outliers were identified based on the three interquartile distance criteria. Thus, 48 participants (31 men), approximately equally divided over four age categories from 20 to 75 years old (mean age 43.1; SD age 16.1) remained in the sample. All participants had at least two years of driving experience. Age and gender were not taken into account as between-subject factors in the statistical analyses.

Driving simulator

The experiment was conducted on a medium-fidelity driving simulator (STISIM M400; Systems Technology Incorporated). It is a fixed-based (drivers do not get kinesthetic feedback) driving simulator with a force-feedback steering wheel, brake pedal, and accelerator. The simulation includes vehicle dynamics, visual/auditory (e.g. sound of traffic in the environment and of the participant's car) feedback and a performance measurement system. The visual virtual environment was presented on a large 180° field of view seamless curved screen, with rear view and side-view mirror images (cf. figure 2). Three projectors offer a resolution of 1024 × 768 pixels and a 60 Hz frame rate. Data were collected at the same frame rate.

Furthermore, the eye movements of the participants were recorded while driving through the scenarios, making use of a camera-based eye tracking system (faceLAB 5 Seeing Machines; see figure 2). The recorded eye tracking data were analyzed with the EyeWorks software package.

Figure 2: Driving simulator and eye tracking equipment

Procedure and scenario design

Participants were asked for their voluntary cooperation and requested to fill out a form with some personal data (e.g. gender, driving experience, date of birth, etc.). After a general introduction to the simulator and tasks, the experiment began with two practice sessions of 5-8km each (one on the highway; one on the secondary road) in which subjects became acquainted with driving in the simulator. Subjects then drove through three scenarios (in a counterbalanced order) with two conditions (RT and LHV). For these experimental scenarios, subjects drove a total distance of approximately 34km with a short break between the sessions. Subjects were asked to drive as they normally would do with their own car and apply the traffic laws as they would do (or would not do) in reality. A GPS voice instructed them during the trip.

In the first scenario with a length of 9.0km, participants drove in a rural area on a two-lane road (lane width: 3.25m) with no emergency lanes and no cycling lanes. The road had broken center lines and continuous edge lines. During the experiment subjects were instructed to drive as they normally would do in similar circumstances on the road. Simulated vehicles crossed the experiment vehicle in the opposite direction every 500m at a speed of 70km/h. Between the two segments (i.e. RT and LHV), subjects had to overtake other slow moving vehicles (a garbage truck and a sweeper). The speed limit was 70km/h and the RT/LHV moved at a desired speed of 55km/h. Figure 3 shows that participants had the possibility to overtake the RT or LHV over a distance of 2,500m (i.e. between 700m-3,200m and 6,200m-8,700m). After these 2,500m the trucks moved to the side of the road and slowed down. The RT and LHV were divided randomly (i.e. counterbalanced) over these 2 sections for the different participants.

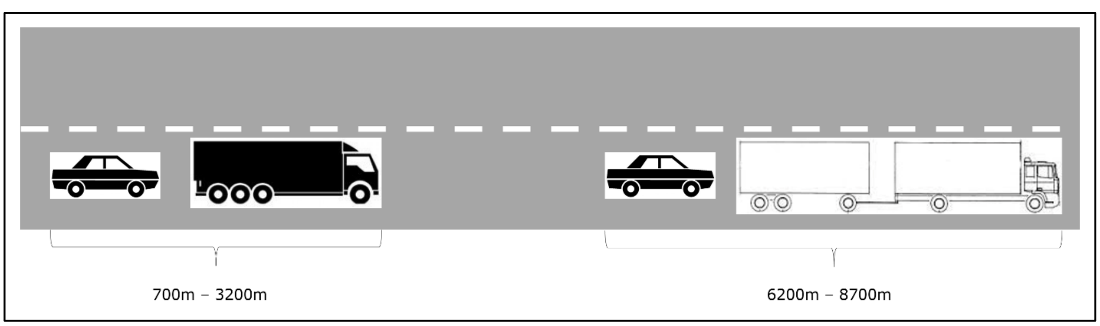

Figure 3: Overtaking scenario on a secondary road

In the second and third scenario (length of each scenario = 12.6km), participants drove on a highway including two lanes (lane width: 3.5m) in each direction, standard lane markings, a median (including barriers) and barriers at the right-hand side of the road. Furthermore, only one on-ramp and one exit were included in the scenario, both having a length of 200m. At the start of the experiment subjects were instructed to enter the highway, using the on-ramp, while an RT or LHV was driving at the right-hand lane (speed RT/LHV = 80km/h) and to exit the highway, using the off-ramp, while an RT or LHV was driving at the right-hand lane (speed RT/LHV = 85km/h) (see figure 4).

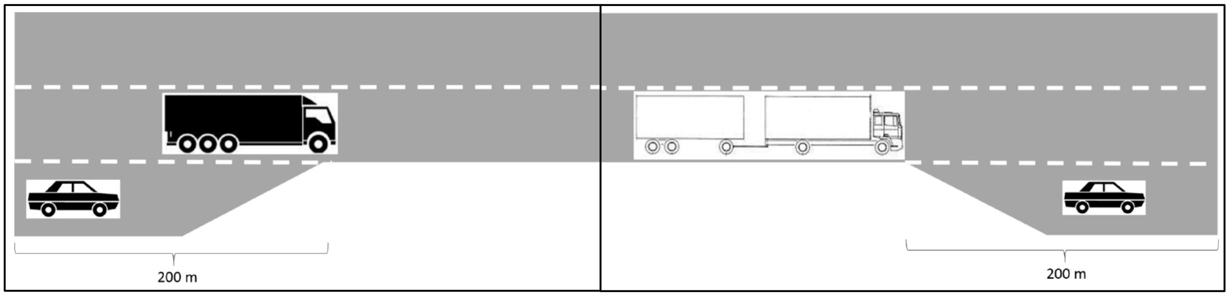

Figure 4: Scenario entering and exiting a highway

Drivers should be able to distinguish the difference between an RT and LHV. Therefore, the LHVs were provided with a sign at the back of the truck: **<<WATCH OUT: 25.25 METERS>>** (see figure 5). This sign should inform drivers that they are driving behind a truck that has a different size (i.e. length) compared to regular trucks. Especially in the case of the overtaking maneuver, this sign can be very useful.

Figure 5: Warning sign at the back of an LHV

Data collection and analysis

The research conducted is a full within design where all test drives are randomized between the participants. If the subjects did not overtake the RT or LHV, the truck ahead drove to the side and the subject could continue the drive.
The simulator in conjunction with the driving environment produced a stream of data used for analysis. In particular, five sources of data were collected and combined to the data file: speed, time, acceleration, longitudinal distance and lateral position. The vehicle data indicates the position, heading, and speed of both the driver's vehicle as well as the RT and LHV, to allow full analysis of the entire environment. Additionally, standard control data is logged, including typical signs of steering wheel position, throttle and brake position, turn signals, and any other accessible controls within the vehicle. Apart from these, it is important to focus on the influence of the eye movements, obtained by the faceLAB eye tracking system. These data represent the actual focus of the driver's visual attention,

including the duration and number of fixations of the subject's eye onto visual landmarks (e.g. LHV's warning sign).

For the further analysis of lane changes on the secondary road, we required some way of partitioning the data stream into zones (see figure 6): (1) zone before overtaking (section before the subject crosses the broken center line), (2) zone while overtaking (when the subject's vehicle fully crosses the broken center line till the subject's vehicle crosses the broken center line in front of the truck; i.e. left lane) and (3) zone when the subject's vehicle fully crosses the broken center line in front of the truck until 300m after the overtaking maneuver.

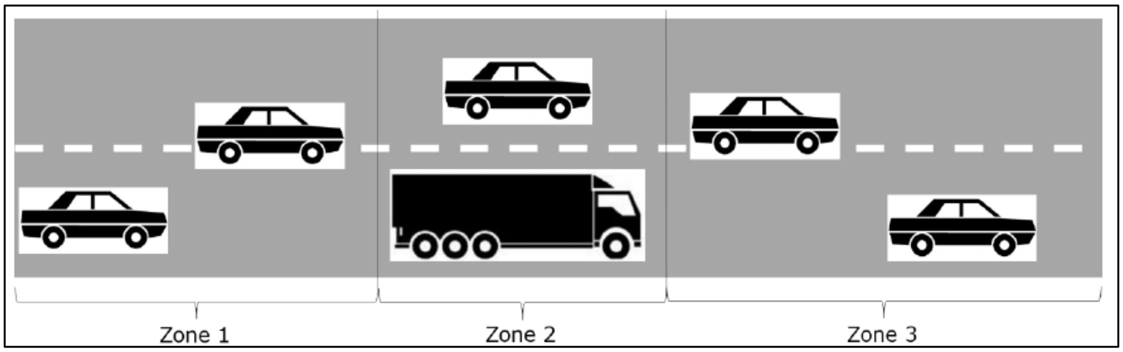

Figure 6: Predefined zones during overtaking maneuver

Below, table 1 gives an overview of the parameters that are analyzed for the overtaking maneuver on the secondary road (i.e. only for the participants that really performed the overtaking maneuver!). These parameters may differ slightly for the three predefined zones, but are in general based on the longitudinal and lateral parameters.

For the overtaking maneuver, also the looking behavior with respect to the warning sign at the rear end of the LHV will be analyzed. Mean fixation duration is calculated for the participants that executed the overtaking maneuver.

Table 2 includes the parameters for the scenarios where participants are entering and exiting the highway. Lateral position is not taken into account for the exiting scenario because this parameter seemed irrelevant in this case. For the entering scenario, the lateral position can be very interesting because participants can drive too close to the truck driving on the highway (right-hand lane) or swerve on the on-ramp.

Table 1: Parameters overtaking maneuver on a secondary road

Zone 1	Zone 2	Zone 3
Speed when crossing center line	Mean speed	Speed when crossing center line
Number of times crossing center line before overtaking (i.e. between first center line crossing and the center line crossing when overtaking; if first center line crossing = center line crossing when overtaking, this parameter is equal to zero)	Standard deviation speed	Acceleration when crossing center line
Distance headway (between driver's vehicle and truck) when crossing center line	Time needed to perform overtake maneuver	Lateral position: rightmost position after overtaking maneuver
Acceleration when crossing center line	Distance needed to perform overtake maneuver	Distance headway (between driver's vehicle and truck) when crossing center line
Number of oncoming vehicles passed after crossing center line for the first time	Mean lateral position	
Lateral position: leftmost position before overtaking maneuver	Standard deviation lateral position	
Time between crossing center line for the first time and overtaking maneuver	Mean acceleration	
Distance between crossing center line for the first time and overtaking maneuver	Standard deviation acceleration	
Distance headway when crossing center line for the first time		

Table 2: Parameters entering/exiting a highway

Entering highway	Exiting highway
Entering speed	Exiting speed
Longitudinal entering distance (on-ramp)	Longitudinal exiting distance (exit)
Mean acceleration on-ramp	Mean acceleration exit
Standard deviation acceleration on-ramp	Standard deviation acceleration exit
Mean speed on-ramp	Mean speed exit
Standard deviation speed on-ramp	Standard deviation speed exit
Mean lateral position on-ramp	
Standard deviation lateral position on-ramp	

To conclude, statistical analysis are performed using SPSS. A t-test for Equality of Means is used to determine if the parameters for the RT and LHV differ significantly on a 95% confidence interval (p-value is set to 0.05).

RESULTS AND ANALYSIS

For each of the proposed parameters, we examined whether there is a significant difference between the RT and the LHV. In this section, we mainly focus on the factors that include a statistically significant difference ($p < .05$).

Overtaking maneuver on a secondary road

Based on the test drives on the secondary road, 41 of the in total 96 potential overtaking maneuvers (i.e. 48 participants x 2 overtaking maneuvers) have been carried out effectively (RT = 21; LHV = 20). This result indicates that there is no significant link between the number of overtaking maneuvers in case of an RT or LHV.

Table 3 shows the results for the segment before overtaking. Only for the two headway distances there is a significant difference between the mean values for the two types of trucks. The mean values show that participants maintain a greater distance headway in the presence of an LHV compared to an RT when they initiate the overtaking maneuver.

Table 3: Results zone 1 (segment before overtaking)

Zone 1	**RT**	**LHV**	**t-test**
Speed when crossing center line (km/h)	62,06	64,33	t (34) = -1.07; p = .292
Number of times crossing center line before overtaking	0,57	0,50	t (35) = 0.23; p = .817
Distance headway when crossing center line (m)	**27,41**	**35,32**	**t (38) = -3.08; p = .004**
Acceleration when crossing center line (m/s²)	0,38	0,34	t (37) = 0.27; p = .787
Number of oncoming vehicles passed after crossing center line for the first time	0,33	0,25	t (37) = 0.52; p = .607
Lateral position: leftmost position before overtaking (m)	-1,75	-1,78	t (38) = 0.43; p = .667
Time between crossing center line for the first time and overtaking (s)	5,91	5,64	t (32) = 0.07; p = .943
Distance between crossing center line for the first time and overtaking (m)	93,49	92,05	t (32) = 0.03; p = .980
Distance headway when crossing center line for the first time (m)	**30,60**	**40,10**	**t (31) = -3.25; p = .003**

Concerning the looking behavior of the participants, we are mainly interested in the eye fixations with respect to the warning sign at the backside of the LHVs. We have 17 useful eye movement observations out of the 20 participants which have overtaken the LHV (dropouts due to difficult calibrations with participants wearing glasses). About 70% of these participants (i.e. 12/17) has fixated on the LHV warning sign with an average fixation duration of 0.7s. Furthermore, most of the drivers (8 out of 12 participants) who fixated on the warning sign, did this after crossing the center line for the first time (i.e. after initiating the overtaking maneuver).

Table 4 presents the findings for the segment during the overtaking maneuver. Only the mean distance that the participant needs to overtake the truck in front differs significantly between the RT and LHV.

Table 4: Results zone 2 (segment during overtaking maneuver)

Zone 2	**RT**	**LHV**	**t-test**
Mean speed (km/h)	74,99	76,93	t (37) = -1.22; p = .231
Standard deviation speed (km/h)	6,66	6,23	t (36) = 0.39; p = .698
Time needed to overtake (s)	11,54	12,79	t (38) = -1.66; p = .105
Distance needed to overtake (m)	**238,89**	**271,28**	**t (38) = -2.39; p = .022**
Mean lateral position (m)	*-0,71*	*-0,88*	*t (38) = 1.93; p = .061*
Standard deviation lateral position (m)	0,82	0,84	t (37) = -0.48; p = .632
Mean acceleration (m/s²)	0,58	0,46	t (38) = 1.17; p = .249
Standard deviation acceleration (m/s²)	0,53	0,57	t (36) = -0.49; p = .624

Table 5 includes the results for the segment after the overtaking maneuver. Also in this segment, only one parameter is statistically significant between the RT and LHV conditions: lateral position to the rightmost position.

Table 5: Results zone 3 (segment after overtaking)

Zone 3	RT	LHV	t-test
Speed crossing center line (km/h)	81,50	81,22	t (37) = 0.11; p = .915
Acceleration crossing center line (m/s²)	-0,0043	0,0053	t (34) = -0.07; p = .948
Lateral position: rightmost position after overtaking (m)	**1,81**	**1,95**	**t (35) = -2.20; p = .035**
Distance headway crossing center line (m)	-41,17	-45,72	t (38) = 1.35; p = .184

Entering and exiting highways

Based on the highway test drives, no significant differences were found concerning the number of entering and exiting actions before vs. after the RT or LHV. In case of the entering maneuvers, 20 participants merged in front of the RT and 18 participants in front of the LHV. Concerning the exiting maneuvers, most of the participants merged behind (i.e. stayed behind the truck; did not perform an overtaking action) the truck (28 participants merged behind the RT and 30 behind the LHV).

Table 6 displays the result of the analysis for the driving behavior of participants entering a highway. The speed of the trucks during the entering and exiting maneuver was set at 80km/h and 85km/h respectively. When drivers want to exit the highway in the presence of an LHV, no difficulties will arise. The results indicate that there are no statistically significant differences between the RT and LHV conditions in the scenario of exiting a highway.

Table 6: Results scenario entering a highway

Entering a highway	SV	LHV	t-test
Entering speed (km/h)	92,16	87,88	t (89) = 0.74; p = .460
Longitudinal entering distance on-ramp (m)	**2873,03**	**2892,13**	**t (88) = -2.44; p = .017**
Mean acceleration on-ramp (m/s²)	0,30	0,39	t (89) = -0.59; p = .555
Standard deviation acceleration on-ramp (m/s²)	0,60	0,64	t (91) = -0.36; p = .722
Mean speed on-ramp (km/h)	88,42	83,84	t (90) = 0.79; p = .434
Standard deviation speed on-ramp (km/h)	3,24	4,18	t (90) = -1.40; p = .166
Mean lateral position on-ramp (m)	**12,46**	**12,57**	**t (94) = -2.15; p = .034**
Standard deviation lateral position on-ramp (m)	0,48	0,47	t (85) = 0.30; p = .763

DISCUSSION

In general, we can state that there is little difference between the RT and LHV conditions when drivers enter or exit a highway or perform an overtaking maneuver on a secondary road. This is in line with a number of previous studies *(Aarts et al., 2010; Aarts & Feddes, 2008; Brijs et al., 2007; Schoon, 1999; Verkeersnet, 2015)*. However, some important findings should be taken into account by the policy makers and road authorities.

Overtaking maneuvers on a secondary road

First of all, we can conclude that there exists no significant difference in the number of overtaking maneuvers that has been carried out effectively (RT = 21; LHV = 20). This implies that the number of overtaking actions is independent of the type of truck (RT vs. LHV). Furthermore, none of the participants has broken down the overtaking action, which sometimes might be the case with LHVs according to conclusions found in the literature *(Hanley & Forkenbrock, 2005; Mazor et al., 2005)*.

Table 3 showed the results for the segment before overtaking (i.e. zone 1). Only for the two headway distances there arises a significant difference between the mean values for the two types of trucks. The mean values show that participants maintain more distance from the LHV than the RT when they initiate the overtaking maneuver (about 8-10m more in the case of an LHV). This is not really in line with *Mazor et al. (2005)*. They concluded that drivers keep sometimes insufficient distance between their vehicle and LHVs, both behind and in front of LHVs. In contrast and out of psychological point-of-view, people tend to misjudge distances of larger objects. In general, a large far

object appears to be nearer than a small near object *(Braunstein, 1976; De Lucia, 1991; Gogel, 1963; Hockberg & McAlister, 1955)*. This may be the reason why drivers keep a greater following distance with respect to an LHV (i.e. larger truck compared to an RT).
Although there are no additional significant differences between the RT and LHV for the other parameters, there are a number of interesting findings. First of all, for the parameter “Speed when crossing the center line” there is an average difference of more than 2km/h between the two trucks (higher speed in the case of an LHV). Apparently, participants anticipate on the length of the LHV by an increasing speed when they overtake this type of truck. Furthermore, participants seem to have less difficulty overtaking an LHV compared to an RT. This conclusion can be drawn by the fact that drivers hesitate less to perform the overtaking maneuver in case of an LHV (i.e. less number of times crossing the center line before overtaking and less number of oncoming vehicles passed after crossing the center line for the first time).

Concerning the looking behavior, not all (i.e. 70%) participants have fixated on the LHV warning sign. Furthermore, most of the drivers (8 out of 12 participants) who fixated on the warning sign, did this after crossing the center line for the first time (i.e. after having the intention to perform an overtaking maneuver). This means that most of the drivers initiated the overtaking maneuver regardless of the type of truck (RT or LHV). The average fixation duration equals 0.7s, which can be considered as a normal value *(Castro & Horberry, 2004; Dewar & Olson, 2007)*. Fixation times longer than 2s can lead to risky driving situations (i.e. eyes-off-the-road).
Although not every driver looks at the warning sign, this sign might be very useful to inform the drivers that they are driving behind an LHV (i.e. longer truck). The technical requirements for LHVs in the Netherlands also indicate that the backside of the truck should come with a warning sign (retro-reflective material with the text "Caution") and the total length (in meters) of the truck *(Debauche & Decock, 2007)*.

Table 4 presented the findings for the segment during the overtaking maneuver. Only the mean distance that the participant needs to overtake the truck in front differs significantly between the RT and LHV (239m vs. 271m) conditions. This makes sense due to the fact that an LHV can measure up to 25.25m, so the driver clearly needs to bridge a significant longer distance to overtake the LHV compared to the RT. This is in line with findings from previous research *(Hanley & Forkenbrock, 2005; Schoon, 1999)*. Although, if we have a closer look at table 4, the parameter “Time needed to overtake” shows no significant difference. We can conclude that participants anticipate on the length of the vehicle by initiating the maneuver at a higher mean speed (see table 3 parameter “Speed when crossing center line”) and a higher mean speed while overtaking (see table 4 parameter “Mean speed”). However, these parameters are not statistically significant for an RT vs. an LHV. An important aspect to keep in mind is that the mean speed during the overtaking maneuver lies above the maximum speed limit of 70km/h, both for the RT (75km/h) and LHV (77km/h) conditions.
A different parameter that needs to be taken into account is the mean lateral position on the left lane. The p-value was equal to 0.061 and thus statistically significant at a significance level of 10% . If we look in more detail at the mean values (RT = -0.71; LHV = -0.88), the difference is real. Participants clearly keep more (lateral) distance in case of the LHV compared to the RT. Therefore it is important for the policy makers to keep in mind that the width of the roads need to be sufficiently wide or a (small) obstacle free zone even should be provided at the roadside. The reason for this difference in lateral position possibly can be explained by that fact that the length of the LHV can scare the drivers while they are overtaking the LHV *(Brijs et al., 2007; Mazor et al., 2005)*.

Table 5 included the results for the segment after the overtaking maneuver (i.e. until 300m after crossing the center line). In this segment (i.e. zone 3), only one parameter is statistically significant: Lateral position to the rightmost position is significant between the RT (1.81m) and LHV (1.95m) conditions. This means that participants drove closer to the right side of the road after overtaking an LHV compared to an RT. This phenomenon can possibly cause some dangerous situations when the road is equipped with an adjacent cycle lane. An explanation for this finding might be found in the fact that drivers drive faster in the LHV condition and therefore have less control over their vehicle (and maybe swerve more) *(Brijs et al., 2007; Hanley & Forkenbrock, 2005; Mazor et al., 2005)*. In the Netherlands, LHVs only drive on roads with physically separated cycle lanes. Although this may be detrimental to the accessibility of economically important areas, the Minister allows LHVs on roads without physically separated cycle lanes only for distances of up to 5km *(Aarts et al., 2010; Debauche & Decock, 2007)*.
If we look at the speed when crossing the center line, we can conclude that the mean speed is on average 11km/h higher than the maximum speed limit of 70km/h and at least 4km/h higher than the mean speed during the entire overtaking maneuver (i.e. in zone 2). A reason for this behavior may be found in the fact that participants speed up while overtaking an RT or LHV. Because the acceleration when crossing the center line is nearly equal to zero (cf.

table 5), we can suppose that participants roll out after the maneuver until they reach the appropriate speed of 70km/h.
Furthermore, the distance headway is not significant in zone 3, but was significant in zone 1. The results in table 5 indicate a longer (but not statistically significant) headway for the LHV (46m) in comparison with the RT (41m), which could imply that participants take into account that LHVs could have a longer braking distance (i.e. drivers want to have a greater margin of safety).

Entering and exiting highways

Based on the highway test drives, no significant differences were found concerning the number of entering and exiting actions before vs. after the RT or LHV. In case of the entering maneuvers, 20 participants merged in front of the RT and 18 participants in front of the LHV. Concerning the exiting maneuvers, most of the participants merged behind (i.e. stayed behind the truck; did not perform an overtaking action) the truck (28 participants merged behind the RT and 30 behind the LHV). This means that there is not a significant difference in the choice of drivers to merge before or behind an RT vs. LHV.

Table 6 displayed the results of the analysis for the driving behavior of participants entering a highway. When drivers want to exit the highway in the presence of an LHV, no difficulties will arise. The results indicate that there are no statistically significant differences between the RT and LHV conditions in the scenario of exiting a highway. This is in line with previous research of *Schoon (1999)*, who found no important differences between the RTs and LHVs.

On the other hand, two significant differences are found between the conditions where drivers enter the highway in the presence of an RT or LHV. The first significant parameter is the average lateral position at the on-ramp. Here, drivers tend to drive closer to an RT (-0.11m) compared to an LHV. In fact, this observed behavior is not dangerous as long as the merging drivers maintain an adequate view on the other (upcoming) traffic at the highway. Likewise with the overtaking maneuver, a possible explanation can be that drivers tend to misjudge (lateral) distances towards larger objects and thus keep a greater margin of safety.
However, a more important significant parameter is the longitudinal distance where the drivers leave the on-ramp and enter the highway (i.e. merging point). Drivers stay longer at the on-ramp in the LHV condition compared to the RT condition (19m on average; t (88) = -2.44; p = .017). Therefore, the merging lanes on highways should be provided with an emergency lane with a minimum length of 250m *(Aarts et al., 2010; Debauche & Decock, 2007)*.
Finally, the parameter “Mean speed at the on-ramp” reveals a (non-significant) difference between the RT (88km/h) and LHV (84km/h) conditions. This means that the mean speed is higher in the presence of an RT. Possible explanations may be found in the fact that drivers don’t know what to do (merge before of behind the LHV?) and thus may hesitate more in the presence of an LHV *(Mazor et al., 2005)*. This lower speed could make the maneuver more risky, especially for elderly drivers *(de Waard, Dijksterhuis, & Brookhuis, 2009)*. Additionally, an extended on-ramp (acceleration lane) can be part of the solution to this problem.

CONCLUSIONS

In general, we can conclude that there is little difference between the regular truck and LHV conditions in case of overtaking maneuvers on a secondary road or entering/exiting a highway. However, some important findings that road authorities should take into consideration are:

- Drivers need a longer distance to perform the overtaking maneuver on a secondary road in the LHV condition;
- Drivers tend to drive closer to the right side of the road after overtaking an LHV. Therefore, only allowing LHVs on roads with physically separated cycle lanes can be an option (and make an exception for LHV trips less than 5km on roads with adjacent cycle lanes);
- Drivers need a longer distance to enter the highway safely in the presence of an LHV. Therefore, the merging lanes on highways might be provided with an emergency lane with a minimum length of 250m.

Additionally, a warning sign at the backside of the LHV is very useful to inform the drivers that they are driving behind a truck with a length of up to 25.25 meters.

To conclude, LHVs may also contribute to the traffic safety issues. In general, rising motorization rates for trucks lead to higher traffic fatalities *(Castillo-Manzano, Castro-Nuño, & Fageda, 2015)*. When LHVs should be introduced, this would lead to a decrease in the number of regular trucks and thus an overall decrease in motorization rates for trucks.

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