DIOMIS

Developing Infrastructure and Operating Models for Intermodal Shift

Assessing new technologies in the wagon field (Workpackage A10)

KombiConsult
beraten planen umsetzen

K+P Transport Consultants
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Contents

1 Objectives and methodology

In its 2001 White Paper, the European Commission mentions a 38% rise in the European domestic freight market (all transport modes included) over the next ten years. It predicts a rail freight market share of 15% in the year 2020 and therefore expects the rail mode to play a significant part in the modal shift needed to sustain the mobility, the environment and the competitiveness of the European economy.

This premise led the Combined Transport Group of the UIC, in partnership with the UIRR, to commission a study on the infrastructure capacity reserves of the European rail network. The outcome of the Capacity Study, published in May 2004, highlighted that, in the current context of infrastructure saturation, in order to realise the modal shift towards rail, several measures need to be taken. These measures range from investments in rail and terminal infrastructure, technical-operational improvements, to the fostering of the working procedures of all the stakeholders in combined transport rail-road. The Capacity Study also showed that individual “best practices” to deal with limited resources or to provide a qualitative and more efficient service exist, but that they are not sufficiently known to and anticipated by other stakeholders at European level.

With the DIOMIS (Developing Infrastructure use and Operating Models for Intermodal Shift) project, the UIC therefore investigates how more efficient management, operating and working procedures may contribute towards:

- relief of the rail network constraints,
- relief of intermodal terminals,
- modal shift in favour of rail transport.

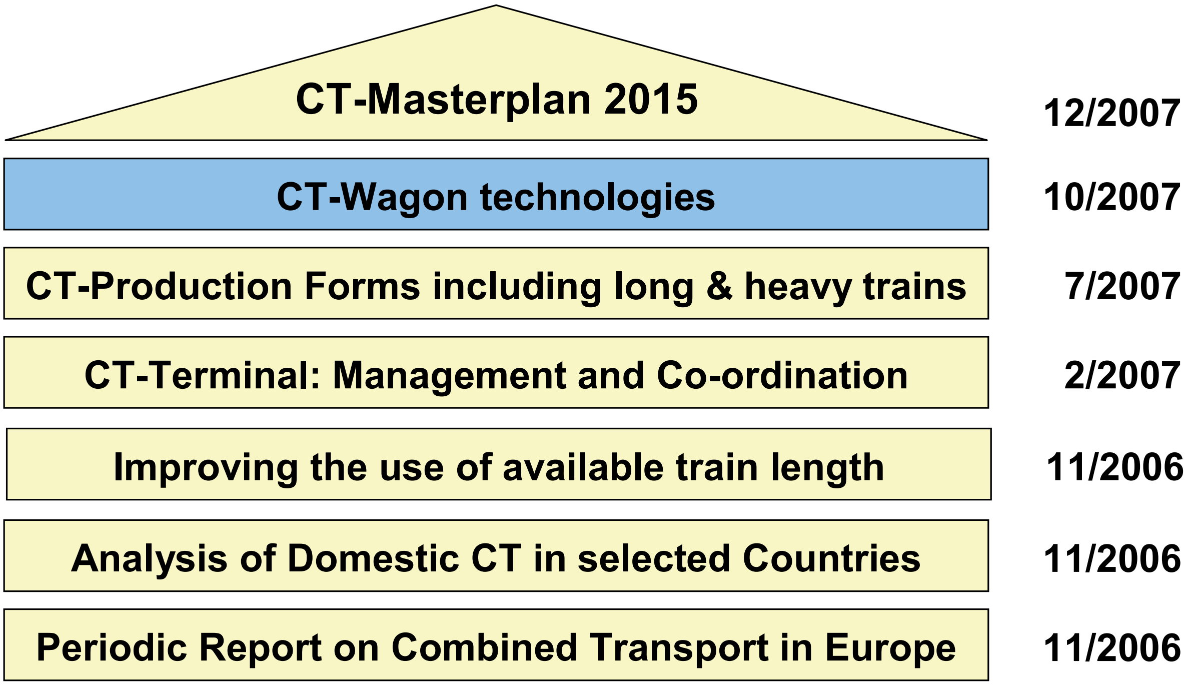
The rail industry has Combined Transport (CT) wagons and technologies on offer, which have not yet been properly referenced in terms of their technical potential or limitations with respect to the above-mentioned objectives. It is therefore required to perform:

- An inventory of existing wagons together with an analysis of the key features of each type of wagon,

- An evaluation of the impact of the wagon-infrastructure-interaction on the relief of infrastructure capacity limitations on the efficiency of CT in general, and
- To conclude requirements for further developments on wagon technologies.

The works have been conducted by KombiConsult GmbH, Frankfurt am Main, between April and October 2007 based on own experience, interviews with stakeholders and an expert workshop organised in Frankfurt am Main on October 19, 2007. The findings of the present study will contribute towards a UIC “Masterplan on combined transport 2015”, which will contain components that enable to improve and promote combined transport in Europe, cf. ***Figure 1-1***. The Master Plan will be completed by the end of 2007.

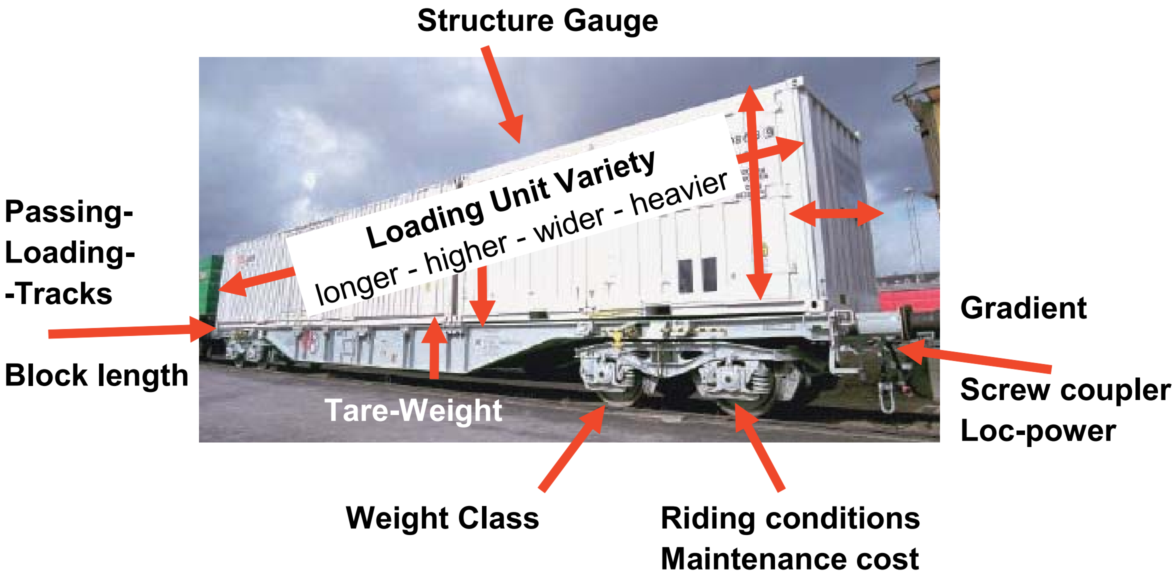
Figure 1-1: Methodology of the DIOMIS-Project to achieve a CT-Masterplan 2015



2 Basic facts

Wagons for CT are an integral element of the Intermodal transport system. Designed to carry certain loading units they have to interact with the railway infrastructure and operating conditions. ***Figure 2-1*** is showing the basic interaction between the wagon and the rail infrastructure.

Figure 2-1: Interaction of infrastructure and wagon



Source: AAE photo and KombiConsult analysis

The elementary influencing factors are:

- Length of loading - / passing tracks / block length
  ➔ total length of trains, e.g. 600-700 m
- Curves' radius
  ➔ bogy pivot pitch (loading length)
- Line gradients (in conjunction with traction power)
  ➔ total weight of trains, e.g. 1,200-1,500 t

- Weight class (superstructure / bridges)
  - ➔ weight per axle, e.g. 22.5 / weight per m, e.g. 8 t/m
- Structure gauge
  - ➔ height / width of loading units -> deck height 0.82 m
- Signalling system / traffic mix
  - ➔ travelling speed, e.g. 100 – 120 (– 140/160 km/h)

2.1 Loading units for Combined Transport (CT)

In general there are three different types of loading units for CT in Europe:

- Sea Containers (ISO-Containers)
- Swap Bodies
- Semi-Trailers

2.1.1 Sea Containers (ISO-Containers)

Sea Containers are available in two common dimensions. The most common kinds of sea containers are 20-foot and 40-foot container. Besides these two very common types of sea containers there are two other less common types (30-foot and 45-foot Ct): Their dimensions are shown in ***Figure 2-2***:

Figure 2-2: Type and dimensions of containers

Type of container	Length	Width	Height	maximum Weigt
20-foot container	6.10 m	2.44 m	2.59 m	24,000 kg
40-foot container	12.19 m	2.44 m	2.59 m	30,480 kg
30-foot container	9.14 m	2.44 m	2.59 m	30,480 kg
45-foot container	13.72 m	2.44 m	2.90 m	30,480 kg

Source: KombiConsult analysis

45-foot containers are mostly designed as high cube containers but they are also available with a height of 2.59 m. Besides the dimensions there are other attributes to distinguish certain types of sea containers. In addition to standard containers there are reefer containers and tank containers.

The 45-foot length is of particular importance in conjunction with pallet-wide loading width.

2.1.2 Swap bodies

Swap bodies are available as A- and C-type swap bodies. A-type swap bodies are 13.67 m long and have a maximum weight of 34,000 kg. C-type swap bodies have a length of 7.15 m, 7.45 m or 7.82 m and a maximum weight of 16,000 kg. The width of swap bodies ranges from 2.50 m to 2.60 m. Their height ranges from 2.45 m to 3.25 m.

2.1.3 Semi-trailers

Semi-trailers have a length of 13.60 m and a maximum weight of 34,500 kg. Their width ranges from 2.50 m to 2.60 m and their height ranges from 3.30 m to 4.10 m. Specially equipped with gripping edges and codified they could be transported in CT.

2.1.4 Other Types of loading units for CT

Besides the above-mentioned loading units there many different types, mostly designed for certain transport purposes and used on a certain lines, for example special containers for waste. There also have been several attempts to establish completely new systems like the ACTS container system that requires special wagons and lorries. However, none of these systems have reached a noteworthy market share at European level and therefore will not considered in this report, which is focusing on a European wide network of unaccompanied CT.

2.2 Wagon types

Wagons for CT can be classified in two major categories:

- Standard Wagons
- Special Wagons

2.2.1 Standard wagons

Standard wagons are able to carry all standard sea containers and swap bodies that do not exceed a certain height. They are not suitable for high cube loading units. Standard wagons are available in different lengths as presented in ***Figure 2-3***.

Figure 2-3: Types and dimensions of standard wagon

Length of wagon	Axles	empty weight	maximum payload
40-foot wagon	2	≈ 11,000 kg	≈ 34,000 kg
60-foot wagon	4	≈ 20,000 kg	≈ 70,000 kg
90-foot wagon	6	≈ 29,000 kg	≈ 106,000 kg
104-foot wagon	6	≈ 30,000 kg	≈ 105,000 kg

Source: KombiConsult analysis

Besides these four very common wagon types there have been several tests with wagons of other lengths, such as 2-axle wagons with lengths of 48 and 52 foot as well as 4-axle wagons with lengths of 40, 52 and 80 foot but none of these wagons were produced in great quantities. There also has been a wagon prototype with variable length, which has not been accepted by the market either. Some of the 2-axle wagons are fitted with impact absorbing devices that enable these wagons to be shunted (gravity shunting) while loaded. As wagons for CT are shunted quite rarely these wagons will not be renewed.

2.2.2 Special wagons

Besides the above described standard wagons there are special wagons for CT, in particular low floor wagons for high cube loading units and pocket wagons for semi-trailers.

Low floor wagons are available as 2-axle or 4-axle wagons. Often there are units with two wagons with tight coupling. The maximum loading length of a low floor wagon is 52 feet.

Pocket wagons for semi-trailers are available as 4-axle wagons for one semi-trailer and a maximum loading length of 52 feet and 6-axle wagons for two semi-trailers with a maximum loading length of 104 feet. There are also 6-axle wagons with only one pocket for a semi-trailer. These wagons are designed to carry one semi-trailer and one A-type or two C-type swap bodies (“mixed articulated wagon”).

Besides pocket wagons there are two other technologies for transport of semi-trailers by rail:

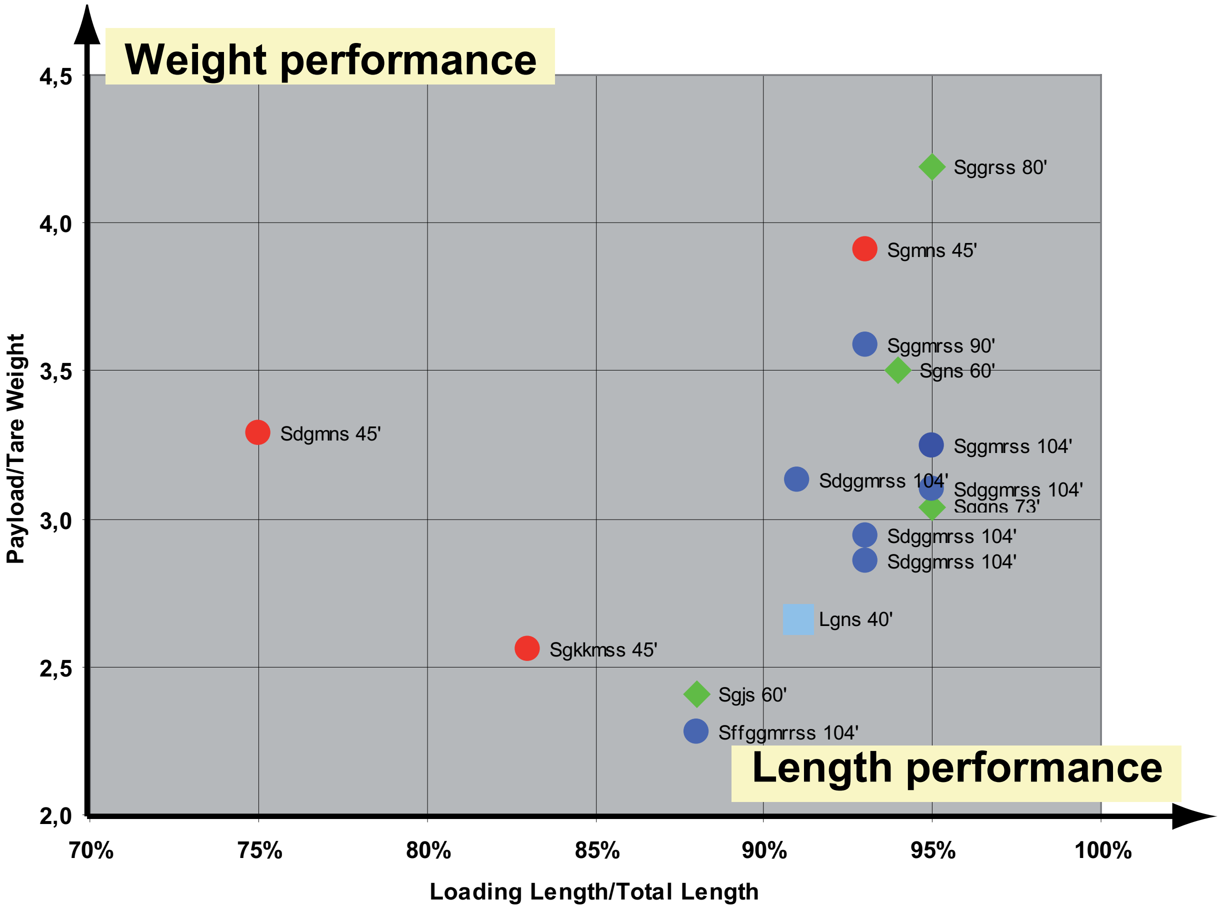
- the Modalohr-system
- trailer trains

The Modalohr-system uses special types of 6-axle wagons that enable truck drivers to drive a semi trailer on the train horizontally. Trailer trains do not need a wagon, because bogies on each end support the semi-trailers. Two semi-trailers are supported by one bogie. Thus the semi-trailers form the train without any wagon need. While the Modalohr-system is in use on dedicated lines to/from France, the trailer train experience has been stopped in Europe.

Figure 2-4 is showing the technical capabilities of different standard CT-wagon in a diagram crossing the weight performance calculated as payload/tare weight and the length performance calculated as loading length / total length.

It can be seen that optimisation in both directions is possible by wagon design, and that wagon such as the Sggrss 80' or Sgns 45' have best technical capabilities in term of weight and length.

Figure 2-4: Technical capability of different CT-wagon



Source: KombiConsult analysis

3 Aspects of efficiency of Combined Transport

There are many factors that affect the efficiency of CT. Among these are four major aspects that have significant influence on the efficiency of CT in respect to the wagon:

- Utilisation of train length
- Utilisation of wagon weight and total train weight
- Train speed and rolling stock circulation
- Handling of wagons in terminals

3.1 Utilisation of train length

The more loading units can be carried on a CT-train, the less are the costs of the transport of a single loading unit. Therefore wagons for CT shall provide a maximum number of carrying positions for loading units for a given train length. Unfortunately there is a broad variety in the length of loading units as shown above. Thus it is only possible to make best use of the train length if the percentage of each type of loading unit is known in advance. The tables below show the utilisation of train length for certain combinations of wagon types and loading unit types. The numbers are given for a wagon train of 600 m.

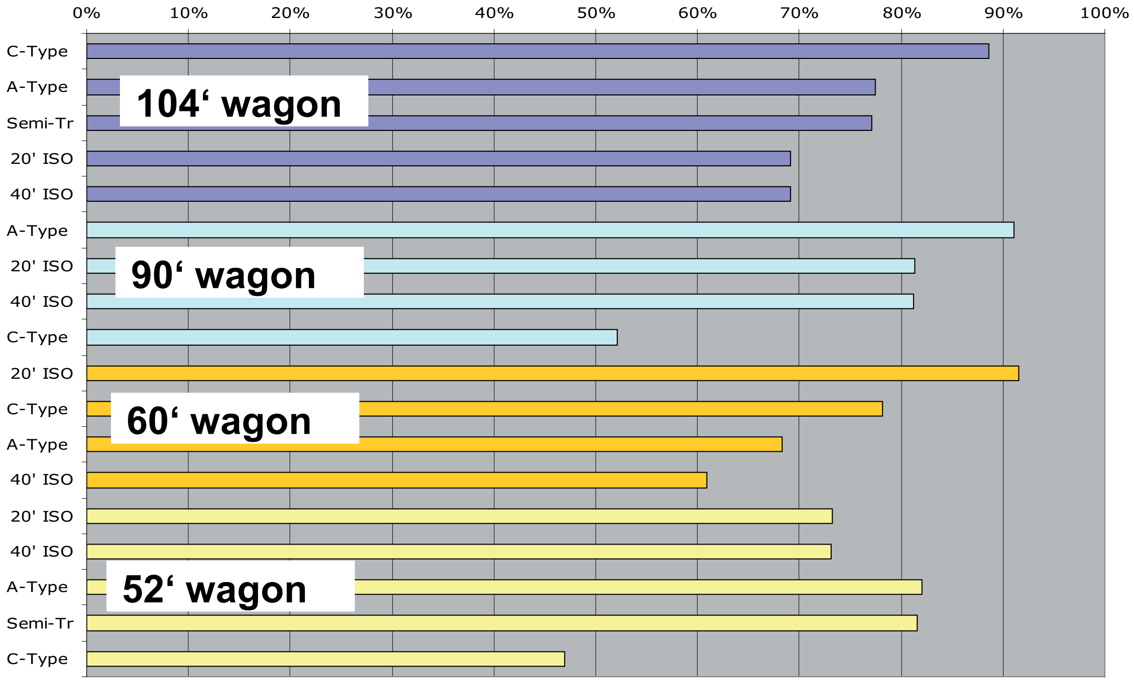
Figure 3-1: Number of loading units on a train depending on wagon type

		loading units on train			
		container		swap body	
Wagon type	wagons in train	20-foot	40-foot	C-Type	A-Type
40-foot wagon	42	84	42	42	0
52-foot wagon	34	68	34	68	34
60-foot wagon	30	90	30	60	30
80-foot wagon	22	88	44	44	0
90-foot wagon	20	80	40	40	40
104-foot wagon	17	68	34	68	34

Source: KombiConsult analysis

This table shows that the utilisation of train length is dependent on the combination of loading unit type and wagon type. If there is a mix of several loading unit types to be carried on one train, it is even more difficult to optimise the utilisation of train length.

Figure 3-2: Utilisation of maximum train length by different types of wagon and loading units



Calculation based on 600 m wagon train length

Source: KombiConsult analysis

For the transport of sea containers a mix of 60-foot-wagons and 90-foot-wagons has proved to be the best compromise, as there are more 40- and 45-foot-containers than 20-foot-containers to be transported. For inland CT-trains wagons with a loading length of 16 m or 2 X 16 m are most suitable. As the number of semi-trailers in CT-trains is growing, there is a growing demand for pocket wagons.

Besides the uncertainty of the mixture of loading units there are operational aspects that make it difficult to optimise the utilisation of train length. Is a certain wagon set optimised for a certain relation, it is possible that this train set is exchanged for another train set in a terminal that is optimised for another relation. Therefore wagon sets are often not optimised for a single relation but for several ones, which increases operational flexibility generally, but reduces the utilisation of the train length in particular case.

Wagons with variable length are interesting in theory but cause a number of problems during operation (shunting loco available during loading operations) so that this feature, although prototyped, has not become accepted in practice yet.

Longer fixed wagon sets with draw bar coupling are able to improve the ratio of loading length to total wagon length, but they are too inflexible in operation as every wagon has to be detached 2 or 3 times a year for technical reason. The longer fixed wagon sets are, the more wagon capacity has to be detached in a case of a malfunction.

3.2 Utilisation of wagon weight and total train weight

In ***Figure 2-3*** it has been shown, how much payload every type of wagon can carry. As also shown above certain combinations of wagon type and loading unit type are needed to optimise the utilisation of the train length. For example the combination of 20-foot containers carried on 60-foot wagons lead to the best utilisation of the train length. Unfortunately 60-foot wagons have a maximum payload of 70,000 kg whereas 20-foot containers have a maximum weight of 24,000 kg. Therefore a 60-foot wagon can only carry two 20-foot containers of maximum weight. As a result 80- or 90-foot wagons (with 6 axles) provide a better utilisation of train capacity for such heavy containers.

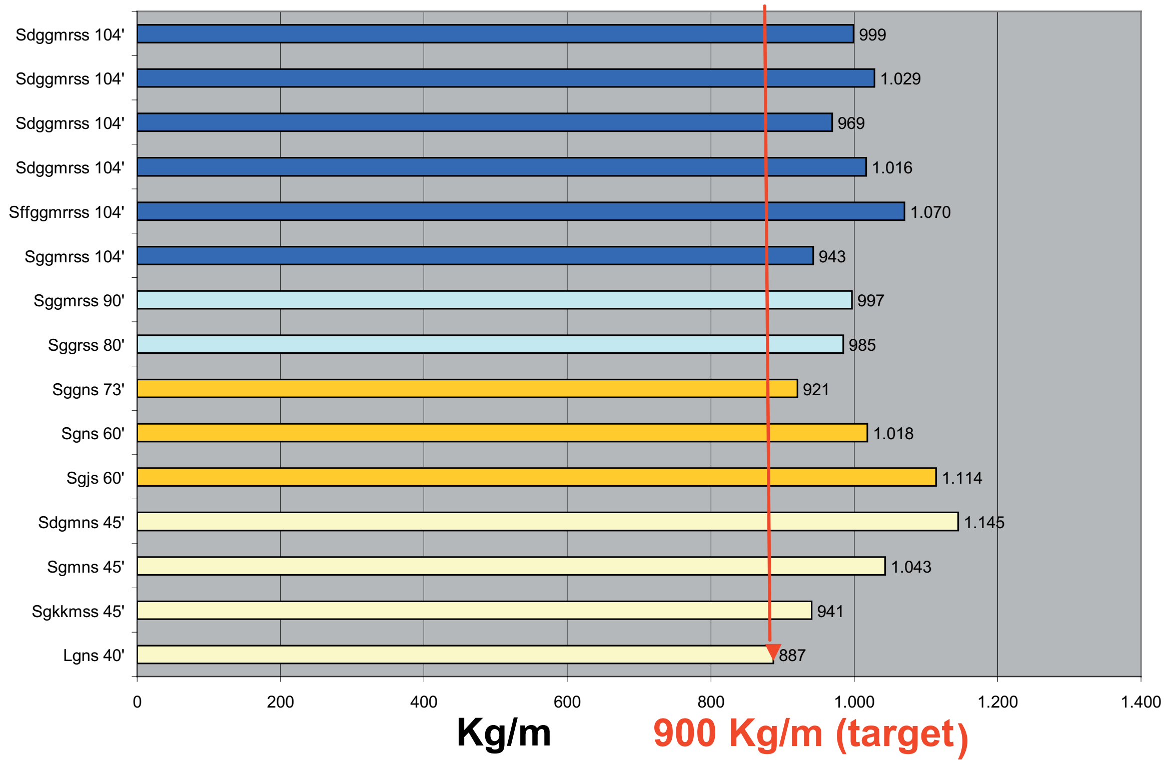
A 40-foot-2axle wagon cannot carry two 20-foot container of maximum weight as well as its payload is limited to 34,000 kg. This explains why 6-axle wagons become more and more popular as they do not cause a limitation to the weight of the loading units. This seems to compensate the disadvantage in utilisation of train length. Maybe efforts should be made to reduce the empty weight of 60-foot wagons to increase their payload and thus resolve the limitation they imply for the maximum weight of the loading units. The CT wagon JMR CTW 2004 of Josef Meyer AG, Rheinfelden, is such a design.

80-foot wagons would provide the best compromise between the utilisation of train length and the utilisation of wagon weight for the transport of standard sea containers. Another advantage in comparison to 60-foot wagons would be that the 80-foot ones do not cause any problems in terms of efficiency if the number of 40-foot containers to be carried exceeds the number of 20-foot containers in a train as such a combination would cause a loss of efficiency if there were only 60-foot wagons.

The advantages of an 80-foot wagon may be compensated by the disadvantage that these wagons cannot carry any loading unit that is longer than 40 feet. Especially they cannot carry A-type swap bodies and 45-foot containers, which leads to the nowadays most popular 90-foot wagons as the best compromise over all.

Figure 3-3 is showing the weight efficiency of different CT wagon. Operators would demand 900 kg/wagon-m as a design target, but UIC leaflet 571-4 requires 1 ton/wagon-m even for CT-wagon. It should be checked whether this requirement could be reduced for CT wagon.

Figure 3-3: Weight efficiency of different CT wagon (tare weight / wagon-m)



Source: KombiConsult analysis

The next limitation for the efficiency of CT is the **total train weight**. If a CT-train shall run 100 km/h on level tracks, the total train weight shall not exceed 1,500 t. If a CT-train shall run 120 km/h on level tracks, the weight limit is 1,000 t. On the most lines with steep gradients trains with a weight of more than 1,200 t need a second locomotive. On the lines across the Alps trains with a weight of more than 800 t need a second locomotive and trains with more than 1,600 t need a third locomotive for pushing.

In the following table is shown, which maximum train weight leads to which number of loading units (fully loaded) that can be carried.

Figure 3-4: Number of loading units on a train depending on train weight and wagon type

		loading units on train			
		container		swap body	
wagon type	train weight	20-foot	40-foot	C-Type	A-Type
40-foot wagon	800 t	35	19		
	1,000 t	44	24		
	1,200 t	53	28		
	1,600 t	70	38		
60-foot wagon	800 t	26	15		14
	1,000 t	33	19		18
	1,200 t	39	23		22
	1,600 t	53	(31)		29
90-foot wagon	800 t	24	17		16
	1,000 t	32	22		20
	1,200 t	38	26		24
	1,600 t	51	35		32
104-foot wagon	800 t			33	
	1,000 t			42	
	1,200 t			50	
	1,600 t			68	

Source: KombiConsult analysis

For the transport of 20-foot containers on 40-foot wagons the weight of each container is limited to 17 t. For the transport of 40-foot containers on 60-foot wagons the train length of 600 m would be exceeded with a total train weight of 1,600 t. This table shows that mostly the total train weight limits the number of loading units that can be transported in one train more than the train length provided that a second locomotive for one train is not an option except for lines with steep gradients.

The latest 60-foot wagons available have an empty weight of 17,800 kg. With a maximum axle load of 22,500 kg these wagons are able to carry three 20-foot-containers of maximum weight. A further reduction of wagon weight will probably cause a disproportional effort. Much more effect on the ratio of payload to empty weight would have an increase of the maximum axle load to 25,000 kg as modern wagons for CT are already designed for this axle load. This would result in an increase in payload of 14 % compared to an increase in payload of only 3 % by reducing the empty weight of a wagon from 20,000 kg to 17,800 kg.

3.3 Train speed

The train speed can affect the efficiency of CT in many ways: It has a significant impact on the capacity of the rail network, influences on the circulation of rolling stock and/or the time, the trains can spend in the terminals for transhipment.

3.3.1 Rail network capacity

The capacity on a certain railway line is highly dependent on the difference between the maximum speed of the fastest and slowest trains, running on that line. A railway line has the highest capacity if only trains with the same speed and the same intermediate stops are operating on this line. Such a line can have a capacity of up to 30 trains an hour. If a great difference between the maximum speed of the different trains running on a certain line is encountered, the capacity drops significantly down to 6 trains an hour. Especially on lines that are used by freight trains and fast passenger trains with a maximum speed of 160 km/h or more, the lines' capacity can be significantly increased if the maximum speed of the freight trains is raised to 120 km/h. Almost all wagons for CT that are build today, are able to run 120 km/h with payload, but most of the older rolling stock for CT can only be operated with a maximum of 100 km/h if loaded.

The disadvantages of a higher speed of CT trains are a lower axle -, thus payload on the wagons and a reduced maximum train weight for a given locomotive. Therefore there is a conflict between an increase in network capacity and in total train weight. There is no easy solution to that problem, as different companies represent the contrary objectives. Whereas the train operating companies try to maximise the total train weight the infrastructure companies try to increase the networks' capacity without additional investment. Thus the train operating companies will only agree to higher train speeds if there is an additional benefit for them.

The reduction of payload can be avoided by changing the brakes of CT wagons, as the reduction of payload is caused by too little braking effect of the recent brakes on CT wagons. A solution could be provided by disk brakes that deliver more braking effect and thus enable CT wagons to carry the same payload at a speed of 120 km/h as they can carry at 100 km/h. This does not provide a solution for the higher demand on traction effort by faster CT trains, though.

Domestic CT trains in Germany are already operated at a maximum speed of 120 km/h whereas almost all international CT trains are operated at 100 km/h, but raising the maximum speed of CT trains to 120 km/h does only make sense, if the condition of the infrastructure enables CT trains to effectively travel at this speed.

3.3.2 Other implications of train speed

A higher train speed reduces the running time of a train, which can result in either improved time windows for the customers (later HLR, earlier MAD) or a more frequent use with given rolling stock. Whereas an increase in the time for transhipment is only a service aspect for the customers that deliver and pick up the loading units in the terminals, a more frequent service with a given rolling stock makes a significant contribution to the efficiency of CT as the necessary investment or the rental for rolling stock for a certain CT service is reduced considerably.

For a given daily service from a port on the North Sea to South East Europe for example a higher train speed can reduce the number of trainsets that are needed to provide this service. On the other hand a higher train speed can require a second locomotive for every train. Thus it has to be separately calculated for every CT service whether a higher train speed leads to a better efficiency.

In any case wagons for CT shall be able to run 120 km/h with payload to fulfil the preconditions for higher train speeds if these are required by the market and offered by the infrastructure managers. A raise of the train speed above 120 km/h is not reasonable for conventional CT, because this will lead to an increase in wagon weight caused by heavier brakes and thus heavier bogies and in addition to that to a further reduction of the total train weight.

The Interunit Technical Committee, that involves railways and CT operators, has voted for a change of UIC leaflet 571-4, which demands that all wagons for CT must have SS brake capacity so that they could run up to 120 km/h. This would bring a benefit for railways that can definitely exclude that their wagon will run faster, while leasing companies which are looking for a flexible use of their wagon and operators engaged in transport to/from and through Germany and France are seriously considering the 120 km/h option for their wagon.

3.4 Wagon handling in terminals

The interaction of terminal procedures and wagon technology is leading to the following requirements. Terminals shall arrange for “train-long” transhipment tracks in order to accept the complete wagon composition without shunting works. Intermodal operators shall use of (mix of) wagon in shuttle train compositions to avoid both marshalling and change of loading grid for outbound trains, because of similarity of inbound and outbound loading units provides for. Wagons therefore shall be provided with a couple of loading positions in order to increase their universal use / flexibility, even they are more expensive. Daily terminal operations show, that a large variety of wagon with “special features” and thus work instructions should be avoided. In addition the use of standardised spare parts should be facilitated.

Articulated wagon of 90’ or even 104’ risk a loss of 4 loading places when damaged. Wagon sets (fixed wagon) longer than 90’ or 104’ loss even more capacity when damaged, and are in most cases not suitable for conventional workshops (length of travelling platforms) and their maintenance becomes expensive, because they have to be detached

Nowadays wagons are detached in a terminal if technical problems occur. This causes interruptions of transhipment procedures and leads to inefficiency in terminal processes. Relief can be provided by maintenance of the wagons during transhipment without detaching wagons that have a technical failure. Although maintenance costs go up by a small percentage, terminal procedures become more efficient and thus lead to a reduction of costs in total and besides the cost reduction a better service quality of CT can be achieved.

4 Further potential for improvement

There is further potential for improvement on CT-wagons to reduce the costs of the wagons and to enable a more efficient design of the wagons.

There are also aspects that have no direct impact on the efficiency of CT but still can make a contribution either by providing additional services for the customers of CT or by increasing the acceptance of rail freight traffic, especially among the residents along the railway lines.

4.1 Standardisation of wagons

A further standardisation of wagons can reduce the investment cost for CT wagons because a greater series of each part can be produced, but there is a conflict between standardisation and optimisation of the wagons for a certain CT service. A further standardisation of wagons may lead to a loss of efficiency in CT operations.

In addition to that, further standardisation is hampered by the large number of national authorities in Europe that are responsible for homologation of rolling stock and their different requirements on the technical design of wagons. Whether the European Railway Agency (ERA) will be able to harmonise legislation on the technical requirements on rolling stock in Europe on short term is seen quite sceptical.

4.2 Legal requirements on wagon design

In addition the harmonisation of legislation regarding the design of rolling stock in general and the design of wagons for CT in particular it seems to be reasonable to revise all existing legislation in reference to the design of CT wagons, whether there is still a necessity for the existing requirements on the design of CT wagons. Legislation shall be limited to indispensable rules with regard to safety issues to enable the rail industry to develop CT wagons that provide a maximum of efficiency in investment and operation.

4.3 Technology to enhance service to customers

Some railway networks – for traditional reason – do provide only for small loading profiles (gabbarit) and the transport of ordinary containers and swap bodies and in particular high cube boxes caused significant problems or as not possible at all. Manufacturers and operators have therefore invested into a couple of wagon with lower deck heights that are possible to gain some coding points. With wagon types “multifret” or even “megafret” it is possible to transport higher loading units because they are able to partly compensate the shortcoming of the rail infrastructure.

Another segment where development is required is the transport of in particular non-craneable semi-trailers in combined transport where two interesting technologies have recently be presented the re-engineered basket wagon and the ISU-system. Te outcome of the demonstrations is to be evaluated carefully with respect to a wider application.

4.4 Technology to maintain the acceptance of CT: Noise reduction

The reduction of noise caused by rail freight traffic is not an aspect with direct impact on the efficiency of rail freight services. Nevertheless this issue must not be disregarded. There is an increasing political pressure from local authorities and residents along railway lines to reduce the noise caused by rail traffic. Thus it can be expected that there will be legal measures against noise emissions of rail traffic from European legislation as well as from national legislation. Especially a ban on night-time operation for noisy trains can be expected.

Therefore any measures to reduce noise emissions are in the vested interest of the railway sector as they can reduce the political pressure on this issue and may prevent harsh legal measures against the rail industry.

Freight wagons can make a substantial contribution to the reduction of noise emissions cause by rail freight traffic. The use of composition K block in the brakes leads to a significant reduction of noise but also increases abrasion on the wheels. Disk brakes may be a better solution. Although they cause more investment, their operational costs are lower than these of block brakes. There are several field trials ongoing which show different interim results and need to be looked at when completed.

Rubber cushion for bogies can also reduce noise emissions, but requires higher investment. As long as there is no financial compensation for example through a reduction of access charges for trains that are less noisy, such measures have little chance to be realised.

The German Ministry for Transport has currently announced a large scale project that will compare different technologies and pricing schemes for the introduction of lower noise wagon in a pilot application in the Rhein valley.

4.5 Technology to enhance train operations: Electric power supply in CT trains

A very controversial issue is electric power supply in CT trains. Advantages are:

- EP-brakes can be used, which leads to a reduction of abrasion of brake blocks.
- Reefer containers can be provided with electric power and do not need to have their own – noisy and expansive Diesel aggregates - power supply.
- Diagnostic systems can be attached to the wagons that enable tailored maintenance.
- Tracking and Tracing devices and devices to detect train integrity can be attached to the wagons.

The disadvantages are:

- Electric power supply in CT trains causes a significant raise in investment for CT wagons.
- Electric power supply in CT trains causes a significant raise in maintenance effort for CT wagons an probably a reduction in the disposability of the wagons.

In addition to the disadvantages, major problems linked with electric power supply in CT trains are yet unsolved. There is either an additional device on every locomotive needed to provide electric power in a usable form for CT trains or the power is supplied by train line, which would require a converter on every wagon to provide the needed form of electric power.

In addition to that, electric power supply for CT trains would cause a significant loss of traction power if diesel locomotives were used to pull the train.

However, research and development efforts are needed to demonstrate the positive impact of these features on the attractiveness of CT transport for additional market segments (reefer units on longer distances) and the operational benefits for the railways and operators.

5 Conclusions and recommendations

A significant reduction of the empty weight of CT wagons in comparison to the latest designs available on the market cannot be expected. Much more impact on the empty weight / payload ratio would have an increase of the maximum axle load from 22.5 to 25 t as almost all newer CT wagons are already designed for a maximum axle load of 25 t according to manufacturers' information. In reference to the utilisation of train length CT wagons will always be a compromise. Further optimisation in this field is hampered by operational needs regarding the flexibility of the use of rolling stock for different CT-services, maritime – continental, and use for different loading unit types. The optimisation will therefore take into account the average structure of loading units per traffic relation:

- Short single wagon for heavy tank swap bodies
- 60' and 80' wagon for maritime traffic (80' = 4x20')
- 104' and 90' wagon for continental traffic (90' = 2 x 45')
- Articulated wagon having a good length and weight balance
- Pocket wagon for the growing demand of semi-trailers

Rolling stock for CT should be able to be operated with 120 km/h with payload. A significant effect on the efficiency of CT can be expected from a raise of operating speed from 100 km/h to 120 km/h if the infrastructure condition allows operating at the higher speed without interruptions, though. A raise of the operating speed of CT trains above 120 km/h does not provide positive contribution to the efficiency of CT, because the payload is reduced significantly and traction becomes quire expansive.

Disk brakes have some positives effects on CT services. First, they allow an increase of payload for wagons operated with 120 km/h. Second, they lead to a reduction in noise emissions and third they reduce operational costs. On the other hand they require higher investment.

Maintenance of wagons during transhipment without detaching can make a significant contribution to the efficiency of terminal processes and thus lead to more efficiency and a higher quality of CT services. A good experience is reported by BTS-Kombiwaggon, ERS and RCA.

Finally existing legislation regarding the design of rolling stock for CT should be revised and limited to indispensable rules in reference to safety issues to enable a more efficient design of CT wagons.

List of figures

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