

## DRIVING DYNAMICS AND STABILITY ISSUES OF THE EUROPEAN ROAD TRAIN CONCEPTS



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### **Abstract**

Some predictions show an increase of 80-100% of the current volume of goods and passengers should be transported in the EU within the next decade, and most of this increase – despite of the efforts made in promoting the rail and waterway transport – will be added to the already overloaded roads. It seems that the only feasible solution is to increase the vehicle overall length and weight at the lowest complexity, requiring maximum utilization of the existing vehicle units with only small modifications. Although these combinations are typical in other parts of the world (North America, Australia) and even in Northern Europe, the Central-European application is somehow different because of more difficult traffic situations. This is the reason that several aspects of dynamic behavior, especially during braking and in critical situations have to be examined.

**Keywords:** European road train, Traffic safety, Dynamic behaviour

### **Résumé**

Une augmentation de 80 à 100% du volume de marchandises et de passagers à transporter dans l'Union Européenne est prévue au cours de la prochaine décennie. Une large partie de cette augmentation de trafic va se reporter sur des infrastructures déjà saturées, et ce malgré les tentatives de développement du ferroutage et du transport maritime. La seule solution réaliste et simple à mettre en oeuvre semble d'augmenter la longueur totale et les poids des véhicules, en utilisant au maximum des unités existantes avec de petites modifications. Ces combinaisons sont utilisées dans d'autres régions du monde (Amérique du nord, Australie) ainsi que dans les pays du nord de l'Europe, mais leur mise en place dans les pays d'Europe Centrale est plus délicate compte tenu de la nature du trafic rencontré. C'est pourquoi, plusieurs aspects du comportement dynamique de ces attelages doivent être examinés, en particulier ceux relatifs au freinage ou au comportement dans des zones critiques.

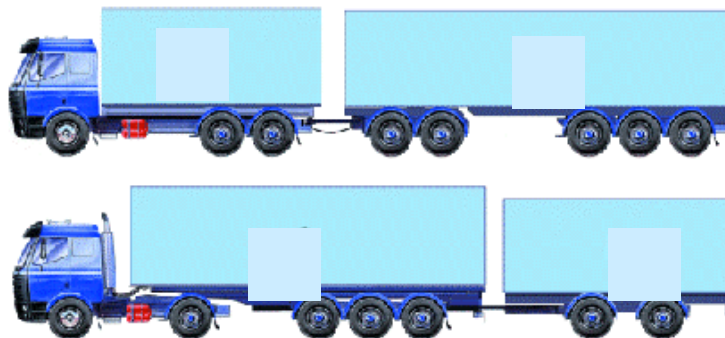
**Mots-clefs:** Train routier européen, sécurité routière, comportement dynamique.

## 1. Introduction

The braking dynamics of the combination has some special considerations, since the combination become difficult. The European trailers normally have electronic braking system, which are capable to conduct an extensive communication with each other (the new ISO 11992 interface makes it possible), and can provide optimal functionality, but cases like back-up mode (when the electronic part of the system does not work) or in case of combining traditional, non-electrical brakes with more advanced systems needs to be examined. A special problem is the brake force balance between the towing vehicles and the rest of the combination, which is handled in a contemporary EBS (electronic braking systems) for a two-unit combination, but should be modified, for a multiple-unit vehicle.

More interesting and important are the lateral stability related issues. Both combinations have some critical components: the first one the dolly, the second one the central axle trailer. Such dollies are used in the Scandinavian countries, but those are not steered, which will not be acceptable. The paper investigates the impact of different standard maneuvers on the combination stability. The paper will discuss in details the applicable brake system based on stability control strategies. Based on the constructed compatibility matrix among the units of the road train, several strategies are being developed and verified in an SIL simulation environment, such as electronic stability control (ESC, including roll-over stability control, RSC) fitted only to the towing vehicle, only RSC on one of the units of the train, ESC on the dolly, etc. The brake system based ESC itself is state-of-the-art technology, it will only be mentioned in brief, however special attention will be paid to the combination of such systems when they will be all fitted and intervene.

After a longer investigation, 2 types seem to win the competition of the architectures as shown in Figure 1: the upper combination is composed of a normal 6x4 truck, a dolly and the ordinary semi-trailer, while the lower combination is a tractor-semi combination with a central axle trailer.



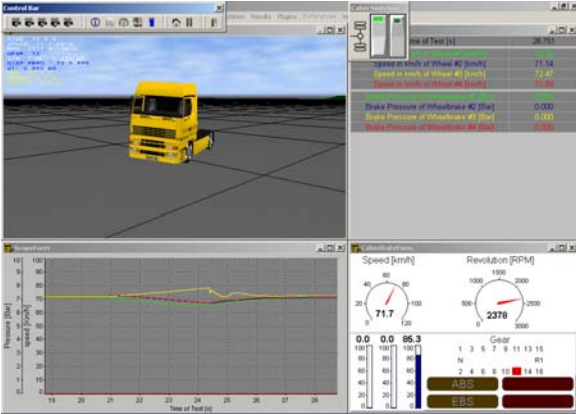
**Figure 1** - The 'winning' road train concepts in Europe

The former one is intended to be used for the heavy loads up-to a maximum of 60 tons, while the latter one is thought to be applied in voluminous transport up-to 48 tons as gross weight.

## 2. Road Train Simulations

Simulations were made to examine the stability of super sized vehicles. Simulations were made in an SDK Simulator, which is a sophisticated vehicle dynamics simulator. The

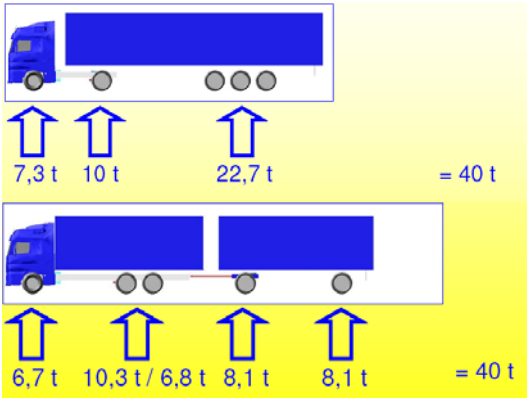
program is capable to run in real time mode and to analyze several vehicle parameters. It has a 3D display to watch the test progress. Figure 2 shows a snapshot on the simulator program.



**Figure 2 - The simulator program**

**3. Simulated vehicle combinations**

Simulated tests were made with five vehicle combinations, to determine the behaviour of the vehicle and the lateral stability. There were two standard vehicles, a semi trailer and drawbar trailer combinations, to compare the results. Figure 3 shows the vehicles and the axle loads.



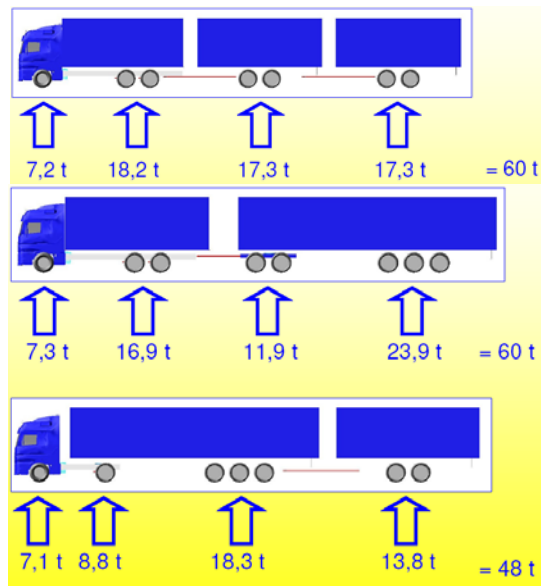
**Figure 3 - The standard combination and the axle loading**

The three road train concepts are shown in Figure 4. Two of them are 60 tons; one is 48 tons gross weight. The first combination is a simple lorry with two central axle trailers. The second combination is a lorry and a semi-trailer connected by a dolly. The third combination is a tractor-semi trailer combination with one central axle trailer.

**4. Simulated test cases**

Five tests were made, four standard ISO lateral stability tests for heavy commercial vehicles and there is one special test track. The four ISO tests are:

- ISO 14791: Lateral stability test: double lane change, with 0.2Hz, 0.3 Hz and 0.4 Hz excitation. ISO standard specifies a simple lane change, but using double lane change causes higher instability. This manoeuvre is more critical, than a simple lane change.



**Figure 4 - Road train combination and the axle loading**

- ISO 14792: Steady-state circular test: 100 m radius circle path, constant acceleration until the vehicle falls over.
- ISO 14793: Sinus steering: at a 50 kph vehicle speed, continuous sinus sweep from 0.1Hz to 2 Hz. The lateral acceleration must be smaller than  $3 \text{ m/s}^2$ .
- ISO 14794: Brake in curve: 100 m radius circle track, speed is 60 kph, the vehicle decelerates with  $3 \text{ m/s}^2$  until it stops.

The special track is a factory test field. The heading speed is 50 kph. On higher speed, the vehicles couldn't pass the track.

## 5. Recorded parameters

There are several parameters which provide information on the vehicle behaviour, some of which are enough to determine stability, and these parameters are listed below:

- Vehicle speed,
- Wheel speeds,
- Lateral accelerations on every joint,
- Steering angle,
- Yaw rate,
- Roll rate,
- Swim angle of the truck,
- Side slip angles of the wheels,
- Brake pressures.

## 6. Results

The results were converted and processed by MatLab. After analyzing test results, several statements can be established. In the Lateral stability test, the lorry with two tandem trailers fell over at 0.3 Hz excitation. Roll rate was 1 rad/sec, double that of the others. Lateral acceleration was higher than 1 g. At the other combinations, lateral accelerations were  $5 \text{ m/s}^2$ .

The steady state circular test did not effect fall over in every case, but the vehicle has a strong oscillation. The most stable combinations were the standard semi-trailer, the semi-trailer with tandem trailer and the lorry with semi-trailer on a dolly.

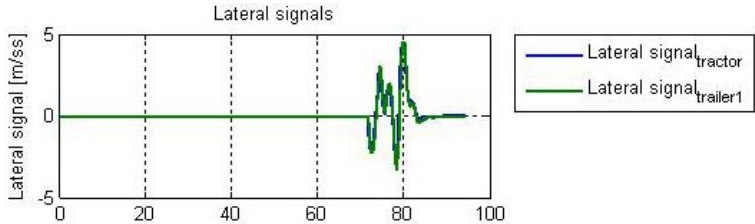
Examining the Sinus sweep test, every combination passed the test, but an amplitude amplifying can be experienced in two cases (in which tandem trailers were used), from the front of the vehicle to the rear. There wasn't critical, but it can cause dangerous situations.

All cases were successful in the Brake in curve test, all combinations were stable. A larger volume caused longer brake distance.

The test course could be performed at 50 kph. At higher speeds, the vehicles rolled over. There are narrow curves on the track, so high lateral accelerations could be measured. At the standard draw-bar trailer, lateral acceleration were  $10 \text{ m/s}^2$ , at the other combinations this value was about  $8 \text{ m/s}^2$ . In this test, the most instable combination was the standard draw-bar trailer.

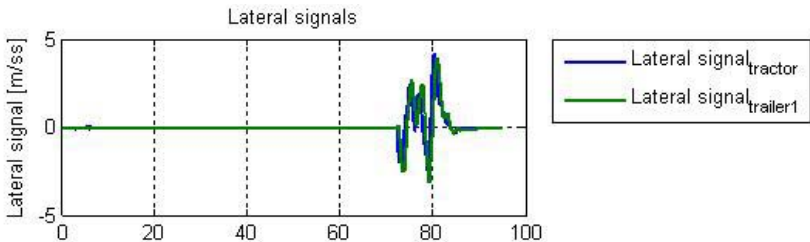
Let us analyze one test case, for example, a lane change with 0.3 Hz excitation. This case was the most critical, because one combination (lorry with two central axle trailers) lost its stability and rolled over. Examine the other four combinations, a standard semi trailer, a standard lorry with a draw-bar trailer and a lorry with a semi-trailer on a dolly and the semi-trailer with a central axle trailer. We discuss about the lateral accelerations, because it gives information on lateral stability against falling over.

Figure 5 shows the lateral signals of the standard semi- trailer combination. The maximum value of the lateral acceleration is almost 0.5 g. That is not a critical value.



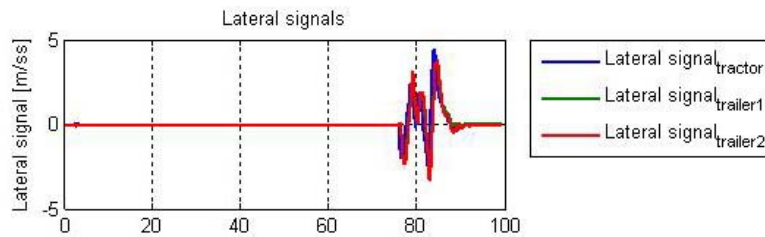
**Figure 5** - Lane change test result for standard semi-trailer (horizontal axis is time in seconds)

Figure 6 shows the lateral signals of the standard draw-bar trailer combination. The maximum value of the lateral acceleration is about 0.4g. That is not a critical value.



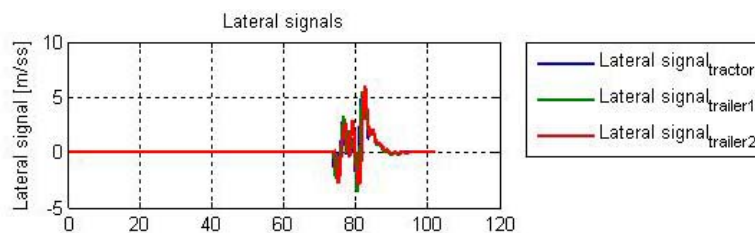
**Figure 6** - Lane change test result for standard lkw6x2 (lkw: lastkraftwagen, heavy duty vehicle, 6x2: 6 wheels, 2 driven)

The next combination is the lorry with a semi-trailer on a dolly. In this case we have three lateral signals. Figure 7 shows it. In this case the signals are mostly the same as the draw-bar trailer combination. The maximum value is lower than the standard semi-trailer's value. The value appears on the first joint of the train. There is no amplifying effect in this case.



**Figure 7** - Lane change test result for lkw6x4 with dolly

The fourth combination is the lorry with a semi-trailer jointed with a central axle trailer. In this case we have three lateral signals. Figure 8 shows it. In this case, the lateral signal is over  $5 \text{ m/s}^2$ , about 25% higher, than the other cases. The highest value appears on the last joint of the train. It seems that the signal is amplified to the end of the train; this effect is more dangerous, because the driver cannot feel the behaviour of the train.



**Figure 8** - Lane change test result for semi-trailer with central axle trailer

Examining these three cases, the lorry with a semi-trailer on a dolly seems to be the best combination, because the behaviour doesn't differ with the standard vehicle. The semi trailer with a central axle trailer is more dangerous, but not critical. The lorry combination with two central axle trailers is critical, because it has rolled over.

## 7. Summary

As mentioned above, two combinations seem to be adequate to achieve the expectations. This predicate is confirmed by driving dynamics stability simulations. The result verifies that these road trains are as stable as the standard trucks. One of them is composed of a normal 6x4 truck, a dolly and the ordinary semi-trailer, while the other combination is a tractor-semi combination with a central axle trailer. The third road train combination (lorry with two central axle trailers) is not proposed because it can cause critical situations.

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