FERRMED
Wagon Concept Study

May 2010

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Content

Preface

Rail freight traffic in Europe has in recent years in many countries seen a remarkable renaissance, ending a downward trend, which had characterized the sector for many decades. Starting around the beginning of the millennium, freight traffic on rail not only increased in absolute terms, but in several big European countries even grew faster than other transport modes, meaning that rail could gain market share.

The current economic crisis certainly has hit the railways hard, but the medium- and long-term perspective remains very positive for the railways. Taking into account quality and cost improvements on the rail side together with rail's high energy efficiency and it's ability to achieve high economies of scale in a time of rising energy and labor costs, and last but not least even rail's outstanding environmental performance are laying the ground for rail to play an important and increasing role on the future transport market.

However, in order to fully exploit the market potential of the railways and to cope with rising demand it is necessary to adapt the European railway system in terms of quality, capacity and efficiency. FERRMED has already presented in 2009 it's Global Study dealing with how to develop a coherent high-standard European rail freight network. The study highlights the importance of improved technical and operational standards on a European scale.

The FERRMED Wagon Study can be seen as a complement to the Global Study and presents conceptual outlines for freight wagons, which make best use of the new infrastructural conditions created by the implementation of the FERRMED Standards for the railway infrastructure.

The FERRMED Wagon Study was carried out on behalf of FERRMED by the Railway Group of the Royal Institute of Technology Stockholm (KTH) in cooperation with the Institute of Technology Berlin (TUB). The authors have participated in many national and international research projects related to the development of rail freight. The project leader is also working as expert advisor in a working group at the Swedish Transport Minister. The authors stand for the content and conclusions in the study.

Stockholm and Berlin, May 2010

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1 Summary

European rail freight has experienced a renaissance during the past decade. In several important countries volumes as well as market share is rising again. However, in order to ensure a continued positive development of rail freight in these countries, as well as in order to spread this positive development to entire Europe, rail freight has to become (even) more competitive.

This can be achieved in three ways:

- By improving economies of scale in the rail freight system, making rail more cost competitive
- By introducing new innovative production methods, making rail more competitive in terms of quality
- By improving the accessibility to the rail system, increasing the rail system's geographical coverage

To do this requires the implementation of a number of measures, both concerning the infrastructure for rail freight as well as rolling stock.

The needs for the development of the railway infrastructure are already addressed in the Global Study, carried out by FERRMED and laying down technical standards for a coherent network of European rail freight corridors.

The other key resource in rail freight is the rolling stock. The freight wagon fleet is an important determinant of both costs as well as quality of rail freight services.

The FERRMED Wagon Concept has to address needs and requirements from a wide range of market actors. The requirements of the transport customers play a key role for the success of a wagon concept. For transport customers both loading capacity, flexibility of wagon use and easy loading and unloading are crucial aspects for their choice of wagon – and in the end their choice of transport solution. In addition to this live-cycle costs as well as initial investment costs of a wagon have to be low.

The concrete requirements vary between different market segments. Differences concern consignment size, goods value, goods characteristics – especially goods density –, transport speed, and competitive situation. When it comes to intermodal transport, one is confronted with different types and sizes of intermodal loading units, which are not fully compatible with each other in terms of dimensions and handling.

In order to address these – sometimes diverging – requirements a future freight wagon concept should have the following characteristics:

→ Cover both intermodal traffic and conventional traffic (wagonload traffic).

→ Within intermodal traffic cover the transport of containers, swap-bodies and semitrailers

→ Be a modular, platform-based concept, from which specific designs can be derived

→ Allow for multi-purpose wagons to ensure a high utilization of wagons and avoid empty running

→ Allow convertible wagons (however, not necessarily in daily operation), so that they can be adapted to other transport needs when market conditions change

→ Improve economies of scale

→ Allow efficient loading and unloading

→ Optionally be equipped with electric onboard power supply both during transport and when in terminals

→ Ensure a sufficient degree of interoperability with the existing wagon fleet as well as with both existing and new infrastructure.

A survey and analysis of existing state-of-the-art freight wagons have been used as starting point as well as a reference for the development of the FERRMED Wagon Concept. The inventarisation of existing wagon designs focused on intermodal wagons, long wagons, wagons with low floor height and wagons for voluminous cargo.

Based on this analysis, the FERRMED Wagon Concept has been developed, comprising three basic designs:

- Design I: The Long Multi-Purpose Wagon (LMPW)
- Design II: The Heavy Cargo-wagon (HCW)
- Design III: The Trailer-on-Flat-Wagon (TOFW)

Design I and II are very similar to each other, the main difference being the length of the wagon. While the LMPW is longer than today's wagons for intermodal traffic and is mainly addressing the market for rather light- and medium density commodities, the HCW is addressing the market for bulk- and other high-density commodities.

The TOFW is addressing the market for semi-trailer transport. Earlier studies (e.g. DIOMIS) have already shown that it is difficult to develop a joint wagon design optimally adapted to both containers/swap-bodies *and* semitrailers. Today's semitrailer-wagons are certainly able to carry containers and swap-bodies as well (but not vice versa), but different wagon designs achieve good efficiency factors in terms of length-utilization and payload/deadweight-ratio only for either containers/swap-bodies or semitrailers, not both at the same time. The main feature of the TOFW is a lower floor height. The TOFW-design requires on selected routes a slightly a slightly increased loading gauge compared to the existing FERRMED standards. Such a loading gauge is already implemented on part of the rail network in Sweden and should be achievable even on other selected routes.

A careful analysis has been carried out of the FERRMED Wagon Concepts Long Multi-Purpose Container Wagon. This wagon is most different from existing wagon designs and can be seen as the FERRMED Wagon Concepts main contribution to the development of the future European freight wagon fleet. It gives also the highest market coverage in terms of types of loading units and goods which can be carried on (or in) it.

The result shows that the FERRMED LMPW-wagon performs better in terms of loading factor, train weight and length than existing wagons designs (60’-wagon, 45’-wagon, 104’-wagon) for a representative European intermodal train. The LMPW is specially advantageous in maritime hinterland traffic and continental traffic with either only class C swap bodies or a mix of class C and A swap bodies.

In addition to this the FERRMED Wagon Concept also features a number of optional improvements as

- automatic or semi-automatic central couplers for longer trains and more efficient train operations
- optional intelligent wagon equipment for tracking & tracing, wagon supervision, etc.

Thus it can be concluded that the FERRMED Wagon Concept can be expected to contribute to more competitive and attractive rail freight in the future, to the benefit of both transport customers and railway undertakings.

2 Introduction

2.1 Background

FERRMED has outlined a Trans-European Great Axis rail freight network. In the future more Great Axis may be defined in order to create a comprehensive FERRMED rail freight network covering the whole of Europe with gateways even to the Trans-Siberian and Trans-Asian landbridges.

Aiming to cover all European Union countries, FERRMED Standards have been defined addressing issues like loading gauge, axle-loads, meter-weight and train lengths. The goal is to considerably improve the conditions for international customer-oriented, competitive and profitable rail freight services across Europe.

In order to fully exploit the new prospects for rail freight offered by the FERRMED Standards, it is also necessary to deploy rolling stock and implement train operating methods, which make use of the future, more generous technical standards of the infrastructure.

2.2 Goal

The study aims at developing an outline of a "FERRMED-Wagon Concept", which utilizes the possibilities of the FERRMED Standards. This includes the specification of a basic vehicle design, of vehicle dimensions and of technical equipment. The concept will incorporate state-of-the-art technology and combine a number of solutions, which so far mostly only have been implemented or tested independently of each other, but which have not yet been combined in a joined concept. The FERRMED Standards make it meaningful to merge these solutions into one concept. By doing so the full effects and benefits of the implementation of the FERRMED-Standards can be more widely quantified and illustrated.

2.3 How to improve competitiveness of rail freight?

The FERRMED wagon concept should be seen as a platform concept, from which different wagon types can be derived in order to address different customer requirements. The common denominator is to make use of the FERRMED-Standards. However, compatibility with existing rolling stock has to be ensured as far as possible and interoperability issues have to be analyzed carefully.

There are three fundamental approaches to improve rail freight, and all three are taken into account in the FERRMED Wagon Concept:

1) To improve economies of scale
2) To introduce new traffic production methods
3) To improve the accessibility to the railway system

These general approaches can be broken down into a number o measures:

Economies of scale mean in short to improve productivity, i.e. to reduce costs per output-unit, e.g. per ton-kilometer, wagon-kilometer or train-kilometer. It can be achieved in first hand by increasing the payload per wagon. Depending on the type of cargo the payload has to be measured either in tons or cubic-meters, in certain cases even in number of units. On train level economies of scale can be achieved by increasing the number of wagons per train. Increasing train length is one of the measures, which could be implemented in relatively short term on selected corridors.

Thus, economies of scale can be achieved in the rail freight system by dealing with the following dimensions (no ranking):

- Wagon-size (length, height, width)
- Axle-loads
- Meter-loads
- Tare-weight
- Train-length

Improving the economies of scale improves rail freight’s cost competitiveness.

New *traffic production methods* include the implementation of new innovative train operating principles as (1) Long Trains, (2) Train-Coupling and -Sharing and (3) Liner Trains, but also IT-applications. All these aspects give repercussions on the vehicle design, e.g. in form of requirements on couplers, running gears, brake systems, “intelligent” wagon equipment for tracking and tracing, wagon supervision etc.

Introduction of new production methods improves rail freight’s quality competiveness, giving it the chance to respond to changing market demands and enter into new market segments – or re-enter into lost market segments.

The *accessibility to the railway system* has to be improved both by adequately designed and suitably located access points to the rail network in form of industrial spurs and rail freight terminals – forming the “interfaces” of the railway system – as well as appropriate wagon designs allowing efficient loading and unloading.

Efficient access points and loading and unloading procedures are important since they represent the logistical link to transport customers and other transport modes. Today these interfaces are often still connected with very time-consuming and resource demanding handling of both the goods and the freight wagons. A good vehicle design can help to facilitate the implementation of efficient loading and unloading procedures and improve the accessibility to the railway system.

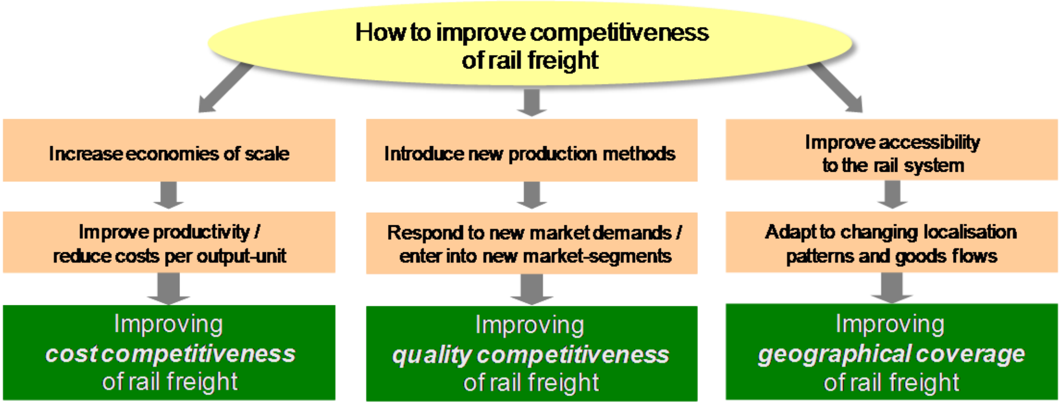


Fig. 2.1: Strategic approaches to improve rail freight's competitiveness (own elaboration).

3 Market requirements on future freight wagons

3.1 Introduction

When developing a freight wagon concept a system perspective should be applied focusing on requirements set by different market actors. The most important market actors in the field of rail freight are on the demand side transport customers and on the supply side railway undertakings. Transport customers, in the sense of users of rail transport services can be shippers (goods owners) as well as forwarding companies, which are organizing transports on behalf of shippers. Intermodal operators are actors on the demand side when it comes to traction services, but organize the wagon supply and define service patterns, e.g. timetables, on their own. Infrastructure managers play a crucial role determining the possibilities of railway undertakings to offer transport services meeting the needs of the transport customers.

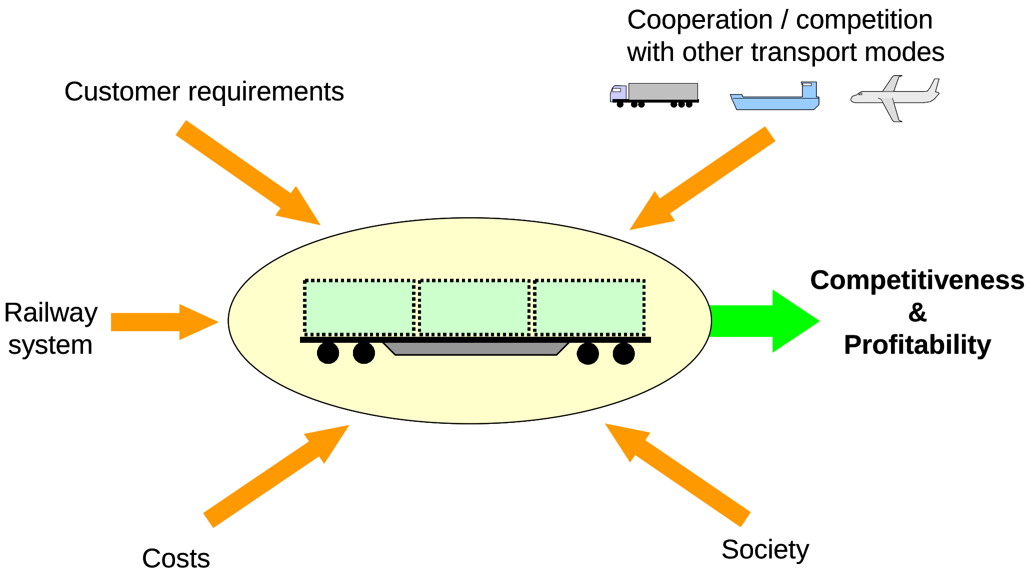
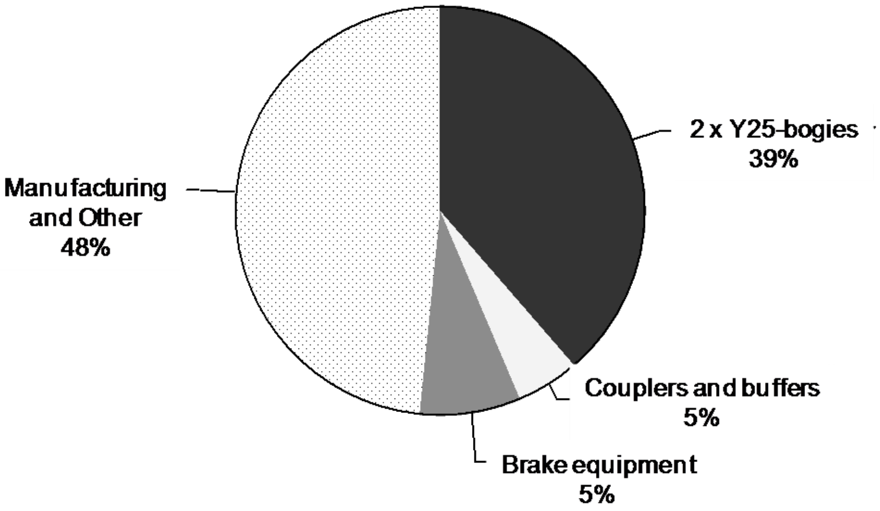


Fig. 3.1: A system perspective for the development of a future freight wagon concept (own elaboration).

In a competitive market – which the deregulated rail freight transport market nowadays is – the transport customer's perspective has always to be the starting point and to be kept in mind when considering changes in the railway system. For this reason it is meaningful to start the analysis of market requirements on a future freight wagon concept with a systematization of the transport customer's requirements (chapter 3.2), followed by requirements from the demand side (chapter 3.3).

In a highly price-sensitive market as the transport market the costs of a freight wagon naturally play a very important role. Rail transport cost analyses carried out by KTH indicate that the wagon costs typically stand for ca. 15-20% of the total transport costs, though variations are big between individual flows; values both below and above this interval can be found. In any case wagon costs are an important cost factor for the railway companies.

The long-term profitability of a freight wagon is determined by its life-cycle costs, however, uncertainty about future transport market development results in customers even requiring low initial investment costs. The figure below shows that running gears (bogies) alone stand typically for more than one third of the total investment cost for a European standard bogie freight wagon. Even here bigger variations can be found, however, running gears represent and important cost factor for freight wagons – an aspect, which certainly has to be considered when developing a new wagon concept.



Source: Modern Railway, sept 1997

Fig. 3.2: Typical cost structure of a European standard bogie freight wagon.

3.2 Transport customer's requirements

The most important requirements that transport customers have are *cost* and *quality*. The *environmental performance* of transport solutions is also becoming increasingly important, in a first phase mainly for transport customers with close contact to end consumers, however, more and more even for transport customers further back in the supply chain.

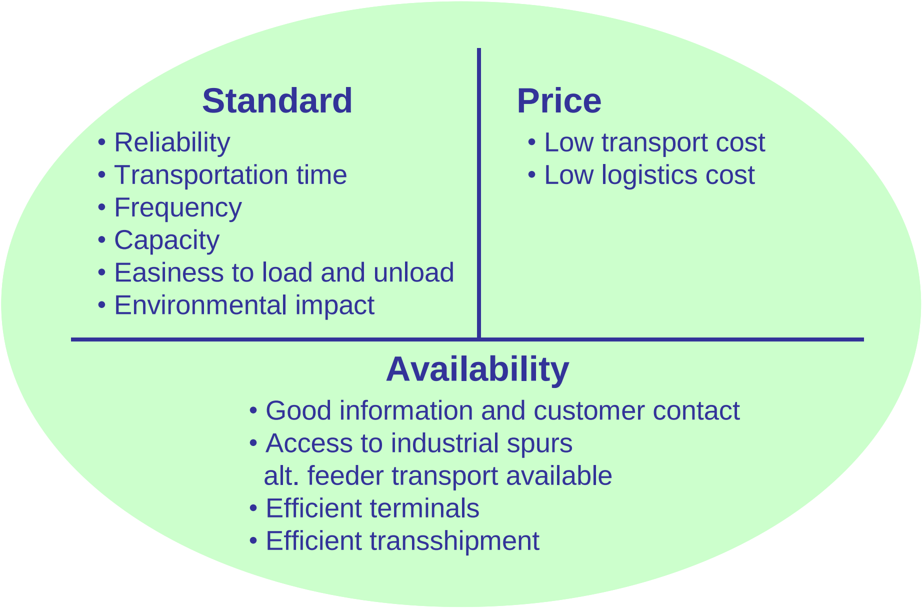


Fig. 3.3: Transport customer requirements

Customer requirements vary widely depending on the market segment. A rough division into market segments can be achieved by breaking down commodities into bulk, basic, product, and service commodities. Typical goods values are in the order of 20€/t for bulk freight, 200€/t for basic commodities, 2.000 €/t for product commodities and 20.000 €/t for service commodities. However, wide variations can be found even within each of the groups.

Somewhat simplified it can be said that rail has its strongest position in the basic commodities market, road transport in the product commodities market, air transport in the service commodities market and maritime transport in the bulk commodities market. This is to some extent reflected in typical transport price levels: 1-1,5 cent/ton-kilometre for bulk commodities, 2-4 cent/ton-kilometre for basic commodities, 6-10 cent/ton-kilometre for product commodities – and 3€/ton-kilometre for service commodities.

Market segment	Typical consignment size	Typical goods value	Typical transport price level	Principal transport mode
Bulk commodities	400 tons	20 €/ton	1-1,5 cent/ton-km	Boat
Basic commodities	40 tons	200 €/ton	2-4 cent/ton-km	Rail
Product commodities	10 tons	2.000 €/ton	6-10 cent/ton-km	Road
Service commodities	10 kg	20.000 €/ton	3 €/ton-km	Air

Fig. 3.4: Characterization of different market segments based on a rough market division (N.B: Typical values, not necessarily exact average values; wide variations occur in each group).

The service commodity market comprises principally mail, parcels and express freight, i.e. freight with an often very high specific goods value. Even certain goods with a low specific value, like foodstuff or newspapers, can be very time-sensitive.

From the above-mentioned it becomes clear that transport customers requirements depend on the nature of the product, which in its turn is heavily determined by at what point in the production process the goods is. However, there are other parameters as well: Different types of industries and their geographical structure may impose special requirements on the transport solutions. Yet another dimension is the size of the transport customer, as well as shipment size, frequency and variability of the flows. All these parameters contribute to often very specific transport requirements when it comes to individual freight flows. They must be put in relation to the characteristics of the transport services that the railways can offer. A lowest common denominator must then be found in the different market segments so that as much as possible of the market is covered by the railways' products. Here the design of freight wagons, especially with regard to their adaptability to different kinds of goods, has strong influence on the level of the lowest common denominator.

The table below shows typical requirements that apply in the different market segments in terms of transport time window, service frequency and price.

The competitiveness of rail or intermodal transport, is also influenced by the loading and unloading process of the freight wagons. Thus, requirements on a wagon do not only arise from the transport itself, but also from the handling at the ends of the transport chain. This is often a crucial aspect, since transport customers are often directly involved in and affected by this process, while the transport itself is in the hands of the railway companies.

In this context it should also be mentioned that there is also an increasing need for power supply of the wagon, partly during transport, e.g. for refrigerated loading units or certain onboard IT-equipment, partly during loading and unloading to operate sliding doors, hatches, etc. There is a need for power supply both for internal applications of the railway undertakings as well as for applications directly affecting the transport customer. While IT-equipment consumes relatively little energy, the power demand for other applications mentioned above is considerably higher, which probably cannot be covered only from batteries. This makes that the question of power supply on the wagon deserves special attention.

Market segment	**Transport time window**	**Frequency**	**Main rail product**	**Main competition /cooperation with**
Bulk commodities	< 24 hours	Regularly	Unit trains	Maritime transport
Basic commodities	National: Day B International: Day C-E	National: Daily International: Daily – several/week	Wagonload	Maritime transport, road transport
Product commodities	National: Overnight (17:00 – 07:00) International: Day B-C	Daily	Intermodal	Road transport
Service commodities	National: Overnight (21:00 – 04:00) or same day International: < 24 hours	Daily – several/day	Postal trains / High speed rail freight / passenger trains	Road transport, air transport

Fig. 3.5: Typical values for transport customer requirements in different market segments and main railway product addressing each segment. (Own elaboration)

3.3 Traffic products for different markets

The freight transport system can be devided into the following main products:

- Unit trains
- Wagonload traffic
- Intermodal traffic
- High-speed freight traffic

The products cover different market segments and differ as regards production systems and vehicle types, resulting in different cost structures and quality characteristics.

Wagonload traffic forms in most European countries still the backbone of rail freight, followed by Unit trains and Intermodal traffic. The latter shows the most dynamic development with the highest growth rates, not least driven by an increasing demand of container transport in port-hinterland traffic as a result of expanding global trade.

The figures below show the share of different products for two European railway companies, Deutsche Bahn in Germany, and Green Cargo in Sweden.

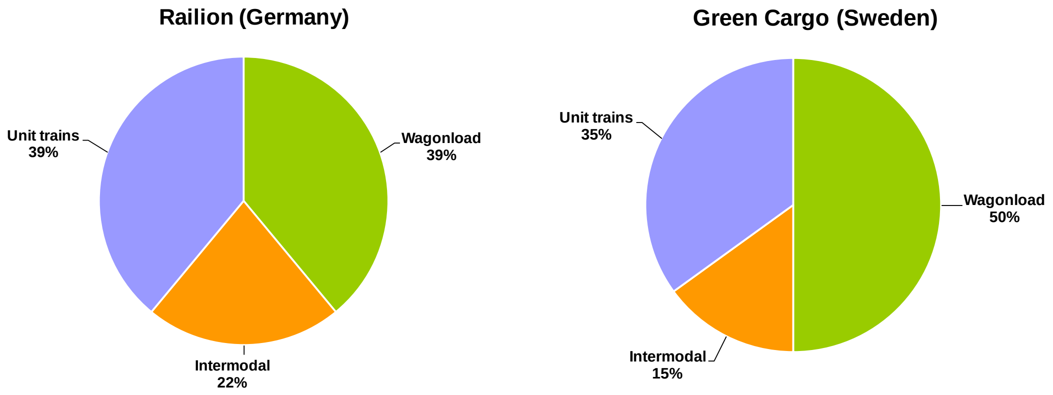


Fig. 3.6: Different rail freight products share of total rail freight ton-kilometers for Deutsche Bahn (Germany) and Green Cargo (Sweden). For Sweden excluding iron ore transport Northern ore line. Sweden ca. 2004, Germany 2006. The figures illustrate the importance of wagonload traffic in the rail freight system of these countries.

3.3.1 Unit trains

Unit trains are operated for single customers and each train is addressing a specific flow – often of bulk or basic commodities. They function as conveyor belts for the industry. One can discern unit trains that operate regularly for long periods of time and form part of well-planned logistic systems and trains operating with short notice for shorter periods of time on the spot market. The first mentioned form an integrated part of customer's logistics systems and the transport solutions, which they form part of, are often optimized to fulfill the transport demand in the best possible way. They are even called program-trains or company-trains. The latter are addressing flows on the spot market, where transport demand is less predictable and less stable over time. Often flows appear for some weeks or months and then disappear again.

In both cases often specialized wagons are used, optimally adapted to the commodity and the transport solution, which they are intended for. This is true especially in the case of program- and company-trains. To address spot flows it is desirable to have wagons, which are able to carry different kinds of commodities, to ensure a flexible and high utilization.

3.3.2 Wagonload traffic

Wagonload traffic forms in most countries in Europe still the backbone of the rail freight system. Principally wagonload traffic addresses the transport needs for raw materials and semi-manufactured goods in single wagons or wagon-groups. These wagons and wagon-groups are consolidated into longer trains in marshalling yards (and deconsolidated again towards the end of the journey). A wagon carrying out a transport is often handled twice in a marshalling yard in national traffic, and even more times in international traffic. The wagons are loaded and unloaded in industrial spurs or at public terminals. Where the consignor and/or consignee has no rail connection of its own, the transportation by rail is combined with feeder transports by road in one or both ends.

The possibility to use wagonload services is highly depending on the accessibility of the railway system via industrial spurs. This form of direct accessibility to the rail transport system often opens the door to very cost-efficient transport solutions. The table below gives an overview over the accessibility of railway network in Sweden for companies with more than 100 employees. As can be seen 72% of the freight customers are close to a railway line and half of them also have access via an industrial spur. They are also the most frequent users of the railway, while customers far from the railway use rail transport only to a very limited extent.

	Proportion of freight customers	Access to railway	Proportion of A using railway	Proportion of A using road
	(A)	(B)	(C)	(D)
Industrial sidings	35%	72% = close to line	43%	92%
Railway local	37%		11%	95%
Railway within 50 km	22%	28% = far to line	7%	96%
Over 50 km to railway	5%		0%	100%
Total	100%	100%	21%	94%

Fig. 3.7: Access to railway and railways' market share (Source: Banverket 1999, Profiling the railway, a survey of companies with more than 100 employees)

3.3.3 Intermodal traffic

Intermodal traffic – or Combined Traffic – is characterized by the use of standardized loading units, which are carried on at least two transport modes (of which one normally is assumed to be rail). Intermodal traffic addresses primarily the product commodity market, however, the use of intermodal loading units has increased considerable during the last decades and nowadays even penetrated other market segments.

The most common types of loading units are (ISO-)containers, swap-bodies and semitrailers. While containers can be transported both by rail, truck and boat, and thus can be used globally, the use of swap-bodies and semitrailers is limited to inland transport (including ferry services). Within each of these groups a wide variety of loading unit sizes exist, the most common – concerning unit length – being 40' and 20' for containers, 7,45-7,82m for swap bodies and 13,6 m for semitrailers. A more detailed overview is given in chapter 3.3. The wide variety of loading units types and sizes presents a key challenge for the design of rail wagons carrying them, since the wagon has to fulfill the – sometimes converging – goals of being able to carry different loading unit types and sizes, while at the same time ensure a high load factor and efficient (length) utilization of the wagon.

3.3.4 High-speed freight traffic

High-speed freight traffic is addressing the service commodity market, comprising mail, parcels and express cargo. Consignment sizes vary typically from the size of a letter to a pallet of some hundred kilograms. As the name indicates this traffic is characterized by high speeds, ranging from c:a 140-160 km/h up to 300 km/h and more. The fastest high-speed freight trains currently in operation are the TGV postal trains with a maximum speed of 270 km/h.

Special rolling stock is required for high-speed rail freight, adapted mainly with regard to running gears and brake equipment. For speeds up to ca. 160-180 km/h – even called semi-high speed rail freight – modified conventional freight wagons can be used. Loading units can still be carried on flat wagons, however require to be locked to the wagon to secure them during transport. For higher speeds rolling stock is normally derived from high-speed passenger trains and goods is carried in enclosed wagons.

In contrast to conventional freight trains high-speed freight trains can use high-speed lines normally reserved for passenger trains. This opens up interesting prospects, taking into account the emerging trans-European high-speed network. However, crucial for the success of high-speed freight transport on rail is the development of interfaces to other transport modes, not least to air transport, and – partly related to this – the development of both cost- and time-efficient loading and unloading techniques.

High-speed rail freight is addressing a – measured in tons or ton-kilometres – quantitatively very small, but due to its high specific revenue potential highly interesting market segment for the railways. However, due to the very specific requirements and technical solutions, which can differ considerably from those for conventional rail freight – not least when it comes to rolling stock – high-speed rail freight is not considered more in detail in this study. This does not exclude, however, that certain parts of the vehicle concepts being presented in this study may be applicable and useful for high-speed rail freight – mot likely especially semi-high speed rail freight – as well.

3.4 The market for intermodal transport

The following table provides an overview of the usage of different loading units in European intermodal traffic.

Combined Transport market segments	**Continental traffic**	**Port-Hinterland traffic**	**Total**
	(swap-bodies, semitrailers, Rollende Landstrasse, containers)	(containers)	
Domestic	2,5 mio. TEU	6,2 mio. TEU	8,7 mio. TEU
International	4,2 mio. TEU	2,3 mio. TEU	6,5 mio. TEU
Total	6,7 mio. TEU	8,5 mio. TEU	15,2 mio. TEU

Fig. 3.8: Overview of usage of different loading units in European Combined Transport in million TEU. (Source: Own elaboration based on UIC Agenda 2015 for Combined Transport in Europe (2008) and UIRR 2007 Statistics (2008)).

Approximately 15 million TEU were transported by rail in Europe in 2007, of which 58% was domestic traffic and 42% international traffic.

29% of domestic traffic consisted of transports in swap bodies (SB), semi-trailers (ST), non-ISO Containers (SB)[1], ISO Containers (C) or was accompanied traffic on Rolling Roads (RR). 71% of domestic traffic was port-hinterland-traffic by ISO containers with a proportion 20'/40'-containers of 25%/75%.

Of international traffic 64% was continental traffic in swap-bodies, semi-trailers, containers or on Rolling Roads; 36% was port-hinterland traffic in ISO-containers.

In other words, of the total traffic of roughly 15 million TEU European-wide 56% was port-hinterland traffic using ISO-containers. For 73% of this traffic the rail-leg was domestic, while 27% passed at least one border.

The other 44% of the 15 million TEU was continental traffic, of which 28% was domestic, while 62% was international.

This yields a distribution of loading units that would look as follows, (measured in TEUs [2]):

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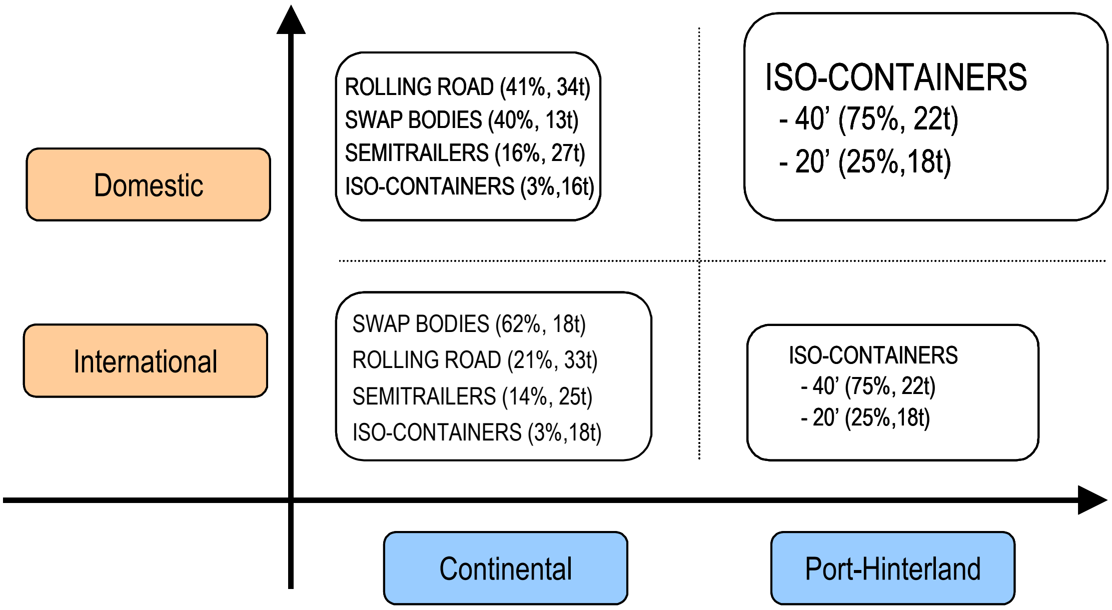
[1] Usually called Swap Bodies too

[2] Do not confuse with percentage of number of carried units. Example: A 75% of total TEUs carried in 40'-containers versus 25% in 20'-containers means a distribution 60/40 between number of units, because a 40'-containers is equivalent to two TEU.



Key (for information given in the boxes):

Type of Loading Unit (percentage of total TEU carried in this type of unit (%), average gross weight of a loaded unit (t))

Fig. 3.9: The European Intermodal market – share of different loading unit types (Source: own elaboration based on UIRR 2007 Statistics, DESTATIS Eisenbahnverkehr 2007, UIC Agenda 2015 for Combined Transport in Europe, BURCKHARDT 2008 The European Swap Body, and internal knowledge)

The usage of different types of loading units varies between different lanes and regions in Europe. Apart from the differences in continental traffic and port-hinterland-traffic, which are indicated in the figures above, semitrailers play an important role especially in regions with many ferry services, like Scandinavia, the Iberian Peninsular and Italy, where they have advantages over swap-bodies when it comes to port handling. In Sweden semitrailers stood in 2008 for 36%, containers for 40% and swap-bodies for 24% of ton-kilometres of all intermodal traffic of the railways. In Central Europe and land-locked countries swap-bodies held a stronger position.

Generally speaking, swap-bodies are a more efficient solution than semi-trailers, when on the train, due to the better payload-tareweight ratio. Therefore, swap-bodies are more common on long distances. In Sweden for example swap-bodies are mostly used between Southern and Northern Sweden, with typical transport distances of 800-1400 kilometres, but very unusual on relations within Southern Sweden with typical distances being in the 300-600 km range.

A severe limitation for intermodal transport of semi-trailers is that the trailers need to be specially adapted for intermodal transport (for handling in terminals by crane or reach-stacker). Today only a very small share – below 5% – of all semi-trailers in Europe is adapted for intermodal traffic, which drastically reduces the market potential for intermodal transport.

The importance of semitrailers in intermodal transport can be attributed mainly to three factors:

1) They are easy to integrate in existing logistical transport solutions; semitrailers offer customers the opportunity to “test” intermodal transport without requiring major changes in their logistics and without need for long-term commitments
2) Intermodal semitrailers do not require any special equipment to be handled at the place of loading and unloading of goods compared to standard trailers. Internal movements at the origin and destination can easily be made by standard trucks.
3) Semitrailers are especially suitable in combination with RoRo-ferry transport, due to easy port-handling.
4) A further reason is that there is an established rental/leasing market for (intermodal) semitrailers, which is not the case when it comes to swap-bodies. This makes that a transport solution based on swap-bodies often requires purchase of the loading-units, resulting in higher initial investments and a rather long-term commitment to intermodal transport.

The semitrailer will even in future be an important “entrance-ticket” to intermodal transport and in some transport solutions even long term be the best solution. However, some factors may do that semitrailers may be replaced by swap-bodies or containers in certain transport solutions:

- When customers start to “trust” in intermodal transport they are probably prepared to rely on intermodal solutions even in a more long-term perspective and will try to optimize their transport solution and be prepared to adapt their logistics. This opens up new opportunities for swap-body- and container-based solutions.
- In certain regions in Europe the creation of new railway infrastructure will result in the replacement of intermodal transport chains involving ferry-transport by all-rail transport from start to destination terminal. In lanes to and from Scandinavia especially the planned fixed link over the Fehmarnbelt has to be mentioned here.

In addition to the above-mentioned intermodal loading units there exist also tailor-made loading-unit types i dedicated transport systems, which do not or only partly comply with general standards.One example are the so-called SECU-boxes, which paper-manufacturer Stora Enso utilizes in a dedicated transport-system between its paper mills in Sweden and Finland and the continental ports in Zeebrugge and Lübeck (see even chapter 5.5.3). These loading units are much wider and higher than standard ISO-containers and only intended to be used in rail and maritime traffic.

3.5 Why wagonload ?

One question often asked is, whether it would be possible – or even desirable – to scrap wagonload traffic in favor for intermodal traffic and unit trains. This has for example been done in Norway and Spain, and there is a trend in this direction in some other countries as well. However, in most European countries wagonload traffic still forms an indispensable part of the rail freight system and in these countries also show a considerably higher market share for rail than the aforementioned countries. Even in North America wagonload traffic has a strong position and is the railways' principal source of revenue.

The fundamental reason for the competitiveness of wagonload traffic is an economical one and directly related to the less restrictive dimensions for wagons compared to intermodal loading units or road vehicles. The dimensions of a container or swap body are determined by the dimensions allowed in road traffic. This means that intermodal loading units do not – an cannot – fully utilize the loading gauge of the railways.

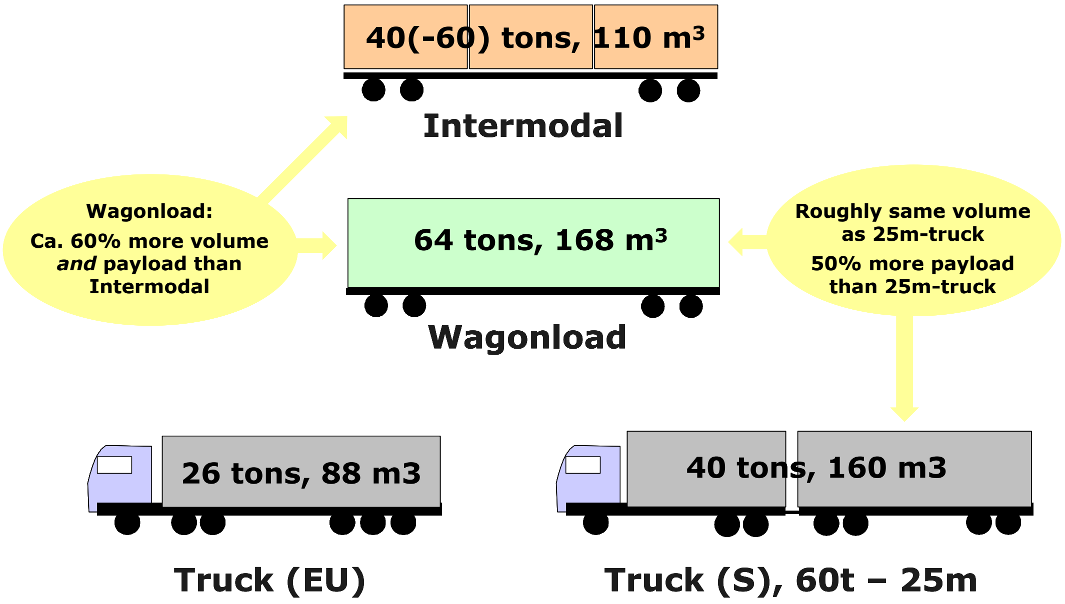


Fig. 3.10: Comparison of a covered bogie freight wagon for wagonload traffic with intermodal transport on a container wagon and a 40 ton-, 18,75 and a 60 ton, 25,25 m-truck respectively (own elaboration).

If cargo is transported in ISO-containers, the maximum loading volume on a standard 60' bogie container wagon is limited to ca. 110 m³ (in three 20'-containers). Theoretically these containers could be loaded with 60 tons of cargo without exceeding the axle-load of the wagon. However, in reality the maximum payload is limited by the weight permitted on a truck and if not each container should be transported separately by one truck each, then the maximum payload of all three containers on the wagon cannot exceed in total ca. 40 tons.

Compared to this a standard four-axle covered bogie wagon of roughly the same length offers a load limit of ca. 64 tons and a load volume of 168 m3, 60% and 52% respectively better than in the case of container transport. Compared to a standard European 18,75m-truck with 40 tons grossweight the load capacity advantage of a four-axle bogie wagon is even bigger. Compared to a Swedish 24 m-truck with a gross weight of 60 tons the advantage is in the same magnitude as compared to the intermodal solution when it comes to weight, while the loading volume is roughly equal. In this comparisons the possibility of increasing the loading gauge and axel-load on the railway has not even been taken into account.

The cost of pre- and posthaulage of intermodal loading units by road from and to the terminal and handling at the terminal are often similar to those for feeder transport by rail and marshalling of the wagon in yards. Intermodal transport is therefore rarely profitable compared to wagonload if a whole wagon can be filled. In this case, and if both the consignor and consignee are connected to the rail network, wagonload traffic is almost always cheaper. However, intermodal transport may be profitable compared to wagonload for small consignments and it represents the only way to make use of rail transport, when the customer does not have direct access to the rail network.

When it comes to freight transport to and from the ports, where the cargo arrives or continues by ship, the competitive situation is somewhat different. In port-hinterland traffic pre- or post-haulage is only necessary in one end of the transport chain. On the ship containers can be stacked in several layers and put beneath each other, which gives a very efficient use of space.

There can also be logistical advantages of intermodal transport over wagonload transport, however, if wagonload traffic would be entirely abolished in Europe, industries' costs would rise dramatically and rails' market share would be reduced. Since an intermodal train carries a much smaller payload than a wagonload train, many more trains would be needed to transport the same volume as is transported in the wagonload system and the ensuing capacity problems in the rail network would be enormous.

Thus, for fundamental economical reasons, it is both desirable and necessary to develop wagonload traffic further. Both intermodal and wagonload traffic (and trainload traffic as well) complete each other and address different parts of the freight transport market. There may occur displacements from one system to the other, however, non of them can be completely replaced by the others. A scenario, which is more likely, is that the delimitations of the systems will become less strict and the systems become more integrated. The FERRMED Wagon Concept presented in this study can be seen as a contribution to this development.

3.6 Conclusions

From chapters 3.2 to 3.5 a number of requirements can be derived for the design of a future freight wagon concept (without ranking):

→ A wagon concept should cover both intermodal traffic and conventional traffic (wagonload traffic).

→ Within intermodal traffic it should address the transport of containers, swap-bodies and semitrailers

→ To cover this relatively wide range of transport tasks it is meaningful to develop a modular, platform-based concept, from which specific designs can be derived

→ Wagon designs should be as far as possible multi-purpose to ensure a high utilization of the wagons and avoid empty running

→ Wagon designs should be as far as possible convertible (however, not necessarily in daily operations), so that they can be adapted to other transport needs when market conditions change

→ The wagon concept should make it possible to improve economies of scale in order to maintain and strengthen rail transports competitiveness on the transport market. This can be achieved by:

- improving the wagons' payload/tareweight-ratio
- increasing the wagons' load limit in tons
- increasing the wagons' load volume in cubic-meters
- enable operations in longer and heavier trains

→ The wagon concept should allow efficient loading and unloading. This can be achieved:

- in wagonload traffic by: loading/unloading of cargo from the side, from above or from the head-end (in wagonload traffic); handling procedures should not vary much from those of trucks
- in intermodal traffic by: flexible loading patterns for different types and sizes of loading units and as far as possible simultaneous handling at several wagons and possibility of selective loading/unloading of individual wagons
- optional automatization of loading/unloading processes

→ The wagon should be able to be equipped with electric onboard power supply both during transport and when in terminals. During transport power should be in the longer term supplied from the locomotive, which requires that all wagons by standard should be equipped with a through cable to be able to deliver energy to wagons further behind in the train consist.

Beside these requirements, the wagon concept must ensure a certain degree of interoperability with the existing wagon fleet as well as with both existing and new infrastructure.

As can be seen, this is a wide range of requirements on a future freight wagon concept and compromises will be unavoidable. It should also be kept in mind, that vehicles (wagons) and infrastructure (railway lines and yards) are highly integrated in the railway system. Thus the highest benefits are often achieved with coordinated measures on both the vehicle and infrastructure side. The implementation of the FERRMED Standards for the infrastructure is thus a big help to achieve the goals for a future wagon concept as well. The development of the FERRMED Wagon Concept should be seen in the light of this integrated system approach.

4 Relevance of FERRMED Infrastructure Standards

4.1 FERRMED Standards and Network

FERRMED has set up standards for Trans-European rail freight corridors defining both a network and a number of key infrastructure parameters (see fig. 4.1 and 4.2). For the development of a wagon concept the following standards are of special relevance:

- Axle load of 22,5 – 25 tons
- UIC GC loading gauge
- Train length 1.500 m
- Train gross weight upp to 5.000 tons
- Reduction of environmental impact of the freight transport system

Fig. 4.1: FERRMED rail network in 2025 (Source: FERRMED Global Study)

- **Reticular and polycentric network** with a great socio-economic and intermodal impact (comprising of three great North-South and three great East-West Trans-European axes, jointly with their corresponding subsidiary main feeder lines).
- In the main branches of the great axes: Electrified **conventional lines** with double track, **giving priority or exclusiveness to common freight traffic** suitable for trains with per axle load of 22,5 – 25 tons.
- **High performance parallel lines** available for exclusive or preferential use of **passenger and light fast moving freight transportation, properly connected with the main airports network**.
- **Width of the tracks: UIC**
- **UIC C loading gauge**
- **Trains length reaching 1.500 meters and from 3.600 to 5.000 tons of loading capacity**
- **The maximum slope of 0, 012** and limitation of the length of the ramps
- **Availability of a network of intermodal polyvalent and flexible terminals with high level of performance and competitiveness, based in the harbors and main logistic nodes of the great axes.**
- **Usable length of sidings and terminals for 1.500 m trains.**
- **Unified management and monitoring systems by main branches of every great axis.**
- **ERTMS system with "two ways working" along the tracks**.
- **Availability of capacity and traffic schedules** for freight transportation "24 hours a day and 7 days a week"
- **Harmonization of the administrative formalities** and the social legislation.
- **Transport system management shared** with several rail operators (free competition)
- **Favorable fees** for the use of infrastructures, bearing in mind the socioeconomic and environmental advantages of the railway.
- **Management philosophy based on the principles of the R+D+4i** in the rail freight network, as an integral part of the global chain of added value.
- **Reduction of the environmental impact of the freight transporting system** (particularly noise, vibration, and CO2 emissions) as a result of the retrofitting of the old railway rolling stock, infrastructural solutions where needed, and an increase in the share of the rail in long distance land transportation of up to 30÷35%.

Fig. 4.2: FERRMED Standards (Source: www.ferrmed.com).

4.2 Interoperability issues

The primary goal of the outline for a FERRMED Wagon Concept, as presented in this study, is to exploit the potential, which the implementation of the FERRMED Standards for the infrastructure offers.

However, a second important goal has been to ensure the concept's interoperability with today's railway system. The interoperability is critical in the following respects:

- between wagons based on the FERRMED Wagon Concept and today's infrastructure
- between wagons based on the FERRMED Wagon Concept and today's rolling stock (wagons as well as locomotives).

It is natural that the benefits of the FERRMED Wagon Concepts are biggest in combination with the the FERRMED Infrastructure Standards (see figure 4.3). However, by ensuring interoperability with both today's infrastructure and today's rolling stock a flexible utilization of the FERRMED wagons is ensured and the implementation of the Wagon Concept (as well as the FERRMED Infrastructure Standards) become easier.

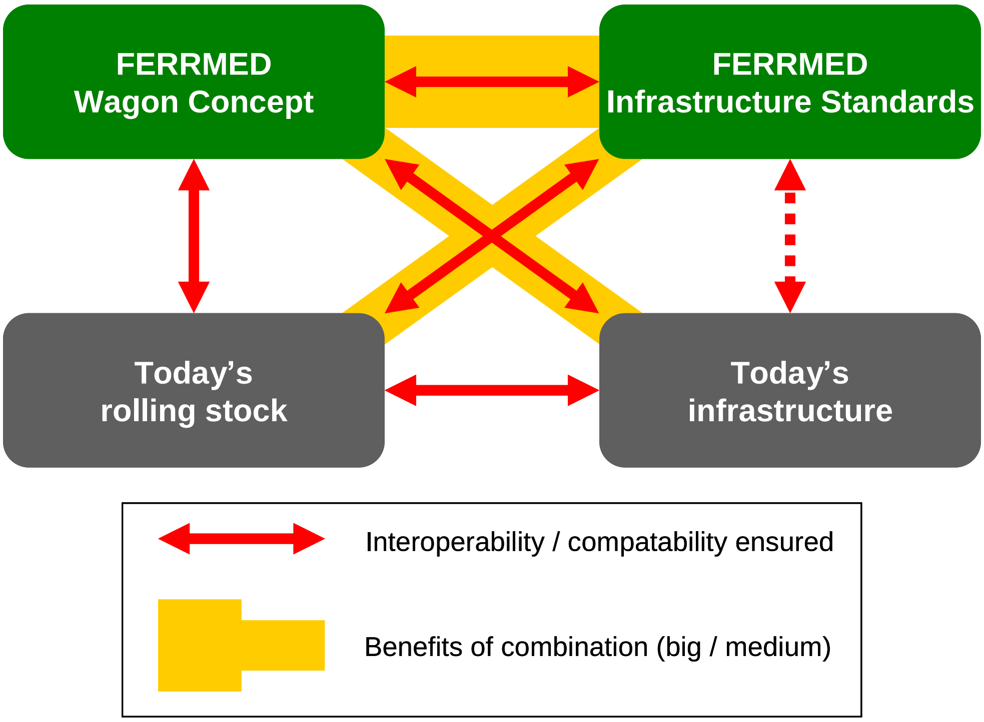


Fig. 4.3: Benefits and compatability of FERRMED Wagon Concept and FERRMED Infrastructure Standards in combination with today's rolling stock and infrastructure. (own elaboration)

The use of rolling stock based on the FERRMED Wagon Concept will thus *not* be limited to lines, which form part of the FERRMED network, but they can be used in principle on (almost) any railway line in Europe. This is guaranteed thanks to the platform character of the concept. Since the superstructure is not permanently fixed to the wagon frame, wagons operating on lines with a less generous loading gauge than on the FERRMED network can be equipped with a smaller superstructure. This may be the normal for 'free network wagons' in wagonload traffic, where wagons need to be able to circulate free in the network. Wagons deployed for longer periods of time on fixed routes – as is the case with wagons in program traffic and as well as part of the wagon fleet in the wagonload system – can be built to more generous standards, if the lines form part of the FERRMED network. In any case the wagons would be based on the same platform.

In intermodal traffic the wagons do not carry any superstructure, but instead intermodal loading units (containers and swap-bodies). No severe restrictions compared to today's intermodal wagons are expected, possibly with exception of few, extremely sinuous lines, where the bigger length of the wagon may cause conflicts for high loading units in the upper corners. However, it is an advantage that rolling stock in intermodal traffic is operating a – compared to wagonload traffic – more limited network and that wagons are often deployed in certain corridors. This means that it will be relatively easy to avoid running FERRMED wagons on few routes, which cannot accommodate them and cannot easily adapted to the FERRMED Standards and to continue operate these routes with today's rolling stock.

The FERRMED Wagon Concept neither requires operation of dedicated trains, but wagons can run in mixed trains together with existing rolling stock. For design 2 – a flat wagon for semitrailers – however, the wagons should operate in fixed consists, which also is advantageous taking into account the characteristics of this kind of traffic. However a compatible coupler console can be adapted to the end of a consist, ensuring compatibility with standard locomotives couplers (and – if desired – other wagons of other types).

The concept foresees in a longer term a change to central push- and pull couplers and the removal of side buffers, simplifying the frame structure and offering weight savings. However, this is optional and the (temporary) interoperability issues arising from the introduction of central couplers are in no way specific for the FERRMED Wagon Concept, but would arise even in case of conversion of today's rolling stock.

It should finally also be made clear, that though the goal has been to ensure a maximum interoperability with todays' infrastructure and rolling stock, this does *not* mean that the FERRMED Wagon Concept presented in this study necessarily fully complies with existing rules surrounding the construction of freight wagons as laid down especially in the relevant TSI (Technical Specification of Interoperability). These rules represent to some extent the smallest common denominator of national rules from many countries; they do not fully take into account the improvements on the infrastructure side, which the implementation of the FERRMED Standards will mean. To strictly adhere to the existing rules would make it very difficult to realize the benefits of the FERRMED Standards for the infrastructure and thus counteract the purpose of this study.

Conflicts with the TSI may arise especially from issues related to the length and the loading gauge of the wagons suggested for the FERRMED Wagon Concept. However, these represent a bearing idea of the Concept. It is therefore worth to note that many of today's freight wagons neither to 100% comply with the TSI (or other relevant rules) – especially not the most innovative ones. However, these wagons operate today daily in many countries to the full satisfaction of railway companies as well as transport customers. They operate often on national level, but also in international traffic based on bi- or multinational agreements.

The authors of this study want to emphasize that any part of the Concept has been elaborated carefully based on in-depth knowledge in the field and that critical aspects of it also have been discussed with experts from wagon manufacturers to make sure that it does not contain any unnecessary, unreasonable, risky or "impossible" solutions. We also want to underline that the Concept to a large extent is based on solutions, which already can be found on the railways today, either in other parts of the world, but in most cases actually even in Europe. The Concept can therefore be characterized as a conceptual synthesis of different innovative, but proven solutions rather than a revolutionary concept based on new untested solutions with still high technical development risks. The strength of the Concept lies first and foremost in the combination of several improvements, resulting in synergy effects, which make that the total benefits are bigger than the sum of all individual improvements.

The railway sector has traditionally shown a quite conservative approach when it comes to changing important system parameters. This can partly be explained by the fact that the railways in Europe have been developed on a national level for most of the time and that any international agreements thus often represent not more than the lowest common denominator, partly by the fact that the different parts of the railway system – especially vehicles and infrastructure – form a much more integrated system than in all other transport modes, with a lot of very specific technical interdependencies.

However, in order to make the railways more competitive on the European freight transport market it is necessary to "push the limits" of the railway system. The current discussions around the increase in truck sizes and weight limits in Europe show that other transport modes are much more active in this respect. The strong (technical) interdependencies make system changes in the railway system more demanding and often more time-consuming. Just for that reason it is even more important for the railway sector to be pro-active and have a long-term system perspective. Any changes must of course happen without jeopardizing the safety of the railway system.

"Freezing" today's standards of the railway system would in the long term jeopardize the competitiveness of the railway system. It is important that today's exceptions from the standards become the standards of tomorrow. The FERRMED Standards together with the FERRMED Wagon Concept should be seen as a contribution to achieve this goal.

5 State-of-the-Art rail freight wagons

5.1 Introductory comments

The inventarisation of state-of-the-art rail freight wagons focuses on the following types of wagons:

- Intermodal wagons
- Long wagons
- Wagons with low floor height
- Wagons for voluminous cargo

The reason of choosing intermodal wagons is that they do in general not have sidewalls or other superstructures whose weight could interfere in the comparison. In other words, intermodal and flat wagons have in principle simpler design than other wagons that enables better comparisons on weight, independent of any superstructures.

The focus on intermodal transportation has another advantage: The wagons may be utilised as multipurpose platforms for getting different kinds of wagons with superstructure adapted to specific needs. In doing so, a standard container wagon with the appropriate add-on attachment can be transformed into a covered wagon, gondola, tank wagon or other type of wagon. The attachment can – but does not need to – be designed so that it can be transferred to a road platform.

Long wagons have been included in the analysis, since they allow more flexible loading patterns for intermodal loading units as well as an decrease of number of axles on a given train length.

Wagons with low floor height are interesting since they allow an increase of the loading volume within a given loading gauge. This aspect is of special interest for the transport of semitrailers.

Wagons for voluminous cargo have been included in order to highlight the importance of the loading gauge aspect for wagon design. An increased loading gauge is a key aspect of the FERRMED Infrastructure Standards.

5.2 Intermodal Wagons

5.2.1 Sgns 60’

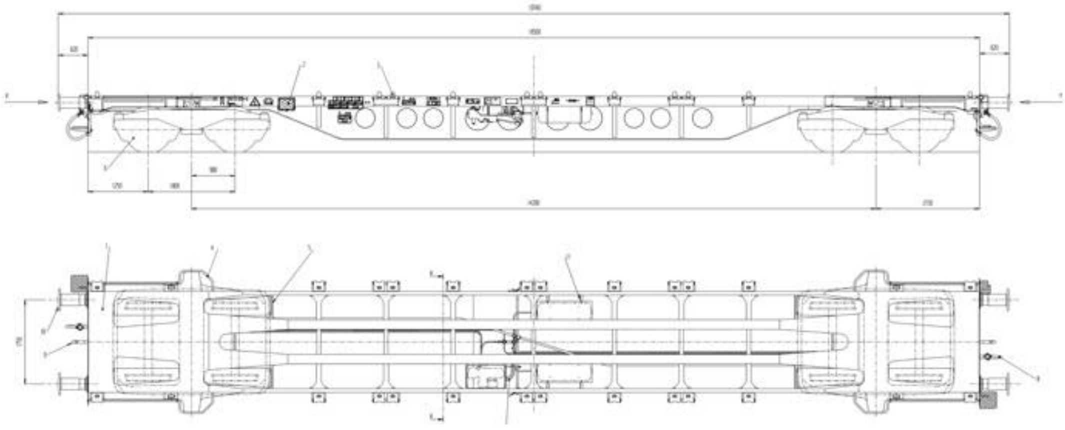


Fig. 5.1: Container wagon class Sgns 60’ (Source: KombiModel)

It is a European wide employed wagon able to carry containers in different load configurations -until 3TEUs depending on loading schema- or two C-type Swap Bodies, or one A-Type Swap Body. It is a compromised solution between a volume-oriented and weight-oriented wagon. In spite of this advantage, its overall weight efficiency can be called into question if compared to other existing wagons. In the last times though, modifications in the design and construction procedures have brought about important reductions on tare weight –up to 2 tones by having lightened central beams (picture)- which has increased substantially its weight efficiency. Yet, an important logistic hindrance with these wagons in respect to maritime container flows is the empty spaces on trains if the proportion of 40’s units its superior to the 20’s, which happens very commonly.

5.2.2 Lgnss 45’, Lgnrss 90’, Lgss 52’…

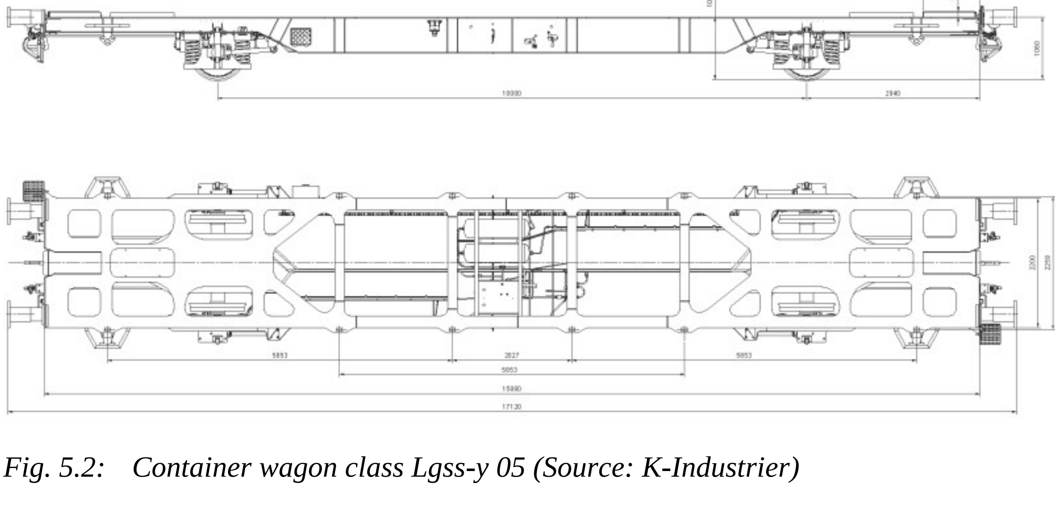


Fig. 5.2: Container wagon class Lgss-y 05 (Source: K-Industrier)

These wagons are the new series – built in the 90's and 00's- of the widely spread 2-axle wagons for the transportation of containers, 2 TEUs. In the last times modifications have been introduced in order to make them longer and more capable. The newer designs can accomodate of 2 swap bodies, 45' containers or to carry up to 32 tons of payload depending on model.

They are basically volume-oriented wagons and due to the axle load limitations they are not adequate for certain kinds of traffic, e.g. heavy 20'-containers, tank-container, etc. In addition they are more prone to derail than bogie wagons, especially at marshalling yards and in shunting operations when empty. In logistics terms, they are adequate for any kind of 40'/20' container proportion and their loading factor[3] would be closer to 1 if it was not for the reduced payload capability they have, which makes them sometimes not able to transport more than one unit.

5.2.3 Sggns 73'

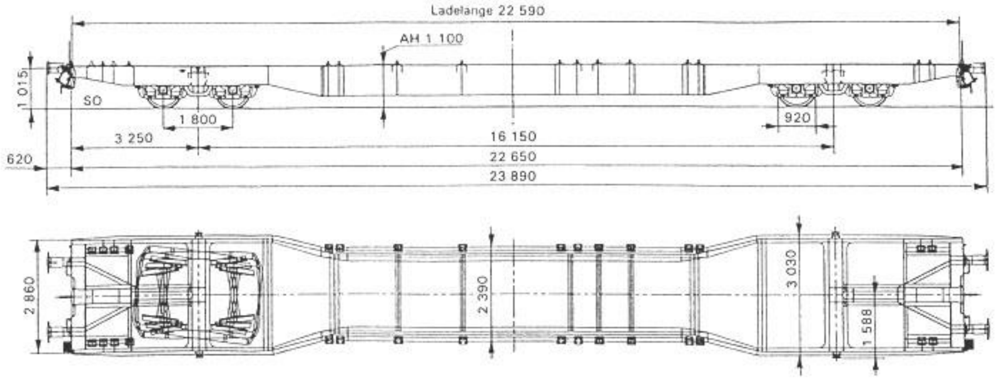


Fig. 5.3: Container wagon class Sggns 73' (Source: KombiModel)

This wagon is the longest non-articulated intermodal wagon in Europe. It is able to transport 3 7,45m swap bodies, in contrast to only two swap-bodies of this size on standard non-articulated intermodal wagons. It has a maximum loading length of 22,6 m. Only few of these wagons exist, and when it comes to containers, their loading capacity is with 3 TEU still the same as that of standard non-articulated intermodal wagons with a loading length of around 19 m, which are dominating the European container wagon fleet. The length utilisation is not very high when loaded with containers.

The comparative advantage of this volume-oriented wagon against 60'-wagons is its adequateness for carrying land containers and A and C Swap Bodies, making this wagon most suitable for Continental traffic with swap-bodies, rather than in port-hinterland-traffic with containers. However, a limitation is that it is not able to carry 3 C Swap Bodies of 7,85 m length.

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[3] Loading factor of a wagon is equal to "utilised length" divided by "available loading length"

5.2.4 Sggmrs 104’ & Sdggmrs 104’

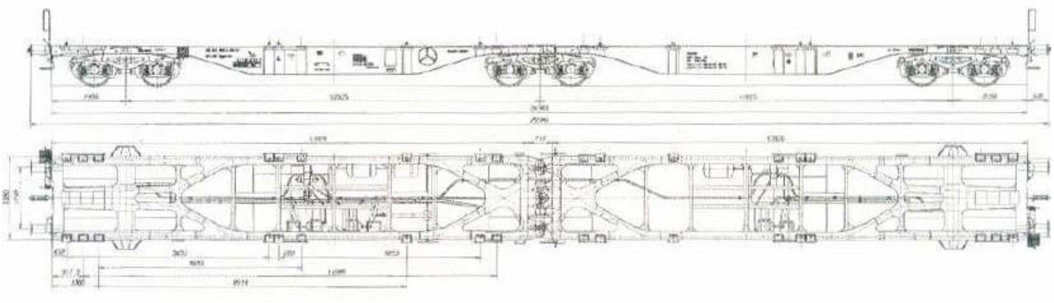

Fig. 5.4: Container twin wagon class Sggmrs and Sdggmrs 104’ (Source: Interlok)

In articulated wagons the payload/tare rate ratio increases because of sharing a bogie –also called Jacob bogie- between two identical wagon frames. By this, wagons can be longer and have fewer axles. Furthermore the total train length usage can be increased by reducing the number of couplings, although this advantage is not very significant in short trains. The 104’, 90’, 80’… articulated wagons have different loading lengths in order to allocate different kinds of loading units that have to be placed on the wagon following a strict loading schema.[4] In the case of a104’ier, it is possible to allocate: 4 x 20’ Containers, 4 x C Swap Bodies (max. 7,15m each), 2 x C Swap Bodies (7,85 or 7,45m)+ 2 x 20’ Containers, 2 x 45’ Containers, and other combinations with 30’, 20’, and 40’ies. Logistically speaking this wagon is quite versatile, having furthermore by Sdggmrs wagons the possibility of hauling two semitrailers. 104’s are more volume-oriented than weight-oriented wagons so they should perform better with large and lighter units, however they still run with unsatisfactory loading factors – in averaged conditions – due to a the existing mix of containers and swap bodies of different lengths in the market.

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[4] It is prescript that loading units next to the Jacob Bogie are lighter than edged ones for example

5.2.5 Container Stack Railcar

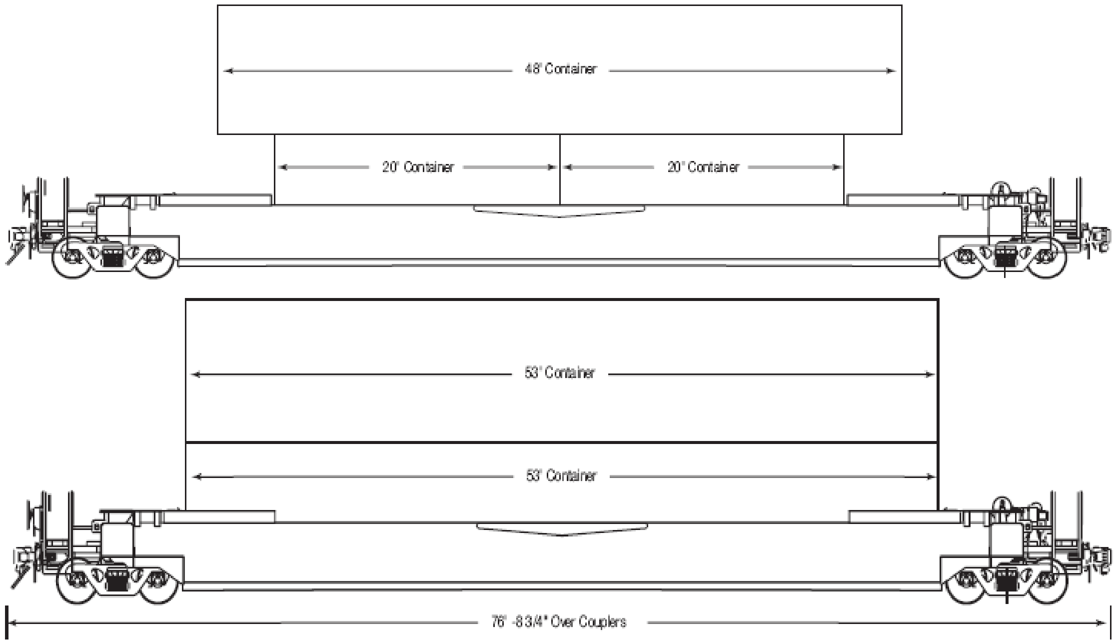

Fig. 5.5: 53' Double-stack container wagon, as used in North America (Source: Greenbrier/WTR Guide to rail cars)

Containerization in maritime transport and the introduction of the landbridge concept in North America, meaning that containers were unloaded in west coast ports and continued their journey by rail to eastern destinations in the USA, led in the 1970-ies to a surge in the demand for container transport by rail, avoiding boat transport through the Panama Canal.

To make this concept competitive versus boat transport to east coast ports it was necessary to improve the efficiency of container transport by rail. This was achieved by loading containers in two layers on a railway wagon. Double-stack container transport by rail has since then spread to Canada and Mexico and is under introduction in India, China and the Middle East as well. The containers are loaded on wagons with a low-floor section between the bogies. To accommodate two containers on top of each other it has been necessary to increase the loading gauge, however, the fact that the railway system in North America and some other parts of the world is not electrified created more favourable conditions for a more generous loading gauge than in Europe (however, in China and India double-stack container transport is under introduction even on new or upgraded electrified lines).

Double-stack container wagons exist in different designs for different stacking configurations. Weight and capacity data Figure 5.5 shows a wagon, which can be loaded with up to 53' long containers on the lower level. Weight and capacity of wagons vary among manufacturer, model and system requirements. Fig. 5.6 gives the main data for Husky-Stack 53' wagon manufactured by Greenbrier, designed to carry 20', 40', 45', 48' and 53' ocean freight containers.

Technical data container stack railcar	
Length over couplers	23,387 mm
Distance between bogie centers	19.080 mm
Well size	16,15 m * 31,2 m
Maximum width	3.250 mm
Height, rail to container surface (empty wagon)	306 mm
Height, rail to centerline coupler	876 mm
Height, maximum	6.147 mm
Top of side sill to to of rail (empty wagon)	1.520 mm
Tare weight	22,9 t
Loading capacity	76,9 t
Max. gross weight (for 220.000 lb track)	99,8 t
Curve negotiability radius:	
Uncoupled	54,9 m
Coupled to like wagon	92,7 m
Coupled to 40' base wagon	91,5 m

Fig. 5.6: Approximate dimensions of a 53' Double-stack container wagon (Source: Greenbrier/WTR Guide to rail cars)

5.2.6 Multi-unit Well Car

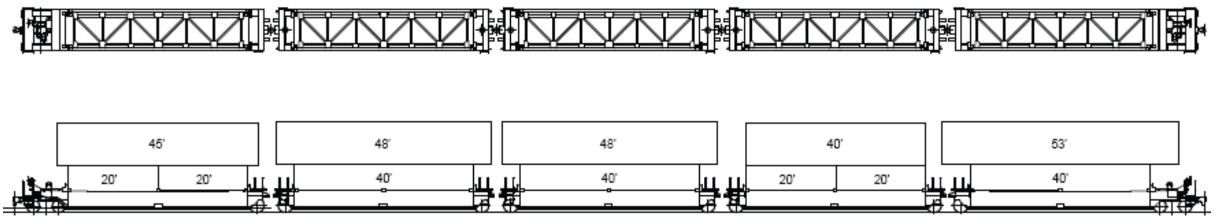

Fig. 5.7: Multi-unit well car, as used in North America (Source: Greenbrier/WTR Guide to rail cars)

The multi-unit well car is a further development of the standard double-stack railcar (see above). The wagon consists usually of five "wells" connected by Jacobs-bogies. A multi-unit well car has fewer axles per given train length and a better length utilization due to less lost space between the wells. Axle-loads are, however, higher and there are restrictions for the stacking configurations when it comes to very heavy containers. Normally the maximum container length on the lower level is 40', while single stack cars take up to 53' on the lower level.

As the single stack car different designs exist and the weight and capacity data depend on manufacturer, model and system requirements.

5.3 Long wagons

The longest, non-articulated intermodal wagon in Europe has been presented above in chapter 5.2.4.

In this chapter non-articulated wagons are presented, whose length exceed that of the wagons presented before. Due to their greater length they are able to carry up to four TEU, i.e. 33% more loading units per wagon than standard non-articulated intermodal wagons. This kind of wagons cannot be found in Europe, which is why we present one North-American and one Australian design. 80'-container wagons are today the standard in North-American single-level container trains. The wagon length of 80' they have in common with a wide range of other wagon designs, including covered wagons (called box cars in America).

However, one European wagon can be found in this overview as well: The Rbns 641 and 646-wagons of Deutsche Bahn. They are not intermodal wagons, but their loading length of 25 m would be in principle sufficient to accommodate up to four TEU, which is why we include them in this overview.

5.3.1 Standard North-American Flat Car for containers and semitrailers

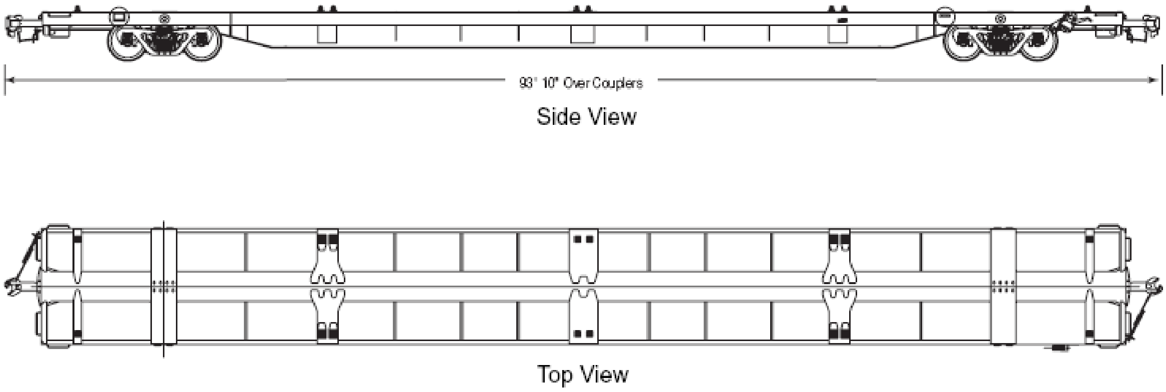

Fig. 5.8: North-American Flat Car for transport of 4 20'-containers. (Source: Greenbrier)

The Flat Car is a standard wagon in North America, widely employed for the transport of containers and semitrailers in what is commonly known as the COFC-concept (= Containers on Flat Cars) and TOFC-concept (= Trailers on Flat Cars). Many wagons can be used in both COFC- and TOFC-services. They are able to carry up to 4 TEU in containers or up to two semitrailers. Wagon lengths are typically 80', 85' and up to 89'.

When carrying two semitrailers trailer-length has earlier been limited to 12,2 m (40'). The trend towards longer trailers in US has made that sometimes three trailers are loaded on two short-coupled 89'-flat cars, with the trailer in the middle resting on two wagons. Up to 1.200 of such wagon-pairs operated for a while on the US rail network.

The construction of longer wagons to accommodate for example two 45'-trailers or -containers is not possible because the US-railroad industry through its industry association, the Association of American Railroads (AAR), has placed a length limit of 89 feet, 4 inches (27.229 mm) as maximum length for any wagons. This length restriction is necessary because of operating problems inherent in long cars having a long end overhang beyond the railway trucks.

Wheel diameters for flat cars are typically 36" (914 mm) or 33" (838 mm), however certain wagons for TOFC-service are equipped with 28"-wheels (711 mm), which can also be found under certain auto racks (car transport wagons).

Flat cars for TOFC-service are equipped with hitches to support the kingpin of the trailers under transport. Hitches can be fixed or retractable – to enable the wagon to be used in both trailer and container services hitches have to be retractable.

Fig. 5.9 and 5.10: Flat Car loaded with trailers (above) and 40'-containers (below).

5.3.2 Australian CQMY 80’-container wagon

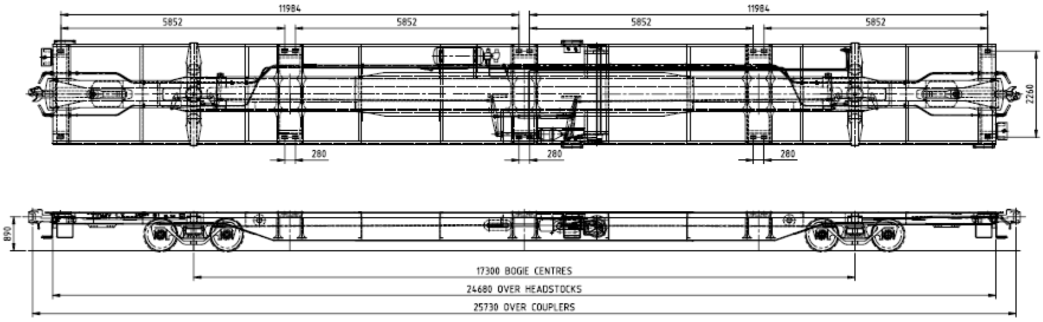

Fig. 5.11: Australian 80’ container wagon class CQMY for transport of four 20’-containers. (Source: Greenbrier)

This relatively wagon is employed in the Australian market for the transportation of containers. It is able to transport until 4 TEU in different container arrangements. It is able to load this wagon even with two layers of containers under severe weight restrictions. In this case 8 TEU can be carried on the wagon, which is mainly used when moving empty containers. Figure 5.12 shows the wagon loaded with four 40’-loading units, equivalent to 8 TEU.

The wagon has a tare of 22 tons and a payload of 70 t, which results in an axle load of 23 t, this is 0,5 t more per axle than the average maximal European allowed load. From a logistical point of view this wagon gives a good length utilization both when loaded with containers – no empty spaces with any 40’/20’ configuration – and with swap bodies, able accommodate 3 type C Swap Bodies of maximal with lengths up to 7,85. The distance between bogie centres is 17,4 m, minimum curve radius is 80 m.

Fig. 5.12: Australian 80’class CQMY wagon loaded with four 40’-loading units, equivalent to 8 TEU. (Source: www.railpage.com.au)

5.3.3 DB Schenker Rail class Rbns 641/646

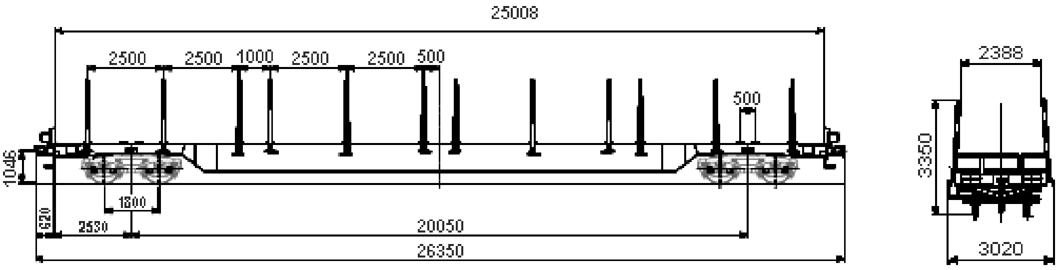

Fig. 5.13: DB Schenker Rail class Rbns 641/646 (Source. DB Schenker Rail)

In order to carry long steel beams DB ordered the class Rbns 641/646 wagons with an uninterrupted loading length of 25 m. It is one of the longest wagons in Europe with a length over buffers of 26,35 m, practically identical to that of standard passenger wagons and the Australian CQMY-wagon presented in the previous chapter.

The bogies are placed closer to the ends than on the Australian wagon in order to reduce the overhang at the wagon ends. This is necessary to ensure that the wagons can be coupled with any other wagons even in curves. The longer span between the bogie-centres, however, requires a slightly heavier frame than its Australian counterpart. With a tare weight of 27,0 t for the Rbns 641 it is roughly 4 tons heavier than a standard Rs-wagon with a loading length of ca. 18,5 m, i.e. ca. 18% more tare for a 35% greater loading length.

The wagon requires special permission for marshalling, however, the wagon is in Germany used in wagonload traffic and marshalled regularly.

The wagon is not intended for transport of containers or swap bodies, but it would be relatively easy to derive an intermodal wagon from Rbns-wagon. The floor height of 1.350 mm and 1.380 mm (Rbns 641 and 646 respectively) is slightly higher than those of standard container wagons and would with today's loading gauges limit the use of a wagon with this floor height for certain type of loading units (especially high-cube containers). However, with the UIC GC-gauge – which forms part of the FERRMED standards – such restrictions would not apply.

Wagon class	**Rbns 641**	**Rbns 646**
Loading length	25.008 mm	25.008 mm
Loading width	2.590 / 2.610 mm *)	2.520 mm
Loading area	65 m2	63 m2
Floor height	1.350 mm	1.380 mm
Distance between bogie-centers	20.050 mm	20.050 mm
Distance between outer wheelsets	21.850 mm	21.850 mm
Length over buffers	26.350 mm	26.350 mm
Tare weight	27.,0 t	29,8 t
Load limits (s-traffic / DB CM and PKP C 100 km/h)		
A	37,0 t	34,2 t
B	45,0 t	42,2 t
C	55,0 t	50,2 t
D	63,0 t	60,2 t
DB CM	57,0 t	54,2 t
PKP C	52,5 t	-

*) with / without stakes

Fig. 5.14: Technical data of DB Schenker Rail class Rbns 641/646 (Source. DB Schenker Rail)

5.4 Wagons with low floor height

5.4.1 General remarks

The usable cross-section in rail transport is on the one side defined by the loading gauge and on the other side by the space required for the wagon itself. To increase the usable cross-section there are consequently two ways: (1) To enlarge the loading gauge, and (2) to reduce the space required by the wagon. Often a combined approach is the most efficient way.

Reducing the space taken up by the wagon can done by lowering the floor height (fig. 5.15). If the floor height should be lowered over the whole length of the wagon (and not only between the bogies), it is mainly determined by the wheel diameter. Standard container wagons in Europe have a floor height of 1.155 mm and a wheel diameter of 920 mm.

By reducing the wheel diameter it has been possible to reduce the floor height with a two-axle bogie design down to just over 800 mm with wheel diameters down to 730 mm. The minimum difference between wheel diameter and floor height in today existing wagon designs is 95 mm.

A reduction of the wheel diameter also reduces the contact surface between wheel and rail, imposing axle-load restrictions on these wagons. In Continental intermodal traffic, dominated by relatively low-density cargo and stowage factors, these axle-load restrictions are certainly a limitation, but not a too severe problem. Axle-loads of these wagons are typically in the 16-18 t range (compared to 22,5 t for standard wagons). Maintenance costs increase due to the higher number of revolutions over a given distance.

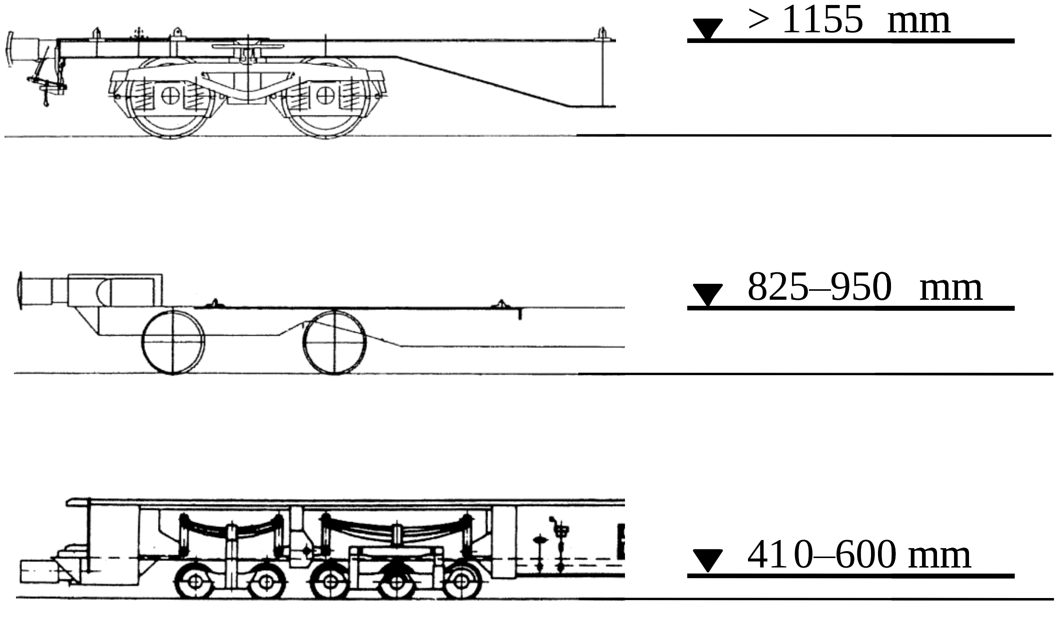

Fig. 5.15: Typical floor heights with different types of bogie/running gear designs (own elaboration).

If the floor height is to be reduced much further, considerably more complicated bogie designs are required. The number of wheels has to be increased and special bogie constructions have to be applied. Such running gears have been developed for Rolling Highway-wagons, where it has been possible to reduce floor height down to 410 mm. However, the extremely high purchase and maintenance costs for these running gears (together with a number of other characteristics of the Rolling Highway) contribute to the bad transport economy for this form of intermodal traffic. This running gears used for Rolling Highway wagons have neither found any application outside this niche.

From the above can be concluded, that it is possible to reduce the floor height down to ca. 800 mm by reducing the wheel diameter, but without giving up the principle two-axle bogie design. For floor heights considerably lower than 800 mm cost increase dramatically and can only be justified for specific niche applications.

In the following chapter a design of a low floor wagon for intermodal transport is presented, which is in use in several countries in Europe.

Rolling Highway-wagons are not included in this study, since the concept of the Rolling Highway for several reasons cannot be considered as model, which could have any chance to find a wider application as general system for intermodal transport. Those Rolling Highways, which exist today, are niche markets and their operation is dependent on heavy public subsidies of up to 50% and more.

5.4.2 Class SFFGGMRRSS Megafret

Fig. 5.16: AAE Megafret-wagon class Sffggmrrss (Source: AAE)

The Megafret-wagon exists in two slightly different designs. Wagon rental company AAE has at its disposal a wagon fleet with a floor height of 825 mm allowing transport of high-cube 9‘6“ containers through the Channel Tunnel into European terminals. Within Continental Europe, e.g. in trans-alpine traffic, the wagons can be used for extra high loading units for voluminous goods. It is possible to transport containers and swap-bodies with an exterior height of 3.220 mm in the C-45 loading profile. The maximum axle-load is 16,0 t and the maximum speed 120 km/h.

In France Touax/SNCF has Megafret-wagons with a slightly higher loading floor at 945 mm. The wheel diameter of these wagons is 840 mm. They have a 2 tons higher axle-load of 18,0 tons and a 20 km/h higher maximum speed of 140 km/h. They are prepared for 20 t axle-load (probably at a lower speed), i.e. only slightly less than intermodal wagons with standard floor height of 1.155 mm.

	AAE	**TOUAX/SNCF**
Loading height	825 mm	945 mm
Wheel diameter	730 mm	840 mm
Axle-load	16,0 t	18,0 t *
Max. speed	120 km/h	140 km/h

* Wagon prepared for 20 t axle-load

Fig. 5.17: Technical data of Megafret-wagons class Sffggmrrss of AAE and TOUAX/SNCF (Source: AAE, TOUAX)

5.5 Wagons for voluminous cargo

5.5.1 DB Schenker Rail class Hbbins-tt 309

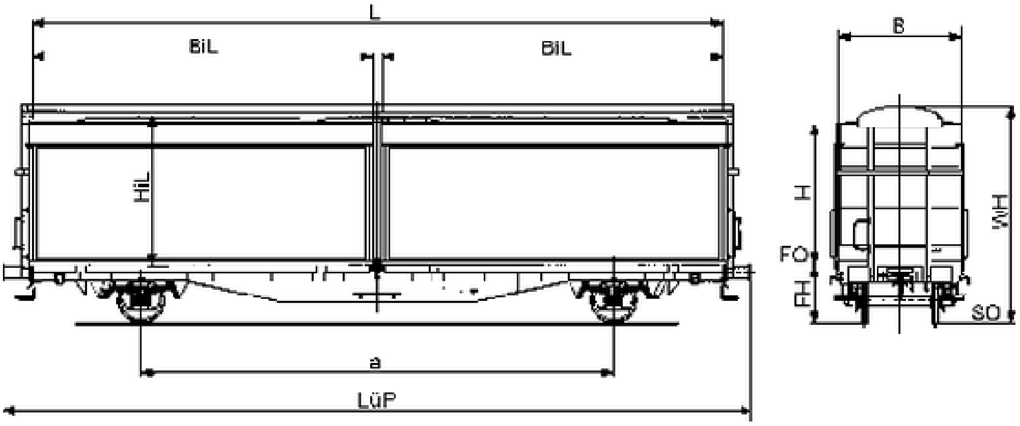

Fig. 5.18: DB Schenker Rail class Hbbinss-tt 309 (Source: DB Schenker Rail)

The class Hbbins-tt 309 is a two-axle wagon with sliding doors with an extra large loading volume of 115 m3 on a length over buffers of 15,9 m. The wagon addresses primarily the customer needs of the automotive industry and is used for transport of car components. An important feature is an internal height of 3.050 mm, compatible to the height in jumbo-semitrailers and thus facilitating multimodal transport planning.

The class Hbbins-tt 309 – and a number of similar wagon classes partly derived from it – utilizes the line clearances for intermodal loading units, which normally are not used for fixed parts of railway wagons. It exceeds slightly the G2-gauge and can therefore only operate on a limited, however still quite extensive network. The fact that this wagon type exists in large quantity shows that today's infrastructure parameters are increasingly a limitation for efficient freight wagons, but also that it is to a certain extent possible to exceed these limits already today without too severe operational restrictions.

Wagon class	**Hbbins-tt 309**
Loading length	14.636 mm
Loading width	2.580 – 2.600 mm
Loading height	3.050 mm
Loading volume	115,0 m3
Floor height	1.200 mm
Distance between axles	10.000 mm
Length over buffers	15.900 mm
Tare weight	16,3 t

	A	**B**	**C**	**D**
S	15,5	19,5	24,5	28,5
120	0,00			

**

Fig. 5.19: Technical data class Hbbins-tt 309 (Source: DB Schenker Rail)

5.5.2 Volume wagon Hiqqrrs-vw^{011} and Hiqqrrs-vw^{041}

Fig. 5.20 + 5.21: Hiqqrrs-vw^{011} (left) and its European version Hiqqrrs-vw^{041} (right). The photos reveal the almost rectangular cross-section of the Swedish version, creating the condition fo an efficient utilization of the loading space, while the European version is characterized by "cutted" upper corners in order to adhere to the G2-gauge (Source: K-Industrier)

Swedish wagon manufacturer K-Industrier has developed a twin wagon for voluminous cargo in two versions, one for the Swedish market, where a more generous loading gauge can be utilized and one for the Central European market according to the G2-gauge. The Swedish wagon is already in commercial use, while a prototype wagon exists of the European version.

The Swedish version offers a loading capacity of 2 * 136 m3 or 16% more than the European version with 2 * 117 m3. The wagon is also built for 25 t axle-load, giving a load capacity of the twin wagon of 67 t. The loading height of the Swedish version is 3,2 m and of the European version 3,0 m, the latter practically similar to those of the Hbbins-tt 309 described in the previous chapter. However, the floor height of K-Industrier's wagon is lower, which means that the loading height can be realized within the G2-gauge.

The wagon is equipped with an electrically powered automatic door opening mechanism and running gears for silent and smooth running, reducing – and often eliminating – the need for extensive load protection during transport.

An innovative feature of the wagon is also that the superstructure is exchangeable, making it easily adaptable to different customer's need and kinds of cargo.

Wagon class		**Data Hiqqrrs-vw^{011} (for use in Sweden)**	**Data Hiqqrrs-vw^{041} "The European"**
Tare weight		33,2 t	33,0 t
Payload at axle-load	22,5 t	56,8 t	57,0 t
	25 t	66,8 t	67,0 t
Speed	Empty	120 km/h	120 km/h
	Laden	100 km/h	100 km/h
Length over buffers		30.080 mm	30.080 mm
Loading length		2 * 13.400 mm	2 * 13.400 mm
Loading width		3.180 mm	2.920 mm
Internal height		3.200 mm	3.000 mm
Loading volume		2 * ~136 m^3	2 * ~117 m^3
Floor height		1.078 mm	1.078 mm
Min. curve radius		60 m	60 m
Electrical connection		400 V	400 V

Fig. 5.22: Technical data of classes Hiqqrrs-vw^{011} and Hiqqrrs-vw^{041}. (Source: K-Industrier)

5.5.3 Stora Enso Cargo Unit on container wagon

Fig. 5.23 + 5.24: Wagon of class Sgmns-w^{982} loaded with a SECU loading unit (above) and empty (below). (Source: Stora Enso, K-Industrier)

Swedish-Finish paper manufacturer Stora Enso has established a transport system, called BasePort, between its Swedish paper mills and the ports of Zeebrügge and Lübeck based on the use of containers with extraordinary dimensions. These containers, called SECU (Stora Enso Container Unit) are not intended to be transported on the road network, but only by rail and boat (via Göteborg). This together with a (further) enlarged loading gauge on the Swedish rail network on a number of lines – from one, which already was slightly larger than in most other European countries (with exception of those with the "broad gauge-countries" in Eastern Europe) – has made it possible to create a highly efficient transport system pushing the limits of the rail system to a maximum.

A SECU has a length of 13,8 m and a cross-section of 3,6 x 3,6 m. The units can hold up to 80 tonnes of paper, which is far more than the average 22 tonne load that is permitted to travel by road in Europe. Instead of the usual paperwork attached to each container, there is a simple radio tag which stores all the relevant data required by the terminal management to keep track of the Secu.

The SECU are transported on class Sgmns-w^{982} bogie container wagons with a length of 15,24 m and 25 ton axle load using K-Industrier's Y25-TTV bogie. The wagon fulfills the requirements of RIV and UIC. The wagon can be used for transport of standard containers as well and is designed in a way that it can be shortened or made longer in able to take other transports. The wagon body is designed for 30 ton axle load.

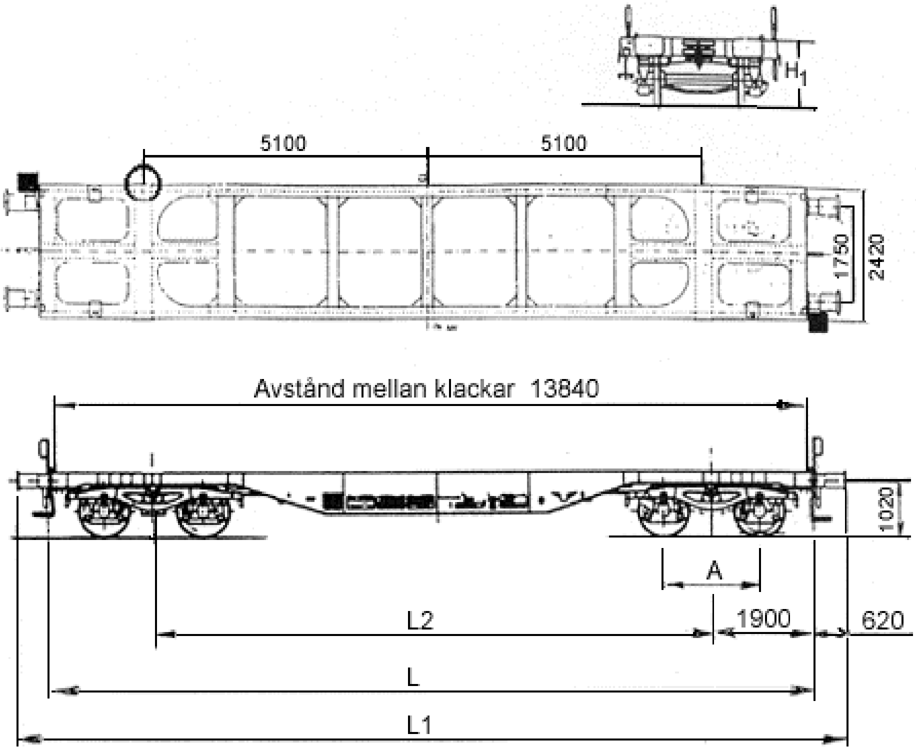

Fig. 5.25: Wagon of class Sgmns-w^{982} used to transport SECU loading units. The wagon is equipped with bogies for 25 t axle-load, but the body designed for 30 t axle-load (Source: K-Industrier)

Wagon data	
Tare weight	18,4 t
Length over buffers	15.240 mm
Loading height (load surface)	1.170 mm
Axle distance in bogie	1.800 mm
Bogie centre distance	10.200 mm
Minimum curve radius	60 m
Wagon can be loaded with a container of the following dimensions	
Maximum load weight	81,6 t
Container length	13,8 m
Container width	3,6 m
Container height	3,6 m
Load height (top of container above rails)	4,3 m

Fig. 5.26: Technical data class Sgmns-w 982 and SECU-container (Source: K-Industrier, StoraEnso)

The efficiency gains of the transport solution achieved in the BasePort-system is highlighted in the table below, giving the payload per wagon-meter with different transport options.

As can be seen the payload per meter in the BasePort-system exceeds with 4,5 t/meter by far all other options. A solution based on semitrailers on trailer wagons would only come up to 1,3 t/meter and a conventional covered freight wagon to 2,5 t/meter. Most remarkable is maybe that the solution performs even 50% better than a North-American double-stack container train, due to the better length utilization (less "air" between the containers) in the BasePort-trains.

Transport solution	**Payload in tonnes/wagon-meter**
13,6 m-semitrailer on trailer wagon	1,3
40' standard container	1,5
45' curtainsider	2,0
Conventional covered freight wagon	2,5
Double stack 40'	3,0
→ Stora Enso Cargo Unit (SECU)	4,5

Fig. 5.27: Transport efficiency expressed in tones/wagon-meter in different transport solutions (Source: K-Industrier, StoraEnso)

The photos below visualize the size of the SECU incomparison with standard containers and conventional freight wagons. The last photo shows a prototype freight wagon making use of the same loading gauge as the SECU (Swedish C-loading gauge, see even chapter 6.4), illustrating the potential for improved economies of scale in the railway system in case of a system-wide implementation of far more generous infrastructure standards. In Sweden the goal is to introduce the new C-loading gauge stepwise network-wide. In Northern Sweden some timber wagons are already making use the new loading gauge as well.

Fig. 5.28: SECU loading unit in comparison with standard ISO-containers (Source: Port of Göteborg)

Fig.5.29: SECU loading on container wagon beside a conventional freight wagon (Source: TfK)

Fig. 5.30: Prototype covered wagon utilizing the same loading gauge as the SECU-trains. Note the yellow line indicating the cross-section of a standard freight wagon (Source: TfK)

5.5.4 Tri-level Auto carrier

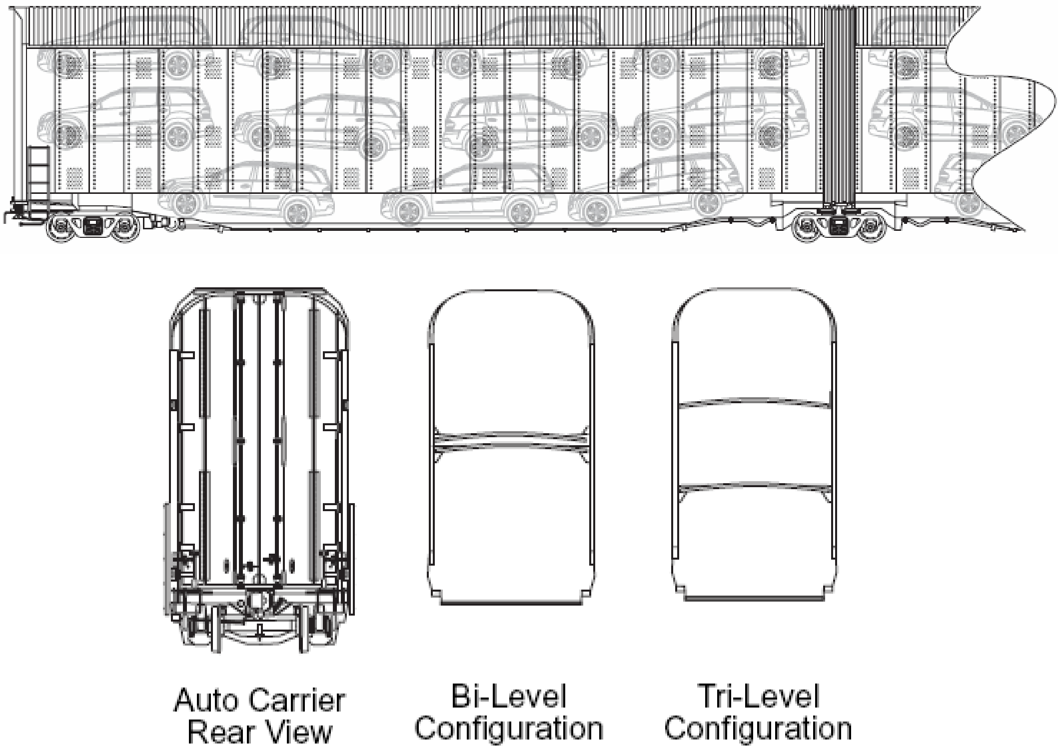

Fig. 5.31: North-American tri-level articulated auto carrier AutoMax II. The wagon uses the same loading gauge as double-stack container trains (Source: Greenbrier/WTR Guide to rail cars)

Auto transport wagons are used both in North America as well as in Europe to transport new cars to distrubition centres and to and from ports for export/import. Roughly half of Europs car production moves by rail before being sold.

While in Europe cars can be transported in two levels in North America increasingly (enclosed) tri-level wagons are used. They make use of same loading gauge as double-stack container trains, increasing the benefit of capital expenditures for enlarging the loading gauge. Minivans and other higher automobiles, which in Europe often only can be carried in one level on flat wagons, can be carried on a bi-level configuration of the North-American car carrier.

The following table gives the dimensione and technical data of Greenbrier's AutoMax II car carrier.

Technical data tri-level auto carrier	
Length over couplers	44,30 m
Internal length	43,06 m
Outer width, at center of units	3,05 m
Outer width, at end of cars	3,25 m
Internal width, between side posts	2,83 m
Internal width, at doorways	2,57 m
Height, maximum	6,15 m
Distance between bogie centers	19,5 m
Tare weight *)	67,1 t
Loading capacity *)	50,8 t
Max. gross weight *)	117,9 t
Curve negotiability radius:	
Uncoupled (horizontal)	54,86 m
Coupled to like wagon	74,68 m
Coupled to 40' base wagon	91,14 m
Uncoupled (vertical)	381 m

*) based on 44,346 lb end trucks and 58,451 lb intermediate truck

Fig. 5.32: Approximate dimensions of and technical data for the AutoMax II tri-level articulated auto carrier (Source: Greenbrier)

5.6 Comparative analysis of wagons

The typical intermodal wagon fleet distribution in Europe looks as follows:

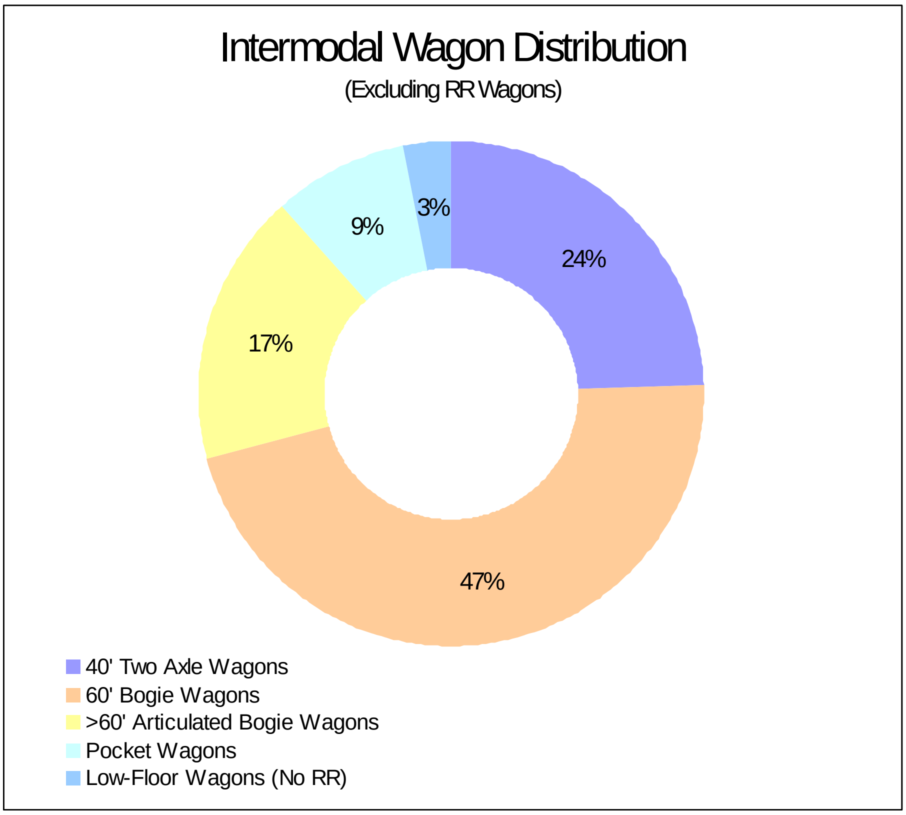

Fig. 5.33: Structure of the European Intermodal wagon fleet. Rolling Highway wagons are excluded. (own elaboration based on data from BTS Kombiwaggon, AAE, United Nations, internal knowledge)

The most popular intermodal wagon is the 60' container wagon able to carry 3 TEU's in multiple loading schemas. This wagon is a universal wagon which versatility has been commended in many cases and for many users. It is able to transport 2 swap-bodies as well up to 7,82 m long, if having the right pin or twist-lock positions. Its market price is between 60.000€-70.000€ (2008)

Two-axle container wagons, representing roughly one fourth of the total wagon fleet, can carry 2 TEU's within limitations on weight (max. payload 28 t). Certain longer designs are also able to carry as well 2 swap-bodies, however 40'-container wagons are only able to carry maximum one single swap body (if they are equipped for it). Market price of a standard two-axle container wagon is around 50.000€ (2008).

Articulated wagons, pocket wagons, and low floor wagons stand for the remaining third of the total wagon fleet. A huge number of different designs address different markets and customer needs. In many cases these wagons are designed for specific infrastructure restrains, for example in England where low floor wagons are widely employed, due to the narrow loading gauge. The cost per wagon is difficult to approximate due to the variability, but can be roughly estimated to be between 18.000€-20.000€ per TEU.

Intermodal wagons are conceived for the transportation of few different kinds of intermodal loading units, mainly ISO-containers and swap bodies, and partly also Semitrailers[5]. The majority of intermodal consignments though are ISO-container shaped due to the huge amount of traffic of deep sea nature participating in combined transportation.

The wagons weight efficiency can be as well visualized with a XY diagram, with the payload/tare-ratio on the abscissa and the TEU/tare-ratio on the ordinate. By looking at the graph, wagons follow a trend line that can be employed to characterize their condition as volume-oriented or weight-oriented. It can be noted that American and Australian wagons can carry double-stacked intermodal units, which place them in a comparative advantageous position. It can be seen that the coordinates for US and AU wagons are placed approximately two times further from the X axis than they appear in the figure.

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[5] Rolling Highway wagons with very small wheel radius are not being evaluated in the present study

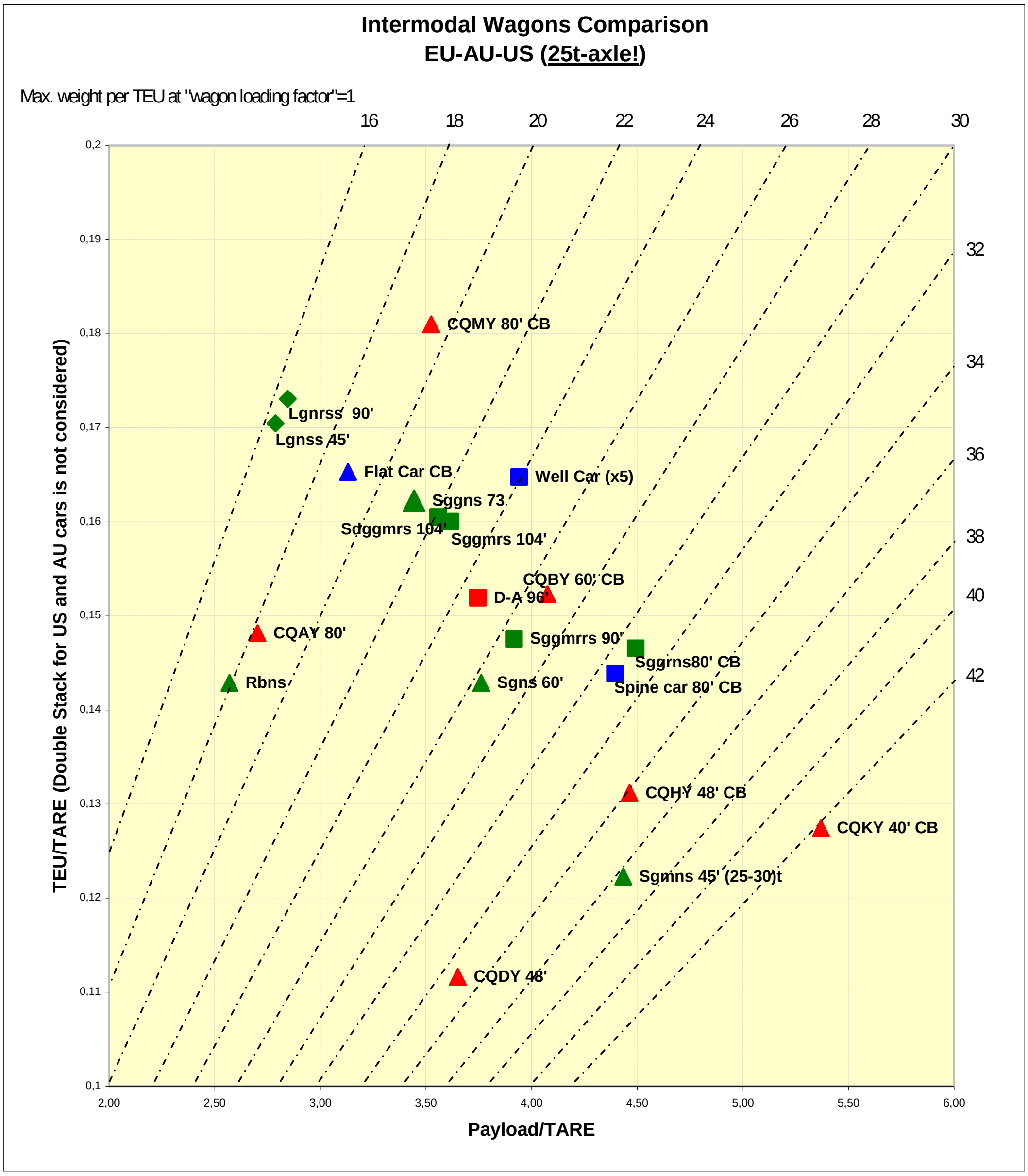


Fig. 5.34: Intermodal wagon comparison. Green: European Wagons, Red: Australian Wagons, Blue: American Wagons. Square: Articulated wagons, Triangle: Bogie non-articulated wagons, Diamond: Non-Bogie Wagons. For all wagons a 25 t axle-load is assumed, double stack is not considered. (own elaboration)

6 Outline of a FERRMED Wagon Concept

6.1 Development approach

As has been pointed out in chapter 2.3 there are three ways to improve rail freight's competitiveness: Improving economies of scale, introducing new production methods and improving the accessibility to the railway system. These strategic approaches have been important aspects in the development of the FERRMED Wagon Concept.

Another important guideline have been the FERRMED Standards for infrastructure, which create new possibilities even in wagon design. Not least because of the close interdependencies between rolling stock and infrastructure in the railway system the development of the infrastructure plays an important role even for the design of the wagons.

Two other aspects, which have been important in the conceptual development of the FERRMED Wagon Concept are *simplicity* and *reliability*, both closely related to each other. Simplicity gives reliability and both together ensure low costs. The wagons should be simple in construction, maintenance and operation. This could be achieved: None of the designs features articulated bogies – which would have added costs and complicated maintenance – or a high amount of technically sensitive movable parts. The goal of simplicity also extends to the terminals: Consequently none of the designs requires any new and untested transfer equipment in the terminals. In the case of the FERRMED-semitrailer-wagon the concept foresees the use of head-end or side-ramps; this has rather to be seen as a simplification, since no cranes or heavy reach-stackers are required for loading and unloading of trailers (however, the possibility of using cranes or reachstackers is maintained, ensuring full compatability with today's terminal equipment).

Reliability was ensured not least by taking as a starting point in this work innovative state-of-the-art freight wagon designs, which are already in operation. The wagon designs presented in this study is to a large extent based on solutions, which already can be found on the railways today, sometimes in other parts of the world, but in most cases even in Europe. The concepts can therefore be characterized as a conceptual synthesis and further development of different innovative, but proven solutions rather than a revolutionary design based on new untested ideas with still high technical development risks. The strength of the concepts lies first and foremost in the combination of several improvements, resulting in synergy effects. The total benefits are bigger than the sum of all individual improvements. The extensive research in the field of freight transport carried out at KTH and TUB has been valuable in this work.

Another important feature of the FERRMED-Wagon Concept is, that it is based on a *joint platform* for *intermodal* and *conventional* wagons. This offers scale effects in production and maintenance and the possibility to convert wagons when demand is changing.

The FERRMED Wagon Concept comprises three basic designs:

- Design I: The Long Multi-Purpose Wagon (LMPW)
- Design II: The Heavy Cargo-wagon (HCW)
- Design III: The Trailer-on-Flat-Wagon (TOFW)

Design I and II are very similar to each other, the main difference being the length of the wagon. While the LMPW is longer than today's wagons for intermodal traffic and is mainly addressing the field of more light- and medium density commodities, the HCW is addressing the market for bulk- and other high-density commodities.

The TOFW finally is addressing the market for semi-trailer transport. Earlier studies (e.g. DIOMIS) have already shown that it is difficult to develop a single wagon design optimally adapted to both containers/swap-bodies *and* semitrailers. Today's semitrailer-wagons are certainly able to carry containers and swap-bodies as well (but not vice versa), but different wagon designs achieve good efficiency factors in terms of length-utilization and payload/deadweight-ratio only for either containers/swap-bodies or semitrailers, not both at the same time. The main feature of the TOFW is a lower floor height.

The different wagon designs are presented in chapter 6.3 – 6.5. In chapter 6.2 a number of joint features of and basic considerations for the FERRMED wagon designs (or in a few cases two of the three designs) are dealt with.

6.2 General features of the FERRMED Wagon Concept

6.2.1 Multipurpose platform

The FERRMED Wagon Concept provides in all three designs a multipurpose platform, which can be equipped with different kinds of superstructures. Thus, the LMPW-concept is modular and highly versatile, which adds flexibility to the production systems of railway services. The advantages of multi-purpose wagons are:

Lower opportunity costs

Mono-purpose wagons are adapted for specific transport tasks, e.g. for a single type of commodity. If the demand on these services decays, the wagons are likely to remain idle. Conversely, if demand peaks, enough wagons may not be available and traffic may be lost to other operators or transport modes. The more specific the wagon is, the less versatile it is, which increases its opportunity cost. With multi-purpose wagons, the opportunity cost of the wagon (the platform) is pre-known, which makes risk assessment easier. The superstructures would remain an element susceptible to higher risk, which opportunity cost has assessed. In conclusion, however, railway undertakings have more options – or knowledge – for counteracting hypothetical external market hindrances, which decreases business risks and increases competitiveness.

Economy of scales

The manufacturing costs of wagons can be reduced by larger series through platform-based and more continuous production patterns and consolidated and standardized technology. Economy of scales can also be achieved in spare-part storage and supply. Furthermore delivery times can be decreased.

Simplified maintenance and increased reliability

Railway undertakings profit from the modularisation too; standardized vehicles are easier to maintain and to repair, and the number of maintenance providers is likely to be bigger, leading to higher competition in the maintenance market. An higher number of maintenance providers also can reduce empty haulage to repair shops and less dwell time in shops. Furthermore, the reliability of the operator increases because having the ability of splitting the different parts of the wagon. A fault on the superstructure does not necessary imply a disabled rolling unit and vice-versa.

Availability of rolling stock

As various wagon types utilise same modularised components there are much more possibilities to find suitable units when

- the railway service is being designed or planned
- a failure on rolling stock or parts thereof occurs during service
- rolling stock and parts thereof are being inspected and maintained

- fluctuations of the demand arise

Hence, the railway undertakings can afford more compromises towards their clients, which increases the quality of the service and helps to consolidate the profiting industry.

Adaptability to demand variations

Transport demand is not constant over time and therefore unit costs – e.g. €/TEU - are never steady, although price charged is often expected to remain constant. By introducing multipurpose wagons, railway companies can better adapt to fluctuations in the market. They can offer more flexibility, which brings about a competitive advantage against other companies and other modes. Furthermore, they can diversify their business by carrying more types of commodities with the same rolling stock. This advantage becomes more important the smaller the railway company is.

Reduction of empty runs

Geographical flow imbalances lead to empty runs of wagons. Such flow imbalances are mostly outside the control of the railway companies. At the same time empty hauls have strong impact on transport costs. The chance to find backload for mono-purpose wagons is much lower than to find backload for multi-purpose wagons. Thus, multi-purpose wagons can contribute to decrease empty haulage and improve transport economy in the load runs.

Logistical advantages

Detachable wagon superstructures enable the introduction of new concepts for loading and unloading – and as well transloading train-train – which can pave the way for innovative production systems in rail freight. This can also contribute to strengthen the less-than-trainload market, which currently is covered by wagonload traffic. Pallets could be loaded in dedicated superstructures and loaded onto railway platforms for long trips without belonging to a specific rail service or network. Or ro-ro superstructures could be loaded on railway platforms with a simple intermodal crane. Thus, the detachable superstructures a promising solution even for smaller flows.

The pictures on the following pages show a number of cases, where the concept of multi-purpose wagons and/or detachable superstructures already can be found today. These pictures may serve as a source of inspiration for future detachable superstructures for the LMP-wagon.

Fig. 6.1 + 6.2: Standard container wagons in Sweden (above) and Austria (below) equipped with semi-permanently fixed stanchions allowing the wagons to be used in timber traffic.

Fig. 6.3 + 6.4: Different type of non-ISO loading units, which can be carried on container wagons.

Fig. 6.5: Detachable superstructure of a railway wagon, which can be handled by standard terminal handling equipment.

Fig. 6.6: A so-called "Dual-waggon" at Thuringia Steelworks, which can be used as

6.2.2 Axle loads

Today, most mainlines in Europe allow 22,5 t axle-load, however, selected lines are upgraded to 25 t axle-load already and new wagons are often prepared for 25 t axle-load as well. In Sweden in connection with new construction or major upgrades of lines the sub-surface, including bridges, is nowadays by standard built for 30 t axle-load and the track for 25 t axle-load.

For the FERRMED Wagon Concept 22,5 t and optionally 25 t are set as standard for both the LMPW- and HCW-design. For the TOFW-wagon a lower axle-load of only 15,5 t is foreseen due to the lower wheel diameter as well as a lack of need to design the wagon for higher axle-loads, since the maximum weight of a semi-trailer, which this wagon primarily is intended for, is limited by the weight limits in road traffic.

Increased axle-loads are often considered beneficial for transport of commodities with a high specific weight (t/m3) mainly. This would mean, that only a limited market segment would benefit from higher axle-loads, mainly comprising – often relative low-value – bulk and break-bulk commodities. Large parts of intermodal traffic would not benefit.

The authors of this study would like emphasize, that the value of increased axle-loads should not be underestimated neither for relative low-density (high-value) goods. Much of this goods is today moving in intermodal loading units

The key to draw benefit for intermodal transport from increased axle-loads lies in the way how to utilize increased axle-loads: As the figure below illustrates, increased axle-loads can either be used to increase the load per meter – keeping the number of axles over a given length unchanged. An alternative way to make use of increased axle-loads is to keep the meter-load unchanged, but instead decrease the number of axle over a given length. It is this latter approach on which the LMPW-wagon design described in chapter 6.3 is based. Since the bogies or running gears of a wagon are usually the most expensive parts of it, there can be achieved cost savings by reducing the axles per train-meter – in this case by building longer wagons.

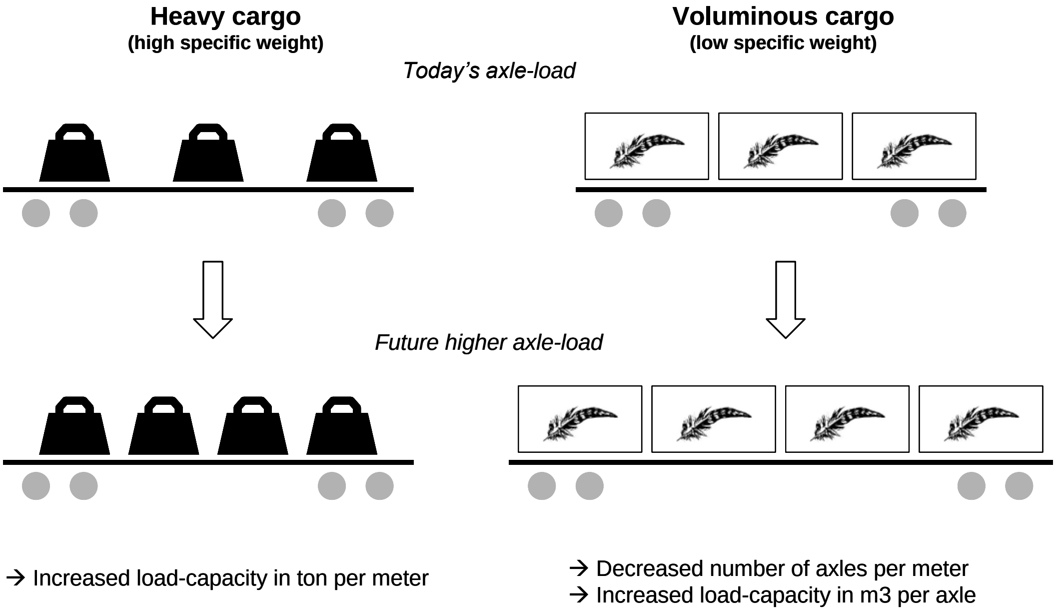


Fig. 6.7: Both heavy cargo with a high specific weight, as well as voluminous cargo benefit from increased axle-load (own elaboration).

6.2.3 Speed

The maximum speed of freight trains in Europe is generally 90-100 km/h. For the FERRMED Wagon Concept a maximum design speed of 120 km/h at 22,5 t axle-load and 100 km/h at 25 t axle-load is foreseen as standard. For the TOFW-wagon a maximum speed even of 130 or 140 km/h may be possible and commercially relevant.

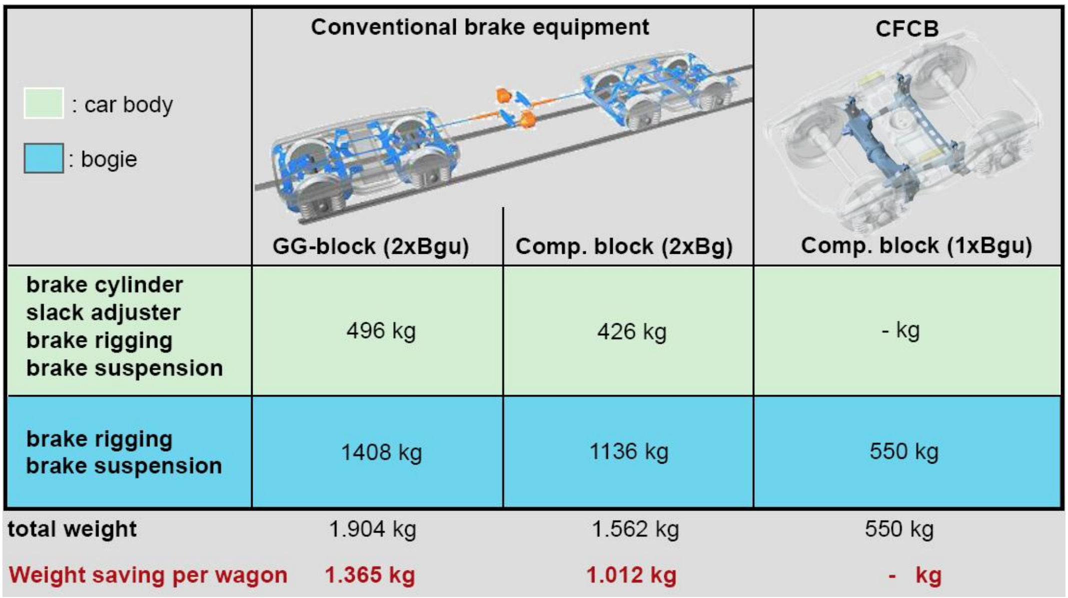
For selected niche markets even higher maximum speeds may be commercially interesting, however, in this case running gears and the brake system would probably need to be specially adapted. Due to the niche character of such applications wagons for higher maximum speeds are not considered in this study. It should, however, be mentioned that parts of the FERRMED Wagon Concept as presented in this study could very well become incorporated even in wagon concepts for higher speeds.

Though the FERRMED Wagon Concept foresees a maximum design speed of 120 km/h, it should be emphasized that from a cost point of view a maximum operating speed of 100 km/h often is preferable. The higher energy consumption – and to a certain degree higher maintenance cost – of running 20% faster is in most cases not compensated by a higher willingness to pay from the transport customers or productivity gains. This is especially true if there is the possibility to make use of higher axle-loads (25 t instead of 22,5 t). In this case it is in most cases more profitable to choose to increase axle-loads rather than to increase the maximum speed.

6.2.4 Brake system

Traditionally part of a freight wagons brake system is mounted under the wagon floor, while another part is mounted in the bogie. Recently a new more compact brake concept has been introduced on the market, which can be entirely mounted in the bogie.[6] This new Compact Freight Car Brake (CFCB) allows weight saving of about 1 ton without modifications of the bogie (fig. 6.8).

The CFCB also allows a more weight-optimal design of the bogie-frame. Since the brakes work on one side of each wheel only (on the sides towards the bogie center), front beams are not any longer necessary to support the brake equipment. Figure 6.9 shows a new bogie Y25Lsi-C without front beams. If the bogie is adapted optimally to the new brake total weight savings per wagon of more than 1,5 ton are possible.



🟩 : car body 🟦 : bogie	Conventional brake equipment		CFCB
	GG-block (2xBgu)	Comp. block (2xBg)	Comp. block (1xBgu)
brake cylinder **slack adjuster** **brake rigging** **brake suspension**	496 kg	426 kg	- kg
brake rigging **brake suspension**	1408 kg	1136 kg	550 kg
total weight	1.904 kg	1.562 kg	550 kg
Weight saving per wagon	**1.365 kg**	**1.012 kg**	**- kg**

Fig. 6.8: Component weights of and weight savings by the Compact Freigth Car Brake (CFCB). (Source: Elstorff-Matthieu)

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[6] Elstorpff, M.-G., Mathieu, M. (2008): Development, Testing and TSI-Certification of the new Bogie Mounted Tread Brake Unit for Freight Cars, presentation Graz, 16 September 2008

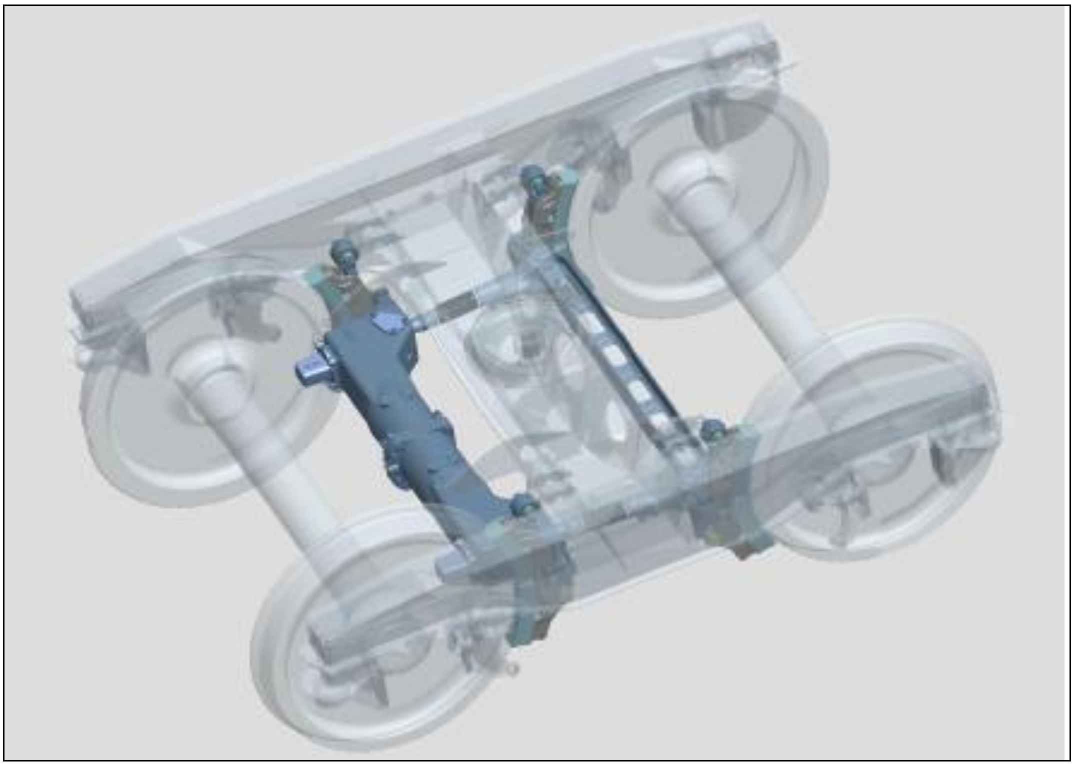

Fig. 6.9: Y25Lsi-C bogie without front beams developed by ELH (Source: ELH)

Other advantages of the CFCB include:

- Low noise emissions due to small number of bearings with low clearance and vibration-damped suspension
- Modularized and standardized design with variable internal ratio
- Full automatic compensation of block and wheel wear
- Largely maintenance free also under severe environmental conditions
- High and constant efficiency, low hysteresis
- Less air-consumption, up to -60%

Due to the better brake performance, lower weight and cost savings the CFCB is foreseen as standard for the LMPW- and HCW-wagons of the FERRMED Wagon Concept. For the TOFW-wagon it remains to be investigated whether the CFCB can be built into the bogie with the smaller wheel diameter, as it is necessary for this wagon design.

Additionally, and following the EU Directives TSI NOI and TSI WAG, the FERRMED Wagon concepts should utilise silent brake blocks as braking friction elements, namely K-blocks (nowadays) and LL-blocks from 2013 onwards (estimated). By this, allowed limits for pass-by noise of wagons should not be exceeded.

6.2.5 Coupling

Today's screw couplers are a critical and often limiting component when it comes to train weight. The heavier a train is the higher the longitudinal forces that appear when this train goes uphill, which can compromise the coupler resistance of the first wagon.

The maximum possible weight of a train with screw couplers is around 2000 gross tons[7]. That means for example that a full tank wagon train with 22 wagons and 2000 tons gross weight could not be further enlarged although its length is still below the maximum length limit for trains on many railway lines in Europe and even far below the length limit according to the FERRMED Standards. A common solution to that problem is to introduce a rear locomotive for pushing the train upwards and thereby reduce the tensions on couplers. However the locomotives on the train have to be manned or the rear locomotive needs to be controlled by an uninterrupted Radio Control system, which has not been homologated yet in Europe.

The introduction of automatic central buffer couplers lead to a simplification of the coupling and uncoupling processes. Since they transmit both tensile and compressive forces there is no need for side buffers; the compressive force is transmitted centrally into the wagon body. The maximum possible tensile and compressive forces are considerably higher than in the case of screw couplers, allowing trains with a gross weight in excess of 10.000 tons.

In other countries of the world, such as USA, Russia, Japan, China and Australia, automatic central buffer couplers became the standard long time ago. In Europe there have been various attempts and technological developments, but the introduction of a new system has - with exception of few isolated operations - never happened. The main reason for this has been the high cost to convert approximately 600.000 wagons in Europe and the difficulty to get a high number of actors to work together. Hybrid central couplers, which are compatible with screw couplers, do exist, but their current price is far from competitive.

However, automatic central coupling should be an optional feature of the FERRMED Wagon Concept, taking into account the benefits in terms of higher train gross weights and possibilities for automatisation of marshalling operations. Together with an electric power line through the train further benefits can be achieved, such as automatic brake tests and electro-pneumatic braking, features which would facilitate even the introduction of longer trains. Furthermore the power supply could be used for monitoring purposes as well as to feed electric power to specialized wagons, e.g. for refrigerated transport.

6.2.6 Reduced tare weight

A reduced tare weight can contribute to an increased loading capacity of a wagon and to lower operating costs.

The loading capacity of a wagon is determined by infrastructure parameters and wagon parameters. Relevant infrastructure parameters are the maximum axle-load and the maximum meter-weight of a line. The relevant vehicle parameter is the tare

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[7] Considering gradients of 2,5%, as on the new railway line Barcelona-Perpignan

weight of the wagon. Any reduction of the wagon tare weight is thus a means to increase the loading capacity. A decrease of tare weights can also contribute to lower operating costs of a wagon, due to lower energy consumption to move the dead weight of the wagon.

However, if a reduction of the dead weight is connected with additional costs – e.g. for more expensive light-weight materials – the cost savings in operation have to balance the additional costs.

Experience shows that extra expenses for weight reducing measures in most cases can be justified only if the reduced tare weight can be used to increase the payload of the wagon. A reduction of the tare weight without increasing the payload – though improving the deadweight/payload-relation – is normally not economically justifiable, if the weight reduction is connected with increased expenses. This is illustrated by the fact that the use of aluminium for freight wagons in North America is almost entirely limited to wagons, which carry commodities where the reduced tare weight can be used to move more cargo per wagon (e.g. coal), while other, more light-weight commodities are carried in (heavier) steel wagons, though these wagons in principal could be built using aluminium as well. Thus, under today's conditions, a driving force towards reduced tareweight is in first hand the possibility to increase payload rather than the weight-saving in itself.

As illustrated in the figure below the highest benefits of decreased tare weight is achieved if the weight can be reduced without increasing costs, and payload can be increased at the same time. If the payload cannot be increased and the measure means higher cost it is difficult to justify the investment. Rising energy prices may improve the economics of measures to reduce tare-weight in the future.

	Tare weight decrease can be used to increase of payload	Tare weight decrease *cannot* be used to increase payload (low density commodities)
Extra cost for weight saving	+	-
No extra cost for weight saving	++	+

Fig. 6.10: Profitability of weight-reducing measures; typical situation (own elaboration)

A reduction of wagons tare-weight can be achieved in three ways:

- by using lighter materials, as high-strength steel, aluminium, composite materials or sandwich constructions
- by changes in the wagons construction (structural weight savings)
- by simplification of certain components (e.g. brake system)

Lighter materials are often more expensive, especially when it comes to composite materials and sandwich constructions. These materials can easily be a factor 10 to 100 more expensive than steel, which is still prevailing in freight wagon construction.

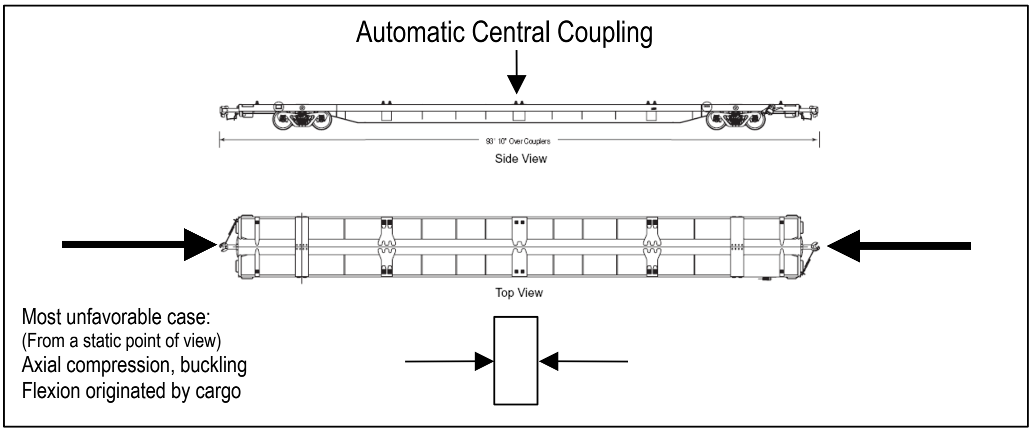
Changes in the wagon construction mean that less material is used, i.e. the material costs decrease. This means that from a cost perspective approach 2 often is more favorable.

Another important aspect, which has to be taken into account is maintainability. Even maintenance tends to become more complicated with more materials built into a wagon.

Thus the most efficient way to reduce a wagons tare-weight is through structural changes. One solution is a centre-beam design instead of the classic side-beam design of today's wagons.

Weight reduction through centre beam design

European wagons have usually a frame-shaped design in order to conduct the tensions originated on the buffers and the screw couplers that circulate along the external rim of the wagon body. Conversely, North American freight cars are usually constructed over a central sill that works basically at compression or traction effort, apart of the flexion effort originated by load, which obviously is present in European wagons too.



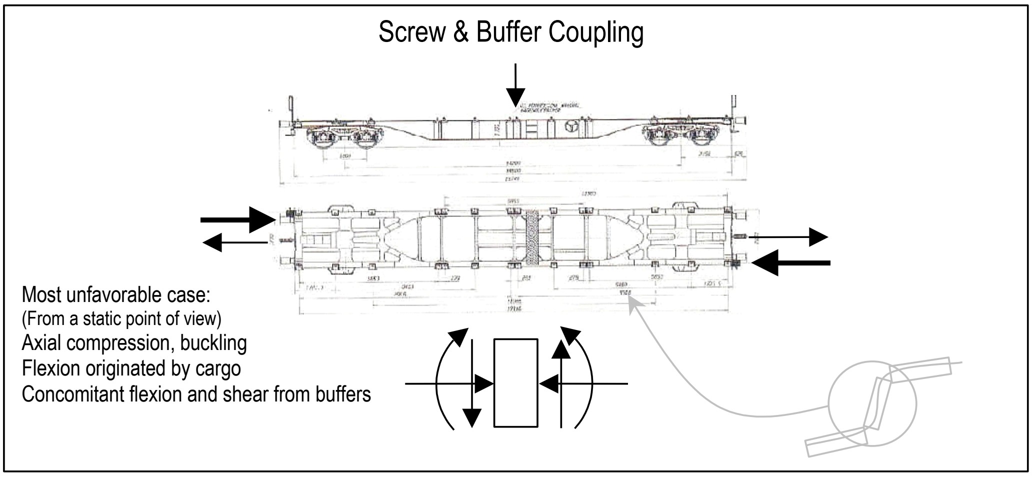
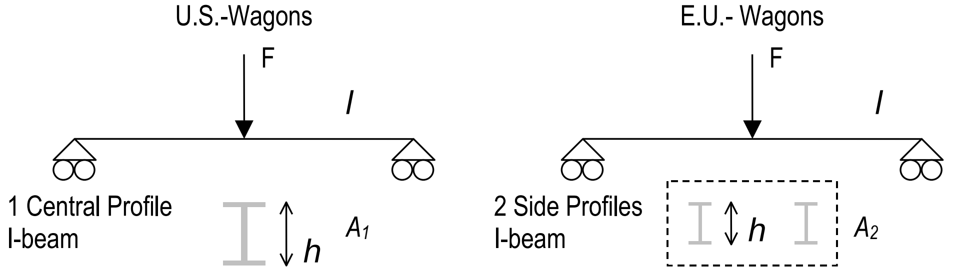


Fig. 6.11 + 6.12: Comparison of North American center-beam design and European side-beam design.

The possibilities of weight reduction on freight wagons using a unique central beam design can be better understood with the following simplified example. It shows that the longitudinal structures on a wagon with a center sill can be up ca. 24% lighter than on wagons side beams.



Max. Admissible Steel Tension $\sigma = \frac{M \cdot h_1}{I_1} = \frac{M}{W_1} = \frac{F \cdot l}{4 \cdot W_1}$

$\sigma = \frac{M}{2} \cdot \frac{h_2}{I_2} = \frac{M}{2W_2} = \frac{F \cdot l}{4 \cdot 2W_2}$

W, Resistance Module of the section $W = \frac{I}{h}\left(\frac{\text{Inertia Moment}}{\text{height}}\right)$

Equalling the expressions σ

$$\frac{F \cdot l}{4 \cdot W_1} = \frac{F \cdot l}{4 \cdot 2W_2}$$

$$W_1 = 2W_2$$

In an I-Beam Profile the relation between the profile cross-area and W (Resistance Module) can be approximated by:

$$A = 1{,}2143W^{0,6018}$$

And after a numerical calculation and a simplification, the relation between the areas is:

$$A_1 ? 1{,}32A_2$$

→ This means that longitudinal structures on wagons with central sill design can be 24% (±1%) lighter than equivalent structures with side beams

Fig. 6.13: Weight saving of center beam design compared to side-beam design.

6.2.7 Electric onboard power supply

Electric power supply on freight wagons becomes in increasingly important issue. There is a need for electric power both for on-board IT-applications as well as other functions, as for example supply to cooling/heating aggregates of reefer trailers or operation of sliding doors in connection with loading and unloading. A need for electric power supply exists both during transport and stationary in terminals.

While the power demand of IT-applications often can be covered by batteries with a long life-time, other functions often require a much bigger power supply.

It lies near at hand to provide electricity – as on passenger trains – with help of an electric line from the locomotive through the whole train. This should also be the final goal for the FERRMED Wagon Concept.

Thus, the following requirements can be formulated for the wagon design:

- Each wagon has to be equipped as minimum with a through cable, so that a power line through the whole train can be created each time a train is build
- The electric connection between wagons (and to the locomotive) is integrated in the Automatic Central Coupler.
- Each wagon has at least one electric socket for stationary power supply at terminals and in yards, when not coupled to a locomotive.

In an initial stage only a few wagons will have an electric power line and it is thus not possible to guarantee that each wagon in a train can be connected to the power line. This situation has to be managed by:

- ensuring that wagons needing electric power (and which are of course themselves equipped with a power line) are always coupled directly behind the locomotive, without being interrupted by a non-equipped wagon

  and/or

- temporarily equipping individual wagons with wagon-bound on-board power generators, e.g. axle-generators or fuel-powered generators. To these wagons further wagons requiring power supply can be attached, so that not all wagons need to be equipped with generators (this assumes that these wagon-groups run in fixed consists)

  and/or

- by loading containers with generators on a train. These power-generation containers would supply the energy to the wagon or a group of wagons

6.2.8 Onboard IT-equipment

There is an increasing need to equip freight wagons with IT, in order to both improve internal planning and operations of the railway companies and to better integrate rail freight in transport customer's logistical IT-systems. Thus users (and suppliers) of information are found within the railway companies, among other partners in the transport chain and among transport customers.

There have been and are several projects going on, e.g. the EU-project F-MAN, to identify and define solutions for IT on freight wagons. This study does not want to anticipate their results, but wants to emphasize the importance of a quick implementation of a European-wide standardized neutral IT-platform. It is also important that this platform comprises both intermodal and wagonload traffic.

6.3 Design I: The Long Multi-Purpose Wagon Concept (LMPW)

6.3.1 Basic considerations

The LMPW-concept addresses in first hand the market for transport of containers and swap-bodies. At the same time it bridges the borders towards conventional wagons. In this way the wagon concept is highly versatile. The basic wagon platform can be adapted to changing market demands during its life-time and be used for both intermodal and wagonload traffic.

Intermodal traffic is characterized by a relatively high share of finished and semi-finished products. Cargo density and/or the stowage factor (the ratio of weight to stowage space) are rather low. This means that actual axle load-limits are today seldom reached in intermodal traffic.

This led to the bearing idea for the LMPW-concept to reduce the number of bogies/axles over a given length, since the bogies/running gears are the most expensive components of an intermodal wagon – both in purchase and maintenance. The consequence is a longer (single-frame) wagon.

With a longer uninterrupted loading platform come also further advantages, e.g. in form of higher degree of freedom in loading patterns for different loading-unit sizes and reduced number of couplers over a given train length, in its turn leading to less slack. Thus a bigger wagon length leads to a number of positive system effects. This also explains why the 80'-container wagon today is the standard in other parts of the world.

In order to avoid as far as possible restrictions for very heavy loading units, which occasionally need to be transported as well, axle-loads can be increased to 25 tons, adding 10 tons of loading capacity to a wagon.

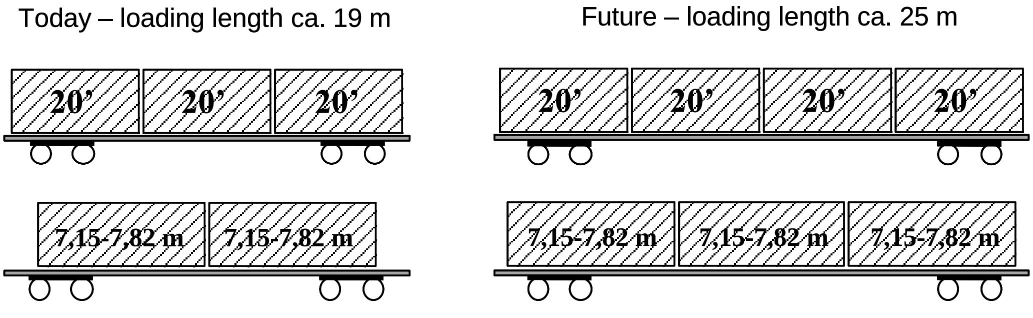


Fig 6.14: The LMPW-concept is based on the idea of longer wagons, reducing the number of axles per given length and giving a higher degree of freedom in loading patterns.

When used in wagonload traffic the wagons can be equipped with (detachable) superstructures, which can be designed according to the specific needs of the customers. In this way a wide variety of wagon types for different types of cargo can be realized on the basis of the wagon platform, e.g. closed wagons, half-open wagons, wagons with stanchions, etc. For natural reasons, the wagons can only be used for commodities with relatively low density. Since there is a trend towards more highly-processed goods in the European transport market and the European freight railways increasingly create services directed at this market segment, the importance of these commodities for the railways is increasing. For the transport of bulk commodities and other high-density cargo, which will remain to be an important market for railways, instead the Heavy-Cargo Wagon (HCW), which is described in chapter 6.4 and also forms part of the FERRMED Wagon Concept, can be used.

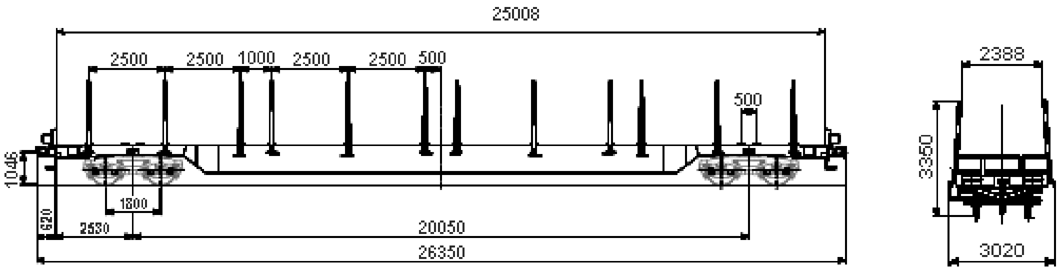
6.3.2 Principal dimensions and key characteristics

Confronted with the task to design a non-articulated extra long wagon for Combined Traffic in Europe certain relations between important parameters of the wagon have to be analysed, namely:

- Tare of wagon
- Available payload
- Loading height
- Distance between bogie centres and distance between bogie centre and buffer head
- Ability of the wagon for being marshalled over a hump
- Minimum curve radius
- Longitudinal dynamics
- Coupling device and its behaviour

An initial formulation of the solution can take as a starting point similar existing wagons.

The Rbns 641 is a 26m long wagon that could accommodate 4 TEUS. For use in intermodal traffic this wagon is still too heavy and the loading height is too high. The newly-build Rbnpss wagon – able to 120 km/h – is similar to the Rbns, but with middle beams instead of lateral ones, it is however even heavier than the Rbns.



	Rbns 641	**Goal for LMPW**
Total length	26350mm	25920mm (-430mm)
Tare of wagon	27t	Less (as small as possible)
Available payload	63t	More (as high as possible)
Loading height	1350mm	1155mm (-195mm)
Distance between bogie centres	20050mm	19620mm (-430mm)
Distance between bogie centre and buffer head	3150mm	3150mm
Marshalling over hump	Yes	Yes
Minimum curve radius	75m	75m

Fig. 6.15: Initial formulation of solution for a LMP-wagon, taking an existing wagon design as starting point.

The problem of having longitudinal dynamic behaviour changed in LMPWs can be solved by borrowing certain dimensions from Rbns, namely:

- Same distance between bogie centre and buffer head. By this, the minimum turning radius, and coupling device behaviour of Rbns are preserved and therefore can be assumed equal for a LMPW
- Same beams' Wx -Resistance Module (cm^3)- than Rbns, to resist bending efforts
- Central Beams and transversal rigging of the frame similar to newly-build Rbnpss to avoid bucking, concomitant with bending and compression efforts

The ability for being marshalled over a hump has to be met by guaranteeing sufficient clearance of the underneath of the wagon over the upper part of the infrastructure. By this the wagon can roll over a hump without rubbing the infrastructure elements under. In the Rbns this distance is about 38cm, which is the distance between the underneath of the side beam of the wagon and the railhead. If considering having middle beams, the clearance can be somewhat relaxed. By this 10cm more of clearance can be gained[8]. The clearance depends naturally on the

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[8] This is because the distance between the railhead and railbase in Rail UIC 54 is about 15 cm

height of the beam, and the latter determines the loading height. Likewise the height of the beam is determined by the bending efforts appearing because of the cargo.

A calculation of the necessary Wx (resistent module for bending effort) of Rbns has resulted in 13400cm^3. This value has been obtained by supposing a very unfavourable punctual load of 70t in the centre of the wagon. The Rbns may achieve the calculated Wx with two longitudinal beams of 90 cm height each. Then so, 38 cm of clearance plus 90cm of beam height plus 10cm of the floor slabs make the nominal loading height of 1380mm.

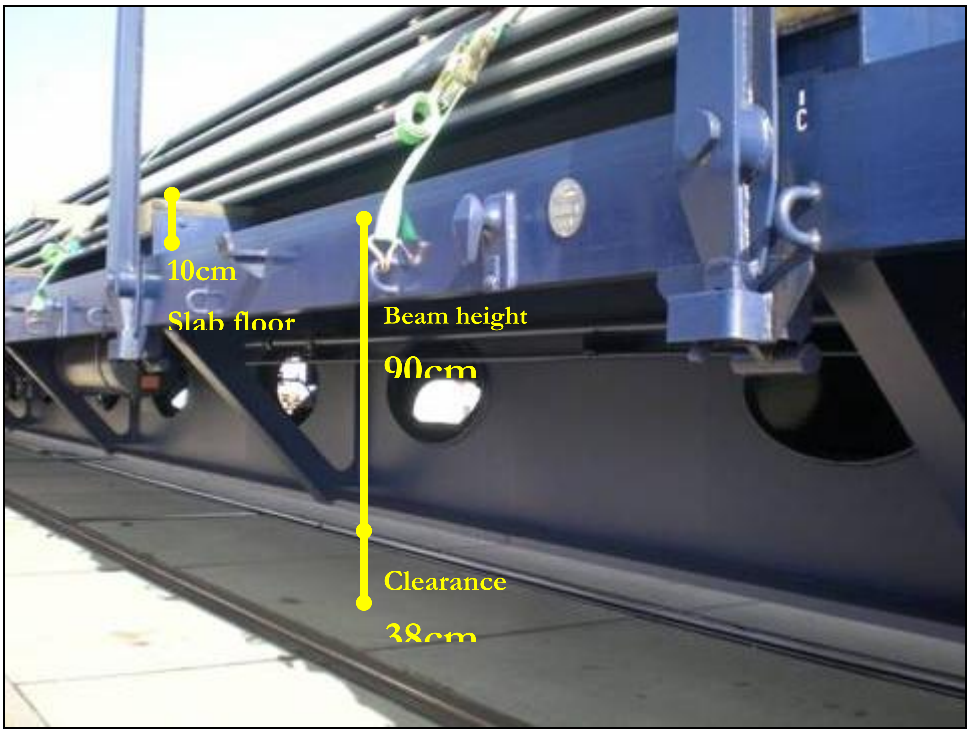

Fig. 6.16: Rbnpss at Innotrans in Berlin (Photo: Sebastien Vincent)

MPWL should not only stand bending efforts but it should be even lighter than Rbns.

A weight reduction can be achieved in the following ways:

- First step is to eliminate the stanchions since they are not necessary for combined transportation. A total amount of 16, each weighing about 80 kg, makes a saving of 1,3 tons
- Slab floor has to be eliminated too, 12 slabs, 76kg each makes a saving of 0,9 tons
- Beams can be castellated[9] to reduce weight. By this, same Wx can be stood with lighter structural elements. A solution should be to castellate a HEA 650 profile into a profile with height 800mm and hexagonal holes in the web. The

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[9] The web of the beam is split lengthwise in a rack-shaped pattern. The halves so obtained are shifted a half-pitch in relation to one another and then welded together at the tops of the teeth. The result is a beam with a row of hexagonal holes in the body.

weight of this beam is 193kg/m, the weight of current Rbns's beam should be 220kg/m. In summary a weight reduction of about 1 ton can be achieved by this measure:

	Wx	t/m	Length	Total Weight
Rbns (2 Beams)	13462	0,440	15,5	6,8
LMPW (2 beams)	14280	0,386	15,07	5,8

The total weight reduction is 3,2 tons, which leads to a first estimation of 23,8t for LMPW tare weight. In spite of that, and for safety reasons, a pessimistic value of 26 tons (tare) has been employed for logistics' related calculations.

Additionally, by using HEA650 castellated beams (h800mm) the loading height can be reduced to 1150mm with no major problems and the marshalling ability of the wagon would be assured. However, more detailed analyses should be necessary in order to determine the exact tare weight of the LMPW at lowest cost.

Further reductions of tare can be achieved by:

- using the Compact Freight Car Brake (CFCB) – see chapter 6.2.4 – giving a weight reduction of ca 1 t
- removing side buffers and using Central couplers, simplifying the frame design in the wagon ends, giving a weight reduction of approximately 1-2 t

Thus, an approximate weight for the FERRMED Intermodal Multipurpose Wagon is

- 24 tons with side buffers and screw couplers (UIC coupling)
- 22 tons with central beam and central couplers

These values can be considered being on the "safe side". Further weight reductions may be possible with new high-strength steels.

The LMP-wagon offers a loading length of 24,5 m, sufficient to carry two 40'-containers. The maximum speed of the wagon is 120 km/h at 22,5 t axle-load and 100 km/h at 25 t axle-load.

The wagon concept foresees the wagon also to be equipped with an electric power line to which several on-board applications can be optionally connected, e.g. for energy supply to refrigeration units on loading units (or the wagon itself), manoeuvring of sliding doors (if equipped with a superstructure) or for onboard IT-applications. Each wagon is also equipped with an electrical socket to allow wagons to be connected to local electricity supply at stations when not connected to a locomotive. The connection of the electric power line between wagons is integrated in the automatic couplers. During an initial phase manual connections may be used. The full system-wide benefits of a electric power supply line through the entire train from the locomotive can first be achieved when the whole wagon fleets is equipped, however. The decision to equip the wagon with an electric power line responds to the increasing demand for onboard application requiring electrical power. This comprises both railway-internal IT-applications as well as applications for customers as mentioned above. While electricity for IT-applications to a certain degree could be provided from on-board batteries, the power demand for other applications is too big for a battery-based power supply.

The main dimensions and key characteristics are summarized in the following table:

Denomination	**LMPW – Long Multi-Purpose Wagon**
Type of goods	Containers, swap-bodies; with superstructures: any light- to medium-density goods
Length over buffers/couplers	25,9 m
Loading length	24,5 m
Distance between bogie centers	19,6 m
Floor height	1.155 mm
Tare weight	24 t
Minimum curve radius	75 m
Max. axle-load	25 t (at 100 km/h) 22,5 t (at 120 km/h)
Couplers	Automatic Central Couplers (with electric power line)
Brake	Compact Freight Car Brake (CFCB)
Electric power supply	Yes, via electric train power line from locomotive and stationary via electric power socket
Other	Can be equipped with detachable superstructures

Fig. 6.17: Key dimensions and characteristics of the LMP-wagon concept.

6.3.3 Loading patterns and capacity

The LMP-wagon offers thanks to its length a higher degree of freedom in loading patterns. The loading length of 80' fits better to the most common container size in port-hinterland-traffic, which is the 40'-container. In Sweden around 80% of all containers in port-hinterland-traffic are 40'-containers. The today prevailing 60'-intermodal wagon makes a high load capacity utilization with 40'-containers difficult. A full utilization of the loading capacity does always require a combination of a 40'-container with a 20'-container (alternatively three 20'-containers, of course). An 80'-container wagon offers more possible loading patterns, and can achieve full loading capacity utilization with 40'-containers alone.

Expressed in TEU the capacity of the LMP-wagon is 33% higher than that of today's 60'-container wagon. Loaded with swap-bodies its capacity is 50% higher, since a 60'-wagon only loads two swap-bodies, while the LMP-wagon loads three.

	Conventional 60'-bogie-container-wagon	FERRMED LMPW-concept	For reference only: 2-axle container-wagon
Axle-load	22,5 t	25 t	22,5 t
Loading length	19 m	25 m +32%	14,5 m
Tareweight	20 t	23 t +15%	12 t
Max. loadweight	70 t	77 t +10%	33 t
Number of loading units			
• 20'-container	3 LU	4 LU +33%	2 LU
• 7,15-7,82m-swap-body	2 LU	3 LU +50%	
Number of loading units per axle			
• 20'-container	0,75	1,00 +33%	1,00
• 7,15-7,82m-swap-body	0,50	0,75 +50%	
Max. load per loading unit (with regard to axle-load only)			
• 20'-container	22,7 t	18,3 t -19 %	16,5 t
• 7,15-7,82m-swap-body	34,0 t	24,3 t -29 %	

Fig. 6.18: Key efficiency indicators of the FERRMED Long Multi-Purpose Wagon in comparison with conventional container wagons

The diagrams on the following pages compare the LMP-wagon with a standard 60'-container wagon and an articulated six-axle 104'-container wagon. As can be seen, when it comes to the number of loading units the LMP-wagon performs better or at least as good as the other wagons. Especially with 40'-containers the LMP-wagon shows a considerably better performance.

When it comes to the number of loading units per axle the LMP-wagon performs in all cases better than the reference wagons.

The maximum payload per loading unit is certainly less, however the loading limit is still so high, that this reduction does not present a severe restriction. In rare exceptional cases, when a very heavy loading unit has to be carried, the number of loading units transported on a wagon can be reduced; thus even very heavy loading units can still be carried on the wagon.

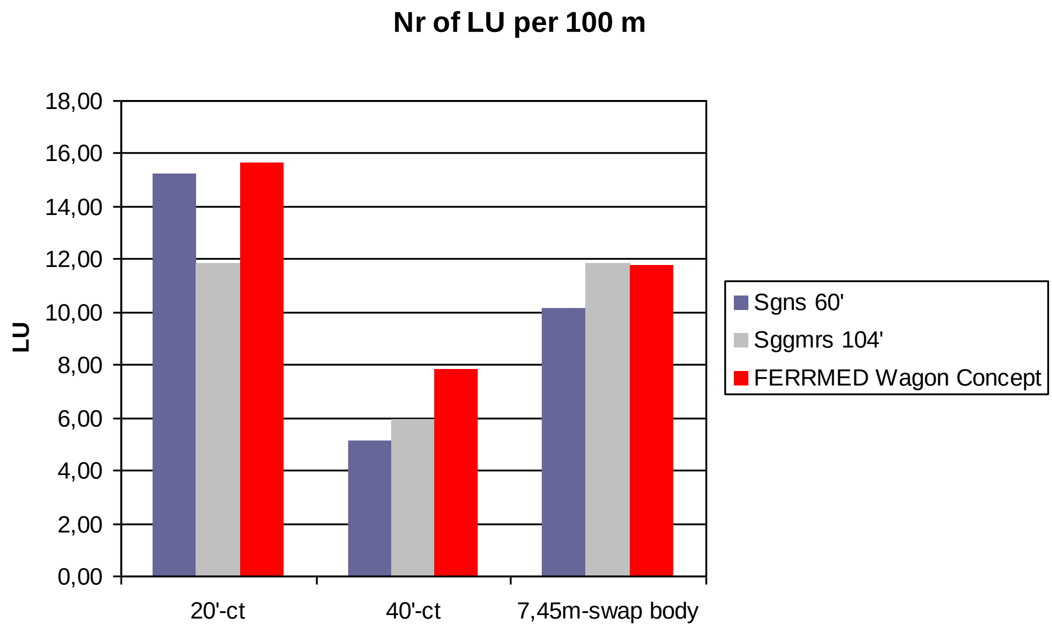

Fig. 6.19: Number of loading units of the FERRMED Intermodal Multipurpose Wagon Concept in comparison with other wagon types (own elaboration)

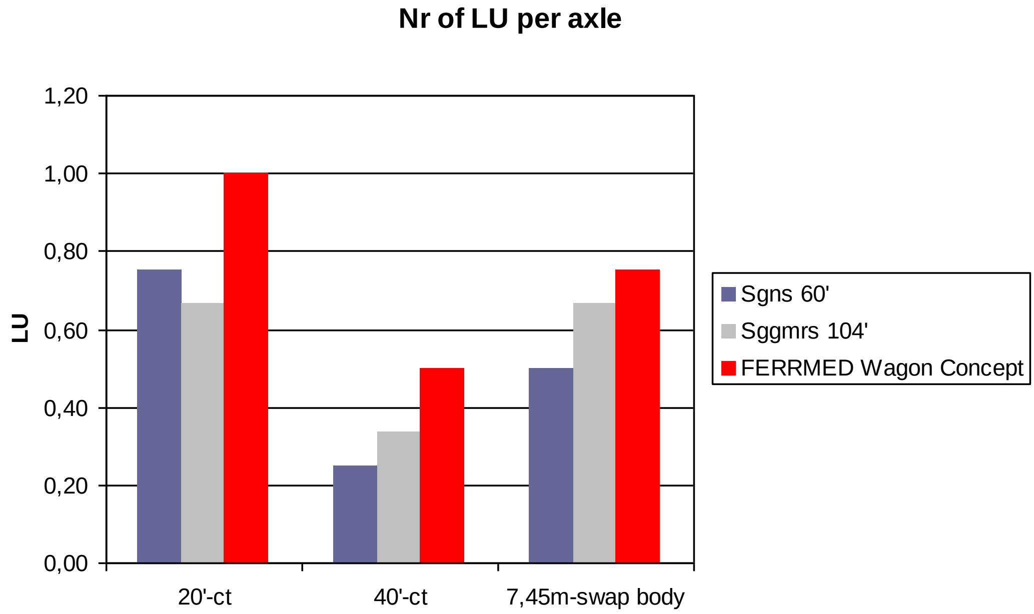

Fig. 6.20: Number of loading units per axle of the FERRMED Intermodal Multipurpose Wagon Concept in comparison with other wagon types (own elaboration)

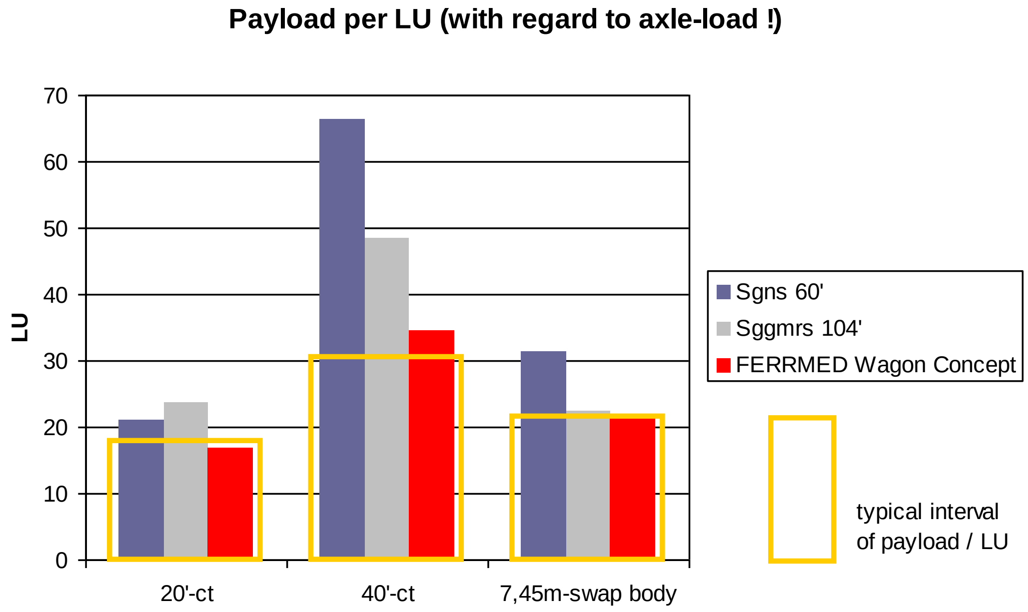

Fig. 6.21: Maximum possible payload per loading unit of the FERRMED Intermodal Multipurpose Wagon Concept in comparison with other wagon types (own elaboration)

6.4 Design II: The Heavy Cargo-wagon concept (HCW)

6.4.1 Basic considerations

The HCW-concept resembles in much the LMPW-concept presented in previous chapter 6.3. The main difference is its shorter wagon length, since it addresses in first hand the market for bulk commodities and other high-density cargo. An optional increase of the axle-load from 22,5 to 25 t is in the HCW-concept used to increase the payload per meter wagon-length (rather than to reduce the number of axles over a given train-length).

Except the shorter length the wagon incorporates all the joint features of the FERRMED Wagon Concept, as Automatic Central Couplers, Compact Freight Car Brake, electric power line for on-board electricity supply, etc. The concept also comprises detachable superstructures to ensure a high versatility and flexibility in daily operations.

With the British class BVA and the Swedish class Sgmmns-w wagons there are already two wagon types, which realize several of the ideas for the HCW-concept (see fig. 6.2.2 and 6.2.3). These two, almost identical wagons are used together with detachable frames (cassettes), which in their turn can be loaded with either steel coils or steel slabs. The cassettes are used on the so-called Steelbridge between Sheffield in Great Britain and Avesta in Sweden in connection with ferry transport over the North Sea and rail transport from and to the ports. In this traffic steel slabs are carried eastbound from the steel-works in Britain to a rolling-mill in Sweden, where the slabs are processed and return in form of steel coils to Britain and other parts of Europe. Thanks to the possibility to transport both slabs and coils on the same wagons they can be loaded in both directions and empty runs are almost completely avoided. The sub-frame of the class Sgmmns-w wagon frame is designed for 30 t axle-load.

The HCW-concept also foresees the possibility to transport containers or swap-bodies, either directly on the wagon or on the cassettes. The latter may offer advantages in connection with ferry transport (certain restrictions for high loading-units may apply, depending on the construction height of the cassette), while the first solution may be applied in other intermodal transport chains. In this way the wagon concept becomes even more flexible and versatile and the HCW-concept can be used for intermodal transports as well. Figure__ illustrates some examples how the HC-wagon can be used. Of course, there is also the possibility for a wide range of other types of detachable superstructures.

Fig. 6.22: Swedish class Sgmmns-w wagon with a detachable cassette loaded with coils (Photo: Kockums Industrier)

Fig. 6.23: British class BVA-wagon – almost identical to the Swedish Sgmmns-w wagon – with the same detachable cassette as in the previous figure, but here loaded with steel slabs (Photo: Kockums Industrier)

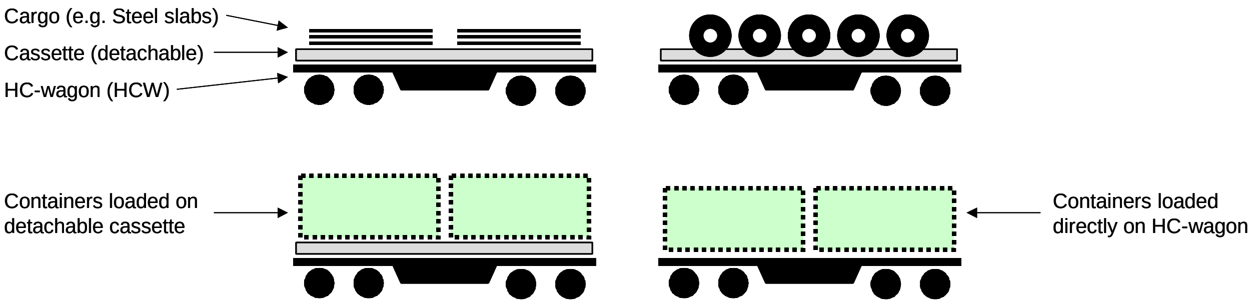

Fig. 6.24: Examples of possible loading patterns in the HCW-concept. The concept also foresees the wagon to be used for transport of containers, increasing flexibility and versatility even more.

6.4.2 Principal dimensions and key characteristics

An exact wagon length is not defined for the HCW, however, since the wagon is intended in first hand for cargo with a high density – as many bulk and break bulk commodities – a typical wagon length will be in the range of ca. 13,5 – 18 meter. Since the wagon is also foreseen to be able to carry standard intermodal loading units, the length should be compatible with standard loading unit sizes.

For very heavy cargo, as steel (in form of slabs or coils) a wagon length of 13,7 m over buffers/couplers appears suitable. This is only slightly more than of the class Shimmns-wagons, which are today used in this traffic, but would allow a loading length of ca. 12,5 m, sufficient for two 20'- or one 40'-container. The dimensions of the Swedish class Sgmmns-w wagon, presented in previous chapter 6.4.1, are in the same range (wagon length 13,9 m).

The tare weight of such a wagon would be ca. 17 ton. At 22,5 t axle-load this would give a load limit of 73 t and a total meter-weight of 6,57 t/m, which means that the wagon can run on line-class D3 (maximum meter-weight 7,2 t). If a superstructure in form of a cassette as shown in chapter 6.4.1 is used the tare-weight of it has to be deducted from the load limit to obtain the maximum payload. A cassette for steel coils and slabs can be assumed to have a weight of ca. 5,5 t.

At 25 t axle-load the load limit would increase to 83 t and the total meter-weight would be 7,3 t/m, requiring line-class E4 (maximum meter-weight 8,0 t/m).

A slightly longer version of the wagon – for commodities with somewhat lower density – could be 17,2 m long, giving a loading length of 16,0 m, sufficient for two swap-bodies of up to 7,82 m.

The tare weight of this longer version would be around 19 ton, giving a load limit of 71 t and a total meter-weight of ca. 5,3 t at 22,5 t axle-load, which means that the wagon can run on line-class D2 (maximum meter-weight 6,4 t). With 25 t axle-load the load limit rises to 81 t and the meter-weight to 5,8 t, still below the limit for line-class E2.

Floor height of the wagons would be ca 1.150 mm, in line with today's wagon designs. Maximum design speed is 120 km/h at 22,5 t axle-load and 100 km at 25 t axle-load. The Swedish Sgmmns-w wagons, equipped with Y25-TTV bogies, already fulfil this requirement.

The table on next page summarizes the principal dimensions and key characteristics of two versions of the HC-wagon. Of course, the wagon may be build with a different length as well.

Denomination	**HCW – Heavy Cargo Wagon**	
Type of goods	Steel, paper, liquid cargo and other high-density commodities, containers, swap-bodies	
	Version A	Version B
Length over buffers/couplers	13,7 m	17,2 m
Loading length	12,5 m	16,0 m
Tare weight	17 t	19 t
Floor height	1.150 mm	1.150 mm
Load limit	83 t (at 25 t axle-load) 73 t (at 22,5 t axle-load)	81 t (at 25 t axle-load) 71 t (at 22,5 t axle-load)
Intermodal loading units	2 * 20'-container 1 * 40'-container	2 * 7,82 m swap-body 2 * 20'-container 1 * 40'-container
Minimum curve radius	60 m	75 m
Max. axle-load	25 t (at 100 km/h) 22,5 t (at 120 km/h)	
Couplers	Automatic Central Couplers (with electric power line)	
Brake	Compact Freight Car Brake (CFCB)	
Electric power supply	Yes, via electric train power line from locomotive and stationary via electric power socket	
Other	Is assumed to be used together with detachable superstructures/cassettes	

Fig. 6.25: Key dimensions and characteristics of the HC-wagon concept.

6.5 Design III: The Trailer-on-Flat-Wagon concept (TOFW)

6.5.1 Basic considerations

The TOFW-Concept addresses the market for transport of semitrailers on railway wagons in intermodal transport. Of the three dominating types of loading units in intermodal transport – containers, swap-bodies and semi-trailers – the LMPW (Long Multi-Purpose Wagon) as described in chapter 6.3 addresses the transport of containers and swap-bodies. The transport of semi-trailers, however, requires special solutions.

In an ideal situation certainly the LMPW could be used for transport of semi-trailers as well, however, even with a standard floor height of 1.155 mm (the LMPW has a higher floor height due to its length, but could in a shorter version be built with standard floor height) – the same as today's container wagons – a standard 4 m high semi-trailer loaded on it would by far exceed the height of the loading gauge.

Today's solution to the problem is to build wagons with a lowered mid-section between the bogies – so-called pocket wagons – , and to load the semi-trailer into this "pocket" (see figure on next page). In the case of the LMPW this solution was not possible due to the length of the wagon, where a lowered mid-section would have incurred severe operational restrictions (the wagons would not have been able to be humped)[10]. Furthermore the tare weight would have increased considerably as well, since a weight-saving center-beam construction would not have been possible.

It neither has been seen as desirable by the authors to solve the problem of semi-trailer transport on railway wagons with help of a lowered mid-section. The reason for this is that it requires vertical loading and unloading of the trailer, meaning that only specially equipped cranable semi-trailers can be handled. Today less than 5% of the European semi-trailer fleet has this equipment. *Thus, today's solution for intermodal transport of semi-trailers excludes more than 95% of European semi-trailers, drastically reducing the railway's potential market.*

This problem has certainly been recognized and a number of wagon concepts have been developed intended to handle even standard non-cranable semi-trailers (e.g. Moda-Lohr, Flexiwaggon; even the Rolling Highway can be mentioned here, though in first hand intended for accompanied transport of complete trucks). The common denominator – and problem – of these concepts is a highly complex, heavy wagon, which is very expensive in purchase, maintenance and operation. Some of these wagon concepts also require special terminals. Therefore a breakthrough has never come so far for any of these techniques and where there are services in operation substantial subsidies are required.

One important reason for the complexity of wagon concepts developed so far for non-cranable semi-trailers is, that the approach has been to consider the

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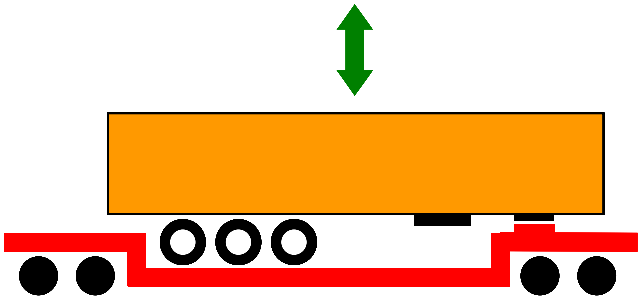
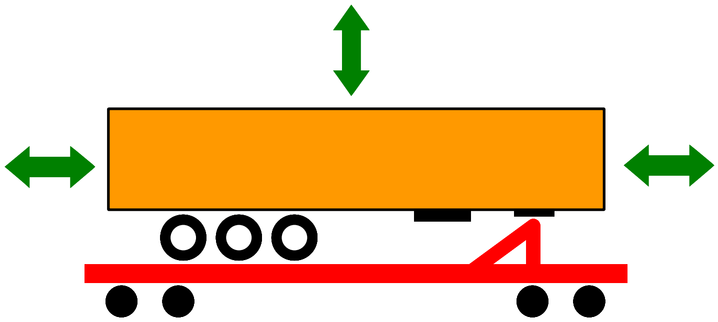
[10] Though it should be mentioned that ca 25 m long single-frame pocket-wagons for transport of two semi-trailers loaded end-to-end existed in Sweden in the 1960-ies and 70-ies. However, these wagons where only allowed to operate on two routes and would not be able to handle today's longer 13,6 m semi-trailers.

infrastructure and its parameters largely as "fixed". The result was, that the necessary space (height) for the semi-trailer had to be won by adapting the wagon – with the known results.



Today – pocket wagon



Future – trailer on flat wagon (TOFW)

Fig. 6.26: Semi-trailer transport today and in the FERRMED Wagon Concept.

The approach chosen by the authors was to let the infrastructure and the vehicle share the "responsibility" for enabling cost-efficient solutions for intermodal transport of semi-trailers.

The first step was to investigate how much the floor height of a wagon could be lowered without needing to abandon a – relatively simple and cost-efficient – two-axle bogie-design and a single wagon frame. The result was that the floor height could be lowered by ca. 35 cm to a height of 800 mm. With this floor height the wagon design could be kept simple, keeping costs low in manufacturing as well as maintenance and operation. No movable parts (except the hatches to support the king-pin of the semi-trailer and standard coupling end beams at end wagons) would become necessary.

After being able to win 35 cm in height by reducing the floor height the next step was to see how much the loading gauge would need to be increased in order to accommodate a standard 4m high semi-trailer. Taking the UIC GC-loading gauge, which already is foreseen in the FERRMED Standards, as reference the result was that it needed to be increased by "only" 18 cm to 4.830 mm (including a margin of 3 cm).

This has been considered as reasonable. The rationale behind this approach is that the implementation of the UIC GC-gauge in any case will require certain adaptations, i.e. works on the infrastructure; it can be assumed that the *additional* investment to increase the loading gauge height ca. 18 cm on selected corridors will be relatively small. It is important to note that this traffic moves on a limited number of lanes and therefore only a limited part of the network will require this additional increase of the loading gauge.

Even terminals can be kept simple and do not require any advanced technical equipment. Furthermore the wagon can easily be build so that it can carry containers and swap-bodies as well.

The new FERRMED Wagon Concept for semitrailers dramatically increases the potential for Combined Traffic in Europe. If only looking at the rail leg of the intermodal transport chain, semi-trailer transport on rail wagons can never be as efficient as containers or swap-bodies, and it perhaps would appear desirable to replace semi-trailers completely by containers or swap-bodies. However, the disadvantages of semi-trailers when transported on rail wagons can often be outweighed by operational and/or logistical advantages in other parts of the transport chain. Trying to eliminate semi-trailers as loading unit in intermodal traffic would therefore probably only in few cases transfer the traffic to swap-bodies and containers, but rather (back) to all-road transport. The use of semi-trailers is specially advantageous in combination with ferry transport.

In the following chapter 6.5.2 the principal dimensions and characteristics of the TOW-wagon are given. Details on the required loading gauge are given in chapter 6.5.3, while terminal-related issues are dealt with in chapter 6.5.4.

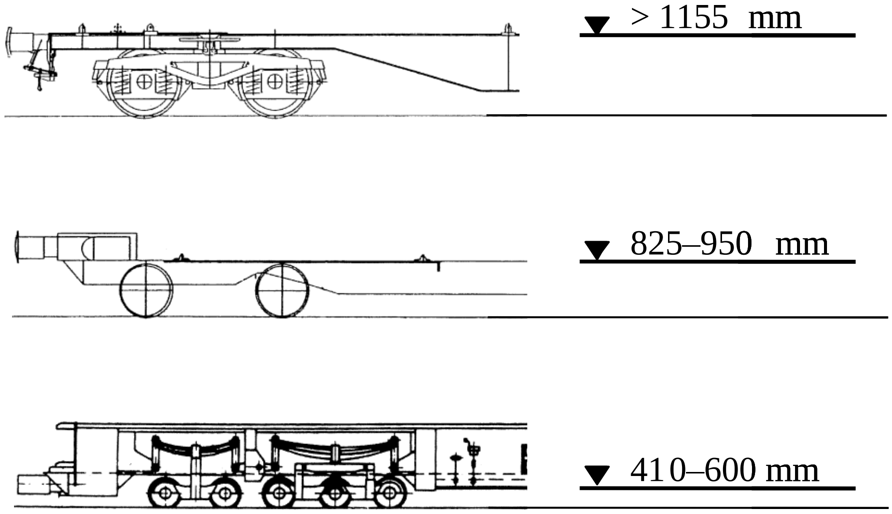


Fig. 6.27: Floor heights of different existing wagon designs. As can be seen that a two-axle bogie design is possible down to a floor height of ca. 80 cm, while a lower floor height – as on Rolling Highway wagons – requires considerably more complex (and expensive) running gears.(own elaboration)

6.5.2 Principal dimensions and key characteristics

The standardized length of a European semi-trailer is 13,68 m. Thus a loading length of ca. 14,7 m would be sufficient for the TOFW-wagon, giving a length over couplers of ca. 15,35 m. With this length the wagon also could accommodate two 20'-containers or two swap-bodies up to 7,15 m.

A longer version would become necessary if trailer-dimensions should increase. Semi-trailer manufacturer KÖGEL has presented a 14,92 m long trailer (Big-MAXX). In order to handle this trailer-length a loading length of ca 16 m would be required, giving a length over couplers of ca. 16,65 m, which is still slightly shorter than the Megafret-wagon presented in chapter 5.4.2 with a length of 18,2 m for one wagon section.

The wagons would run in dedicated trains or wagon-groups and be close-coupled with each other by special low-floor couplers. The ends of a wagon-set have to be equipped with removable standard coupling ends – with either buffers and screw couplers or Automated central couplers – in a similar way as Rolling Highway wagons. Since the wagons can be expected to run in rather fixed formations only the end-wagons need to be equipped in this way. For loading and unloading the coupling ends need to be swung aside.

Fig. 6.28 + 6.29: Standard 13,68 m semitrailer (above) and 14,92 m long prototype semitrailer from KÖGEL. The trailer length defines the length of the TOFW-wagon (Photo: Valerius, Kögel).

The wagons floor height is, as mentioned earlier, 800 mm and kept over the whole loading length. The wheel diameter is 700 mm.

The low wheel diameter demands a lower axle-load than standard wagons with larger wheel diameter. Maximum axle-load is therefore set to 15,5 t at 120 km/h, which gives with a tare weight of 17,5 t (ca. 18,2 t with standard coupler end beams) a maximum load-weight of 44,5 t (43,8 t). This is more than sufficient for transport of semi-trailers, which normally have a maximum weight of about 30-33 t, due to the weight dimensions in road traffic. Thus the maximum axle-load will not be utilized in normal situations when loaded with semi-trailers, however, may be reached when loaded with swap-bodies or containers.

Maximum speed should be 120 km/h, however, loaded with semi-trailers higher maximum speeds of e.g. 140 km/h should be possible.

In the same way as the other wagons of the FERRMED Wagon Concept, even the TOFW-wagon can be equipped with detachable superstructure. This may be an interesting option for very light-density volume cargo, as for example for transport of new cars (with a superstructure with two loading levels).

Compared to today’s solution with semi-trailers carried on pocket-wagons, the TOFW-concept gives a considerably better length utilization with a utilization factor of ca. 90% compared to 75% today (length utilized by trailers / total train length). This also contributes to a better length-utilization of tracks in the terminals – and potentially higher capacity. The wagon tareweight per semi-trailer decreases by ca. 16% from ca. 21 t to 17,5 t. Assuming an average payload of 22 t per semi-trailer and a tare-weight of the trailer of 7 t the payload/deadweight ratio improves from 0,44 to 0,47.

The main dimensions and key characteristics of the TOFW are summarized in the following table.

Denomination	**TOFW – Trailer on Flat Wagon**
Type of goods	Semi-trailers, containers, swap-bodies; with superstructures: light-density volume goods
Length over couplers	15,35 m
Loading length	14,7 m
Distance between bogie centers	11,0 m
Floor height	800 mm
Tare weight	17 t (17,7 t with standard coupler end beam)
Minimum curve radius	150 m in train formation, 75 m as single wagon
Max. axle-load	15,5 t (at 120 km/h)
Maximum load-weight	44,5 t (43,8 t with standard coupler end beam)
Couplers	Special low-floor couplers for connection between TOFW-wagons Movable end beams with Automatic Central Couplers (with electric power line) at end wagons
Brake	GP-A-K
Electric power supply	Yes, via electric train power line from locomotive and stationary via electric power socket
Other	Can be equipped with detachable superstructures

Fig. 6.30: Key dimensions and characteristics of the LMP-wagon concept.

6.5.3 Loading gauge for TOF-wagons

Figure 6.31 shows different loading gauges in Europe. Generally loading gauges in the South and South-West of Europe (mostly UIC GB-gauge) are more restrictive than in Central and Eastern Europe. In case of new-built or upgraded lines normally the UIC GC-gauge (marked in grey in figure below) is applied. The GC-gauge also forms part of the FERRMED Standards.

The most generous loading gauges in Europe are – apart from the "broad gauge-countries" in Eastern Europe – today found in Sweden, which has started to implement a 3,6 m wide and 4,83 m high loading gauge. This loading-gauge is today utilized by unit trains with intermodal rail-sea loading units regularly running between six inland paper mills and the port of Gothenburg (see chapter 5.5.3). An important feature of the Swedish C-gauge is that is has no corner-height restrictions, while the historically inherited loading gauges have their corners "cutted" in the upper edges, making it difficult to fully utilize both the maximum width and height at the same time. This circumstance limits especially the possibility to design covered wagons and loading units utilizing the height and width of the loading gauge.

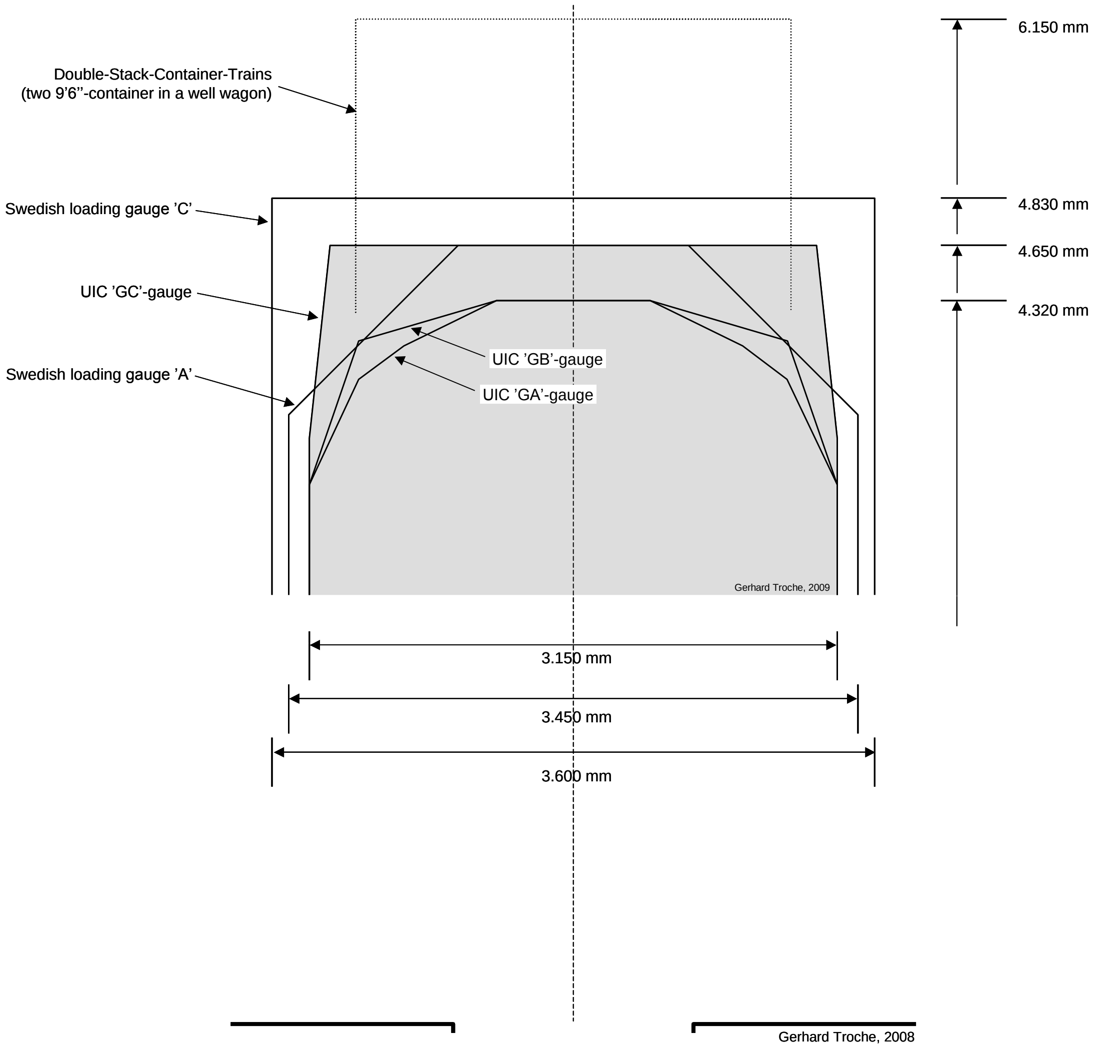


Fig. 6.31: Comparison of different European loading gauges (own elaboration)

The figure below shows in grey and with a solid red line the UIC GC-gauge from the previous figure. In light grey and with a dotted red line an extended loading gauge is marked, which is necessary to introduce the TOFC-concept according to chapter 6.4 with 4 m high semitrailers on 80 cm high flat wagons. This extended loading gauge can be seen as a combination of the Swedish C-loading gauge, with which is has the height in common, and the UIC GC-gauge from which is has taken the width.

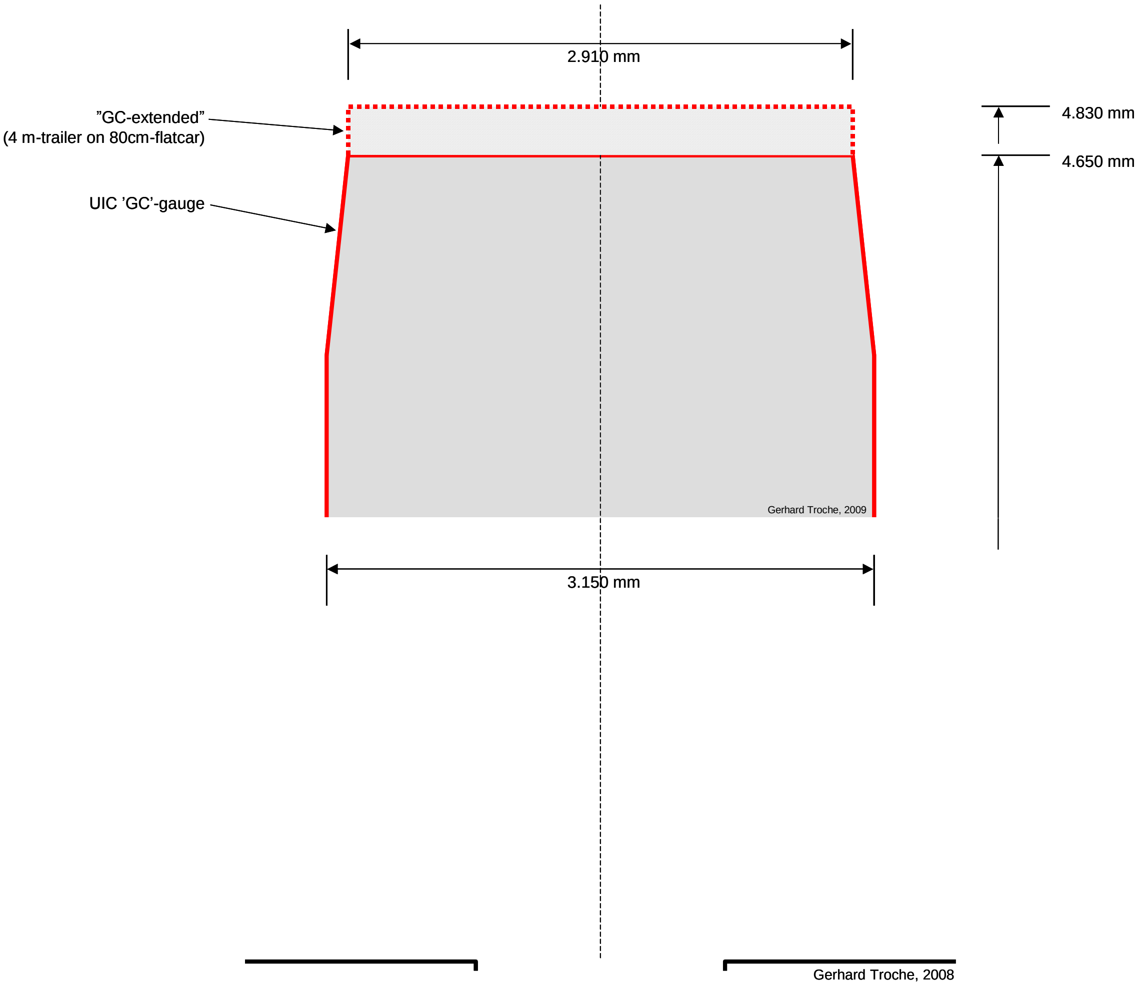


Figure 6.32: Loading gauge UIC GC and suggested extended loading gauge "GC-extended" for TOFC-operations (own elaboration).

This compromise recognizes the fact that it would be very difficult to implement a loading gauge with the same width as in Sweden on a European level, taking into account existing track distances and structures along the railway. It has however been considered reasonable to slightly increase the loading gauge height by ca. 180 mm on a network of selected corridors.

The rationale behind this approach is, that it will be most likely in any case necessary to carry out certain work on the infrastructure to create the clearances for an implementation of the UIC GC-gauge, which forms part of the FERRMED standards. Thus there is already a certain, fixed cost connected to the implementation of a larger loading gauge as laid down in the FERRMED standards. It is likely that the additional cost – i.e. the portion of the cost variable with the amount of the increase – on many corridors is *relatively* low.

The authors want to underline that the extended gauge as suggested here does not need to be implemented on the whole FERRMED network, but only on selected corridors. Of special interest in this context are not least corridors with important trailer flows from and to ferry ports. The authors are also aware of that decisions on the implementation of an extended loading gauge have to be foregone by careful analyses and that a case-by-case decision will be necessary. However, we want to suggest that the implementation of a slightly higher loading gauge than the UIC GC-gauge should be investigated in every case, based on analyses of demand and infrastructural conditions. Otherwise there is a risk of missing the chance to achieve a larger loading gauge at relatively low cost and loose the positive system effects it can give for intermodal traffic.

6.5.4 Loading and unloading the TOF-Wagon

The competitiveness of intermodal transport chains is not only determined by the efficiency during rail transport, but also by the efficiency in terminal handling and pre- and post-haulage on the road. While the pre- and post-haulage does not have direct implications on the wagon design the loading and unloading of the loading units to and from the freight wagon has and requires therefore special attention.

Trailers are today loaded and unloaded vertically by crane or reach-stacker with help of spreaders (see fig. 6.33). The TOFC-concept is fully compatible with this handling technique. This means that trains with TOF-wagons can be handled in all today existing terminals without any changes of terminal equipment or working routines. All current intermodal semitrailers can also be loaded, unloaded and transported on the TOF-wagons without restrictions.

Fig. 6.33: Loading of a semitrailer onto a rail wagon by reachstacker with help of spreaders. The trailer needs to be equipped with side gripping pockets. Only

ca. 5% of semitrailers in Europe have this equipment. (Photo: Port Logistics Ltd.)

However, as has been pointed out before, this vertical transshipment process requires a special trailer design with reinforced structure and with side gripping pockets. The fundamental idea of the TOFC-concept is just to avoid the need of specially equipped semitrailers.

The TOF-wagons are intended to be loaded and unloaded horizontally with help of Terminal Tow Tractors – even called Tugmasters, like they are used today in large numbers in ports for loading and unloading semitrailers onto and from RoRo-ferries (see fig. 6.34 and 6.35). Thus the TOFC-concept does not require the development of new transshipment techniques but relies on well-proven equipment.

Fig. 6.34: Tugmaster or Terminal Tow Tractor used for handling of semitrailers in ports and for loading / unloading of RoRo-ferries (Photo: Port Logistics Ltd.)

Fig. 6.35: Tugmaster or Terminal Tow Tractor used for handling of semitrailers in terminals and ports (Photo: MAFI GmbH)

A critical question, when applying this loading and unloading solution is the time needed to load and unload a trailer and to load and unload a whole train. A precondition, which has been set is that a train can remain intact in the terminal (this precondition earlier wagon designs for horizontal loading of trailers failed to fulfill).

There are several methods possible to manage the loading and unloading in terminals. The most simple form would be to attach a (movable) head-end ramp to one end of the train and to load and unload the trailers via this ramp (see fig. 6.36). A variation of the method would be to use a side loading quay at the end of the train in combination with a platform wagon, which would have to be attached to the train in order to be able to load/unload the last trailer on the train. These solutions mean that the trailers would be loaded serially; it would take relative long time to load/unload longer trains, since the Tractor would need to go forth and back on the train to handle one trailer. No other trailer can be handled during this time. For this reason these solutions, are only practicable in small terminals with few trailers to be handled and preferably rather short trains. Here they can offer a low-cost solution to operate a minor terminal.

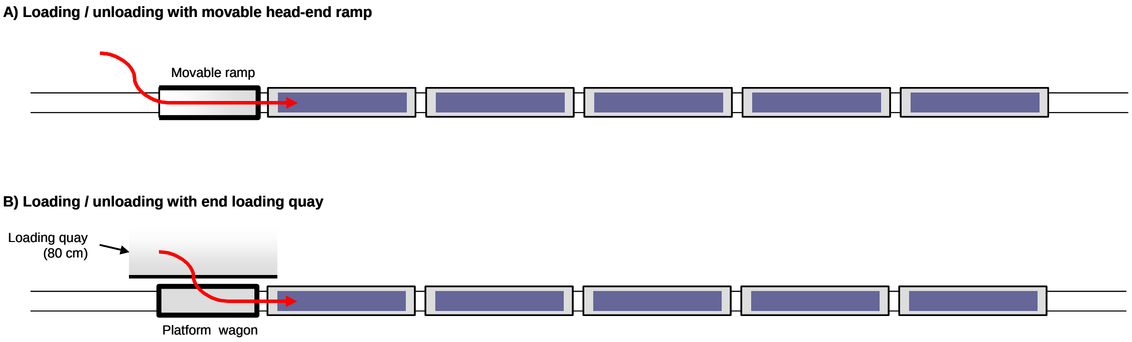


Fig. 6.36: Method A and B: Loading / unloading of TOFC-train via movable head-end ramp or side end loading quay and platform wagon (own elaboration)

As standard solution, however, the authors suggest to build a side quay along (at least one side of) the loading track over the whole train length (plus one trailer length on each side for handling the first/last trailer on the train) (fig. 6.37). The quay must have the same height as the wagons (80 cm). With this solution the trailers can be placed on the quay close to their position on the train and then be loaded with short movements, drastically reducing the time needed to handle one trailer and consequently also drastically shortening the time to handle a whole train. For unloading the procedure would be carried out vice versa. A train could also be loaded and unloaded in sequences, however, in order to allow handling of the last/first trailer in each sequence it would be necessary to keep free one wagon between each sequence. With modern IT-planning tools this should be possible to manage.

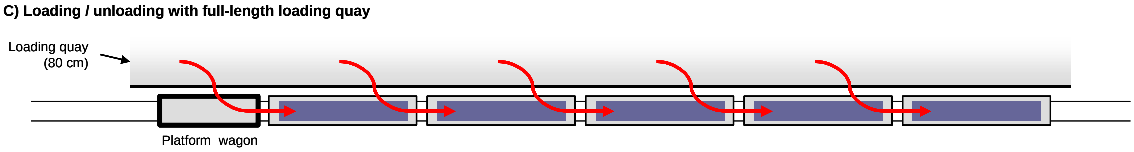


Fig. 6.37: Method C: Loading / unloading of TOFC-train via full-length loading quay (and platform wagon for loading / unloading of last wagon) (own elaboration)

If trailers are loaded/unloaded from both ends of the train, all wagons can be loaded without the need to have an empty wagon in the middle (it is assumed that the trailers face from middle of the train to the nearest end of the train). This solution should be considered in case of long trains. The handling time for a whole train could be halved in this way.

It should be emphasized that the existence of a loading quay on one or both sides o a loading track does not need to interfere with the possibility to handle loading units even with crane, reachstacker or forklift, since containers are put down and taken up to/from ground level already today. Thus, even containers and swap bodies could be handled in the same terminal (and if necessary at the same train).

7 Evaluation of FERRMED Wagon Concept

7.1 Existing situation versus optimal wagon fleet

This section describes the potential benefits a FERRMED Wagon Concept should have in respect to current situation. The evaluation focuses on the Long Multi-purpose Wagon (LMPW), since this wagon represents the most different design compared to existing wagon designs. The HCW is rather similar to existing wagon designes and the TOFW covers a market niche – though an important one. The LMPW can thus be expected to be the most important contribution the FERRMED Wagon Concept can give to the future development of the European rail freight wagon fleet.

A simulation model and a scenario thereto have been developed. As FERRMED strives for a European macro-scale corridor promotion it is necessary to consider the whole west European Intermodal market as scenario for the evaluation.

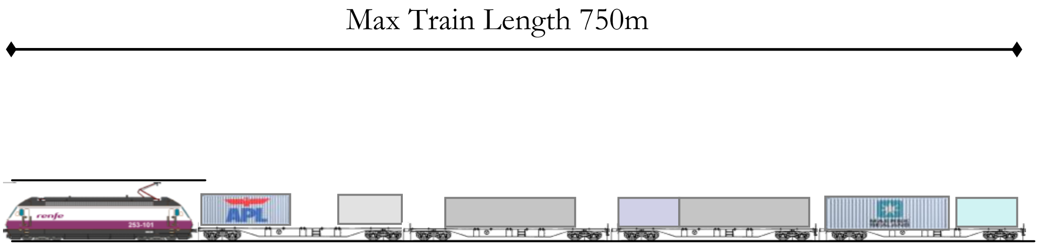
As understandable, the whole European intermodal transport market is a system which complexity makes it difficult for a whole modelling and simulation. For that reason the calculation on performance has been rationally simplified in order to narrow down the variability on results and at the same time to enable reaching valuable and meaningful conclusions.

First of all, it has been defined a reference case to which make a comparison. The reference case synthesizes key European characteristics of intermodal trains and enables to extract some conclusions when comparing it to an idealistic train formed by LMPW (80’) wagons.

The following criteria have been adopted for establishing a reference case, a reference train with:

- A maximal length of 750m
- A capacity of 100 TEU
- A distribution of loading units based on the average European container, swap body and semitrailer distribution, assuming the values according to figure 7.2.

- A wagon formation based on the obtained typical wagon split of European intermodal transportation, see figure 7.3.



Capacity = 100 TEU
Loading Unit Schema = European Average
Wagon Scheme = European Average

Fig.7.1: Reference train for evaluation of the FERRMED Wagon Concept (own elaboration)

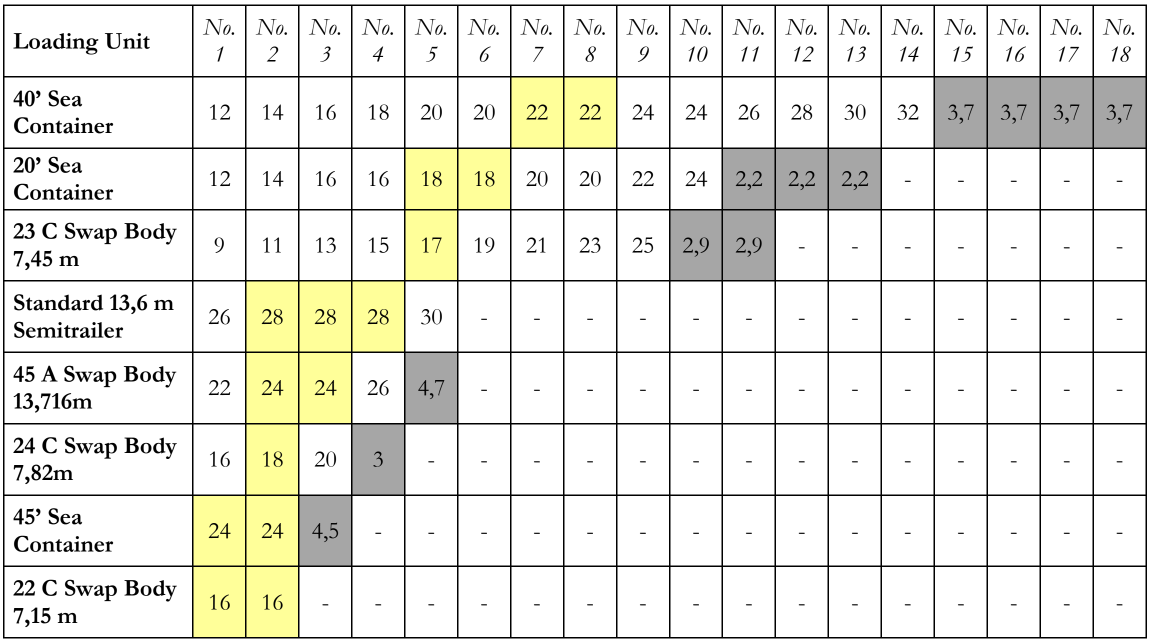
Loading Unit	**Equivalence in TEU**	**No. Units** (100 TEU train)	**% Empties**	**Average Weight** (Loaded, Gross Tons)	**Max. Weight** (Gross Tons)	**LU Weight Distribution** X~$N(\mu,\sigma^2)$
20' Sea Container	1	13	20%	18	24	N(18,16)
40' Sea Container	2	18	20%	22	34	N(22, 49)
45' Sea Container	2,3	3	30%	24	36	N(24, 49)
22 C Swap Body 7,15 m	1,2	2	20%	16	26	N(16, 36)
23 C Swap Body 7,45 m	1,25	11	20%	17	27	N(17, 36)
24 C Swap Body 7,82 m	1,3	4	20%	18	28	N(18, 36)
45 A Swap Body 13,716 m	2,3	5	20%	24	30	N(24, 12,25)
Standard Semitrailer	2,3	5	1%	28	32	N(28, 6,25)

Fig.7.2: Loading pattern of the reference train (Sources: UIC, UIRR, Rotterdam Port Authority, Eurostat, Destatis)

Wagon	Wagon Length (m)	Capacity Wagon TEU	Wagon Payload (t)	Nr. of wagons	Wagon Group Length (m)	Wagon Group Capacity (t)
Sgns 691 (60')	19,7	3	70	**14**	276	42,0
Lgns (40')	14	2	30	**7**	98	14,0
Sggmrs 715 (104')	33,9	5,2	104	**5**	170	26,0
Sdggmrs 739 (104')	33,9	5,2	87	**3**	102	15,6
Sgkkms 698 (52')	19,13	2,6	46	**1**	19	2,6
Total				**30**	**664**	**100,2**

Fig.7.3: Train configuration of the reference train (Sources: DB, BTS Kombiwaggon, AAE, United Nations, Internal Knowledge)

The containers and other loading units have a variable weight distribution that in absence of reliable statistics has been supposed Gaussian with different μ and σ^2. The result in loading unit weight and distribution can be visualized below:



Loading Unit	*No. 1*	*No. 2*	*No. 3*	*No. 4*	*No. 5*	*No. 6*	*No. 7*	*No. 8*	*No. 9*	*No. 10*	*No. 11*	*No. 12*	*No. 13*	*No. 14*	*No. 15*	*No. 16*	*No. 17*	*No. 18*
40' Sea Container	12	14	16	18	20	20	22	22	24	24	26	28	30	32	3,7	3,7	3,7	3,7
20' Sea Container	12	14	16	16	18	18	20	20	22	24	2,2	2,2	2,2	-	-	-	-	-
23 C Swap Body 7,45 m	9	11	13	15	17	19	21	23	25	2,9	2,9	-	-	-	-	-	-	-
Standard 13,6 m Semitrailer	26	28	28	28	30	-	-	-	-	-	-	-	-	-	-	-	-	-
45 A Swap Body 13,716m	22	24	24	26	4,7	-	-	-	-	-	-	-	-	-	-	-	-	-
24 C Swap Body 7,82m	16	18	20	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45' Sea Container	24	24	4,5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22 C Swap Body 7,15 m	16	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Fig. 7.4: Loading unit weight on the reference train in tonnes; grey cells indicate empty containers; yellow cells are average weights (own elaboration)

Summarizing, the reference train is a European train with 30 wagons, of which

- 14 are 60' wagons
- 7 are 40' wagons

- 5 are 104’ wagons (not able to carry semitrailers)
- 3 are 104’ wagons (able to carry semitrailers)
- 1 is 52’ wagon (low floor wagon)

Having a nominal capacity of 100 TEUS

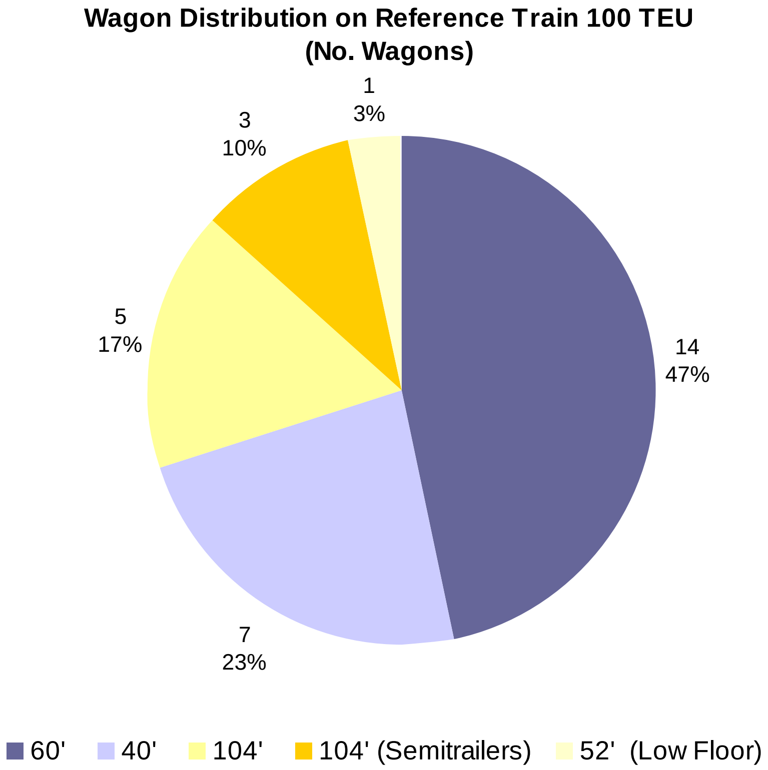


Fig. 7.5: Wagon distribution of the reference train for 100 TEU (own elaboration)

And the average European loading unit distribution corresponding to 100 TEU:

- 18 ISO 40’containers (equivalent to 36TEU, 4 empty)
- 13 ISO 20’containers (equivalent to 13 TEU, 3 empty)
- 11 swap bodies of 7,45m (Equivalent to 13,75 TEU, 2 empty)
- 5 standard semitrailers (equivalent to 11,5 TEU, no empties)
- 5 swap bodies of 13,716m (equivalent to 11,5 TEU, 1 empty)
- 4 swap bodies of 7,82m (equivalent to 5,2 TEU, 1 empty)
- 3 ISO 45’ containers (equivalent to 6,9 TEU, 1 empty)
- 2 swap bodies of 7,15m (equivalent to 2,4 TEU, no empties)

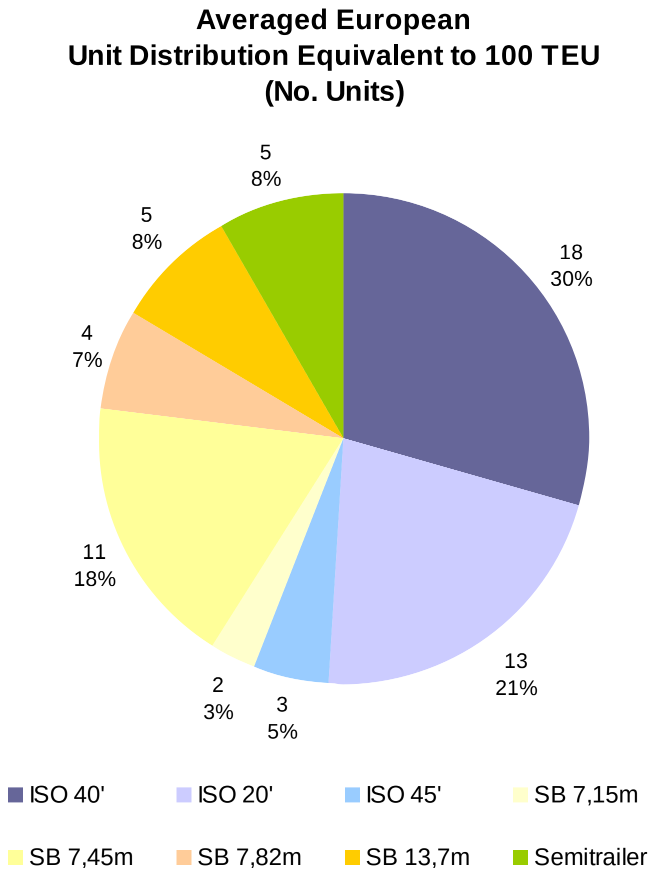


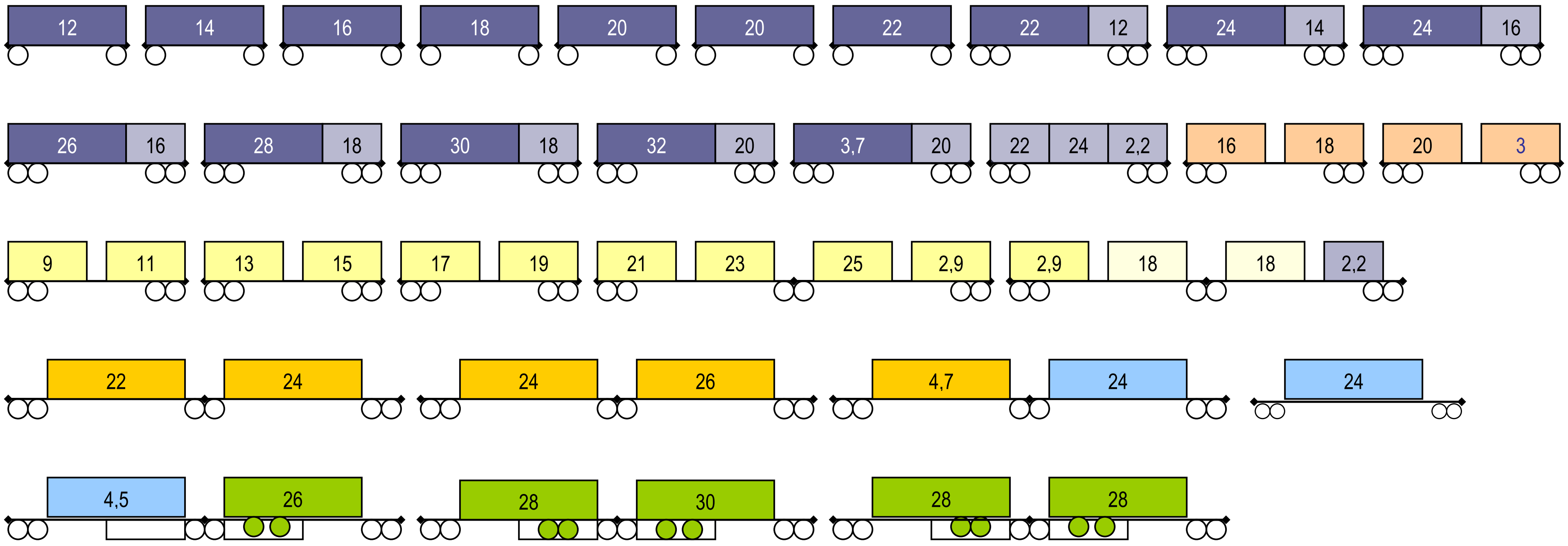
Fig. 7.6: Average European Unit Distribution Equivalent to 100 TEU (own elaboration).

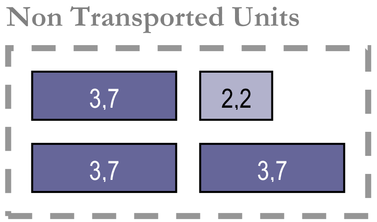
The given amount of units are distributed on the reference train following a loading plan. The loading plan determines which units go in which wagon and where on it. In the current praxis the terminal operator compares the data of loading units - number weight, length, height, dangerous goods qualification, etc.- with the nominal loading schema of the wagons to produce the loading sequence. An additional rule is that loaded units have priority on empty ones. In so doing managers intend to obtain the optimal loading of the train by making efficient use of the available loading length and available payload; this is to achieve a loading factor close to 1.

The reference train has the following properties:

• Nominal volume capacity:	100 TEU
• Length (30 wagons):	664m
• Tare (30 wagons):	657t
• Transported volume:	93 TEU
• TEU Loading Factor:	0,93
• Axles:	122
• Transported TEUs/axle:	0,76

100 TEU of Aggregated Traffic on Reference Train





Figures in loading units indicate weight in tons

Nominal Capacity: 100 TEUs

Train Length: 664m

Tare: 657t

Transported Volume: 93 TEUs

Loading Factor: 0,93

Axles: 122

Transported TEUs/Axle: 0,76

The reference train abandons 4 empty containers on the floor -7TEUs- since they just do not fit on the train. In the normal practice the railway operators would adjust the wagon composition to match the given, or expected, container, swap body and semitrailer incoming share. An optimal adaptation is actually not always possible since the wagon resources are limited, just as their type's share, and in any case the kind and amount of loading units will change from trip to trip. For that reason the proposed distribution and reference train performance should offer a valid reference on macro intermodal European scenario to which a compare an alternative solution, this is a solution with LMPWs (80' Container Wagons).

The LMPW Train is made out of 21 80' container wagons, which has been adapted in order to accommodate semitrailers by adding 3 double pocket wagons. By this the train presents the following characteristics:

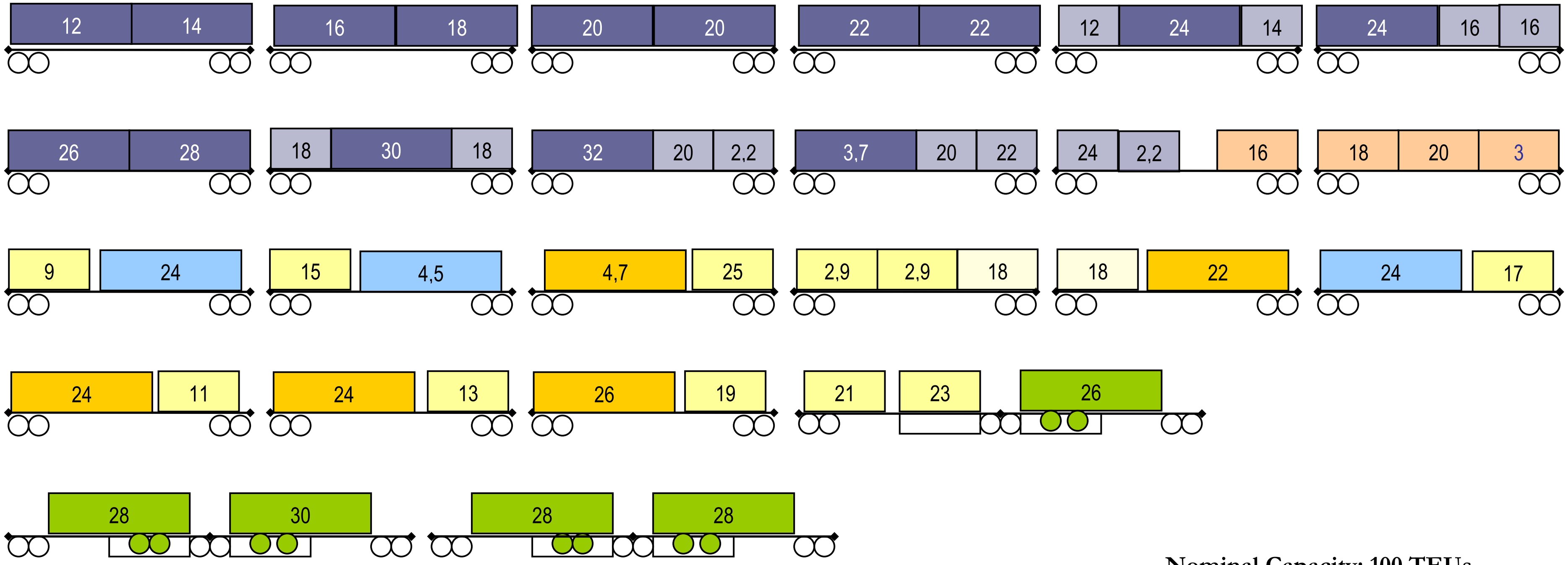
Nominal Volume Capacity:	100 TEU
Length (24 Wagons):	616m
Tare (24 Wagons):	645t
Transported Volume:	93 TEU
TEU Loading Factor:	0,93
Axles:	102
Transported TEUs/Axle:	0,91

In comparison with the reference train a table with the most important differences and advantages can be described:

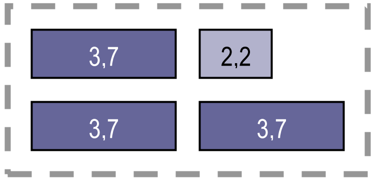
Parameter	**Transported TEU/Length**	**Transported TEU/Tare**	**Loading Factor**	**Transported TEU/Axle**
Reference Train	1	1	1	1
LMPW Train	1,08	1,02	1	1,2
Comments	8% more capacity for a given length means better efficiency of train surface and also more compression of units along the train (aerodynamic advantages, lower friction)	Lighter trains for same amount of TEUS, lower energy consumption (2% save)	The trains offer the same transportation ability over the nominal capacity	16% less axles, this is directly related to maintenance costs of wagons, a very important cost item on railway transporttation, additionally lower rolling friction because fewer axles; potential energy savings

Fig. 7.8: Aggregated Traffic Comparison

100 TEU of Aggregated Traffic on LMPW Train*



Non Transported Units



Figures in loading units represent weight in tons

* With added wagons to meet semitrailer traffic

Nominal Capacity: 100 TEUs

Train Length: 616m

Tare: 645t

Transported Volume: 93 TEUs

Loading Factor: 0,93

Axles: 102

Transported TEUs/Axle: 0,91

The previous comparisons lead to the conclusion that trains with LMPW would perform better than the current European wagon system. In that way, important gains in maintenance of wagons due to fewer axle requirements and decrease on energy consumption are acknowledged.

The comparison can be more precise and undertake different markets areas. For example it can be analyzed the performance on the two main areas of combined transportation, namely:

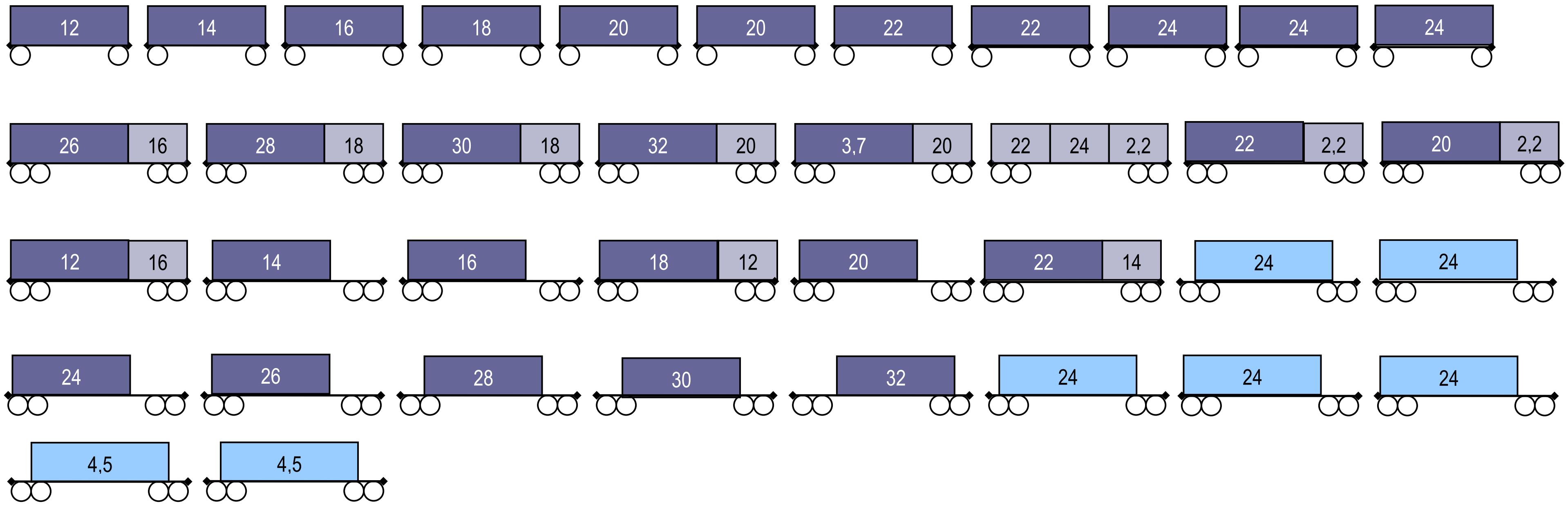
- Rail Hinterland Maritime Traffic
  - Typical ISO container traffic proportion (20'/40'/45')=(23/64/12%)
  - Reference container wagon distribution (40'/60')=(30/70'%)
- Rail Continental Traffic
  - Swap body and semitrailer (ST) distribution (7,15m/7,45m/7,82m/13,7m/ST)=(5/31/12/26/26%)
  - Reference container wagon distribution (104'/104'ST)=(65/35%)

The analyses lead to similar comparison tables:

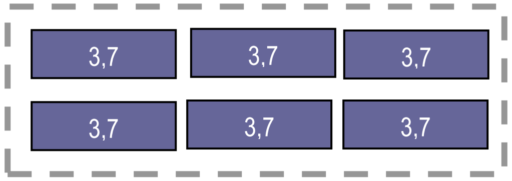
Parameter	Transported TEU/Length	Transported TEU/Tare	Loading Factor	Transported TEU/Axle
Reference Train	1	1	1	1
LMPW Train	1,18	1,04	1,09	1,37
Comments	18% more capacity for a given length means better efficiency of train surface and also more compression of units along the train (aerodynamic advantages, lower friction)	Lighter trains for same amount of TEUS, lower energy consumption (4% save)	LMPW have better utilisation of nominal capacity than conventional trains 10% more; loading factor 0,96, it encompasses better the existing unit load share	20% less axles, this is directly related to maintenance costs of wagons, a very important cost item on railway transportation, additionally lower rolling friction because fewer axles; potential energy savings

Fig. 7.10: Hinterland Maritime Traffic Comparison

100 TEU of Maritime Hinterland Traffic on Reference Train



Non Transported Units



Figures in loading units represent weight in tons

Nominal Capacity: 100 TEUS

Train Length: 666m

Tare: 685t

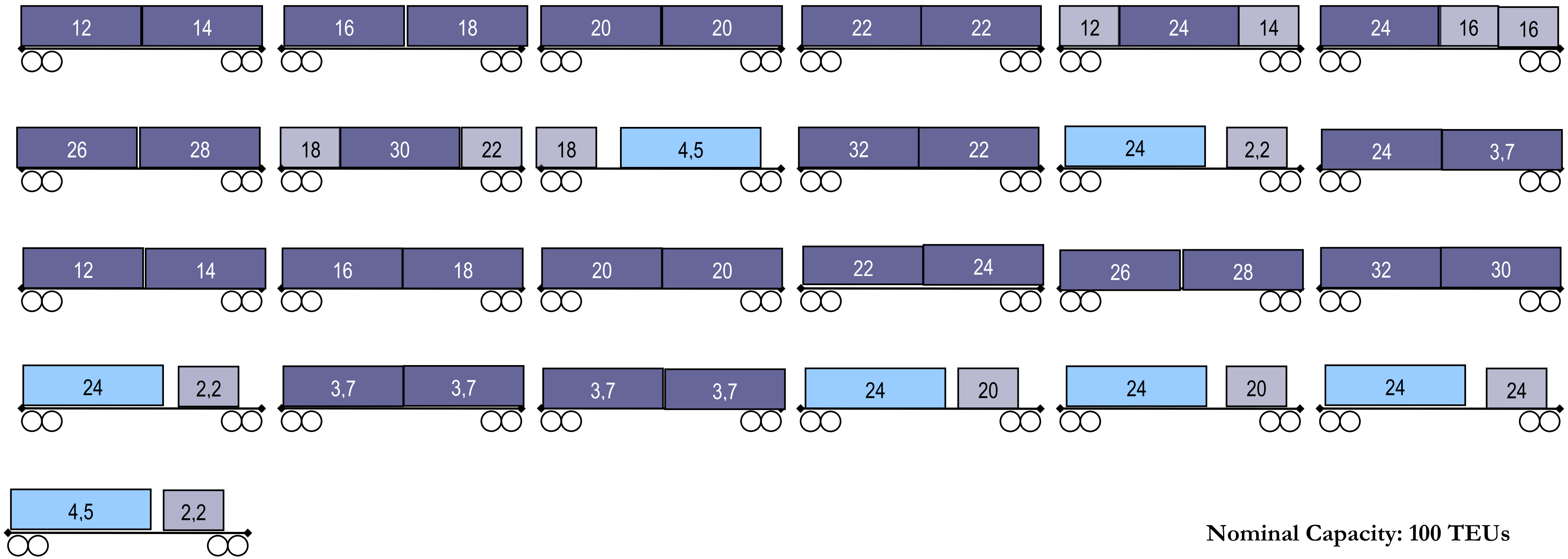
Transported Volume: 88 TEUS

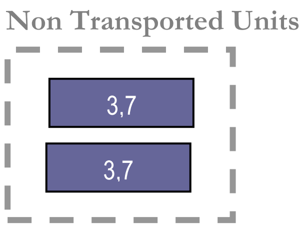
Loading Factor: 0,88

Axles: 126

Transported TEUs/Axle: 0,79

100 TEU of Maritime Hinterland Traffic on LMPW Train





Figures in loading units represent weight in tons

Nominal Capacity: 100 TEUs

Train Length: 613m

Tare: 650t

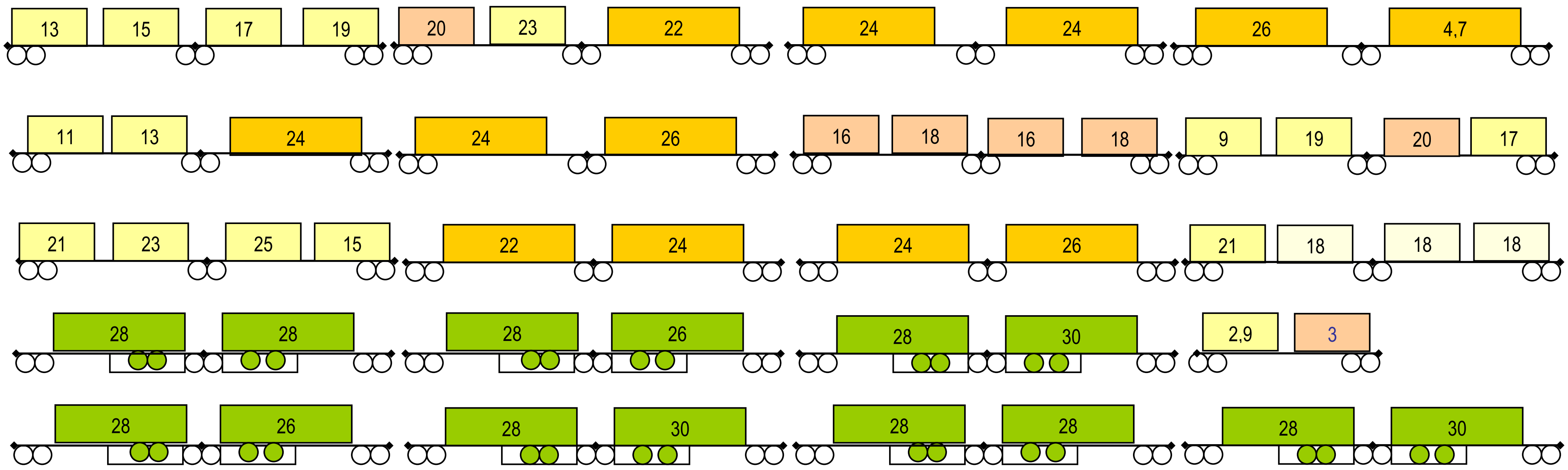
Transported Volume: 96 TEUS

Loading Factor: 0,96

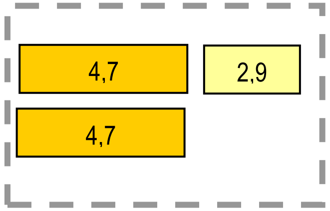
Axles: 100

Transported TEUs/Axle: 0,96

100 TEU of Continental Traffic on Reference Train*



Non Transported Units



Figures in loading units represent weight in tons

* Only with 104’ articulated wagons

Nominal Capacity: 100 TEUs

Train Length: 663m

Tare: 621t

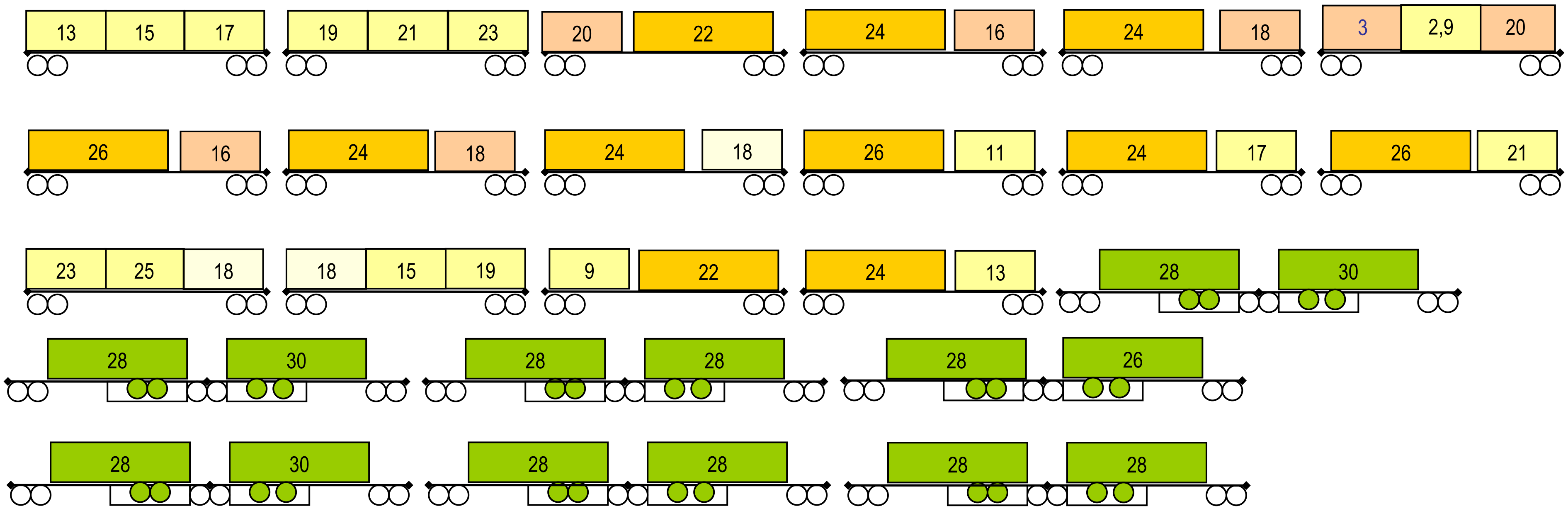
Transported Volume: 94 TEUS

Loading Factor: 0,94

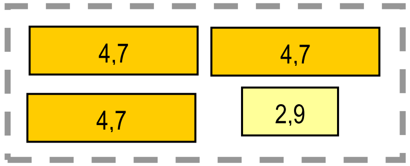
Axles: 118

Transported TEUs/Axle: 0,79

100 TEU of Continental Traffic on LMPW Train*



Non Transported Units



Figures in loading units represent weight in tons

* With added pocket wagons to meet semitrailer traffic

Nominal Capacity: 100 TEUs

Train Length: 629m

Tare: 647t

Transported Volume: 92 TEUS

Loading Factor: 0,92

Axles: 106

Transported TEUs/Axle: 0,87

Parameter	**Transported TEU/Length**	**Transported TEU/Tare**	**Loading Factor**	**Transported TEU/Axle**
Reference Train	1	1	1	1
LMPW Train	1,03	0,94	0,98	1,09
Comments	3% more capacity for a given length means better efficiency of train surface and also more compression of units along the train (aerodynamic advantages, lower friction)	LMPW wagons do not reach in terms of weight the efficiently of 104' articulated wagons, it is also true that articulated 104's are not always available (few number in fleet)	LMPW have lower nominal capacity utilisation than 104' wagons. If the continental traffic has a high amount share of long loading units (45'), the efficiency worsens even more; in spite of that , 53' units could not be transported on 104' but yes on LMPW	10% less axles, this is directly related to maintenance costs of wagons, a very important cost item on railway transportation, additionally lower rolling friction because fewer axles; potential energy savings

Fig. 7.15: Continental Traffic Comparison

The condensed graph of the previous cases looks as follows:

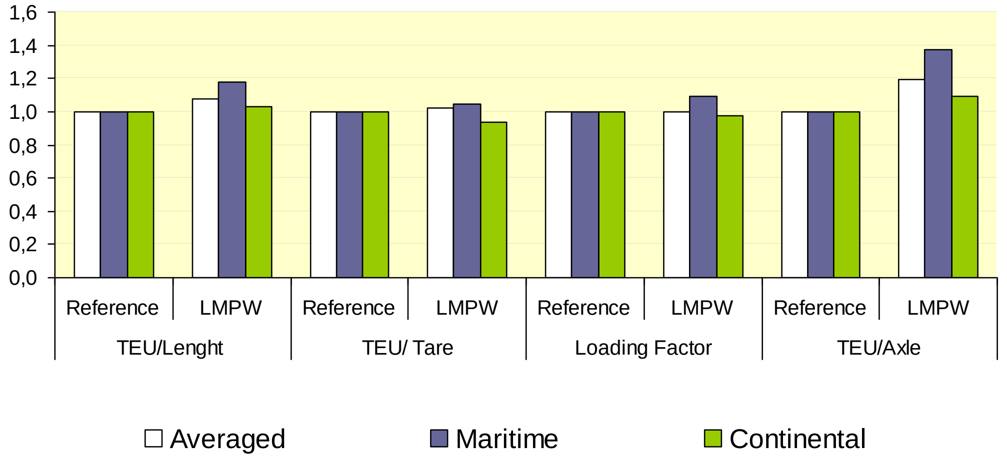


Fig. 7.16: Condensed graph of previous cases (own elaboration)

7.2 Conclusions and recommendations

It has been analyzed to what extent an innovative wagon of 4 TEU loading capacity could contribute to performance enhancement of the main haul between terminals. Since the new wagon concept suits both containers and swap bodies, the investigation is done for hinterland as well as continental traffic. With the consideration of the most often used wagon types and the LMPW different train configurations are formed. In the calculation, the technical data of the various wagon types is analyzed according to loading capacity, weight and their effect on the resulting performance per transported TEU.

The results of the investigation show that the LMPW wagon is especially productive with mixes of loading units of different sizes or small loading units of up to 2 TEU. The transport of only larger units of 2.3 TEU is problematic because it decreases the utilization of the loading capacity available leading to low loading factors. However the transportation of extra long units (53') (Typical of U.S. continental market) is possible and compatible with the current European short swap bodies' lengths.

In the "Aggregated Traffic Unit Distribution" scenario the LMPW train is the most productive train when handling a wide range of different loading units in type and size. It produces the better performance per TEU. This is achieved with

1) a loading factor just a little below the theoretically highest, making good use of the loading capacity,
2) one of the lightest train weights resulting in lower weight dependent costs and
3) the least wagons in a train leading to lower wagon costs. The mixing of LMPW with current wagons enhances the performance too.

In the "Hinterland Maritime Traffic" scenario LMPW is clearly the most efficient solution. The LMPW train has the better performance per TEU for all transportation demands in hinterland traffic. In comparison to the Reference Train the greatest advantage of LMPW lies in the transportation of 40' containers, the higher the share of 40' units the better the efficiency. However, for heavy hinterland traffic with short units (20') the FERRMED train is not the best choice, but neither the 60' container wagon.

Although the FERRMED train does not produce the best performance in the "Continental Traffic" scenario, its performance is significantly better than the 60' container wagons. The 104' articulated platforms are better suited for this market but it needs to be considered that articulated bogie wagons and wagons longer than 60' together have a share of 17 % in the average European intermodal wagon fleet today. The share of the 104' wagon alone is even smaller which restricts its availability. Therefore, the LMPW should achieve good productivity for continental transport demands of either a swap body mix of class A and C or of class C swap bodies only. In case of only transporting class A swap bodies the FERRMED wagon's use cannot be recommended because its productivity is significantly lower than the 60' trains.

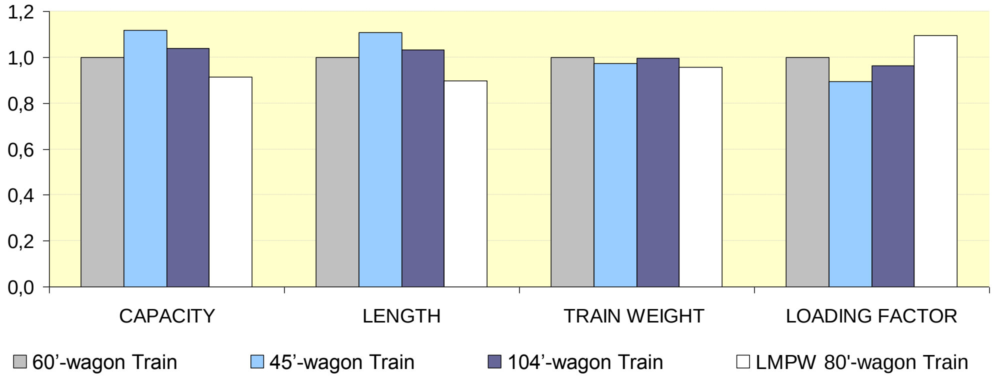


Fig. 7.17: Comparison of key indicators for different train scenarios (own elaboration)

Therefore Long Multipurpose Wagons (LMPW) are indicated for Hinterland Traffic and in Continental Traffic where either only swap bodies class C or a mix of swap bodies class C and A is transported. The combination of better use of the loading capacity and need of fewer wagons in a train should reduce costs significantly. Thus the LPMW wagon would improve intermodal transport, making it more competitive.

It is also important to emphasize that the "Representative European Intermodal" train depicted above does not represent a typical European intermodal train nor has the typical European intermodal loading scheme. This is because the typical European intermodal train and the typical intermodal loading unit distribution do not exist as such, but vary upon the kind of traffic they are addressed to. However, big intermodal operators, wagon leasing companies and railway undertakings must keep a coherent wagon fleet in order to deal with the many markets existing on intermodal transportation. In that context, the example should help to understand why there is such a wagon park in Europe, mainly represented by 60' and 40' wagons, which has been quite efficient so far. It happens as well that in the Russian market there is a similar proportion of 40' and 20' feet wagons being (40'/20'/80') = (66%/32%/2%)[11] having in the recent times a special interest in platforms of 80'.

There is no doubt that logistically 80' wagons are more suitable for container traffics than 60' ones, especially when having higher proportion of 40 feet containers than 20's – e.g. in maritime traffic.

Seen in a wider perspective the FERRMED Wagon Concept reflects a world-wide trend towards longer wagons and higher axle-loads giving higher load capacity per wagon; to this adds higher loading gauges in selected corridors, especially for Combined Traffic, which the TOFW-wagon of the FERRMED Wagon Concept helps to make maximum use of. With optional automatic couplers it opens up for a partly automatisation of rail freight traffic. Optional electric power supply of the wagons benefits both railway undertakings by improving especially braking performance, as well as transport customers by enabling them to operate e.g. cooling equipment with train-bourne electric power.

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