Study of stability measures and legislation of heavy articulated vehicles in different OECD countries.

Prof. Johan Wideberg, Dr. Erik Dahlberg, Martin Svensson

University of Seville, Spain
Scania, Sweden
KTH, Sweden

Johan Wideberg

Professor of Transportation Engineering
ESI, Descubrimientos s/n, 41001 Sevilla, Spain
+ 34 954 487 470
wideberg@esi.us.es

ABSTRACT

This study was carried out to compare a number of stability measures of European heavy trucks with the performance of other high capacity vehicle combinations in a range of OECD countries.

Comparisons are made with truck combinations according to legislation in the United States of America, South Africa, Central and Southern Europe, and Scandinavia. Also the legislation for high capacity configurations in the above mentioned countries are compared, e.g. maximum weights and dimensions. This paper addresses the relationship of truck size and weight policy, vehicle handling and stability, and thus safety. Handling and stability are the primary mechanisms relating vehicle characteristics and safety. Vehicle characteristics may also influence safety by mechanisms other than handling and stability. For example, vehicle length may affect safety through interactions with other vehicles, such as passing manoeuvres and in clearing intersections, in addition to its influence on vehicle handling and stability. Here the difference, due to tradition and other reasons are great when comparing vehicles in different countries.

The analysis is performed using the multi body simulation tool ADAMS. The different manoeuvres analysed are handling on circular circuit, lane change and sudden change in steering angle. In addition to the dynamic performance, also the static measure turning radius of the different configurations is compared.

STUDY OF STABILITY MEASURES AND LEGISLATION OF HEAVY ARTICULATED VEHICLES IN DIFFERENT OECD COUNTRIES.

Prof. Johan Wideberg, Dr. Erik Dahlberg, Martin Svensson

University of Seville, Spain
Scania, Sweden
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1 INTRODUCTION

The dimensions of heavy vehicles differ substantially between different parts of the world and even between neighboring countries. For instance recent studies [Backman et. al.] conducted in Holland and Scandinavia indicates that significant operational and environmental benefits can result from giving operators the option of using different combinations of trailers and semi-trailers linked together up to a maximum length of 25.25 meters (which is the maximum length in Scandinavia today). These combinations would be highly suitable for high volume freight and because of their length would operate between distribution hubs. The benefits include: 32 per cent reductions in vehicle km's; 15 per cent less fuel consumption; 15 per cent less NOx and CO2 emissions; less congestion and 23 per cent savings in operational costs. Increased road wear due to higher axle loads seems to be insignificant and from a road safety angle, the greater risk is posed by congestion on the roads, rather than longer vehicles.

This European perspective is similar to discussions in other parts of the world. North American for instance has a number of different types of vehicles depending on country and state boundaries as discussed further on. Having done this introduction what this paper is going to concentrate on is the handling and maneuvering characteristics of trucks from several different regions of the world.

2 LEGAL REQUIEREMENTS

This section briefly describes the restrictions in the different countries studied, and gives a short background for the truck type modeled from each country. At the end of this section is a table summarizing the most important restrictions considering weights and dimensions for road trains in all the countries considered in this study.

2.1 North America

The dominant combination in North America is three-axle tractor with two-axle semi trailer configuration, and has been so for the last fifteen years. Approximately half of the goods being transported in North America (NAFTA) by such truck combinations.

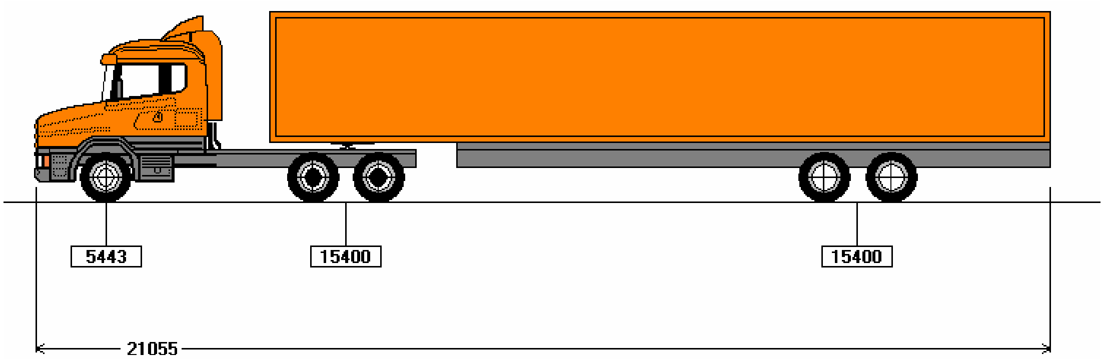

Figure 1: Dominant truck type in North America[1]

In Canada the total length of the vehicle or the length/wheelbase of the tractor is controlled and all over North America there are restrictions concerning the trailer length. Hence many American trucks have longer tractors, looking the way most people imagine a typical American truck [NAFTA], see figure 1.

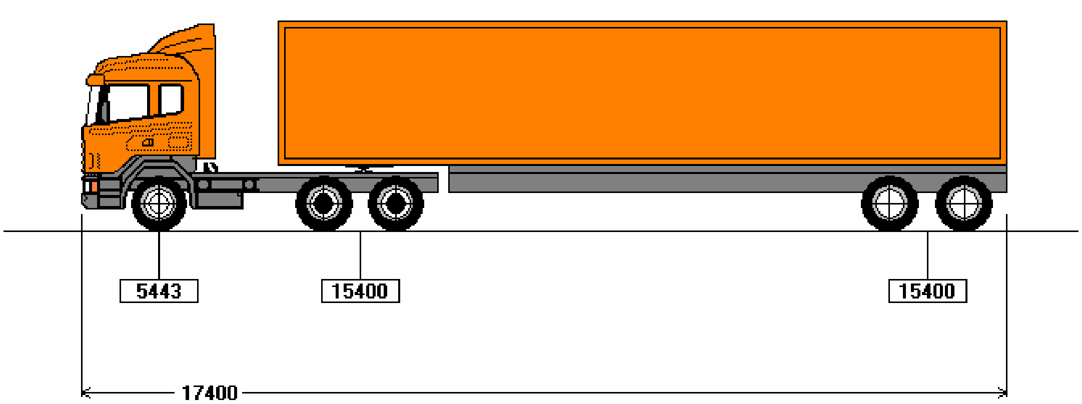

Figure 2: Truck with the shorter tractor, allowed in both the US and Canada

The truck modeled for this study is American shorter (6x4) tractor with semi trailer showed in figure 2, allowed to travel almost all over the US. However the state regulations are different and may depend on axle loads, wheelbases and kingpin placement.

[1] The units indicated in the figures are metric tonnes and metres

2.2 Finland and Sweden

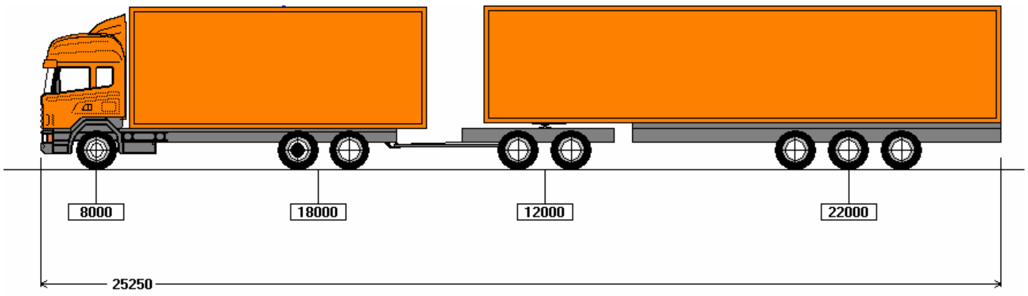

Figure 3: Typical Scandinavian truck configuration

The Scandinavian[2] truck type is the longest one in Europe, measuring as a maximum 25.25 meters in total. The most common configuration (and the one used for this study) is the 6x2 tractor with a 2-axle dolly and a 3-axle semi trailer. It is allowed to travel on most major roads in Scandinavia, with restrictions on some bridges and in and around major cities. The Scandinavian roads are divided into three categories: BK1, BK2 and BK3. On BK1 roads the highest axle loads are allowed, and on BK3 the lowest. The data in Table 1 apply to BK1 roads.

2.3 Central and southern Europe

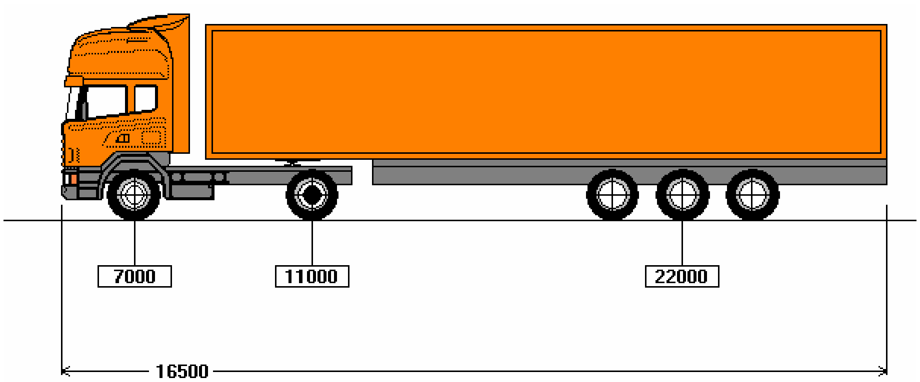

Figure 4: European truck

The restrictions are listed below, in general five-axle combinations are allowed throughout the EU, with a maximum weight 40 ton, as long as the load on the driving axle does not exceed 11.5 tons. The maximum height of the vehicle, a vehicle not higher than 4 meters is guaranteed free circulation in the EU, if the vehicle is higher than 4 meters the national limits must be respected.

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[2] In this article Scandinavia refers to Finland and Sweden.

2.4 South Africa

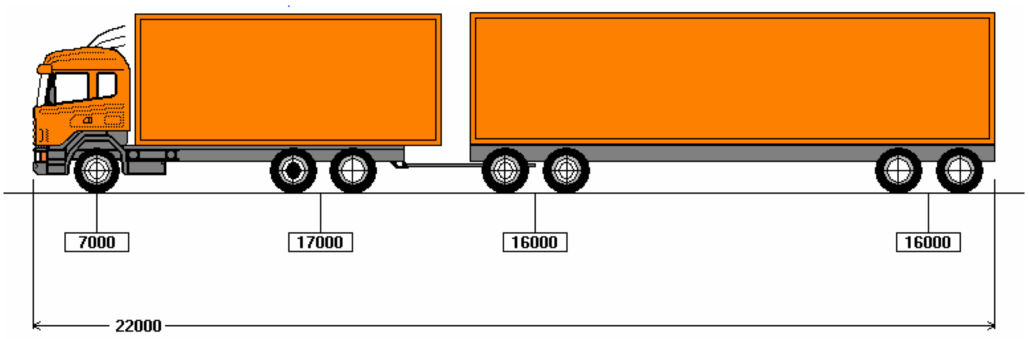

Figure 5: South African truck

2.5 Brazil

A typical Brazilian combination have similar dimensions to many of the above mentioned models although what is differencing is the use of B-trains and also that the height is particularly high.

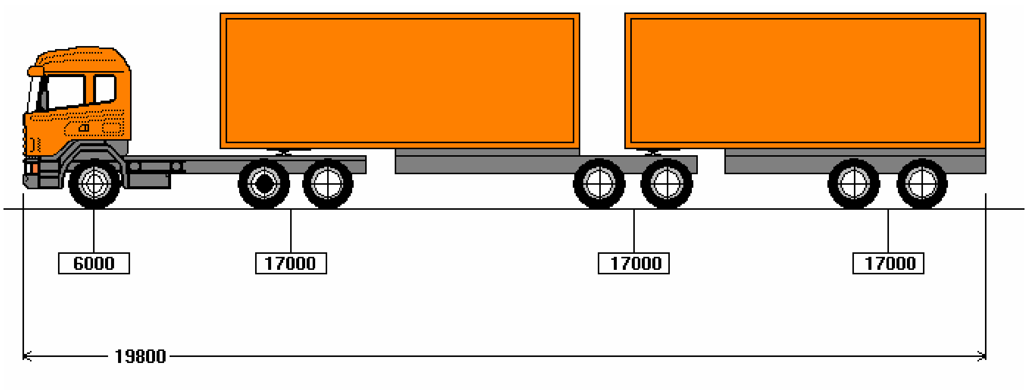

Figure 6: Brazilian truck

2.6 Table comparing the most important restrictions in all the countries

All units of length are given in meters, and all units of weight are given in tonnes. Note that all fields have not been filled, as not all countries have limitations for the same parameters.

	North America	*European Union*	*Scandinavia*	*South Africa*	*Brazil*
Dimensions					
Total length	-	16.5	25.25	22	19.8
Width	2.6	2.55	2.55	2.6	2.6
Height	4.15	4	4	4.3	4.4
Trailer length	16.2	13.6	13.6	12.5	-
Weights					
Total gross weight (TGW)	36.3	40	60	56	57
Steering axle	5.443	10	10	7.7	6
Driving axle	-	11.5	11.5	-	-
Single axle (2[3])	8.16	10	10	8	6
Single axle (4)	8.16	10	10	9	10
Tandem axle group(4)	15.4	11-20[4]	11.5-20[5]	16	12[6]
Tandem axle group (8)	15.4	11-20[2]	11.5-20[3]	18	17
Tri-axle group (6)	15.4-28.5[7]	21-24[8]	21-24[3]	24	-
Tri-axle group (12)	15.4-28.5[5]	21-24[6]	21-24[3]	24	25.5[6]

Table 1. Comparison between the most important regulations regarding dimensions and weights in the different regions. A siphon indicates that there is no limit in that dimension/weight in that region.

[3] Number of tyres per axle group
[4] Depending on the distance between the axles and only applies to trailers, the restrictions of the tractor tandem is 11.5-19 tonnes depending on axle spacing and suspension.
[5] Depending on the distance between the axles
[6] Must be steering axles
[7] Depending on axle spacing and state/country
[8] Applies only to trailers and semi trailers

3 CONSTRUCTION OF THE MODELS

All models are based on the truck model that is available for download from the MSC website. It is the model of a typical American truck and hence, few changes were necessary in order to model the American truck. Because of this, the first model constructed was the American one, and then the other models were modeled using components, which were modified, from this American truck.

This section of the paper will first of all describe the way in which the American model is built; all other trucks are modeled in a similar way. Examples of major changes are significant changes in the suspension, rebuilt cab, and different tires for instance.

Changes made in the original American model where restricted to spring and damper characteristics, plus weight and minor dimensional changes of the trailer.

In all the models the center of gravity of the cargo has been moved to achieve close to maximum weight of the trailer and its cargo, and also to make sure that the load limits of the trailer axle group will not be exceeded.

Because of how the model is built, it has not always been possible to keep each axle under the limit for single axles, i.e. the front axle in a tri-axle group of a trailer may exceed the maximum allowed load limit for single axles because it's closer to the center of gravity of the trailer. However, this is assumed to have little or no significance for this study.

Also the loads of the axles of the tractors have been made sure that they do not exceed the allowed limits, with the same exception as goes for the trailer. The global coordinate system in the models has the x-axis running along the vehicle longitudinal axis, the y-axis in the lateral direction and the z-axis in the vertical direction, forming an inertial system.

3.1 The American model

The front suspension of the tractor is modeled as a leafspring with two dampers, 1050 mm apart. The distance between the leafsprings is 800 mm. Note that in the picture it seems like the dampers or leaf springs do not touch either of the axles, but this is just the appearance of the model.

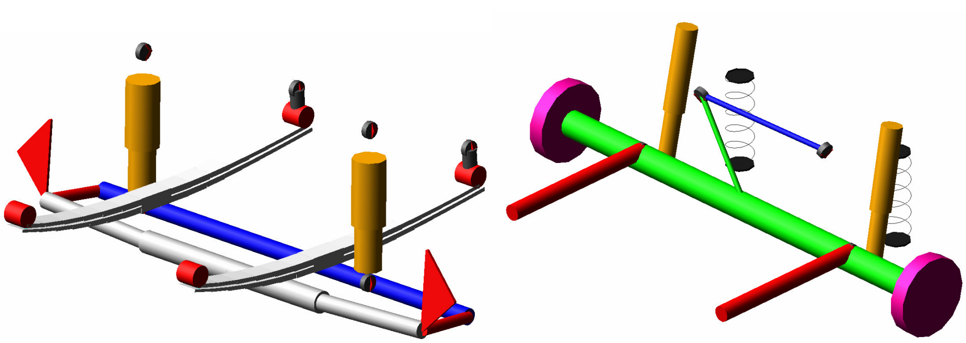

Figure 7: Tractor front suspension with leaf springs (l) and drive axle (r).

The trailer axles are made up from two pairs of dampers and one pair of springs. The damping of the leaning[9] dampers are about 1/5 of the damping of the upright[10] dampers. The distance between the upright dampers, as well as the distance between the springs, is 992 mm. The distance between the leaning dampers is 788 mm. The upright damper contributes to about 30% of the damping in vertical direction, and the leaning damper to about 70%.

The tires used in all models are models of the Michelin 315/80 R22.5. Different tires types are used for steering wheels, driving wheels and non-driving wheels. The tires are modeled using the magic formula (Pacejka). The fifth wheel of all the models has a roll stiffness of 5000 kNm/rad, accomplished by giving the two bushings a translational stiffness in vertical direction.

4 RESULTS OF SIMULATIONS

4.1 Dynamic measures

Using a simulation program as ADAMS it is often easy to be overwhelmed by the number of data that can be extracted. One measure of the dynamic of an articulated vehicle which is very representative and easy to present and compare is rearward amplification. It is defined as the ratio of the maximum lateral acceleration of the rearmost trailer to that of the tractor during obstacle avoidance or sudden lane changes. Higher rearward amplification is not desirable because it may lead to that the rear trailer is more likely to roll over during an abrupt steering maneuver or that the trailer can swing out and hit other vehicles or even jack-knife.

	Rearward amplification[11]	***Yaw damping***	***Transient high-speed off-tracking***	***Load transfer ratio***
US	1.18	0,55	-0.024 mm	0.18
EU	1.29	0,50	0.16 mm	0.32
Scandinavia	1.81	0.39	0.29 mm	0.36
South Africa	1.56	0.22	0.57 mm	0.74
Brazil	1.88	0.36	0.28 mm	0.39

Table 2. Result for dynamic measurements.

[9] Drive axle dampers
[10] Dampers on tractor front suspension
[11] Double lane change, RA measurements where made on the center of gravity.

4.2 Static measures

As a complement to the dynamic measures, also the static measure turning radius is also compared on a neutral basis, i.e. the same basic cab and hence front overhang is used for all combinations. The minimum kerb radii as well as the minimum wall radii are presented in the table below.

Turning radius	***North America***	***European Union***	***Finland and Sweden***	***South Africa***	***Brazil***
Kerb	12.9 m	9.8 m	11.5 m	11.8 m	10.8 m
Wall	13.3 m	10.2 m	12.1 m	12.3 m	11.2 m

Table 3. Result for static measurements.

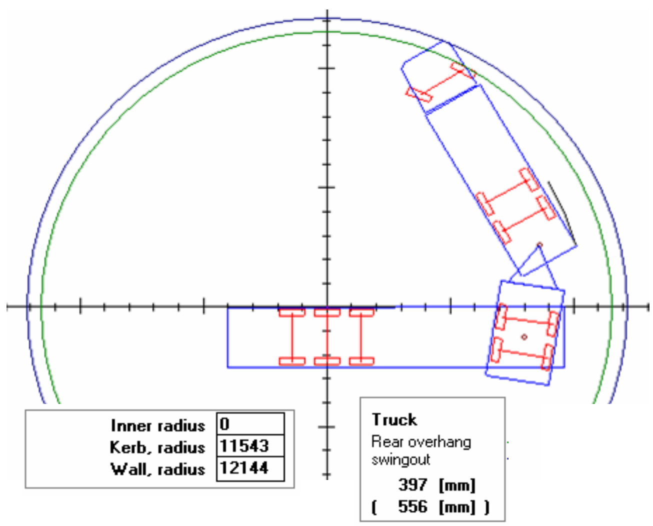

Figure 8: Calculation of turning radius for the Scandinavian example.

5 CONCLUSIONS

In general, the longer and heavier the truck combination, the more likely it is to have worse stability measures. Results from the five standard combinations from different continents compared indicate this, although the stability indicators are not strictly correlated. Rearward amplification, yaw damping, transient high speed off-tracking and load transfer ratio are affected by many parameters such as: axle distance, axle load distribution, center of gravity height, axle suspension and type, number of articulations and trailer lengths.

In addition to the differences in stability measures, the combinations differ in transport efficiency. As a general rule the efficiency correlates in the opposite direction, i.e. the longer and heavier the combination, the more efficient the transport. In order to make a relevant comparison, one has to take into account also the local infrastructural conditions, e.g. a measure such as rearward amplification may have little importance on wide and straight roads.

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