Container railcar versus container lorry transport - a comparative study

F. R. Haferkorn
Fachhochschule Dortmund / University of Applied Sciences

Abstract

The system advantages of rail transport: minimal rolling resistance, trains of any length with excellent wind shadowing, small motive performance required and energy consumed, high velocity, safety and reliability (just in time) and automated operation may all be derived from the strong connection of steel wheels to steel rails. They make railway transport economically and environmentally acceptable.

We have used our simulation tool AERORAIL and the Dortmund formulae to calculate air resistance of vehicles and trains. This tool was tested with data from simulations, measuring series in wind tunnel and literature and until now proved to be correct. Nevertheless vehicles and systems based on formula calculations have to be tested as scale prototypes and in pilot projects in real reality.

The recently developed container railcar CargoSprinter was compared to container transport on lorries using the interport line between Rotterdam and Kaliningrad as a background. Our economic calculations depend on a system of technical cost indicators: Number of trains/lorries required as a model for staff costs, motive performance installed for depreciation, and motive performance applied for operational costs. Limitations were an overall transport impulse of 1 million tkm/h and a heavy lateral storm adding continuously 80 km/h to the rolling velocity.

Railway trains, especially the streamlined version, showed much more efficiency than lorries. Of course we omitted infrastructure costs for both competitors, trains and lorries. In Germany rail customers are exempt from such costs only during pilot projects.
We think that generally infrastructure costs ought to be raised by the government and the rail network must be opened for everybody with a suitable train fleet. By this way private and neighbouring railway companies will be able to compete and co-operate on the European rail network, supplying an effective and environmentally reasonable network for users.

**Introduction**

Providing sustainable mobility and reducing energy consumption and air pollution in traffic is an important challenge for our society.

Many different solutions to achieve both aims have been discussed. The solutions vary from new technologies e.g. exhaust catalysts in automobiles to political measures e.g. environmental taxes and traffic prohibitions in smog situations.

**The task, 1 million tkm/h between Rotterdam and Kaliningrad**

The line between Rotterdam and Kaliningrad with stops in Bremen, Harburg, Schwerin, Szczecin and Gdynia was chosen because of several reasons:

- The line is plain and not far from the North Sea and Baltic Sea, so we could take as the worst case for all competitors a heavy lateral storm adding another 80 km/h to the rolling speed and preferring vehicles with a good near-streamlined surface.

- Because containers of 40 feet length and 30 t payload had to be shipped, Rotterdam as Europe's biggest container port and Kaliningrad as the last harbour with rail connection in normal gauge seemed to be the best choice.

- Four European countries, the Netherlands, Germany, Poland and Russia, had to co-operate on shipping containers on this line.

An assumption was made about source and destination traffic and the relations between the seven stations, so that the charge between Rotterdam and Schwerin was almost the same and decreased towards Gdynia and Kaliningrad. The data in Figure 1 are calculated for a total of 1 million tkm/h.

**Different time tables all producing about 1 million tkm/h**

To get a basis for further calculations three different time tables were constructed as shown in Figure 2. Originally, they were supposed to allow velocities of 80, 160 and 240 km/h and payloads of 600, 1200 and 1620 t for 32 convoys of 20 lorries, 8 CargoSprinter and 4 AeroSprinter trains. This part of our study will have to be repeated to be adjusted to the assumptions made and results achieved in the meanwhile.

Nevertheless these timetables seem to be useful examples to demonstrate the strong relationship between velocity, payload and number of vehicles required. We decided to continue the study with the formula

\[ n = \frac{1 \text{e}6 \text{ tkm/h}}{V / mN}, \]

where \( n \) is the number of trains, \( V \) is
velocity and mN is payload.

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charge: 351 353 351 285 214 93 [Containers/24 h]

km: 417 115 123 253 353 226

Figure 1: The task, 1 million tkm/h between Rotterdam and Kaliningrad
Figure 2: Different Time Tables all producing about 1 million tkm/h

**Lorry, freight trains, CargoSprinter, AeroSprinter**

Figure 3 shows the five competitors: Lorry, the two different freight trains FT and FTE, CargoSprinter and AeroSprinter.

To be as fair as possible to the main competitor lorry, all competitors were loaded with 40 ft sea containers. Two 20 ft containers would be too heavy and two C782 containers would be too long for one lorry, whereas one 20 ft or one
C782 would be too light.

The CargoSprinter is a recently developed container diesel railcar which is able to carry all types of containers at a maximum velocity of 120 km/h. As compared to ordinary freight trains, it is well powered with more than 8 MW per train. So it fits well into the schedules of passenger trains.

To have a container train that suits even the schedules of express passenger trains we imagined a streamlined AeroSprinter with 25 m long understructures on 6 axles, all of the same design, all driven by two Diesel motors and allowing for 2 containers 40 ft, 4 containers 20 ft and 3 containers C782.

The freight trains have been redesigned on the basis of CargoSprinter to test the effects of weak performance, reduced payload and wide gaps respectively of empty containers to fill the gaps.

![Diagram of competitors]

Figure 3: The Competitors Lorry, Freight Trains, CargoSprinter, AeroSprinter

The profile area of them all is about 10 m², the length of a lorry is 18 m whereas all trains are about 750 m long. While lorry, Cargo- and AeroSprinter are fully loaded with 1, 40 and 54 containers respectively, the freight trains are loaded with 16 containers only, FT has wide gaps whereas FTE closed the gaps with empty containers. Payload is calculated to 30 t per container, and the gaps
according to 12 m per container. The gross mass of lorry is assumed to 40 t, the freight trains’ to 1280 and 1300 t, and the Cargo- and AeroSprinters’ to 2000 t.

Motive performances $P$ vary strongly: 0.265 MW for lorry, 2.65 MW for the freight trains, 8.5 MW for CargoSprinter, 15.9 MW for AeroSprinter. Air and rolling resistances, maximum velocity according to performance and resistances and the cost indicator $iC$ will be discussed in the following chapters.

Air and rolling resistances assumed for the competitors

Figure 4 shows the Rolling Resistances of radial tyres for lorry as taken out of literature [3] and of steel wheels on steel rails [1]. Besides limited payload rolling resistance is a lorry’s worst handicap which will be shown in this study. Compared to a lorry the rolling resistance of trains is about one tenth and might be neglected.

![Air Resistance and Vehicle Length](image)

![Rolling Resistance and Velocity](image)

Figure 4: Air and Rolling Resistances assumed for the Competitors
Figure 4 also shows the air resistance $c_w$ for CargoSprinters of different length and both for calm air and lateral storm as calculated with our prototyping kit AeroRail [2]. The values for a well shaped lorry are taken from literature [3], and the ones for freight trains and AeroSprinter are estimations.

**Performance, number of vehicles and velocity**

As an input to the calculation of the Cost Indicator $iC$ which is described in the following chapter and for a proper time table we have to find out the maximum velocity.

As the line Rotterdam to Kaliningrad is traced horizontally without any hills, the only resistances to speed and performance are rolling and air resistances. The rolling resistance force $F_R$ is calculated according to the formula

$$F_R = f_R m g,$$

where $f_R$ is the dimensionless rolling resistance of Figure 4, $m$ is the vehicle gross mass in [kg] and $g$ is the gravitation constant.
The air resistance force \( F_w \) is calculated according to the formula

\[
F_w = c_w A \rho / 2 v^2
\]

with the dimensionless air resistance \( c_w \) of Figure 4, the profile area \( A \) of vehicles (about 10 m\(^2\)), the air density \( \rho \) (about 1.3) and the air velocity \( v \) in m/s. As we assume a heavy lateral storm, the driving velocity has to be increased by 80 km/h.

Both forces, \( F_R \) and \( F_w \), are added to withstand acceleration. They may be multiplied by velocity \( v \) [m/s] so blind performance \( P_x = P_R + P_w \) works against performance \( P \) until at maximum velocity \( V \), \( P_x \) and \( P \) become equal as shown in Figure 5.

With this velocity and payload the number of vehicles is calculated as required for 1 million t km/h: \( n = 1e6 / V h n N \). The results are plotted in Figure 5, too.

**The result, payload, velocity and cost indicator \( iC \)**

To be able to compare the competitors we prepared the same task for all competitors, to transport an impulse of 1 million t km/h in 40 ft sea containers each with a payload of 30 t in a lateral storm adding 80 km/h to the velocity of vehicles. To achieve the task the competitors required a number \( n \) of vehicles or trains and a total performance \( nP \). At maximum velocity \( V \) the required performance \( nP_x \) equals the installed performance \( nP \).

For personnel costs, operational costs and depreciation for one competitor we assumed \( n, nP_x \) and \( nP \). We assumed that for lorries 40 % of the transportation costs were for personnel, 40 % for operation and 20 % for depreciation. With \( n, nP_x \) and \( nP \) required for lorry transport we calculated three factors to multiply the technical values of all competitors so that lorry transport got 100 %, freight train FT 58 %, freight train FTE 40 %, CargoSprinter 28 % and AeroSprinter 18 %. These percentages we called the Cost Indicator \( iC \).

In Figure 6 Cost Indicators of the competitors are plotted against payload and against velocity for detailed discussion. It seems that transportation costs are not only a function of payload and velocity. Comparing the freight trains FT and FTE there may be an influence of surface shape as well. And comparing lorry to the trains the rolling resistance of rubber tyres on asphalt seems to be a handicap.

**Conclusions**

The question arises why in real life lorries have an advantage to trains. One part of the answer is that CargoSprinter and AeroSprinter with excellent results in our model are not yet part of the business, CargoSprinter is still in the test phase and AeroSprinter only exists in this paper. Shipping empty containers to improve train surface and cost indicator as does FTE is not yet usual practise on railways. So freight train FT with an \( iC \) of 58 % is the only really existing competitor to the lorry. The difference to 100 % may be declared by the amount of infrastruc-
Figure 6: The Result, Cost Indicator $iC$ as a Function of Payload and Velocity

tural costs that always have been spent by the railways and always have been paid by governments for lorries, ships and aeroplanes.

But let us be optimistic: the competitors lorry and railways might start to co-operate in alliances and to learn from each other. Railways e.g. might learn how to speed up trains and rising payload by filling the gaps not only with empty con-
tainers but rather with additional cargo canvassed by a very flexible pricing and information system. And railways should speed up operation using the fast and flexible railcar trains CargoSprinter and AeroSprinter.

References


