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ARTICULATED VEHICLES OF 25 METER AND 60 TON IN THE NETHERLANDS - THE START OF A PILOT PROJECT.

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ABSTRACT
At this moment the total allowable length of an articulated vehicle in The Netherlands is 18.35 meter and its total maximum weight is 50 ton. Several Dutch transportation organisations requested a pilot project with longer and heavier vehicles for heavy goods transportation. Because of the environmental benefits to society, the Ministry of Transport was prepared to consider such a pilot project. The Ministry decided that, before a decision could be made several questions had to be answered, such as about legal aspects in relation to European laws, and about infrastructure, environment, economics and road safety. It was also decided to make an inventory of such questions together with the branch organisations. Information to answer these questions was gathered, also in close collaboration with the branch organisations, by studying literature, interviewing key persons in countries where longer and heavier vehicles are operating at the moment, and by using existing mathematical models. The TNO Road-Vehicles Research Institute has investigated the safety aspects. The vehicle stability is one of these aspects and many publications have been made on this item. Other items concerning safety are:

- Overview on the right side of the vehicle combination in a right turn;
- Crosswind disturbance;
- Overtake manoeuvres by other road users on single carriage ways;
- Traffic flow;
- Crash behaviour.

The main questions concerning the economical, infrastructure, environmental and legal aspects will be described in broad outline , whereas the safety aspects will be described in more detail. This is followed by the methods by which the answers were collected and by a description of the results. On the basis of this information an advice to the Minister was formulated to conduct a pilot project under restricted conditions. Finally, the suggested pilot project restrictions will be described.

1. INTRODUCTION
Dutch transportation organisations have asked the Dutch government to agree to conduct a pilot experiment with larger and heavier trucks than are admitted at this moment. Economical considerations were the main reason for their request. They suggested that as a result of the larger and heavier vehicles the total number of heavy vehicles would decrease, with a positive effect on traffic efficiency. A total of 35 transport companies declared to be willing to

participate in such a pilot project. The result of which might be used for the discussion on modifying the legal maximum dimensions of articulated vehicles.
The use of longer and heavier vehicles can potentially decrease the fuel consumption and the negative environmental effects of the heavy goods transport by road in The Netherlands. Because of this positive environmental effect, the Dutch Government in principle could agree with the pilot project under the condition that prior to a definitive decision, the effects of these vehicles on traffic safety, infrastructure damage and the environment were quantified.

An inventory study was started to collect available (international) data and experience [1, 2, 3] and to quantify these effects by using existing mathematical models. A project-group of people from different departments of the Ministry of Transport would supervise this inventory and at the end advise the Minister [4]. This paper describes this study and gives an overview of the results and the ensuing political discussion.

One of the spearheads in the policy of the Ministry of Transport is to stimulate the transport of heavy goods by railroad and water (intermodal transport). As a consequence a number of intermodal terminals are built at this moment. One of the conditions for the pilot project was that the introduction of larger and heavier trucks would not have any negative effect on this intermodal transport.

2. LEGAL REQUIREMENTS IN THE NETHERLANDS AND IN EUROPE

For the legal requirements for the transport of heavy goods by road, one should distinguish between national and international transport. The maximum length is 18.35 meter for national and international transport. The maximum vehicle mass is 50 ton for national and 40 ton for international transport. In the future the European Union Regulation EU 96/53 will percribe the maximum dimensions and mass for heavy goods vehicles. For international transport the maximum length will be 18.75 meter and the maximum mass will be 40 ton, although under certain conditions a maximum mass of 44 ton will be allowed. An article in this regulation gives governments the possibility to enlarge these maximums (e.g. to 50 ton) for national transport (see Table 1).

Table 1: Maximum length and mass according to EU 96/53

	National transport	International transport
Maximum length	18.75 m	18.75 m
Maximum mass	$50 \cdot 10^3$ kg	$40 \cdot 10^3$ kg

3. RESEARCH QUESTIONS

What are the consequences of enlarging the maximum mass and length of heavy goods vehicles on road safety and what are the effects on the environment, the mobility, the infrastructure, the economy and on the intermodal transport. The purpose of the study described in this paper is to inventory these consequences by collecting research data, information available in other countries by interviewing key-persons in Sweden and Australia, and by using available mathematical models.

Questions on safety to be solved were identified as:

- Can the driver of these longer vehicles observe his total vehicle in a 90° right turn (left hand driven vehicle) by the rear facing mirrors?
- What can be said about the crosswind disturbance when a longer vehicle overtakes a passenger car towing a caravan?

- Are there any problems to be expected on highways, especially when these longer and heavier vehicles will enter the highway or when these vehicles will change lanes?
- Overtaking manoeuvres by passenger cars on single carriage roads will last longer. What are the expectations on crashes?
- Crossing an intersection will last longer. What are the expectations on crashes?
- What is the impact of these vehicles when they run into the rear of a traffic jam on a highway?

Other questions were:

- What are the consequences of enlarging the maximum mass and length of heavy goods vehicles on the number of trips, number of kilometres driven and the exhaust of CO_2 in The Netherlands?
- What are the economical consequences of enlarging the maximum mass and length of heavy goods vehicles for the transport companies and for the Dutch economy?

The longer and heavier vehicle configurations will all have a total vehicle length of 25.25 meter, a vehicle width of 2.55 meter and a total mass of 60 ton, and can be further described as follows:

- a three axle truck with a three axle full-trailer coupled with a two axle A-dolly (**see Figure 1**), named as 'Vehicle A';
- a three axle tractor with a three axle semi-trailer and a central axle trailer with two axles (**see Figure 2**), named as 'Vehicle B';
- a nine axle B-double (**see Figure 3**), named as 'Vehicle C'.

These vehicles were compared with two reference vehicles, a normal 18.75 meter six axle truck full trailer and a 16.5 meter tractor semi-trailer each with a total mass of 50 ton, regarding the issues listed above.

4. THE SAFETY ASPECTS [5]

Overview on the right side of the vehicle combination in a turn

In a right turn, the overview of the driver on the right side of his vehicle will decrease, because of the articulation angle between the elements. The driver's overview is restricted, in accordance to regulation 71/127/EEC **(see Figure 4 & Figure 5**).

With the computer simulation tool PLBAVA, built for calculation of a vehicle swept path (see **Figure 6**), the driver's overview in a ninety degrees turn to the right with a radius of 12.5 meter was evaluated, to see whether the reduced overview is acceptable.

In each simulation run the restricted areas on the right side of the vehicles in the mentioned regulations were cross-linked with the right outer boundary of the vehicles itself. The reduced overview for each mentioned vehicle is expressed in **Figure 7 to Figure 9**. The horizontal axes represent the travelled distance of the front part of the vehicle, starting two meter before and ending 38 meter after the right hand turn. The vertical axes represents the overview expressed in percentage of the length of that specific vehicle articulation (trailer1 and/or 2), that can be seen by the driver for a standard side mirror and a wide range side mirror.

The right hand side of Vehicle A remains fully in sight with wide range side mirrors. The overview on the second trailer of vehicle B decreases to 70% and it decreases to 60 % on the second trailer of the B-double (Vehicle C). During part of the cornering manoeuvre these articulations are out of sight from the driver's position. The probability of an accident like running over bicyclists and pedestrians in such turn manoeuvres will increase, but at this moment it is hard to quantify this probability.

The swept path increases compared to the normal 16.5 meter tractor semi-trailer and 18.75 meter truck full-trailer combinations, which will also increase the risk of earlier mentioned accidents.

Additional requirements should restrict the minimum right side overview area for these vehicles. These requirements could be fulfilled by extra wide range mirrors or mirrors that rotate with the articulation angle between the first and second vehicle element or with cameras and/or video screens.

The swept path will be reduced by means of rear-steered axles on the trailer, but the use of these axles might reduce the stability of these vehicles at higher speeds.
There is no extra risk for slow traffic straight line overtaking. The truck driver should of course realise the total vehicle length. 'Close side protection' should be fixed to reduce the risk of running over bicyclists or pedestrians, or alternatively, these vehicles should be allowed only on roads with special separated bicycle lanes.

Crosswind disturbance

The aerodynamic disturbance from these longer vehicles on other road users has been evaluated with a vehicle model of a passenger car coupled with a trailer-home combination, overtaken by the longer vehicle combinations. The relative angle of the wind was assumed to be twenty degrees and the clearance between the passing vehicles was assumed to be one meter. The aerodynamic effects from these longer vehicle combinations on both passenger car and trailer-home are represented by the lateral force and the yaw and roll moment time history (**see Figure 10**). These effects were estimated using the measured time signals from Dave Weir [6, 7], where the signals had to be scaled to match these longer vehicles and passenger car type.

These estimated lateral force and yaw and roll moment for each vehicle combination were used as inputs for the simulation runs. The output of the simulation runs consists of the lateral acceleration and the yaw velocity in the centre of gravity of both passenger car and trailer-home (**see Figure 11**). The results are evaluated for several differences in speed between the truck and the passenger car.

In case of no natural wind, the length of the heavy vehicle is hardly of influence on the crosswind disturbance to other road users when overtaking. There is no significant difference between the mentioned longer vehicles up to 15 km/h difference in speed. The disturbance on a passenger car trailer-home combination from Vehicle A is the lowest. There is no significant difference with Vehicle B up to 30 km/h in comparison with the normal 16.5 meter tractor semi-trailer combination. Significant differences in disturbance occur at difference in speed exceeding 15 km/h, for the Vehicle C and Vehicle A.

Overtake manoeuvres of other road users on 80 km/h roads

Overtaking longer vehicles on single carriage roads requires more time (**see Figure 12**). This increase in time results in the necessity of longer free space length between two cars in the traffic of opposite direction. Most single carriage roads in The Netherlands are curved, in which case it might be very hard to see if there is enough free space available. Chances are that accidents will increase.

The acceptance of drivers of passenger cars on this free space for overtaking these longer vehicles combinations has not yet been studied. A realistic assumption is that the increase of the number of these overtake manoeuvres, the additional time required as well as the increase in accidents from these overtakings are to some extent due to the total vehicle length. No information has been found nor are models available to calculate the increased accident risk.

The mean vehicle speed of these heavier vehicles might decrease due to lack of engine power.

The increase of total vehicle mass might be compensated by increase of power. The power of the engine should be restricted with a ‘power to weight’ ratio. For national 50 ton transport the power to weight ratio is 6 to 8. For the 70 ton vehicles the same factor might be used which means a 370 kW drive line. Rear marking-plates with an indication that the vehicle is longer than usual will minimise the number of dangerous overtaking situations.

Another restriction for the drive line can be set by a certain percentage of climbing capacity and a certain time for the vehicle to accelerate from zero speed. This will determine the minimum number of driven axles since the traction forces between the tires and the road is limited.

Traffic flow

The influence on the traffic flow has been investigated by TNO-INRO, using the software package MIXIC to simulate and analyse in detail the flow of traffic and the problems which might occur. Simulations of the traffic flow with and without these longer and heavier vehicles show the effects on the process of the flow, the chance on accidents and the increase in the number of lane changes.

The used traffic flow model was not yet capable of the simulation of discontinuities, that is why merging these longer vehicles with other traffic when the difference in speed was too high, is simulated with some restrictions. The used traffic flow had a relatively low density with an intensity/capacity factor of 0.5 to 0.75 and with a relatively low number of these longer vehicles (1% to 5% of the total number of vehicles in the traffic flow). There was no significant influence of these longer vehicles. Increasing the transport capacity with the same traffic flow is feasible, and does not seem to yield serious problems.

Crash behaviour

By means of a trend predicting model, the severity of running in the rear of a queue of passenger cars is evaluated in comparison to each of the conventional vehicle combinations. The Crash Safety Centre of TNO Road-Vehicle Research Institute has specific expertise in relation to the impact of car crashes and derived this model with the use of the simulation tool MADYMO.

The behaviour of these vehicles during crashes has been studied with the modelling and simulation tool MADYMO. The created models could not yet be validated, so a quantitative value could not be calculated. With the staged situations as running into a traffic jam and jack-knifing of the vehicles, trends can be observed. The following conclusions can be drawn:

- The stopping distance of the 70 ton longer vehicles increases about one passenger car, in comparison to the 50 ton vehicles and about two passenger cars in comparison to the 40 ton vehicle. The difference in stopping distance is a result of the relatively low resistance from the traffic queue to these heavier vehicles;
- The main part of the impact of the truck into the traffic jam is dissipated by the deformation of the first passenger car. The injury of the driver of the first car in the row will be fatal. With the heavier vehicles the second car has a high risk on fatal injury;
- The jack-knifing behaviour of the B-double (Vehicle C) is the most stable;
- The influence of jack-knifing on the vehicles to the traffic jam in the side lane is low.

5. CONSEQUENCES FOR ENVIRONMENT

The analysis of the consequences for the environment is based on the determination of change in the number of trips as a result of transportation with longer and/or heavier vehicles. The basis for this calculation is formed by databases in The Netherlands of the amount of the transportation of goods. Databases of 1994 of inland transport trips were used. As a consequence of the Dutch policy to stimulate intermodal transport, only trips that started outside an area with a radius of 25 km around an intermodal terminal were taken into consideration. For each trip the following variables were used: region, the amount of ton, kind of goods based on an NSTR code, vehicle type, vehicle combination, loading capacity, container class, number of containers, trip kilometres divided into loaded and empty km's. Based on this information and the limiting conditions it was determined wheater the transportation of payload could be done with a larger or heavier vehicle. The results depend, of course, on the admitted length and mass of the combinations and are given in Table 2. In this table the maximum effects on the total number of trips, the number of km's driven and the CO_2 exhaust as a function of 5 scenarios is given.

Table 2: Reduction of the number of trips, number of kilometres driven and carbon-dioxide exhaust when replacing existing HGV vehicles by 'Road trains' compared to the existing situation in The Netherlands [8].)

	Total HGV [10^6]	25.25m. - 50 ton [%]	18.75m. - 60 ton [%]	25.25m. - 60 ton [%]	18.75m. - 70 ton [%]	25.25m. - 70 ton [%]
Number of trips	37,3	-6.0	-2.4	-7.6	-4.1	-10.1
Number km's	3523	-8.1	-3.4	-10.5	-5.8	-14.0
CO_2 exhaust in kg.	3402	-5.8	-2.4	-5.2	-4.2	-8.1

When the maximum length is enlarged to 25.25 meter, with the same payload to be transported, this will lead to a reduction of 6% of the total number of trips, a reduction of 8.1 % of the number of km's and a reduction of 5.8% in the CO_2 exhaust. For the best scenario the reduction on CO_2 exhaust will be 8.1%.

6. ECONOMICAL AND INFRASTRUCTURE CONSEQUENCES

It was expected that with the same load factor larger vehicle dimensions will lead to a more efficient transport and therefore to smaller transport costs. But larger dimensions will also lead to higher investment costs, higher taxes and insurance premiums. The costs per kilometre were calculated by NEA [8]. There is a small increase in costs per kilometre, e.g. a 60 ton truck semi-trailer combination (16,5 m) will cost NLG 2.69 per kilometre while a 25.25 combination with the same payload will cost NLG 2.93 (increase of 9%). But due to the fact that the longer combination will transport more goods the total benefit for the transport companies is expected to be positive. The increase in payload volume is 35% to 55% and in vehicle mass 20%.

7. ADVISE TO THE MINISTER AND POLITICAL DISCUSSION

Based on the results of the study the project-group advised to conduct a pilot project under restricted conditions concerning road safety and infrastructure aspects [5]. These restrictions are described in **Appendix 1**.

Because of a possible interference of the larger and heavier vehicles and other modalities of transport, and the already mentioned policy concerning the stimulation of other modes of transport e.g. by rail and water, an extra restriction was added after the political discussion: in the pilot project only trips to or from an intermodal terminal with a trip distance of less than 50 km are allowed for the project.

This set of restrictions is sent to transport organisations with the invitation that companies who want to participate in this pilot project make their interest known to the Ministry of Transport, Public Works and Water Management.

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AUTHORS BIOGRAPHIES

R.B.J. (Boudewijn) Hoogvelt, M.Sc., B.Sc.

Graduated at the Polytechnic College of Technology The Hague 1976 as a Mechanical Engineer and the Delft University of Technology, Faculty of Mechanical Engineering and Marine Technology, specialism Measurement & Control. Since 1981 he is working at the Vehicle Dynamics department of the Road-Vehicle Research Institute of The Netherlands Organisation for Applied Scientific Research. He is a research engineer, project manager and acting section head. Most of his research projects concern the stability and safety of heavy vehicles as e.g. roll-over accidents of heavy vehicles in The Netherlands and an active roll stabiliser for heavy vehicles. He was a member of the OECD IR2 & IR6 expert groups and leader of Element 4 of the OECD DIVINE project.

J.J.W.(Hans) Huijbers, M.Sc.

Graduated at the technical University Eindhoven in 1975 as a Mechanical Engineer, specialism biomechanics. Worked at the Institute for Road Safety Research (SWOV). Took part of EEVC working groups: Pedestrian Injury Accidents and Cycle and light powered two-wheeler accidents. In 1989 he conducted a study on behalf of the European Community to recommend new requirements for helmets in Europe based on the existing requirements and scientific knowledge.

From 1989 he is working as a senior consultant at the Transport Research Centre of the Ministry of Transport and Water Management in the Safety and Environment division. He is a research co-ordinator for Heavy Goods Vehicle Safety and a project leader for the study of the admission of ‘Road Trains’ in The Netherlands.

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Appendix 1

Requirements for the pilot experiments

General

- Only admitted on pre-defined roads;
- The pilot experiment will extend over 2 years;
- The number of vehicles (one per transport company) will be limited to 15;
- Different kind of trips, vehicle configurations (truck semi-trailer, truck and trailer), masses and length;
- In principle outside peak hours;
- Not allowed when the view distances are less than 200 meter and during slippery road conditions;
- No dangerous goods according to European definitions.

Vehicles

- The maximum mass will be 60 ton, the maximum length: 25.25 meter;
- ABS on all wheels;
- Minimum ‘power to weight’ ratio: 5 kW/ton;
- Stability according to performance criteria conform Dutch and EU regulations;
- Swept path maximum of 8 meter in a 90 degrees turn with an outer radius of 14.5 meter;
- Equipped with extra wide range mirror;
- Equipped with closed side protection;
- Equipped with splash and spray provisions;
- Equipped with side-marker-lamps; retro-reflecting side and rear-marking with strips and retro-reflecting rear-marking plates for heavy and long vehicles with superscription;
- Super singles not admitted on driven wheels;
- Front under-run protection system (bumper) according to ECE regulation R93;
- Vehicles have to be tested by the Vehicle Technology and Information Centre (RDW) before road admission.

Drivers

Special certificate after examination by an authorised training school.

Stretches

- Acceleration lanes longer than 250 meter;
- Admission by local road authorities;
- Not in rural areas. On single carriage ways in principle only when separate bike lanes exist;
- No automatic railway level intersections;
- Trips in principle on motor ways, on single carriage ways a maximum distance of 5 km.

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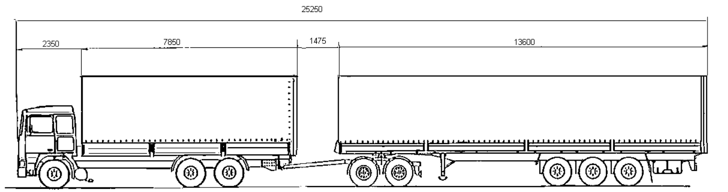

Figure 1: Vehicle A (truck, full-trailer)

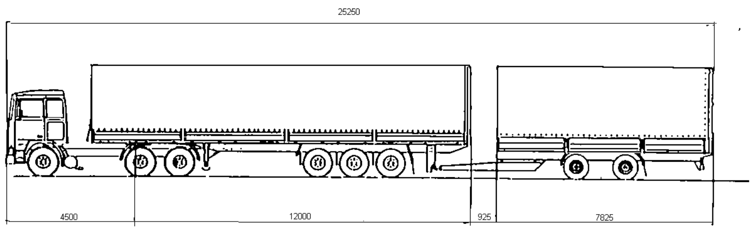

Figure 2: Vehicle B (tractor, semi-trailer, central axle trailer)

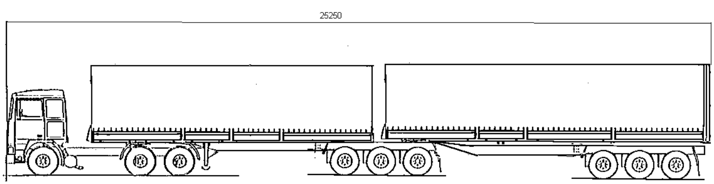

Figure 3: Vehicle C (B-double)

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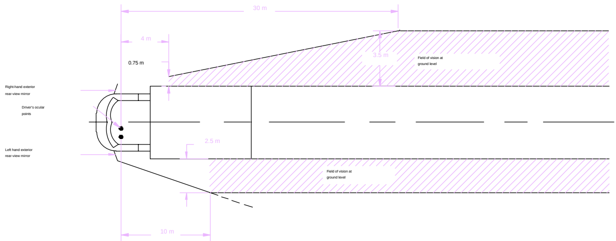

Figure 4: Overview with standard mirror

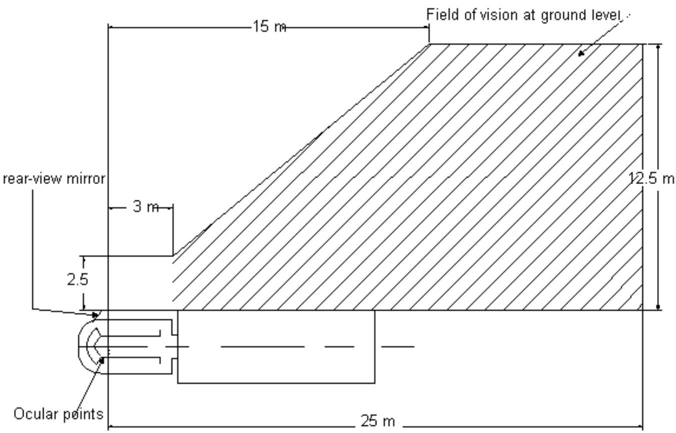

Figure 5: Overview with wide range mirror

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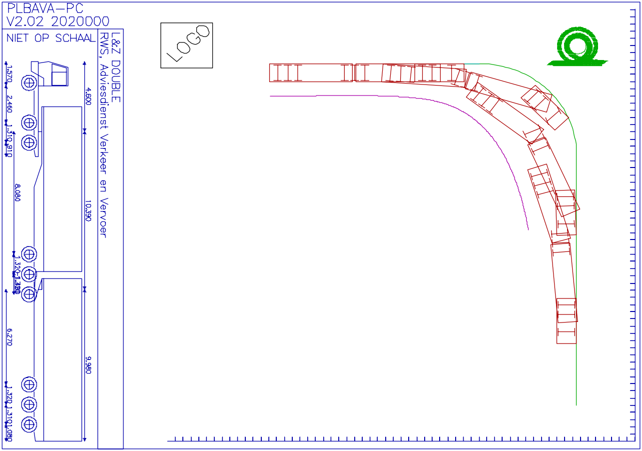

Figure 6: Swept path calculation (Vehicle C)

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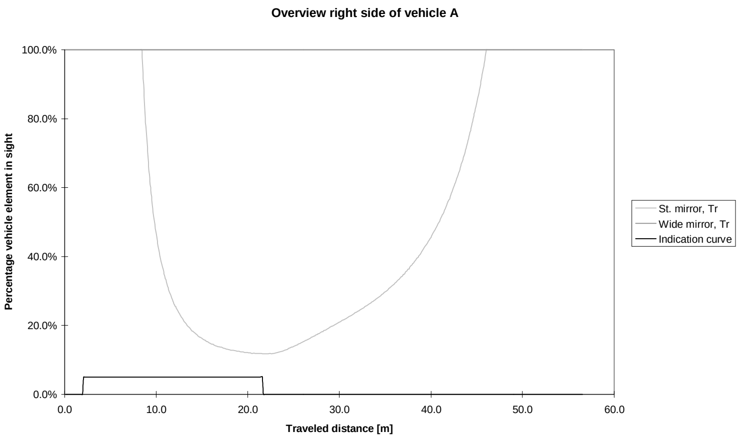

Figure 7: Overview on the trailer of Vehicle A

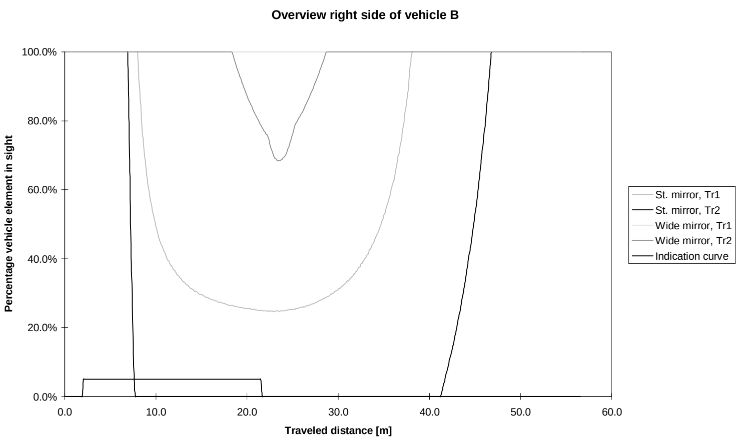

Figure 8: Overview on first and second trailer of Vehicle B

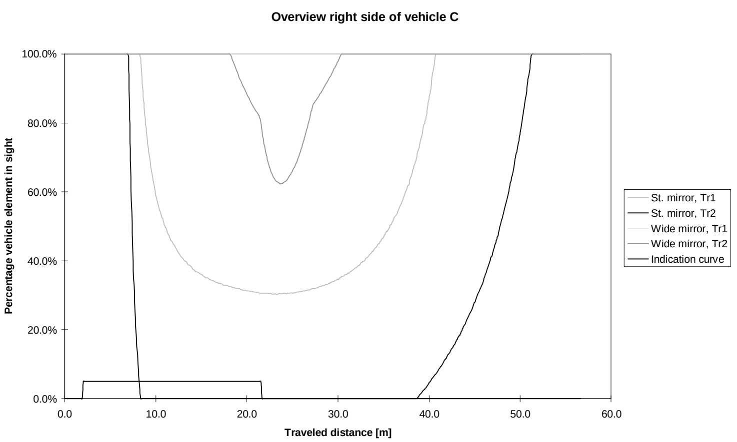

Figure 9: Overview on first and second trailer of Vehicle C

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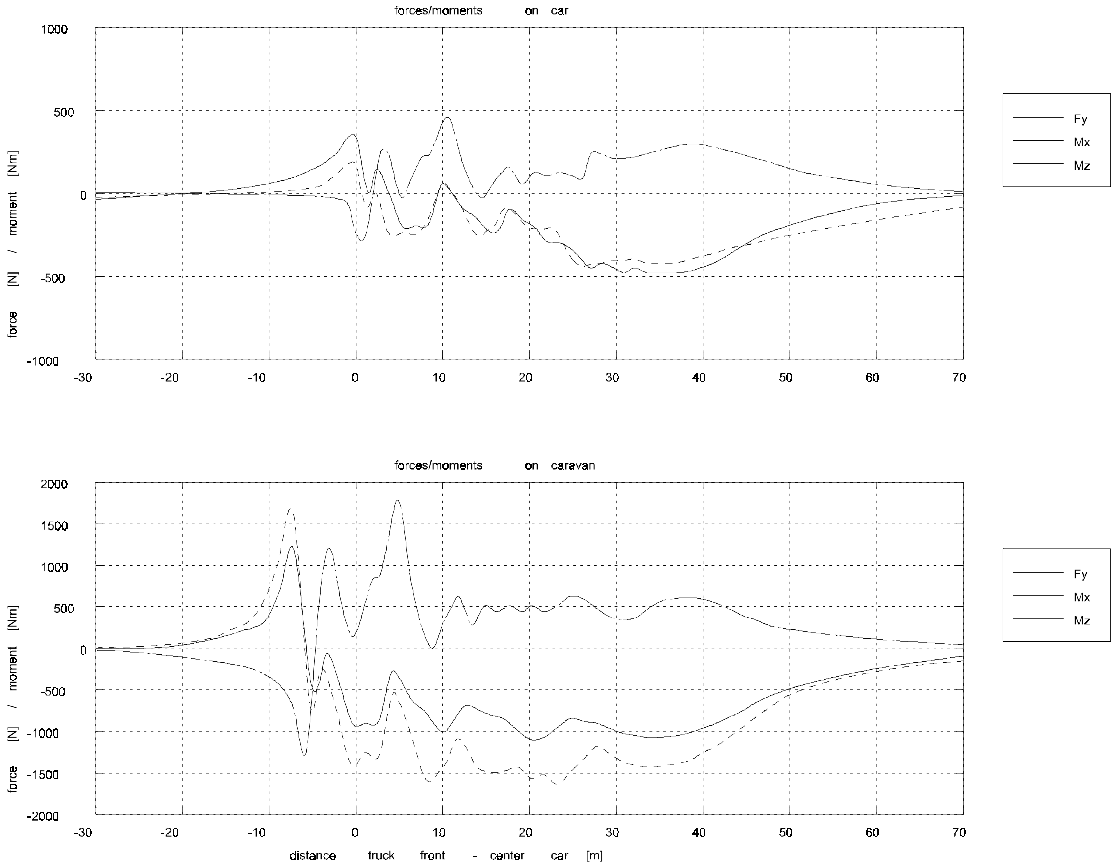

Figure 10: Aerodynamic lateral force and yaw and roll moment on the passenger car and caravan

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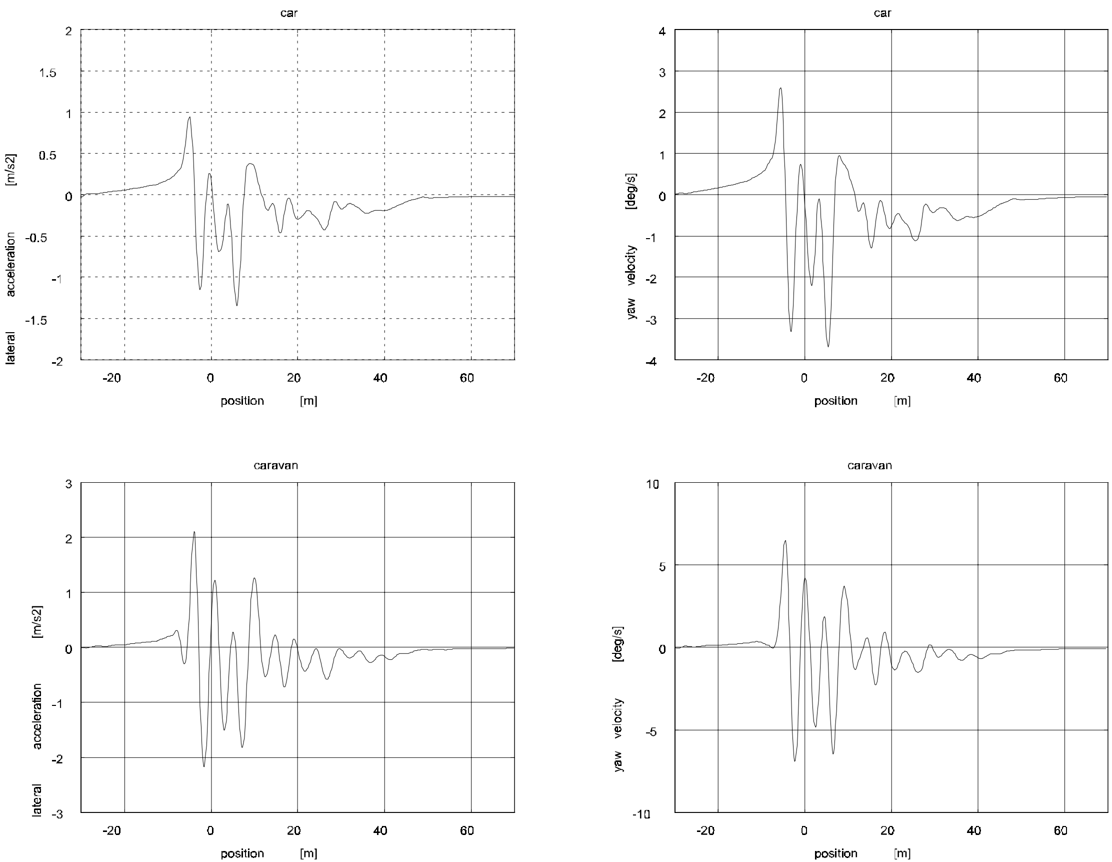

Figure 11: Lateral acceleration and yaw velocity in COG of passenger car and caravan

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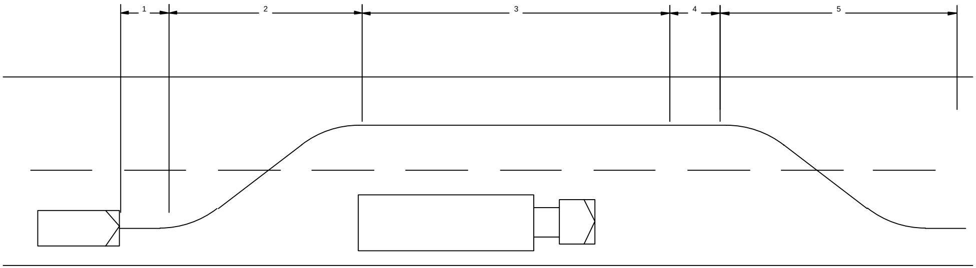

Figure 12: Overtaking a heavy vehicle

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