

German field trial with longer trucks

Federal Highway Research Institute

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1 Introduction

In 2011, the Federal Ministry of Transport, Building and Urban Development commissioned the Federal Highway Research Institute to conduct a supporting scientific study of the nationwide field trial of overlength vehicles and vehicle combinations¹ (longer trucks). Longer trucks may be designed with a greater length (up to 25.25 m) than is allowed under the current regulations. However, a higher gross weight than the currently applicable 40 tonnes (or 44 tonnes on the initial and terminal hauls in combined transport)² is not permissible. Figure 1 shows possible configurations of the five different types of longer trucks permissible in the field trial.

The trial was launched on 1 January 2012 and was scheduled to run for five years. It is part of the Federal Ministry of Transport and Digital Infrastructure's Freight Transport and Logistics Action Plan. The legal basis for the conduct of the field trial is constituted by the Regulations issued by the Federal Minister of Transport on Exemptions from Road Traffic Law Provisions governing Overlength Vehicles and Vehicle Combinations ("the Exemption Regulations") of 19 December 2011 and the relevant amending regulations.

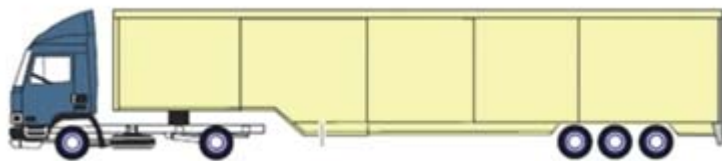
The final report presented by the Federal Highway Research Institute at the end of the field trial builds on an interim report (Irzik et al., 2014) presented in 2014. The thematic structure of the final report follows that of the interim report. The final report contains not only the legal bases and available findings from the literature that are required for the overall study approach, but also the summaries of the various research projects from all study phases of the supporting scientific research. All reports on the field trial can be downloaded from www.bast.de.

2 From the "Gigaliner" to the "longer truck"

Compared with international experiences, Germany has so far not been able to draw on much empirical evidence when it comes to an assessment of the operation of overlength/overweight vehicles and vehicle combinations. Since there is no sign of the discussions in Europe on this issue coming to an end and these new vehicle designs are seen as a component of the strategy to manage the forecast rise in the volume of freight traffic, the Federal Government elected in 2010 stated in its coalition agreement that it would evaluate the opportunities and risks associated with such vehicle designs within the framework of a nationwide field trial based on real world operations.

¹ Hereinafter often referred to simply as "trucks". This means that in this report, the term "trucks" is used to refer not only to single vehicles but also vehicle combinations.

² Hereinafter abbreviated as "40 t/44t (CT)".



1. Tractor with extended semi-trailer (articulated vehicle), total length not exceeding 17.80 metres



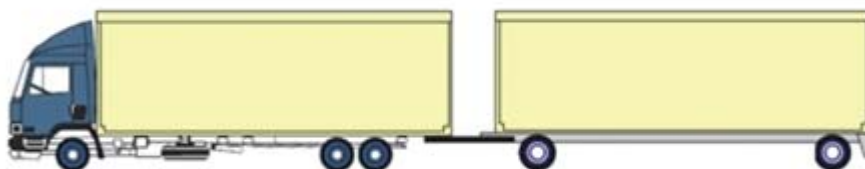
2. Articulated vehicle with centre axle trailer, total length not exceeding 25.25 metres



3. Tractor with dolly and semi-trailer, total length not exceeding 25.25 metres



4. Articulated vehicle with a second semi-trailer (B-Double), total length not exceeding 25.25 metres



5. Tractor-Trailer Combination, total length not exceeding 24.00 metres

The maximum authorized mass of the longer trucks may be 40 t/44 t (CT), as is currently the case for conventional trucks. On the other hand, the actual number of axles may be lower than shown in these examples.

Figure 1: Possible overlength vehicles and vehicle combinations (longer trucks)

Earlier studies conducted by the Federal Highway Research Institute (GLAESER ET AL., 2006) have already shown that the infrastructure, especially the bridge structures, is not designed for vehicles or vehicle combinations with a gross vehicle weight higher than that which is currently permissible (40 tonnes or 44 tonnes in CT). Moreover, the higher kinetic energy associated with an increase in weight would, in the event of an accident, involve a significant deterioration in road safety. It was for this reason that the Federal Government agreed to allow only longer, and not heavier, trucks to be tested in a field trial. The associated focus on the movement of goods that are as lightweight as possible is also designed to have the effect that the railways and inland waterways face little or no competition.

These issues, especially that of higher weights, are emotionally charged in public and are generally linked to the "Gigaliner" label (longer and heavier vehicle). For the purposes of clear differentiation, the term "longer truck" has been coined for the trucks that are only longer and not heavier. However, numerous reports, individual surveys and many discussions have illustrated that this terminological distinction is often still unclear even towards the end of the field trial.

Another aspect that results in misunderstandings in the discussions surrounding longer trucks is that in some cases a basic distinction has to be made between the different types of longer trucks. Conversations with people who have already heard the term "longer trucks" reveal that they often only associate it with Types 2, 3 and 4, which have a maximum length of 25.25 m (cf. Figure 1). Whereas Type 5, with a total length not exceeding 24.00 m, can still be considered as belonging to this group with regard to many issues, Type 1 often requires separate consideration. Because although this longer truck, with a total length of 17.80 m, is 1.30 m longer than a conventional articulated vehicle, it is almost one metre shorter than a conventional tractor-trailer combination.

3 Parameters of the field trial

3.1 Legal bases

The field trial has been underway since 1 January 2012 within the scope of Exemption Regulations limited to five years and based on section 6(1) in conjunction with section 6(3) of the Road Traffic Act. These Exemption Regulations regulate the conditions that have to be met for certain overlength vehicles and vehicle combinations to be allowed to use the roads in derogation from the provisions of the Road Traffic Regulations and the Road Vehicles Registration and Licensing Regulations. In particular, they define the requirements to be met by the vehicles or vehicle combinations and by the drivers. In addition, they list the requirements relating to loads, road user behaviour (overtaking) and participation in the supporting scientific research.

The Federal Ministry of Transport, Building and Urban Development did not see any alternative to the Exemption Regulations, because the option of the federal states issuing permits under section 29(3) of the German Road Traffic Regulations presupposes the carriage of indivisible loads. This means that the parties involved in the field trial do not go through an explicit authorization or approval procedure, but simply have to meet the requirements and conditions set out in the Exemption Regulations. One of these conditions is that they have to inform the Federal Highway Research Institute of their involvement in the field trial (cf. section 12 of the Exemption Regulations).

3.2 Approved routes and authorized network

Although longer trucks also have to meet the turning circle requirements set out in section 32d of the German Road Vehicles Registration and Licensing Regulations, experience so far suggests that it might not per se be possible for the vehicle combinations, especially those with a length of up to 25.25 m, to operate on all highway facilities. Longer trucks may therefore operate only on suitable origin-destination pairs, i.e. only on roads that have been declared suitable by the competent ministries of the federal states concerned for the operation of longer trucks, that have been notified to the Federal Ministry of Transport and Digital Infrastructure and that have been subsequently published in the Exemption Regulations. In accordance with section 2 of the Exemption Regulations, therefore, longer trucks may only be operated on the routes stipulated in the Annex to the Regulations (authorized network). One exception is the articulated vehicle with a total length not exceeding 17.80 m (Type 1) shown in Figure 1 above. In the seven federal states actively participating in the field trial at the time of entry into force of the Exemption Regulations (Bavaria, Hamburg, Hesse, Lower Saxony, Saxony, Schleswig-Holstein and Thuringia), articulated vehicles with an extended semi-trailer may use the entire road network of any given federal state. North Rhine-Westphalia joined the scheme as the eighth federal state with the entry into force of the Fifth Amending Regulations on 15 July 2015. In the other federal states participating in the field trial, Type 1 vehicles may only use the road network approved for Types 2 to 5.

Figure 2 shows the authorized network as at 31 October 2016. However, this map does not have a legally binding effect. Only the legally binding precise definition of the approved routes in the Sixth Amending Regulations on the field trial applicable at the time of reporting have such an effect. According to the Sixth Regulations amending the Regulations on Exemptions from Road Traffic Law Provisions governing Overlength Vehicles and Vehicle Combinations, the authorized network has a total length of almost 11,600 kilometres, of which around 70 % are federal motorways. This is equivalent to just over 60 % of all federal motorways in Germany. The sections of federal highways, regional roads and district roads approved for use by longer trucks account for only a small percentage of the total length of the inter-urban roads (excluding federal motorways) of the federal states participating in the field trial. The proportion of local roads on the authorized network in terms of all local roads in Germany is a few permille.

Some federal states refuse to allow the operation of longer trucks. This resulted in a situation where several federal states were not involved in the field trial from the outset and thus have not designated any suitable routes for the authorized network on which longer trucks may operate. In Saxony-Anhalt, for instance, there are just a few isolated infills of gaps between motorways. It was not until the Second Amending Regulations that Bremen approved its motorways and Mecklenburg-Western Pomerania approved individual routes for use by longer trucks. With the Fifth Amending Regulations, Baden-Württemberg notified part of its motorway network and individual routes on the secondary network as suitable. Finally, the Sixth Amending Regulations saw the addition of routes in Brandenburg. Thus, at the end of the field trial, only three federal states are not participating in the field trial at all, although, according to press reports, Rhineland-Palatinate and Saarland now also want to notify routes.

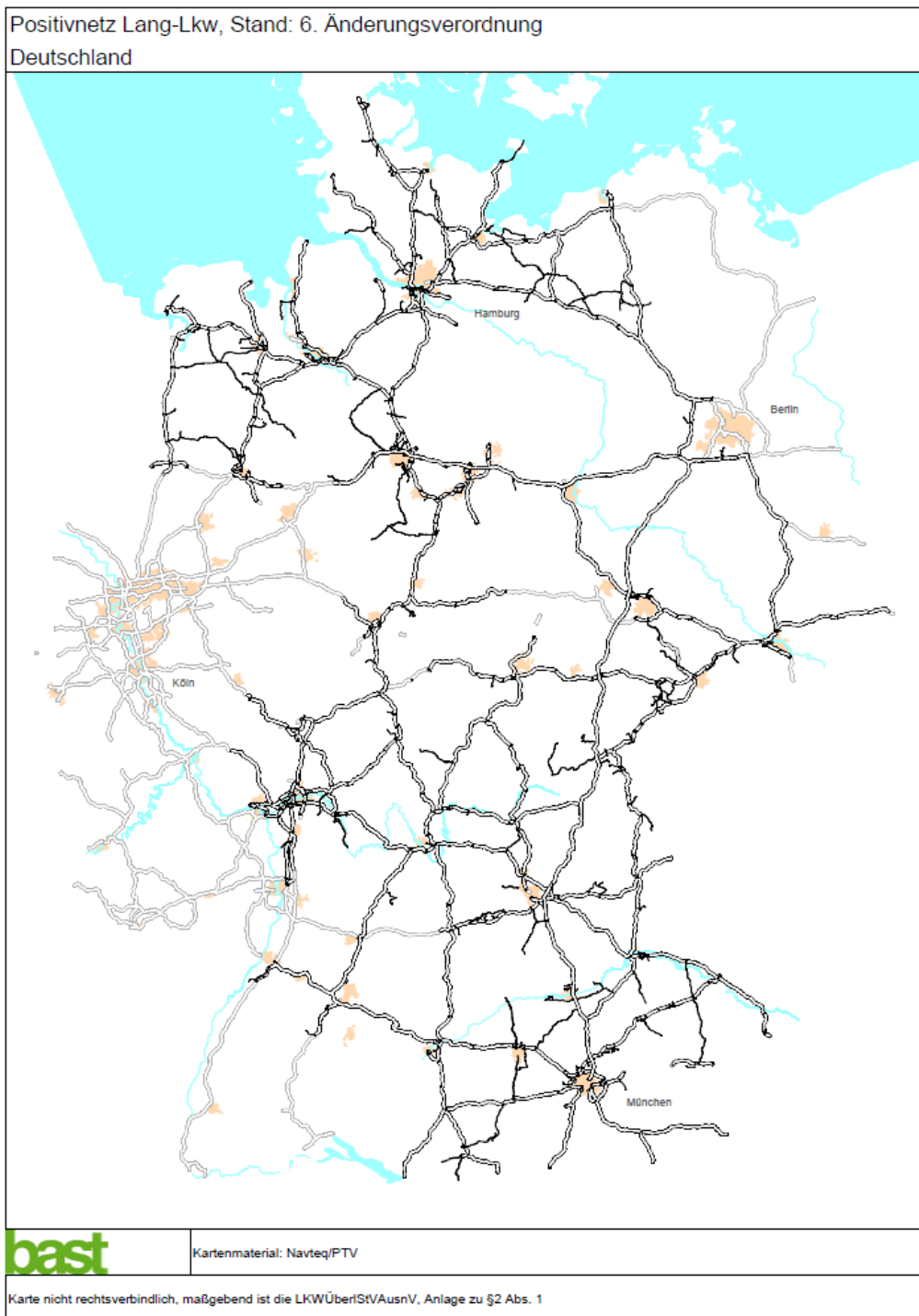


Figure 2: Non-binding overview of the authorized network in accordance with the Sixth Regulations amending the Regulations on Exemptions from Road Traffic Law Provisions governing Overlength Vehicles and Vehicle Combinations of 29 April 2016

4 The approach to the supporting scientific research

The purpose of the supporting scientific research was also to bring greater objectivity to the discussions on the issue of "longer trucks". Taking as their starting point the arguments advanced in the past

against longer and heavier trucks, pressure groups representing the railways, environmentalist groups and motoring organizations also expressed concerns regarding the increase in length, which was the only subject addressed in the field trial. The criticism concerns, as a matter of principle and in a relatively wholesale manner (i. e. primarily without differentiation between the different types of longer trucks, cf. section 2), the following three key issues:

1. It is claimed that longer and/or heavier trucks would be detrimental to road safety.
2. The pavement load imposed on the infrastructure by longer and/or heavier trucks would be so great that its strengthening and/or repair would place a huge cost burden on the general public.
3. As a result of the likely efficiency enhancement and the associated cost advantages in the road haulage sector, freight traffic would be shifted from the railways to the roads and/or new road traffic would be induced, meaning that ultimately there would be more rather than less road freight traffic.

Nor has the fact that "longer trucks" means exclusively longer and not heavier trucks brought about any fundamental change in the discussion. One of the key issues in the discussions is the fear regarding the impact on the demand for transport, which assumes a modal shift to the detriment of the railways.

| | |
|---|--|
| <p>Vehicles</p> <ul style="list-style-type: none"> • Deceleration • Vehicle dynamics • Wind stability • Blind spot • Rate of accidents/<i>conflict analysis</i> • Recovery and towing possibilities • Obstructing the vision of other road users • Suction effect on two-wheeled vehicles • <i>Vehicle marking</i> • <i>Aerodynamics</i> <p>Infrastructure</p> <ul style="list-style-type: none"> • Stress and load on road infrastructure • Tractrices/trafficability of transport facilities • Overtaking, clearance at junctions • Effects on traffic flows • Roadworks sites • Safety barriers • Fire behaviour in tunnels • Adherence to/acceptance of the route | <p>Drivers</p> <ul style="list-style-type: none"> • Psychological aspects – drivers • <i>Shortage of drivers</i> • <i>Road user behaviour</i> <p>Freight transport, logistics and the environment</p> <ul style="list-style-type: none"> • <i>(Operational) efficiency</i> <ul style="list-style-type: none"> – Fuel consumption • <i>Emissions</i> • <i>Effects on transport demand</i> <ul style="list-style-type: none"> – Modal shift impact – <i>Induced traffic</i> • <i>Impact on CT, inland connections, swap body traffic</i> • Fine distribution/loading and unloading points • Vehicle productivity • <i>Impact on industrial settlements</i> • <i>Impact on commercial structures</i> <p>Miscellaneous</p> <ul style="list-style-type: none"> • Psychological aspects – other road users • <i>Public response</i> |
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Text in italics: additional proposals by the external experts

Figure 3: Outcome of the colloquium of experts on 17 May 2011

The objective of the approach to the supporting scientific research was to comprehensively take into account all hopes in and reservations concerning the operation of longer trucks discussed in public. By way of preparation for the trial and the associated supporting scientific research, the relevant questions were first identified. Within the scope of a study of the international literature, and taking account of the regulatory framework and the public discussion, those aspects mentioned in various sources as possible opportunities and risks regarding the operation of longer trucks were identified and listed.

This list was discussed during a colloquium of experts in May 2011. The outcome was an overview of the thematic issues deemed to be relevant and to be studied (cf. Figure 3).

The experts attending the colloquium were also in agreement that, to complement the observations and surveys in the practical part of the field trial, certain issues should be evaluated experimentally or theoretically – for instance impact tests on safety barriers or fire behaviour in tunnels.

The study programme of the supporting scientific research thus covered the thematic areas listed in Figure 3. To answer the questions, several research projects were launched. Some of these were conducted by the Federal Highway Research Institute itself, but most were done by external research institutes.

5 Statistical analyses

Within the scope of the field trial, empirical surveys were carried out among the participating haulage operators regarding corporate structures, vehicles and transport operations. In 2013, a twelve-month continuous trip survey (Burg, Röhling, Klaas-Wissing, 2014) was conducted. To validate the findings of this baseline survey and to generate new findings, a three-month follow-up survey was carried out at the end of 2015 (Burg, Schrempp, Röhling, Klaas-Wissing, Schreiner, 2016). The main findings of the surveys regarding transport operations can be summarized as follows (values from the baseline survey in parentheses):³

- After extrapolation, around 61,900 (13,500) transport operations by longer trucks per annum were recorded in the follow-up survey.
- The resultant 13.6 (2.53) million vehicle kilometres were travelled by a total of 120 (46) longer trucks operated by 46 (21) companies, although it should be noted that the number of participating operators and the number of longer trucks deployed rose in the period covered by the survey. The mileage of longer trucks documented in this way is roughly equivalent to 0.5 (0.1) permille of the tolled trips made in 2015 (2013) (29.7 (27.2) billion km).⁴
- The volume of freight carried by the longer trucks was 843,500 (144,000) tonnes.
- The average trip length per longer truck trip was around 240 (200) km, with the values ranging from just over 10 km to almost 800 km per trip.
- More than 91 (83) % of the trips were between warehouses and/or production sites as shuttle services or as the main leg.

³ The absolute quantitative data from the follow-up survey (2015/2016) were seasonally adjusted using findings from the baseline survey and extrapolated to one year.

⁴ Federal Office for Goods Transport (BAG): *Mautstatistik Jahrestabellen 2013 und 2015*

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- The spectrum of the goods carried by the longer trucks ranges from parts for the automotive industry through domestic appliances (white goods), air cargo, clothing and food to packaging material.

Based on the statistical analyses within the scope of the studies by SÜßMANN, FÖRG, WENZELIS (2014) and FÖRG, SÜßMANN, WENZELIS, SCHMEILER (2016) and their partial updating by the Federal Highway Research Institute, the following information can be provided on the longer trucks registered at the Federal Highway Research Institute:

- At the time of publication of the final report (30 September 2016), 59 haulage companies had notified 158 longer goods vehicles to the Federal Highway Research Institute for participation in the field trial. Thus, the longer trucks participating in the field trial account for around 0.3 permille of the number of vehicles subject to tolls⁵ calculated by the Federal Office for Goods Transport in 2013 of around 580,000 (Federal Office for Goods Transport, 2014).
- Individual leaps in the continuous increase in the number of notifications can usually be explained by a prior enlargement of the authorized network within the scope of amending regulations.
- However, the number of participants notified is not equivalent to the number of persons actually driving. The information concerning this is sketchy. The reason for this is that the Exemption Regulations do not require participants to notify the Federal Highway Research Institute when they withdraw from the scheme. From personal discussions, it is known that some haulage companies announced their intention to participate and then did not participate in the field trial after all or are no longer participating.
- By far the most frequently deployed type is the longer truck of Type 3 (cf. Figure 4), consisting of a tractor with dolly and semi-trailer. Type 2 is in second place. Deployment of this type increased significantly towards the end of the field trial. Type 4 and 5 play virtually no role in the field trial. There has also been a significant increase, albeit at a lower level, in the deployment of Type 1 since publication of the Interim Report. In mid-2014, only one single extended articulated vehicle had temporarily participated in the field trial, whereas by the time of publication of the final report this figure had risen to 13 trucks.

⁵ Since 1 October 2015, vehicles and vehicle combinations with a maximum permissible weight of 7.5 tonnes or more have been subject to tolls. For this reason, 2013 was chosen as the reference value, as was also the case in the Interim Report (cf. IRZIK ET AL., 2014), because at that time only trucks with a maximum permissible weight of 12 tonnes or more were recorded as vehicles subject to tolls.

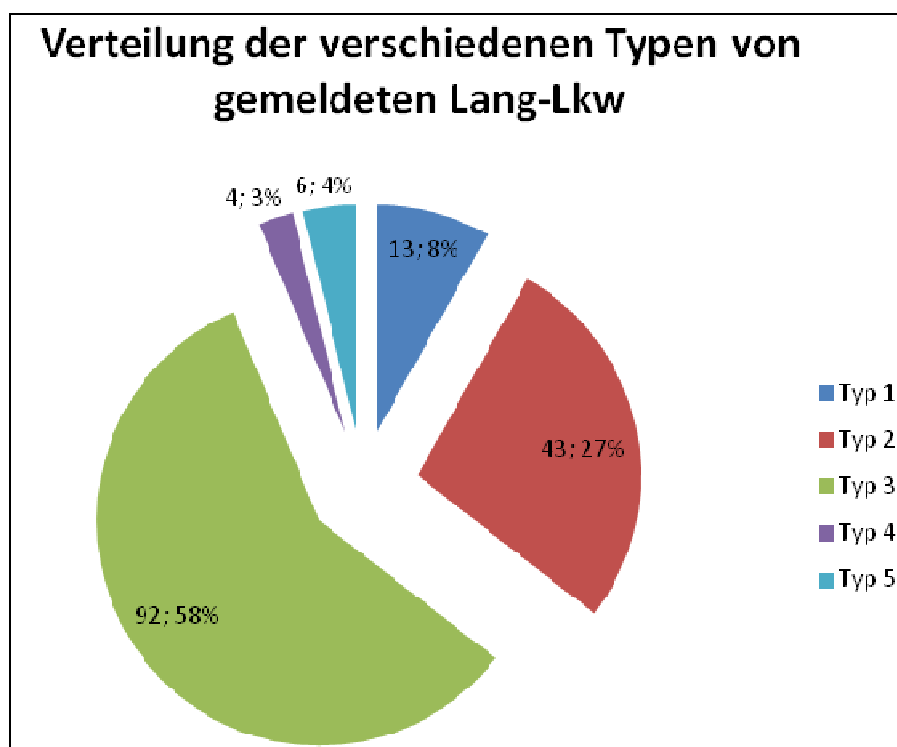


Figure 4: Distribution of the various types of longer trucks in accordance with the Exemption Regulations notified to the Federal Highway Research Institute (as at 30 September 2016)

6 Findings from the study

Despite the fact that the number of participants rose only slowly, although continuously, over the course of the field trial, the supporting scientific research is able to present resilient and thus meaningful findings on numerous issues. For a large number of the issues identified and to be deemed relevant and thus to be studied, the number of participating vehicles and vehicle combinations plays only a minor role. One example here is the review of the trafficability of road facilities. Here, it is not so much the number of participating longer trucks that is of importance. It is much more important that as many different types as possible with unfavourable configurations (wheelbases, points of articulation) in terms of trafficability can be observed.

Against the background of the question as to what impact the operation of longer trucks has on the questions identified compared with the situation without longer trucks, the main findings are summarized and evaluated below.

6.1 Opportunities and risks

On the basis of the findings of the scientific research supporting the field trial, the following positive effects of the operation of longer trucks have become apparent:

- Within the scope of the field trial, the two studies on the impact on transport demand (BURG, RÖHLING, KLAAS-WISSING, 2014 und BURG, SCHREMPF, RÖHLING, KLAAS-WISSING, SCHREINER, 2016) and on the pavement load (WELLNER, UHLIG, 2015 und UHLIG, 2016) were able to determine, in

surveys independent of each other, that, if Type 2 to 4 longer trucks are deployed, two trips by longer trucks replace on average somewhat more than three trips by conventional trucks.

- This results in efficiency gains and fuel savings between 15 % and 25 %. However, this is clearly connected with an almost optimally arranged utilization of volume and slots, which was observed in the field trial, although it should be noted that high-capacity utilization is usually necessary for the economically beneficial deployment of longer trucks.
- Also within the scope of the studies on the impact on transport demand and on the pavement load, it was possible to determine that, if a Type 1 longer trucks is deployed, one trip by the extended articulated vehicle replaces on average 1.07 trips by standard articulated vehicles.
- Building on the empirical foundations, the model results calculated for transport demand show that there are hardly any intermodal shifts from the railways and inland waterways, not even in terms of freight kilometres (0.1 and 0.3 permille respectively). Thus, on the whole, there is a positive impact on transport demand with regard to a reduction in the number vehicle kilometres actually driven and accordingly also in levels of climate change gases and air pollutants. It should be noted that possible rebound effects – in the form of the transport costs of the freight sector falling as a whole as a result of the efficiency benefits of longer trucks compared with conventional trucks, leading to a greater demand for transport – cannot be derived empirically and thus could not be seriously taken into account in case such effects did occur.

In addition, the supporting scientific research addressed a multiplicity of presumed risks or even fears regarding a more or less great need to adapt the infrastructure. On the basis of the comprehensive study programme, it emerged that the deployment of longer trucks will have no adverse impact on a large number of the aspects under consideration under the general conditions of the field trial. It will be possible to compensate for some of the potential challenges that may arise depending on the type and number of longer trucks using the highway facilities by substituting longer trucks for conventional trucks, as observed in the field trial ("turn 3 into 2"), and remedy them to varying degrees by modifying the road infrastructure. Longer trucks' share of the total volume of freight traffic is the main factor for appraising the risks identified. Low shares, which would appear likely given the most recent findings from the field trial⁶, may result in them being classified as acceptable or manageable. More specifically, the aspects in question are as follows:

- The subject of the field trial is the deployment of longer vehicles and vehicle combinations. On the proviso that, in comparison with the current provisions in section 34 of the German Road Vehicles Registration and Licensing Regulations, the maximum permissible weight of longer goods vehicles of 40 t/44 t (CV) does not change, there are not likely to be any effects on the impact energy in a rear-end collision. The traffic load impacts relevant to bridges result from the heaviest vehicles and

⁶ Thus, for instance, with the help of transport demand modelling, it has been possible to determine that on 90 % of all motorways (the main place where longer trucks will operate), longer trucks' share of heavy goods vehicle traffic will be less than 0.5 %, and less than 1 % on 99 % of all motorways.

vehicle combinations (especially the carriage of abnormal loads), their frequencies and overloading in the entire population of heavy goods vehicles. For this reason, and assuming that the same freight is transported, the replacement of trips made by conventional trucks ("turn 3 into 2") by longer trucks that tend to be heavier but remain within the legal maximum permissible weights and are thus lawfully heavier is not likely to cause any relevant changes in the maximum loads on structures.

- Intermodal shifts from the railways and inland waterways to longer trucks were not apparent in the empirical observations of BURG, RÖHLING, KLAAS-WISSING (2014) and BURG, SCHREMPP, RÖHLING, KLAAS-WISSING, SCHREINER (2016), nor are they considered likely given the logistical and freight structures observed in the deployment of longer trucks. This assessment is backed up by the studies into the impact on transport demand.
- In general, it was not possible to identify any vehicle technology problems under the given specific conditions. Thus, for instance, if a holistic view is taken of the brake trials from the studies by SÜßMANN, FÖRG, WENZELIS (2014) and FÖRG, SÜßMANN, WENZELIS, SCHMEILER (2016), it can be assumed that longer trucks have braking distances comparable to those of conventionally designed trucks. However, in certain loading conditions, the handling of Type 2 is very demanding in terms of vehicle dynamics, although, on the basis of current knowledge, this is offset by the EVSC systems, which are mandatory in any case.
- The impact on the pavement load imposed by all the longer trucks observed in the field trial by WELLNER, UHLIG (2015) and UHLIG (2016) on the service life of pavements is comparatively and marginally lower than the load on the roads imposed by the present-day population of conventional trucks.
- In addition, it can also be concluded, on the basis of the axle load distributions resulting from the control groups formed with different shares of longer trucks, that the deployment of longer trucks complying with the permissible maximum weight of 40 t/44 t (CT) is not likely to result in accelerated damage close to the surface (for instance rutting). Accordingly, under the specific conditions of the field trial, it is not apparent that the deployment of longer trucks will result in any higher need for structural maintenance of the carriageways.
- An increase in fire size in tunnels – not possible until longer trucks' share of heavy goods vehicle traffic reaches levels that appear unrealistically high – as a result of the higher volume of goods carried by longer trucks compared with conventional trucks can be countered by taking compensatory measures (for instance improved ventilation system).
- The initial fear that longer trucks would crash through an H4b safety barrier on the central reservations of motorways, which was designed for the impact of a 38 tonne articulated vehicle, proved unfounded. The possibility of vehicle parts falling on the original carriageway, thus presenting a risk to traffic approaching from behind that has to be assessed, also exists at present (albeit with less probability) for multiple-unit vehicle combinations without overlength – i. e. conventional tractors towing a trailer. It would thus likewise have to be accepted in the event of an accident.

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- Given the likely overall increase in the volume of heavy goods vehicle traffic and the findings on the handling of longer trucks, it should be discussed whether it would be advisable to raise the containment level from H2 to H4b on the central reservation when constructing a new or renewing an existing safety barrier. This could reduce the risk of vehicles crashing through the safety barrier on the central reservation for both conventional and longer trucks.
 - The danger of heavy goods vehicles falling off bridges – both conventional and longer trucks – can be reduced by the degree to which bridges are equipped with safety barriers of containment level H4b in accordance with present-day regulations (possibly supplemented by a requirement regarding the minimum height of the safety barriers).
 - Problems concerning traffic flows or road safety on motorways in general, at grade-separated junctions and entrances in particular or vehicles driving through roadworks sites have not occurred so far and are scarcely likely to occur in the future, even if the number of longer trucks rises.
 - Longer trucks up to 25.25 m in particular – and here especially the Type 2 – do not completely fit into the emergency bays in tunnels, which are shorter than those on open stretches of road. However, the fact that these tunnels are monitored around the clock and that additional measures are taken to reduce the extent of incidents guarantees a level of safety for tunnel users that complies with the regulations.
 - On the basis of the routes and trip distances observed in the field trial, the amount of parking space required by longer trucks would appear to be low compared with conventional trucks. In terms of length, only Type 1 fits into angle parking slots at rest areas. All other types of longer trucks are too long for the standard angle parking slots at rest areas. In addition, because of the parking angle, all longer trucks have problems entering their own parking slot without sweeping or driving over adjacent parking slots. Simply remarking the available car parks would entail a loss of parking capacity, even if the deployment of longer trucks theoretically reduces the number of trips. Parking longer trucks at private truck stops may represent a possible option for longer trucks. Moreover, the studies by LIPPOLD ET AL. (2016) have shown that if there is an increase in the amount of parking slots required by longer trucks in the future, there are various approaches for improving the parking situation of longer trucks at rest areas, which means that the parking of longer trucks, which has been mentioned as a problem, can be classified as manageable. In the event that none of the options identified is suitable for use in a specific locality, there is ultimately the option of not including the facility in the authorized network.
 - In the case of at-grade junctions and roundabouts, there are different findings, likewise depending on the type of longer trucks. With a few restrictions regarding Type 2, the tractrix curves of longer trucks are compatible with the junction geometry, which is in line with the actual design guidelines. In the practical trials, however, marginal areas, such as adjacent lanes or shoulders, were repeatedly used, because the spaces for manoeuvre provided in addition to the tractrix curves are no longer available. Thus, compensatory measures, such as open grid paving or pavement on the shoulders, would be necessary in the areas around the junctions. This is even more true, if the extended articulated vehicle (Type 1) is to exploit its forecast market potential.

- The observations by ZIMMERMANN, RIFFEL, ROOS (2015) on the clearance of at-grade junctions are largely of a theoretical nature, but they give no reason to assume that the greater length compared with conventional trucks could present problems regarding traffic flow or road safety.
- Because longer trucks operate predominantly on motorways, only a relatively small proportion of their mileage is on single carriageways. There are thus very few cases of longer trucks being overtaken by other road users where the overtaking vehicle has to use the lane for oncoming traffic. The overtaking manoeuvres observed by ZIMMERMANN, RIFFEL, ROOS (2015) and Zimmermann, KÖHLER, ROOS (2016) were no more dangerous than is normally the case with overtaking of trucks on single carriageways.
- GLASER ET AL. (2015, 2016) were unable to identify any stress or higher levels of psychological strain on the part of the truck drivers.
- Although the data basis is small, the analysis of the accident situation in the field trial does not suggest that the deployment of longer trucks could have any adverse impact on road safety.

Finally, guidance was developed on possible amendments or more detailed definition of a general nature, such as the procedure for checking compliance with the turning characteristics ("turning circle") and individual requirements for longer trucks. The latter can be taken into account if there is any further operation of longer trucks after the end of the field trial in the interests of further optimization.

6.2 Special consideration of individual types of longer trucks

6.2.1 The extended articulated vehicle (Type 1)

The Type 1 longer trucks plays a special role in the field trial. The main reason for this is its length (cf. also 2). Lengthening the conventional semi-trailer by 1.30 m means that the additional gain in volume is significantly lower than with Type 2 to 5 longer trucks. With a mean factor of 1.07 (number of trips by equivalent conventional articulated vehicle for one trip by a Type 1 longer truck), the substitution effect is thus also significantly lower than with the other types of longer trucks (around 1.5 on average). These facts have a direct impact on the market potential for Type 1 longer trucks. Unlike the market potential for Type 2 to 5 longer trucks, whose operation is restricted to an authorized network and whose efficiency potential is greater as a result of their higher capacity, the market potential for the Type 1 longer goods vehicle does not depend primarily on distinctive features in the logistical structures and fields of application, but is generally seen to be in the replacement of the existing fleet of conventional articulated vehicles. However, for this to happen, the entire road network (at least the German network) would have to be authorized.

Because the number of Type 1 longer trucks participating in the field trial was low (cf. Figure 4), it was not possible to answer three questions, in particular:

- Regarding the trafficability of road facilities, the extended articulated vehicle often appears less favourable as a result of the changed tractrix curve compared with a standard articulated vehicle. However, car transporters (which, including the front and rear overhangs, have a total length of 20.75 m and are thus already longer than the generally permissible 18.75 m for tractor-trailer combina-

tions) are a vehicle combination using the entire road network today whose turning characteristics are very similar to those of the Type 1 longer trucks and may result in similar difficulties when using traffic facilities. The fact that these difficulties caused by the operation of car transporters have not (yet) resulted in any major adverse impact (as far as is known) can be explained by their frequency of occurrence. According to information given by the Association for Automobile Logistics in the Association of German Freight Forwarders and Logistics Operators, the operational fleet of car transporters in Germany comprised around 6,000 vehicle combinations in 2014, for instance. All experts are of the opinion that the potential for Type 1 longer trucks is many times higher than that. The question as to whether the feared adverse impact on the trafficability of road facilities will present itself if there is a higher frequency of occurrence of Type 1 or whether relevant improvements in turning characteristics can be achieved by taking technical measures was to be answered by extending the field trial for this special type.

- Unlike the Type 2 to 5 longer trucks, it was not possible to obtain an adequate data basis for Type 1 to be able to identify the fields of application for this type with a sufficient degree of accuracy. It was thus only possible to estimate the market potential – as an important input variable for determining the impact on transport demand of the operation of Type 1 longer trucks – on the basis of a best guess, assuming that one half of all conventional articulated vehicles is replaced by Type 1 longer trucks. An extension of the field trial with parameters that result in companies deploying Type 1 in greater numbers should check these assumptions by carrying out corresponding studies on the fields of application of Type 1.
- The positive result for Type 1 longer trucks with regard to the pavement load is due to the fact that at the current point in time it is mainly articulated vehicles with a single or two-axle semi-trailer have been replaced by Type 1 longer trucks. Here, too, an extensive trial will be required to determine how the result will change with a higher incidence of Type 1 when (inevitably) more conventional articulated vehicles with a three-axle semi-trailer are replaced.

6.2.2 Articulated vehicle with centre axle trailer (Type 2)

To a certain extent, longer trucks of Type 2 also play a special role. The supporting scientific research showed that the articulated vehicle with centre axle trailer exhibits the poorest turning characteristics of all longer trucks. In addition, however, there is evidence – obtained on the basis of simulations – of handling in highly dynamic manoeuvres that is critical in some cases unless a stabilization system is used. The simulatory analysis of the dynamics of the various types of longer trucks conducted by SÜßMANN, FÖRG, WENZELIS (2014) without taking account of electronic vehicle stability control systems (EVSC systems) showed that the basic stability of the trucks studied is highly dependent on the loading condition and the manoeuvre performed. A blanket assessment of individual types of longer trucks is not possible. In general, however, it is the case that tractor-trailer combinations, because of their low absorption between the tractor and the trailer, are more difficult to stabilize than articulated vehicles at high dynamic excitation. The Type 2 longer truck represents a combination of both. Its additional centre axle trailer can, especially if the loading condition is unfavourable (fully laden trailer towed by unladen articulated vehicle), exercise a significant adverse impact on the towing tractor and the semi-

trailer when pronounced steering manoeuvres are performed (risk of overturning). It is currently assumed that it will be possible to effectively control these critical areas of vehicle dynamics by means of EVSC systems. In addition, in the case of the real world vehicles and vehicle combinations, a safety gain is apparent, resulting from the requirement for "on-board axle load weighing", which indicates unfavourable or dangerous loading conditions to the driver. To further this safety gain, the exemption regulations could be amended to include an additional requirement making it mandatory to check for unfavourable loading conditions. However, when a simple lane change is performed, the lane offset of the Type 2 longer trucks (not taking into account EVSC systems), even in a conventional loading condition, is significantly higher than that of the corresponding reference trucks and also of the other types of longer trucks.

Finally, the consultants commissioned with the automotive engineering studies recommend that the dynamics of the Type 2 longer trucks should be studied further in order to back up the findings (cf. FÖRG, SÜßMANN, WENZELIS, SCHMEILER, 2016). The reason given for this is that, as already mentioned, the Type 2 has, in simulations, turned out to have less favourable vehicle dynamics in certain driving situations and without taking stability control systems into account. In addition, FÖRG, SÜßMANN, WENZELIS, SCHMEILER (2016) also draw on statements by the manufacturers of EVSC systems that the EVSC function has not been specifically adapted to the Type 2 longer truck and was backed up in the trial. It is true that all longer trucks are certified as exhibiting safe handling, because the EVSC system is designed to be conservative, i. e. in the interests of road safety, and comes into action at any early stage, especially if further units are attached, as is the case with longer trucks. Moreover, as far as is known, the field trial has not as yet produced any critical situations involving longer trucks of Type 2 in which insufficient control by the EVSC system has resulted in unstable vehicle dynamics.

However, regarding the dynamics of vehicle combinations, be they longer trucks or conventional trucks with their trailers, the EVSC stability control system could, simply because of certain loading constellations and the physical constraints (e. g. current coefficient of friction), reach the full extent of its stabilizing capacity. Such a constellation – conceivable, but certainly unlikely because of the resultant traction problems – would be if the entire load were placed behind the last axle or the last trailer were loaded. Against this background, and by way of precaution, the following approach is recommended regarding the permanent operation of Type 2 longer trucks: Before Type 2 longer trucks are approved for permanent operation, further studies should be conducted to back up the findings of the predominantly theoretical deliberations with regard to vehicle dynamics, in particular.

7 Overall assessment

Because of the special position of the Type 1 longer truck, the following overall appraisal of the operation of longer trucks refers exclusively to Types 2 to 5.

The overall assessment of the operation of longer trucks has to be seen against the background of the forecast volume of longer trucks. As the studies of the market potential and transport demand impact have shown, the market potential for Type 2 to 5 longer trucks is low relative to the total volume of freight traffic. Moreover, as a result of the established regulatory framework (for instance operation on

an approved network), which is mainly necessary for reasons of road safety and to reduce the burden imposed on the road infrastructure, only a small proportion of this potential will be exploited. This means that, in the modelled maximum scenario for 2030, there would be a forecast annual mileage of around 100 million vehicle kilometres for Type 2 to 5 longer trucks.

From the empirical trip surveys conducted, an average mileage per year and per longer truck of just under 100,000 km can be calculated (roughly equivalent to the mileage of a conventional articulated vehicle in Germany). Taking as a basis the simplifying assumption that the mileage is evenly distributed among the heavy goods vehicles, the mileage forecast for 2030 would be accounted for by around 1,000 longer trucks. Even if this figure were to be underestimated by a factor of 2, the resultant figure would be a maximum of 2,000 longer trucks. This figure still appears low compared with, for instance, the size of the operational fleet of car transporters in Germany, which the Association for Automobile Logistics in the Association of German Freight Forwarders and Logistics Operators states as being around 6,000 vehicle combinations. Even for the motorways (the main place where longer trucks will operate), it has been possible, with the help of transport demand modelling, to estimate that on 90 % of all motorways, longer trucks' share of heavy goods vehicle traffic will be less than 0.5 %, and less than 1 % on 99 % of all motorways.

Given these parameters, it can be stated, by way of summary, that significant problems did not emerge in the field trial. Measured against the multiplicity of issues that were considered, the number of potential risks identified is low. Moreover, given the currently existing number of longer trucks participating in the field trial, and assuming that longer trucks' shares of the total volume of freight traffic will be significantly higher than forecast in the studies on the transport demand impact, the risks identified can be classified as acceptable or manageable. This also applies to the issue of 'parking longer trucks on rest areas' – which had not been resolved at the half-way stage of the supporting scientific research – because it has been possible to develop problem-solving approaches that are suitable for use in practical applications.

Regarding the overall result of the supporting scientific research, it should be noted that the overall assessment of a possible deployment of Type 2 to 5 longer trucks is often based on a risk assessment. The risk can be described as the product of the extent (of the damage) and the probability of its occurrence. One of the reasons for the overall assessment that the possible risks of the deployment of longer trucks could be classified as acceptable or manageable is their low probability of occurrence. This is due to several important factors.

1. The mandatory safety equipment for longer trucks going beyond the general requirements and the special requirements to be met by drivers (and their training).
2. The substitution effect ("turn 3 into 2") for Type 2 to 5 longer trucks that was observed in the field trial and the resultant lower number of trips by heavy goods vehicles.
3. The tonne kilometres operated by Type 2 to 5 longer trucks are likely to be comparatively low.
4. The restriction of operation to an authorized network and the fact that Type 2 to 5 will operate predominantly on dual-carriageways with no at-grade junctions.

Regarding the possible extent (of damage), account has to be taken in some of the issues of the fact that, as a result of the 50 % higher loading capacity of longer trucks compared with equivalent conventional trucks, the individual extent would be more negative in terms of road safety, even in the most unlikely event of occurrence. In such an individual case, a volumetrically laden longer truck carrying almost its full payload, for instance, would have a greater fire impact than an equivalent conventional truck laden with the same but less cargo. In a one-to-one comparison under identical general conditions, an overtaking manoeuvre would take at least a few seconds longer. Emergency stops in a lay-by in a tunnel would be more problematic.

It should also be noted that some of the results obtained are based on the very specific conditions of the field trial. In some cases, these conditions result from the requirements of the Exemption Regulations governing the field trial, and in a few cases also from the fact that the longer truck drivers adapted their behaviour under the conditions of the trial. Should there be changes to these conditions, new light would have to be shed on certain issues (cf. also paragraph 8).

Ultimately, however, it can be stated that, in the trial, the deployment of longer trucks demonstrated a positive impact on transport demand in terms of a reduction in the number of vehicle kilometres driven and accordingly also a reduction in levels of climate change gases and air pollutants and can also have this impact in the future. So far, it has been apparent that intermodal shift effects from the railways and inland waterways have been very low, mainly because of the existing weight restrictions as well as the actual/modelled route restrictions, and are thus negligible. Although it is clear that longer trucks only represent a possible partial solution for containing the growth in freight traffic and the associated environmental impact, their deployment is beneficial in terms of operations and transport demand in certain spheres and areas of application.

8 Looking ahead

Although the supporting scientific research will come to an end when the field trial is concluded on 31 December 2016, there is certainly a need for further research. Even when the supporting scientific research was still at the conceptual stage, there was agreement with the circle of experts consulted that some questions cannot be answered by either field trials or by experimental or theoretical model studies. If at all, the answers will not emerge until there is real world operation lasting many years. In addition, it was apparent, as early as the mid-term review of the field trial, that no resilient evidence will be possible regarding some questions even after the end of the field trial. Finally, the studies conducted in the final phase produced findings regarding more extensive research issues that would also be of interest for conventional trucks.

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