

THE USE OF MULTI-TRAILER SYSTEMS

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ABSTRACT

The development of the multi-trailer system was started at Delft University of Technology some 22 years ago. Since then this system has been in service to transport containers in various harbours. The five constituent trailers of a multi-trailer have been designed in such a way that they are track following. That is to say that each trailer follows the same track as the one in front of it. These vehicles are currently operated at a maximum speed of 30 km/h. If longer distances are to be covered, higher speeds would be desirable.

A multi-trailer system that has been carefully designed could be used at speeds of 50 km/h or more. This would provide a cost-effective means of transportation that is safe and environmentally friendly.

Simulations have indicated that the implementation of a speed dependent steering mechanism called "Safetrail" leads to a considerable improvement in road holding behaviour.

This paper focuses on experiments that have been executed with a truck and a single trailer in order to assess the performance of the steering system "Safetrail".

The experiments have confirmed the encouraging results that were derived from the simulations.

1.0 INTRODUCTION

Cargo transport plays an important role in the Dutch economy. However, congestion is an increasing problem that is resulting in declining accessibility and increasing transport times and costs. One possible way to overcome these problems is to use large capacity vehicles.

Some years ago Delft University of Technology introduced a concept based on road multitrailers (Drenth, 1996). This concept has the following characteristics:

- The five constituent trailers are track following. That is to say that each trailer follows the same track as the one in front of it. This property is essential in a densely populated area such as the Netherlands.
- The vehicles will be operated at night. Because there is little traffic this permits the separation of cargo and passenger traffic which in turn will lead to an improvement in road safety. This also minimises the risk of damage to the underlying infrastructure due to a low pavement temperature at night.
- The vehicles use a common 6 (3 + 3) lane highway, the left lanes of which have been closed to other vehicles in each direction. The left lanes were chosen to prevent interaction with other traffic pulling out or cutting in.
- The system was designed to facilitate container transport between terminals in the port of Rotterdam and the Dutch hinterland. The separate trailers can be used as normal road vehicles during the day.

Figure 1 gives an impression of the concept.

The idea originates from the use of multi-trailers for the internal transport of containers at terminals. The experience thus gained has proven that this type of vehicle is cost effective, safe, cheap and reliable. However, the road multi-trailer must be modified in order to cope with the conditions encountered at higher speeds (Groenendijk, 1998). Alterations in the design of the existing multi-trailers that have been suggested include:

- four axles per trailer (maximum axle load)
- lowering of the loading platform (maximum vehicle height, low COG)
- Air suspension (road-friendly suspension)
- EBS braking system (to minimise stopping distance)
- A "Safetrail" steering system (to ensure stability at high speed)

These features have been implemented in a preliminary design. The detailed specifications and a drawing are given in Figure 2.

This paper focuses on experiments that have been executed with the "Safetrail" steering system.

Multi-body simulations of a five-trailer combination equipped with the system had already yielded promising results (Boezeman, 1998). The next step was to test the system in a prototype vehicle. Although all simulations had been executed with a fully loaded five-trailer combination for practical reasons it was decided that the experiments should be done with an empty truck and single trailer combination.

After a new series of simulations, this prototype was constructed by Buiscar BV (Angevaren, 1998). An overview of the test combination is given in Figure 3.

Currently work is in progress on the design of a tractor.

2.0 PRINCIPLE OF SAFETRAIL OPERATION

Some years ago the Transport Technology Section of the Mechanical Engineering Department of Delft University of Technology initiated the design of a new steering system for multi-trailers. This system was called Safetrail and its objective was to ensure *both* optimal track-following behaviour at low speeds and stability at high speeds.

In order to achieve this a velocity-dependency had to be introduced into the steering system. Figure 4 depicts the prototype trailer in the low speed (left) and high speed (right) positions.

In the current generation of multi-trailers, the rotation of the tow-bar A (the letters refer to Figure 4) and steering arm B is directly coupled. In the Safetrail system this direct link is disconnected and instead an extra steering rod, C, is connected between the trailer's steering arm B and the rear of the vehicle in front. At low speeds, A, B, and C form a triangle, providing the same steering properties as the current type of multi-trailer. At high speeds the position of steering rod C can be changed; the triangle then opens up to include the rear of the vehicle in front, to form a quadrilateral.

With the system in the high-speed position the trailer will essentially have a different virtual point of traction. In fact the adjustable steering rod extends the tow bar to the imaginary point were the lines along the tow bar and steering rod intersect. This has a stabilising effect for two main reasons:

- The hitch offset is very small or even negative. The hitch offset is the longitudinal distance between the (virtual) rear axle (neutral point) and the hitch. A large hitch offset disturbs the steering signal of the trailer. Due to the yaw motion of the preceding vehicle, the initial steering signal of the trailer is in the wrong direction.
- 2. A lateral motion of the preceding vehicle leads to a small steering effect on the trailer due to the long tow bar. This prevents the occurrence of a whiplash effect.

The experiments were designed to answer the following questions:

- 1. Does the system give the improvement in road handling behaviour that was concluded from the results of the simulations?
- Is a two-position mechanism sufficient or is continuous system adjustment as a function of velocity necessary. A two-position mechanism would be preferable because of the simplicity of the regulator.

3.0 DESCRIPTION OF THE EXPERIMENTS

3.1 The test vehicle

The test combination is depicted in Figure 3. It consists of a TU Delft test truck and one modified Buiscar trailer. A structure was mounted at the back of the truck to facilitate the use of additional elements of the Safetrail system such as hydraulic components and a "box" with an embedded guidance system for the steering bar adjustment.

One of the consequences of adding this structure was that the hitch offset was enlarged. In a road multi-trailer, a trailer would follow another trailer. All the trailers have a steering back axle and therefor a very large hitch offset. The test truck reproduces this situation.

Both the front and rear axles of the truck have leaf spring suspensions. In particular, the rear axle suspension is very stiff. The specifications of the truck are:

Total mass	7000	[kg]
Wheel base	4.70	[m]
Tires	12 R 22.5	[-]
Hitch offset	3.5	[m]

The trailer is basically one single trailer of a multi-trailer train of five. The rear axle is a steering axle and is connected to the front axle by a torsion bar and two steering rods. For the tests two elements of the steering system were modified. The four bar mechanism between the tow bar and the front axle was replaced by a cable. This measure was intended to reduce the turning radius. The Safetrail steering system was also used. The specifications of the trailer are:

Total mass	8300	[kg]
Wheel base	9.556	[m]
Tires	11 R 22.5	[-]

The rear axle of the trailer is not sprung. The front axle was suspended with very stiff rubber blocks in order to provide a load-dependent braking system.

3.2 Circumstances

The experiments that are discussed here were executed on a dry brick pavement road (ECT container terminal).

The results were recorded by a video camera. The use of accelerometers was considered. However due to the questionable accuracy and complexity of the instrumentation accelerometers were not used.

Performance indicators were not used in a qualitative sense. The yaw motion of the trailer gave an indication of the stability of the trailer. In addition, the squealing of the tires and the torsional deformation of the chassis were clear signs of trailer instability.

The experiments that were executed were:

- An ISO lane change (60 and 70 km / h, Figure 5).
- Swerve tests at constant speed (60 and 70 km / h) with increasing frequency.

All experiments were been executed with Safetrail in both low speed and high speed positions. In the low speed position the trailer behaved as a standard single trailer (without Safetrail installed).

4.0 RESULTS

The results of all experiments mentioned here are available on video.

Low speed position

During the lane change tests the rear end of the trailer showed a tendency to break away (Figure 6). In the 70 km / h run in particular, the squealing of the tires could be heard.

In the swerve tests (at both speeds) the driver had to stop steering because with a high frequency of the steering input (> 0.5 Hz) the yaw stability of the trailer dropped below an acceptable level.

High speed position

The trailer is less sensitive to high frequency (> 0.5 Hz) steering inputs. The trailer was able to accomplish the lane change under all conditions. Even after several deliberate attempts it was not possible to achieve a situation in which there was trailer instability in swerve tests.

5.0 CONCLUDING REMARKS

This paper has attempted to demonstrate the improvement of high speed stability while maintaining low speed manoeuvrability that results from the use of a speed-dependent steering mechanism.

The proposed mechanism, called Safetrail, has proved to be of practical use. The additional costs of the system are low.

Several multi-body simulations had already yielded promising results. The more recent experiments have confirmed the improvement of road holding behaviour. This demonstrates the potential of simulation technology.

The Safetrail system has been granted a patent.

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Figure 1. Artists impression of a road multi-trailer (Rijsenbrij, 1999).



Figure 2. Specifications of a road multi-trailer.



Figure 3. Overview of the test combination.



Figure 4. Safetrail in low speed (left) and high speed (right) positions.



Figure 5. The ISO double lane change manoeuvre.



Figure 6. The ISO double lane change manoeuvre at 70 km / h with Safetrail in the low speed position (The trailers rear end breaks away).



Figure 7. The ISO double lane change manoeuvre at 70 km/h with Safetrail in the high speed position (Safetrail activated).