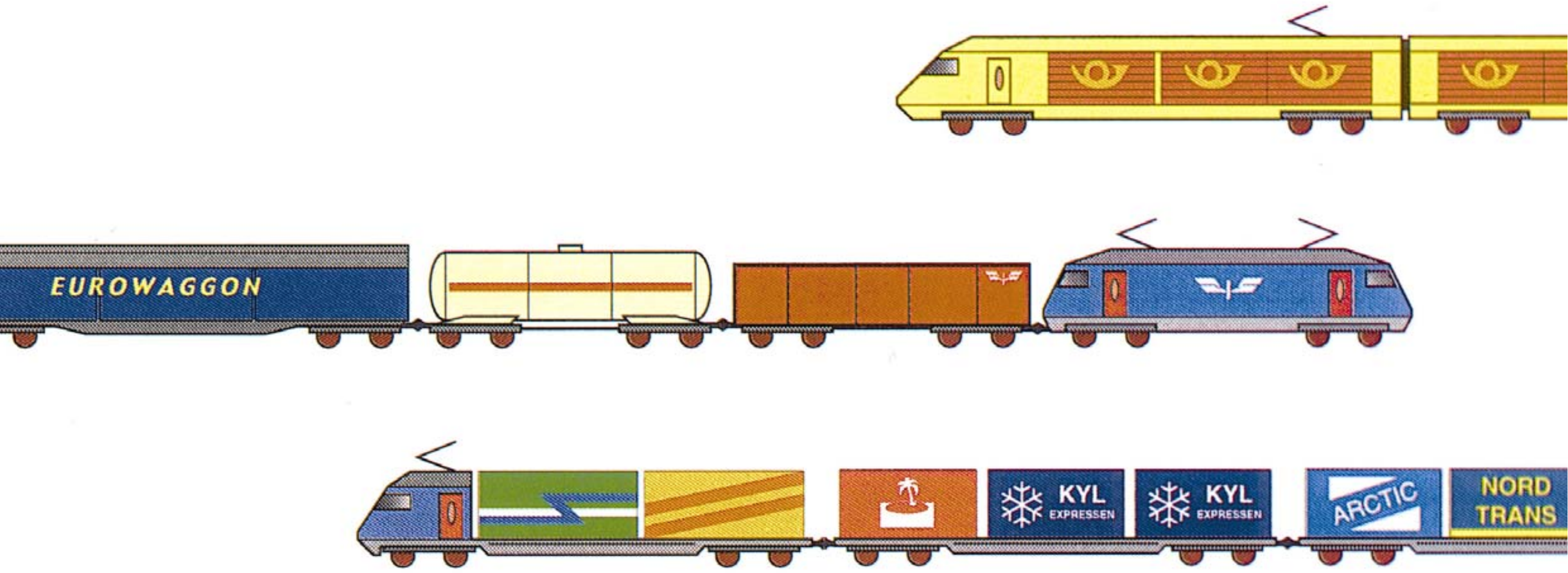
Centre for
Railway Technology

Efficient train systems for freight transport

Summary



KTH Railway Group
Report 0503
Stockholm 2005

KTH Railway Group
S-100 44 Stockholm, Sweden
www.kth.se

Background and purpose

The railways in Europe have lost market shares in an expanding market – almost all the increase has gone to road haulage. This is true of both high-value freight and low-value freight. The railways' position is especially weak when it comes to international traffic, despite long distances and substantial volumes. This is a result of bureaucracy and high track access charges, that make it difficult to control the whole transport chain and guarantee customers adequate quality at competitive prices.

The European Union has proposed a number of measures to deregulate the rail market but these have hitherto only been implemented to a limited extent. The most important measures needed are for infrastructure to be separated from operation, track access charges to be set on the basis of economic principles, and for all operators to be able to compete on the same terms in all countries without bureaucratic obstacles. What is most essential in the short term is for the railways to really be deregulated. This is primarily a question of politics and organisation, rather than a technical issue.

When this has been done, the railways must also develop products, traffic systems, and engineering that permit higher levels of quality and lower transportation costs, and consequently a greater market share. This project has aimed to identify development potential in a long-term perspective. The point of departure was on the one hand the customer requirements in different sub-markets and on the other the possibilities that exist to develop the supply both on the part of the railways themselves and in combination with other modes of transport.

Forecasts for rail traffic in Sweden show that if nothing is done, the railway's market share will continue to fall. If international traffic is completely deregulated and new, efficient train systems developed along the lines presented in this study, the railway's market share can increase from today's level of 24% to 35% by 2020. At the same time as industry's transport costs will be reduced as a result of greater efficiency in the railway's transport systems, the environment will be subjected to less strain, and better prerequisites will be created for long-term sustainable development.

It is important to establish long-term development projects. The operators can not be expected to be able to afford to run such projects themselves; joint action is required from the member states of the European Union. Demonstration projects need to be set up to develop new products. A prioritised European freight network must be established, first organisationally through free access and reasonable track access charges, and then in the engineering perspective through high capacity and interoperability.

First printing 2005
Text and diagrams by Bo-Lennart Nelldal
English translation by Ian Hutchinson
Layout by Maria Thulin
Photographs by Jan Lindahl (p 15), K-industrier (p 18), TFK (p 20), Gerhard Troche (others)

Printed by Intellecta docusys

Railway development in the transportation market

The railway's market share of freight transport in Europe has been halved over the past 25 years, at the same time as the total freight transport market has grown by almost 75%. This means that the railways have not even been able to maintain their transportation volume in absolute figures. The whole increase has gone to road haulage, which has taken market share from both rail and shipping.

Viewed in terms of productivity, Sweden's railways have a market share that is twice that of railways in the rest of Europe, but Sweden also has the largest trucks. The railways' market share of international transport, however, is only half that for domestic haulage despite long distances and large volumes of freight.

The railways in the USA have a considerably greater market share than in Europe and Sweden, and the figure has remained unchanged for some time. The USA differs from Europe in that they have a large market with no national borders and that the railways are not owned by the government or any of the states. In the USA the railways are private, profitable enterprises. They combine large-scale traffic and small-scale traffic and their technical performance level far exceeds anything in Europe. Wagonload traffic is strong and operates in a well-developed network with many industrial sidings, while passenger traffic is marginal.

The restructuring of the European railways has not always meant improvements in international transportation for Swedish customers. The problem is that it is often hard to guarantee transportation times and compete with road haulage. Operators find it difficult to cooperate and do not dare to compete. The deregulation of truck traffic, on the other hand, has brought prices down, which has meant that the railways often also find it difficult to compete on price.

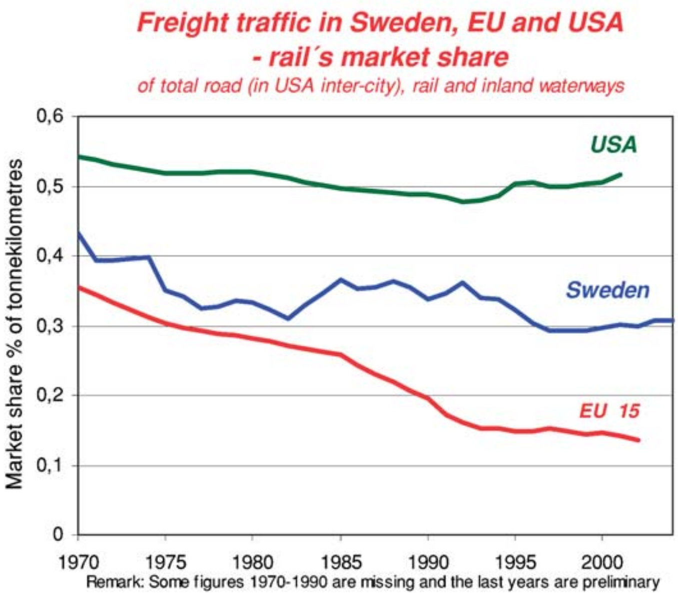
All EU decisions in the area have aimed to open up the railway market to new operators and thus also put pressure on the old operators. Most of the proposals have hitherto not had sufficient impact. There are apparently still some practical obstacles, for example bureaucracy and high track access charges in some countries. Despite a number of positive signs, including new transportation concepts and new operators, most of the good intentions still remain to be realised in practice. This is thus a question of organisation and policy, rather than a technical issue.

Customer requirements and traffic products

Transport customers' most important requirements are *cost* and *quality*. The environment is also coming increasingly to the fore. In somewhat simplified terms, customers stipulate a number of basic requirements as regards quality, i.e. delivery reliability, frequency and transportation time. When these have been met, it is a question of competing to offer the lowest price.

Most transportation is relatively simple, but many assignments are also a part of complicated logistics systems where the customer has invested in terminals and load carriers. Add to this the fact that the fright transport market is less flexible than the passenger transport market, which means that it is of strategic importance to the freight customer that the railway is accessible through industrial sidings or terminals and feeder traffic – otherwise it is not a viable alternative.

Customers' requirements vary greatly depending on the market. The market can be roughly broken down into a number of categories: *bulk freight, basic commodities, product market and service market.* The railway has the strongest position in the basic commodities market, road haulage in the product market, shipping in the market for bulk freight, and air freight in the service market. Somewhat simp-



Development of the railways' market share in Sweden, Europe, and the USA. Source: EU and AAR statistics.

	Sweden	Germany	USA
Average payload per train (tons)	490	332	2,624
Average hauling distance (km)	343	235	1,355
Average revenue per ton-km (SEK)	0.19	0.42	0.13
Maximum rail axle load (tons)	22.5	22.5	35
Maximum gross truck weight (tons)	60	40	36

Freight transport conditions in Sweden, Germany & the USA in 1996. Source: Statistics from Swedish State Railways (incl. northern ore line), German Rail (DB) and the Association of American Railroads (AAR).

Market category	Total market volume in billions of ton-km	Typical consignment size	Typical market value (SEK/ton approx.)	Typical price level (SEK/ton approx.)	Predominant transportation mode
Bulk freight	24	400 tons	200	0.10	ship
Basic commodities	34	40 tons	2000	0.20	rail
Product market	22	10 tons	20,000	0.60	road
Service market	0.3	10 kg	200,000	30	air

Some characteristics of (Swedish) freight market categories.

lified, we can say that price is according to market.

With regard to bulk freight, i.e. raw materials for the process industry, the demand for continuous dispatch is often more important than a certain transportation time. Here it is a matter of large-volume system transportation, which a consequent demand for high capacity at low prices. The demand for precision is also high, since the railway is often operating as a warehouse on wheels in this case.

Basic commodities, e.g. raw materials and semi-manufactures that are transported between industries and warehouses, are generally produced during the day and transported overnight, preferably with daily departures. In the case of international haulage, however, the daily routine is often different. As a rule, prices must be low, because the goods have not been fully processed. This means a demand for high capacity in weight or volume. Quality requirements vary.

Goods in the product market category consist of semi-manufactures and finished goods that are transported to warehouses or directly to consumers. The have the same transportation time demands as basic commodities, but the overnight requirement is more precise, between 5 p.m. and 7 a.m. the next day. Higher quality is also required with regard to handling, securing the cargo, temperature etc, and have a more disparate structure. The higher service level means that prices are higher than in the basic commodities market.

Service includes mail, parcels and spare parts and the requirements are the same as for passenger traffic: high average speed, frequent service, available most of the day, and extensive geographical coverage. Prices in this market are relatively high compared to the other types of freight transport.

The railways' products

The railways' transportation system can be divided into products that cover different market segments and differ as regards production system and vehicle, which gives them different cost structures and quality characteristics.

Wagonload traffic comprises the transportation of whole wagons that are loaded and unloaded by the customers at industrial sidings or loading platforms. Wagonload traffic may be either single wagons or groups of wagons. The wagons are often shunted twice or more during their journey.

Unit trains are complete trains operated for a specific customer with dedicated wagons and according to their own timetable. Unit trains use basically the same techniques as wagonload traffic.

Intermodal traffic is the transportation of single load carriers, principally containers, swap-bodies and road trailers on special railway wagons directly between the rail terminals or as groups of wagons in the wagonload trains. Feeder traffic is by road. Container and trailer traffic to ports and ferry berths is extensive.

High speed freight trains generally transport mail and parcels overnight with late departures and early arrivals so that collection and sorting can be done at the terminals before departure and sorting and distribution upon arrival. Modified passenger train equipment is often used.

Express freight consists of smaller consignments that can be transported on passenger trains. The consignments are transported on day trains during the day and night trains during night time. This system has been discontinued in Sweden but is being extended in other countries.

Measured in ton-kilometres, wagonload traffic accounts for 40% of all freight transported by rail in Sweden. Unit trains account for 28% and intermodal traffic (road-rail) for 12%. The northern ore line, which is also a unit train, accounts for 20%.

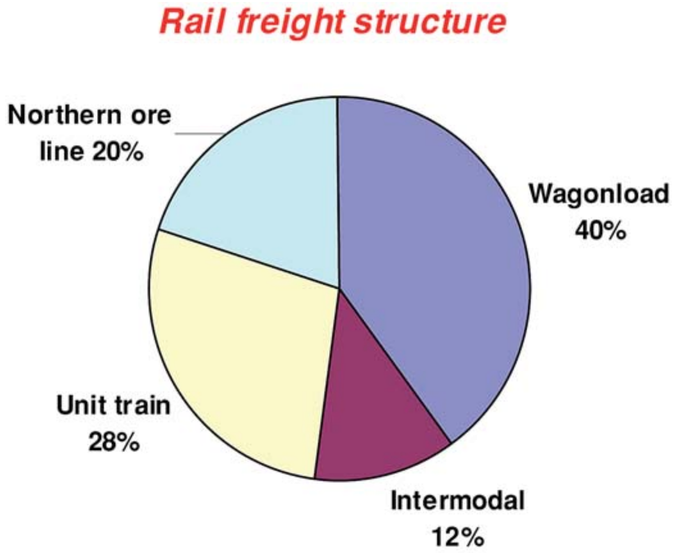
How much of the traffic is intermodal?

Of the total freight transported in Sweden (not including ore and oil), 36% is intermodal traffic, i.e. the freight is transferred to another transport mode along the way. Most intermodal transportation is by sea, 82%, while road haulage has the smallest proportion, 12%. 45% of rail freight is intermodal. The differences are explained mainly by the geographical availability of the different modes of transport.

Not including ore, 55% of rail freight was transported to/from industrial sidings in 2000, and 15% to/from ports, i.e. some 70%. 15% was transported via terminals or hauled by road to loading docks and another 15% was intermodal. A total of 30% of all rail freight was thus a combination of road and rail, see the table below.

Railways' accessibility

Swedish industry is still largely located in places that can be reached directly by rail. Even if the freight is transported to and from places in the rail network, there are not always industrial sidings or local terminals with freight train connections.



A survey of companies with more than 100 employees showed that 72% of the freight customers had industrial sidings or direct access to the railway, or were located within 50 km of the railway, and only 5% were located further than 50 km from the railway. On the other hand, it was almost only those companies that had industrial sidings, 35%, that used the railway to any great extent, but almost all made use of road haulage, as the table below shows.

As stated above, industries and their freight transportation are still located close to the rail network to a surprisingly great extent, but the railway has considerable potential if industries' transportation needs can be met. Freight transportation by rail was once considerable, but traffic has ceased and the local infrastructure in the form of industrial sidings no longer exists. In Sweden, the number of industrial sidings has been halved over the 1990s, from about 12,000 in 1992 to about 600 in 2001.

Wagonload traffic

The wagonload system is characterised by high fixed costs for feeder traffic and marshalling. To improve productivity, operators often try to abandon feeder traffic to places with the smallest freight volumes. In addition to the reduction in transportation in the locations that are closed down, other companies may also drop rail as an alternative because the availability is too small. Revenues disappear immediately while costs change more slowly. This means that it is difficult to improve profits quickly.

The process eventually leads to a situation where only the major customers with a degree of regularity in certain relations remain. These customers are also able to force prices down, and profitability will therefore often be still low despite the efficiency measures taken.

One consequence of poor profitability is that the operators have difficulty in financing modernisation of their rolling stock and that the development of new products is limited. An operator who wishes to buy new locomotives and wagons is forced to concentrate the system to those flows that can bear the investment. The system is thus driven towards large-scale operation and smaller contribution margins in relations outside the biggest flows.

The deregulation of the railways has accelerated the major state-owned operators' rationalisation process. Small private operators have also established themselves. The new operators have mainly competed for system transport with the national companies. These are in most cases low-price concepts with used stock and more efficient personnel utilisation, although a number of new systems have been established.

While the major operators cut costs by discontinuing traffic to and from industrial sidings, the smaller operators can often see an opportunity to increase their revenues by maintaining the industrial sidings and opening new ones. Their production is more flexible and can be adapted to the local market's needs. Somewhat simplified, we can say that the major operators are better at handling large customers' transport efficiently, while the small operators are better at doing the same for small customers.

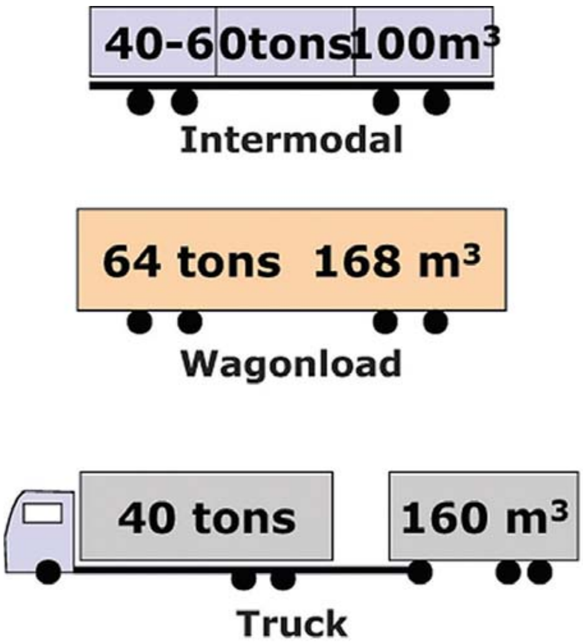
Loading/unloading	*Share*
Wagonload via industrial siding	55%
Wagonload via port	15%
Road-hauled wagonload	15%
Intermodal	15%
Total	100%

Freight transported, not including ore, in tons. Approximate figures for 2000. Source: Jakob Wajsman, Green Cargo.

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

Access to the railway and rail's market share. Source: Banverket 1999:"Profiling the railway 1999…", a survey of companies with more than 100 employees.

Why wagonload traffic?



Comparison between a Swedish 24-metre truck with a gross weight of 60 tons, a wagonload with 22.5 tons axle load and a normal load profile, and an intermodal configuration with three 20-foot containers on a bogie wagon.

One question that can be asked is if it would be possible to scrap wagonload traffic in favour of intermodal traffic and unit trains. This has for example been done in Norway, and developments are also moving in this direction in some, but by no means all, other countries. In the USA, wagonload traffic has a very strong position, and is the railways' principal source of revenue. New operators in Sweden most often concentrate on wagonload and unit trains. In Sweden, wagonload traffic is the predominant form of transportation with 40% of the total transportation effort, while intermodal traffic has not made any great advances over the last 20 years.

The fundamental reason for the competitiveness of wagonload traffic is transportation economy. The dimensions of a container or a swap-body are restricted by the length, width, and height of the trucks and permitted axle loads and gross weights. In Sweden, a truck can be a maximum of 25.25 m long and 4.5 m high and weigh 60 tons, which in practice means a loading height of 3.5 m, a payload of approx. 40 tons, and a volume of approx. 160 m^3.

If the freight is to be transported by container, volume is limited to 100 m^3 because the height of the container is normally 2.5 m. A truck or bogie wagon can accommodate three 20-foot containers. Given a container's payload of 20 tons, 60 tons can be loaded on a railway wagon but only 40 on a truck.

In the case of freight that is heavy or that requires more volume, it is generally possible to load much more in a conventional railway wagon than in containers or swap-bodies, as the figure clearly shows. The difference is even greater if the axle load is increased to 22.5 tons and the loading profile extended, measures that are being taken in Sweden.

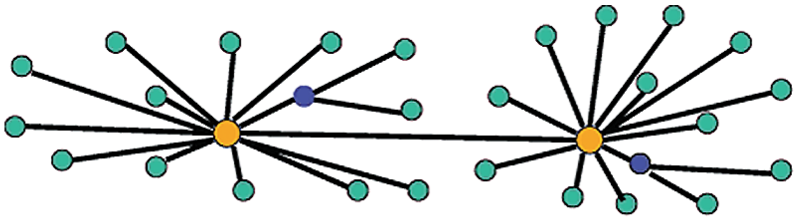
There are many transport concepts where intermodal transportation has logistic advantages, but if wagonload traffic were to be generally discontinued in Sweden, trade and industry's transportation costs would increase dramatically and rail freight's market share would shrink. Since an intermodal train has a considerably smaller payload than a wagonload train, a great many more intermodal trains would be required to transport the same volume, which would lead to capacity problems.
Fundamental economic reasons thus indicate that wagonload traffic should be developed and not phased out. This is one of the principal aims of this project, at the same time as we have also analysed how intermodal traffic can be developed to increase the railways' profitability and total market share.

Wagonload traffic in the future: Liner trains instead of node systems

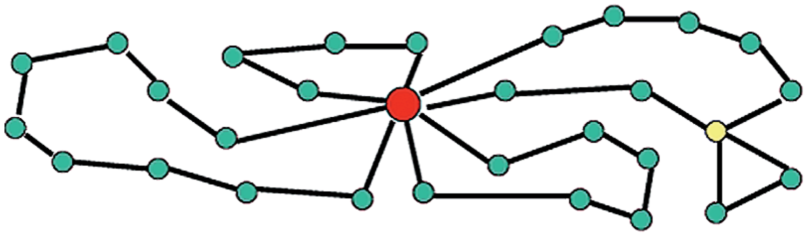
Instead of a conventional system of junctions, a system of "liner trains" is proposed, where the trains run on a main route and wagons are picked up and dropped at the stations along the way. In many cases, feeder trains can be avoided and the wagons no longer need to be shunted at a marshalling yard and hauled long distances. The liner train system is combined with a hub system partly through the fact that the trains can exchange wagons at suitable places, and partly through the fact that a central marshalling yard, in Sweden at Hallsberg, can handle many non-standard relations. The top figure at next page is an outline of a conventional wagonload system consisting of 30 nodes of which two are marshalling yards and two are secondary nodes. To link the system's terminals, at least one long-distance train in each direction is required every day, between the marshalling yards, and 26 feeder trains in each direction. This makes a total of 56 train movements a day. In addition to the liner locomotives, terminal locomotives are needed at most terminal nodes.

The bottom figure shows a liner train system where the trains pick up and drop wagons along the route. The system consists of 5 loops, 4 of which meet at a central marshalling yard, and one meets another at a local node. This system needs only 10 train movements in each direction each day to cover the same terminals as the node system.

The figure at page 9 illustrates one of the effects of switching from a node system to a loop system. It shows that transportation costs are reduced by 17% in the case of wagonload traffic between Helsingborg and Sundsvall. If duo locomotives are used, the transportation costs can be reduced by a further 5%.



Node system (today)



Liner train system (future)

Duo locomotives all day instead of diesel during daytime and electric at night

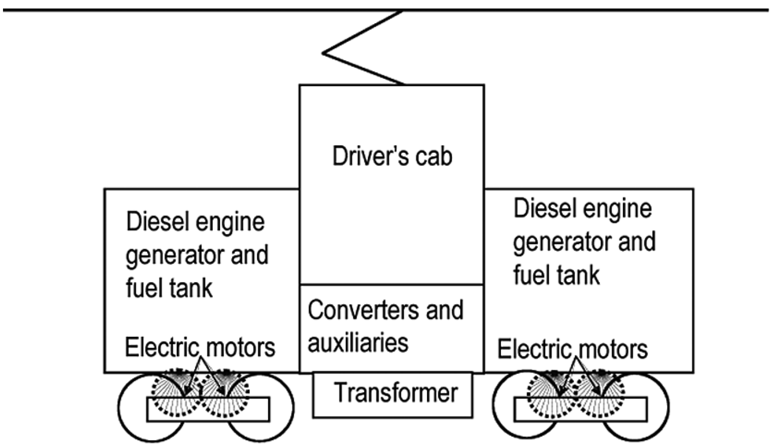
In many countries, heavy electric locomotives are used to haul freight long distances at night, and light and heavy diesel locomotives for shunting, feeder traffic, and for trains on some branch lines during the day. The reason for this is partly that many branch lines and sidings are not electrified. This means in principle that two fleets of locomotives are needed. With a duo locomotive – a combined electric and diesel locomotive – the same locomotive can be used for feeder traffic during the day and long hauls at night.

Many diesel locomotives are diesel-electric, i.e. they have a diesel engine that drives a generator that drives electric motors in the bogies. An electric loco has a transformer with control devices to drive the electric motors instead. It is thus technically possible to design a combined electric and diesel loco. Greater standardisation of components and larger series are crucial to reduce prices. One possibility is to use components from modern railbuses in combination with modern industrial or diesel truck engines to produce a cheap, reliable duo loco.

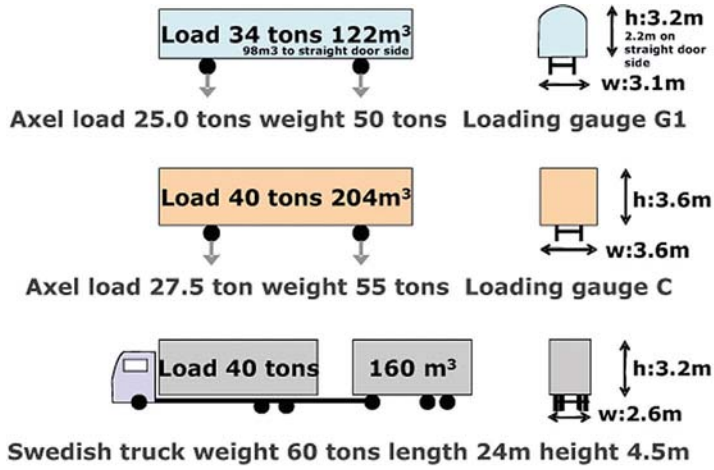
Such a loco would be roughly as strong as an Rc loco when used as an electric loco and a T44 when used as a diesel loco. It is somewhat smaller than the largest modern electric and diesel locomotives. The idea behind this is to make it possible to have several small locomotives instead of a few large locomotives, since smaller trains can be operated more economically when they are needed, for example in feeder traffic, and larger trains than today when they are needed, by coupling two or three duo locomotives together.

	Year	Output MW	Axle load tons	Train-weight tons	At speed km/h	Max speed km/h	Approx cost Euro millions
Rc	1967	3,6	19,5	1 600	100	135	(0,5)
T44	1968	1,2	19,0	900	100	100	(0,3)
Duo-electric	2010	3,6	22,5	1 600	100	120	2,7
Duo-diesel		1,0	22,5	900	70	80	
T66	2000	2,6	21,0	2 000	100	120	2,2
DB 152	2000	6,4	22,0	1 800	140	140	2,7
EG 3100	2000	6,5	22,8	2 800	120	140	3,9

Comparison between old and new locomotives and sketched duo locomotive.



Sketch of duo loco.



Comparison between a wagon with 25 tons axle load, a wagon with 27.5 tons axle load and a Swedish truck.

The locomotives used for long-haul traffic in Sweden, the Rc locomotives, can manage a weight of 1,600 tons in 10 permille gradients and can also be combined into multiple units. Since there are 220 Rc locomotives with an average age of 30 years, any future system must be based on a new generation of locomotives.

One alternative when purchasing new conventional locomotives would be modern 4-axle locomotives, for example Railion type 152 or 185. A somewhat heavier variant with a higher axle load would be able to haul trains of 2,000 tons. If more tractive power is needed, an alternative might be to purchase 6-axle locomotives. The locomotives used to haul trains over the Öresund bridge, DSB EG 3100, are designed for a train weight of 2,800 tons at an axle load of 22.8 tons.

An alternative to 6-axle locomotives is to use two 4-axle duo locomotives combined into multiple units. This would give sufficient tractive force to handle train weights up to 3,000 tons, which is the limit for the screw coupling used at present.

If new 4- and 6-axle electric locomotives are bought, they will be able to haul heavier trains, so fewer liner locomotives will be needed while the number of terminal locomotives will not be affected directly. When new terminal locomotives are purchased, they will probably be more efficient than the ones they replace, so fewer will probably be needed. If duo locomotives are purchased, the same number will be needed as the present Rc locomotives, but they will also replace a great many diesel and terminal locomotives.

The total cost of replacing both liner and terminal locomotives has been calculated for different alternatives, using Green Cargo's locomotive fleet as an example. The total cost of replacing the whole locomotive fleet amounts to approx. 7 billion SEK for the alternative with new 4-axle liner locomotives and modern diesel locomotives. With 6-axle locomotives, fewer are needed but the cost is 10% higher. With duo locomotives, the total cost is approx. 15% lower, mainly because fewer diesel locomotives are needed.

A great many calculations were also made of the size of train that different types of locomotive can haul, and then of how heavy the trains can be with different axle loads, loading profiles, train lengths, and types of trains and wagons. A general calculation was also made of operating costs, which indicated that duo locomotives are the most efficient alternative in this respect too.

The results show that 6-axle locomotives are a solution that is only appropriate to medium-heavy unit trains, while simple 4-axle locomotives can be used for the lighter unit trains and double 4-axle locomotives for the heaviest unit trains. This means that is not economically viable to purchase 6-axle locomotives for a future wagonload and unit train.

One conclusion is that developing new 4-axle duo locomotives that can be used for long-haul trains, loop and liner trains, and for marshalling and shunting, is a very interesting prospect. This would radically reduce the total number of locomotives needed and would also contribute to increase the level of utilisation in the system with a greater market share as a result.

Efficient rolling stock

The same development with regard to wagons can take place in a further developed wagonload system and in a new system with liner trains and duo locomotives. In principle, the weight of the load, or the quantity of freight per wagon, is increased through a combination of higher permitted ax-

Vehicle		*Capacity*	*Max. volume*	*Capacity*	*Max. volume*
Truck in Sweden		40 ton	160 m^3	40 ton	160 m^3
Truck in the EU		26 ton	100 m^3	26 ton	100 m^3
Railway wagons					
Max. axle load	*Loading gauge*	2-axle wagons		4-axle wagons	
22,5 ton	G1 (EU)	30 ton	108 m^3	64 ton	168 m^3
25,0 ton	G1 (EU)	34 ton	122 m^3	72 ton	189 m^3
27,5 ton	G1 (EU)	38 ton	135 m^3	81 ton	200 m^3
25,0 ton	C (S)	33 ton	164 m^3	71 ton	251 m^3
27,5 ton	C (S)	40 ton	204 m^3	81 ton	281 m^3
30,0 ton	C (S)	42 ton	209 m^3	88 ton	310 m^3

Capacity of Swedish truck and railway wagons of different configurations.

le weight and weight per metre or by making the wagon lighter while maintaining the permitted gross weight.

Higher axle loads
The highest permitted axle load today is 22.5 tons on most parts of the Swedish rail network, but improvements are under way to allow this to be raised to 25 tons for general freight traffic and 30 tons on the northern ore line.

Higher axle loads in a market perspective
It is a great advantage if the railway wagons' loading capacity is the same as that of a normal truck. This would allow full interchangeability between railway wagon and truck, which is an advantage when companies are building up their logistics systems. A 60-ton truck and trailer with an enclosed superstructure has a loading capacity of not quite 40 tons, which is roughly the same as for a 2-axle wagon with an axle load of 27.5 tons with a standard loading gauge. It would therefore be a great advantage if the maximum permitted axle load of 27.5 tons could be permitted some time in the future. A light wagon would then be able to load 40 tons. Using running gear and engineering that does not wear the track, it may be possible to allow this on track that today is being upgraded for 25 tons axle load.
Higher axle loads affect the transportation costs for heavy freight. An increase from stax 22.5 to 25.0 tons means a decrease in cost per ton of 9%, to 27.5 tons 17% and to 30.0 tons 23%.

Larger loading gauge
A larger loading gauge is of great importance for volume freight. A 2-axle wagon with loading gauge G1 can load up to 122 m^3, which increases to 204 m^3 with loading gauge C. The transportation costs are reduced by 28% in one example, as shown in the figure.

Lighter wagons of lighter materials
A lighter wagon with the same gross weight can be obtained by using lighter materials to construct a wagon with the same exterior dimensions (length, width and height). Examples of light construction materials are fibre composites and sandwich constructions. Light constructions have hitherto been used mainly in wagon components, for example doors, in tank containers or reefer containers, and fibre composites in brake shoes.
Lightweight constructions have gained ground thanks to their relative strength and rigidity combined with low weight. Other advantages are that it is possible to increase the structure's fundamental frequency and reduce noise and vibration. Functions such as insulation can be integrated into the construction and the need for maintenance can be reduced.

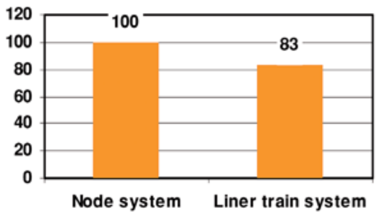
A lightweight construction requires more design effort and may need new maintenance methods. Materials are usually more expensive, which means that a life cycle perspective must be adopted to be able to justify introducing lightweight construction concepts.

Efficient wagons at different axle loads
Calculations have also been made of how the payload changes both for wagons and for whole trains at different axle loads, loading gauges, train lengths, and degrees of fill for typical 2-axle and 4-axle wagons. 4-axle short-coupled wagons are here regarded as 2-axle wagons. Examples of data for some different wagons are shown in the tables. The conclusions drawn from the comparisons between different development alternatives is are these:

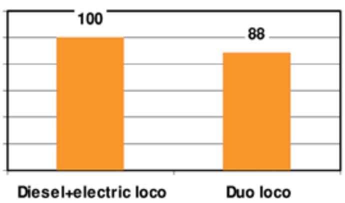
Axle load increased to 25 tons: In national and international wagonload traffic, 2-axle wagons with an international loading gauge are of interest. For national unit trains, wagons with Swedish C gauge are recommended, either 2-axle or 4-axle bogie wagons.

Axle load increased to 27.5 tons: What is of great interest here is to develop a lightweight 2-axle wagon with Swedish D gauge, that allows 40 ton loads on both wagonload traffic and unit trains. This will allow full interchangeability between truck and train in Sweden. In international wagonload traffic, a 2-axle wagon with an international loading gauge is needed.

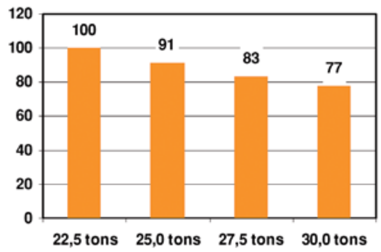
Axle load increased to 30 tons: With regard to national wagonload traffic and national unit trains, it is primarily 2-axle wagons with the Swedish C gauge that are of interest. In international wagonload traffic, a 2-axle wagon with an international loading gauge is of interest.



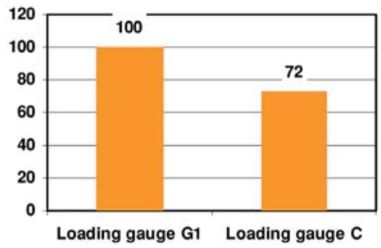
Transportation cost index for a node system and a liner train system; two covered bogie wagons between Helsingborg and Sundsvall.



Transportation cost index for diesel locomotives for feeder transport and electric locomotives for long-distance hauls compared to duo locomotives all the way.



Transportation cost index for axel load 22.5, 25.0, 27.5 and 30 tons for heavy freight. Two fully loaded covered bogies between Helsingborg and Sundsvall.



Transportation cost index with loading gauge G1 and loading gauge C for volume freight. Two fully loaded covered 2-axle wagons between Helsingborg and Sundsvall of 101 and 149 m^3 respectively.

Running gear for higher axle loads and speeds

In simple terms, we can say that the freight wagons' running gear (axles and bogies) has looked the same for 100 years, but development has now taken off, partly through modern methods of calculation, and completely new designs have seen the light of day.

Smoother running gear with good suspension that does not damage the track and produces low dynamic forces may be one way of increasing axle load or speed on existing track without making any major investments in the track. Better measurement methods, for example intelligent goods wagons that sense overloading are also another way of allowing higher axle loads because the present norms always contain a broad margin for overloading.

Technology for less noise and vibration

Noise and vibration affect the surroundings and is an environmental problem for the railways. Noise-damping screens are one solution, but are relatively expensive. The best alternative is to reduce noise at its source. Disc brakes are also expensive but composite brake shoes exude less noise than cast-iron shoes. New freight wagon designs can also reduce noise and vibration.

A number of different techniques have been developed to insulate the track's surroundings from vibration that are based on the principle of stopping its propagation by inserting an elastic element along the propagation line.

The freight can also be protected by insulating it from harmful vibration and jolts with modern running gear and good suspension. Another way is to use a computerised system to monitor the freight's position, temperature, and vibration.

Unit trains

Today, diesel locomotives are often needed to shunt the trains into and out of loading and unloading positions. The reason for this is that the loading and unloading equipment often prevents the installation of overhead contact lines above the tracks. Another problem is that many terminals only dispatch one loaded train a day. This means that the diesel locomotives must be used for tasks other than those of the unit trains, so as not to burden the latter with excessive capital costs.

Using duo locomotives, the same locomotive can take the system trains all the way from the loading location to the unloading location. This also avoids the need for special terminal locomotives. This is an enormous efficiency potential. A calculation has been made of the gain from using a duo locomotive to haul a unit train between Mora and Gävle. The total cost is reduced by 14% per train compared to today's system.

The Rc locomotives used at present have too little tractive power for a single locomotive to be used to haul a full-length unit train with high axle loads. On the other hand, two Rc locomotives or two duo locomotives have sufficient tractive force for any kind of train.

In unit trains, the degree of fill is normally 100% outbound while they are almost always empty on the return run. The freight transported often has greater density than the freight transported in the wagonload system, so a high axle load is important, sometimes in combination with a larger gauge.

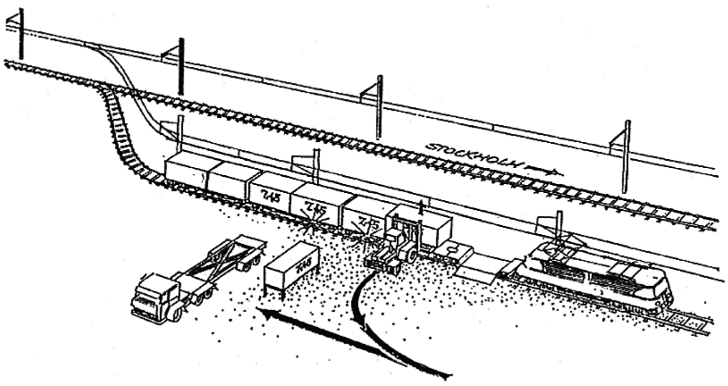
When the weight of the freight is the dimensioning factor, bogie wagons are most efficient using today's technology, because the tare is then less in relation to the weight of the load. By increasing the axle load from 22.5 to 30 tons, the loading gauge to C, and the train length from 650 to 750 metres, the payload can be increased from 1,620 tons to 2,370 tons or by 46% using bogie wagons.

Intermodal traffic

Great hopes have often been placed, not least by politicians, in intermodal traffic taking over traffic from the roads. The process, however, has been a slow one. The railway companies have sometimes used intermodal traffic to rationalise wagonload traffic and tried to persuade customers to use intermodal traffic instead of wagonload traffic. Ultimately this has resulted in volume freight's complete disappearance from the railways to be transported entirely by truck.

Intermodal traffic is mainly domestic traffic. Where international freight is transported in intermodal traffic, it is often transhipped at a port or ferry terminal. One type of freight traffic that has developed very positively is the intermodal traffic to the Port of Gothenburg. The port has been the prime mover and has organised shuttles to various places, "dry ports", with different operators. In this case, intermodal traffic is efficient because feeder transport is only needed at one end and containers can be stacked on top of and next to each other on the vessels.

Efforts have often been made to improve intermodal traffic through organisational measures. It is quite clear, however, that many different organi-



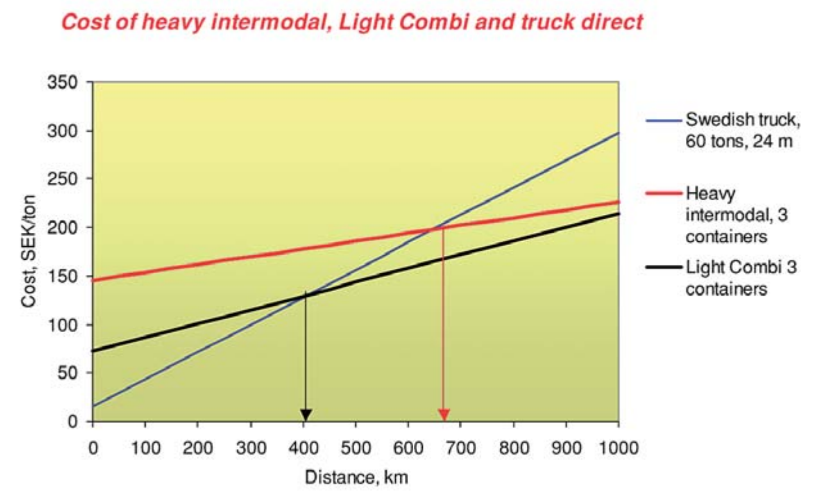
In the "Light Combi" system, terminals may be situated at sidings directly accessible from the main line. Loading and unloading are performed under "live" catenary using a fork lift truck. The fork lift can be carried on the train and is operated by the train driver.

sation models have been tried but that the intermodal traffic system and technology are fundamentally the same, even if the components have been further developed. In this project, we have therefore tried to find new transportation system solutions and technologies. This does not mean, though, that intermodal traffic does not need good organisation and management.

One important reason why conventional intermodal traffic has not developed more positively is that costs are relatively high in relation to transport capacity. Intermodal traffic has inherited the container from sea transportation and the trailer from road haulage. For road-rail intermodal traffic, the swap-body has been developed. This means that a great many different load bearers exist that must be handled using lifting equipment of different weights, dimensions and standards.

In road-rail intermodal transportation it is the trailer that is often the system's dimensioning factor and demands specific terminal equipment and wagons, which entails high costs. Light containers and swap-bodies can be transported on relatively simple wagons and can be handles using fairly simple techniques. Trailers and heavy containers are thus the cost-drivers and require large-scale terminals to be handled efficiently.

Large-scale systems are very well developed in the USA, with for example long trains and Double-Stack containers. These are very good for long hauls and large volumes and function like container ships on land. Intermodal traffic's problem in Sweden and Europe is first and foremost that it has difficulty competing over short distances and dispersed flows where the major markets are. In Sweden and large parts of Europe it is therefore of interest to develop a system that can function over short distances and in several relations in conjunction with road haulage.



Cost in SEK/ton for different types of intermodal transport and truck depending on distance. The feeder distance is 60 km in heavy intermodal and 30 km with Light Combi at both ends. Payload is 33 tons for heavy intermodal and Light Combi and 40 tons with the truck.

Traffic systems

Conventional intermodal traffic, "heavy intermodal", that handles trailers, containers and swap-bodies requires large terminals that are expensive to build and operate. This means a small number of large terminals and feeder distances that tend to be relatively long. Efficient train operation requires relatively large trains that run directly between one terminal and another. This limits the market to just a number of fairly distant destinations.

In the heavy intermodal system, the highest costs are in the handling at the terminals and the feeder runs. New solutions must therefore be sought primarily in terminal technology and feeder traffic. To expand the market and reduce costs, the principle is to have a liner train system with many small, simple terminals close to the customers. If the system is restricted to containers and swap-bodies with a maximum weight of 25 tons and trailers are not handled in the system, terminals and handling equipment can be made much simpler. This system is therefore known as "Light Combi".

Liner train traffic, which means that the train follows a defined route and stops at several places along the way, makes it possible to reach a larger market. Liner train traffic needs only simple terminals situated on train sidings with both ends connected to the main line, so that the train does not have to be shunted, If the train stops every 100 km (depending naturally on where the market is), this means that there will often be a terminal closer to the customer than in a heavy-haul intermodal system. Feeder distance is shorter and transportation is more often in the right direction.

The Light Combi system is dimensioned for swap-bodies with a maximum length of 11 m and normal-size 20-foot containers, both with a maximum weight of 25 tons. This means that normal industrial forklift trucks can be used that do not require the same terminal space as heavy intermodal. Such trucks are often available on industrial sites. The combined cost of terminals and lifting is then considerably less. If the typical lifting cost in a heavy intermodal system is 300 SEK/lift, the corresponding cost in a Light Combi system is approx. 150 SEK/lift.

In the Light Combi system, both terminal and handling costs are lower. The trains are smaller and thus not as efficient as the heavy intermodal trains, but the total costs are still lower except on long hauls and in major relations. Light Combi can be competitive over distances of 300-400 km, while conventional intermodal traffic often requires double the distance, see figure. By establishing Light Combi systems, conventional intermodal traffic, "heavy combi", can be concentrated to the biggest terminals.

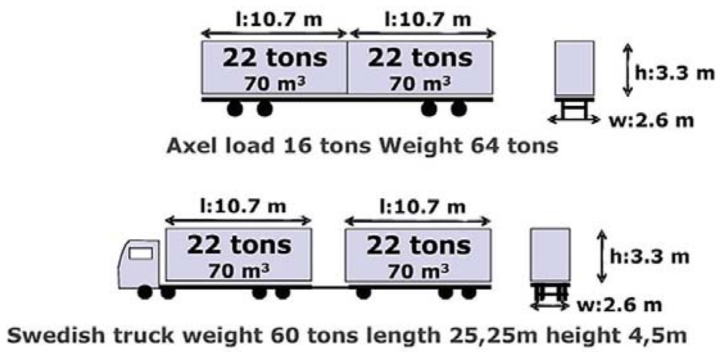
The cost of intermodal transportation of two swap-bodies between Helsingborg and Trollhättan has been calculated. In this case, the heavy intermodal terminals are located in Malmö and Göteborg and the Light Combi terminals in Helsingborg and Trollhättan. The calculation shows that the total transport cost is 25% lower with the Light Combi system due to shorter feeder distances and cheaper handling in the terminals.

Terminals

Heavy intermodal traffic requires a small number of large terminals, known as “Freight Services Centres”, that should preferably be located on the road, alongside the railway, or in the port, and where the logistics flow can be optimised. There should also be space for warehousing and some industrial activity related to the terminal’s operation. Ports should be used as heavy intermodal terminals as far as possible.

Light Combi needs a large number of small terminals or “stops”, where it is possible to switch transport mode to optimise the logistics chain. The terminals should be located on sidings connected to the main line at both ends, and a 400-metre train is estimated to consist of 20 2-axle wagons at most. Alongside the track is a hard surface where containers and swap-bodies can be handled with a forklift. The forklift can be replaced with automatic loading and unloading equipment some time in the future.

The estimated cost of a Light Combi terminal is 3-7 million SEK, which can be compared to the cost of a conventional heavy intermodal terminal, which generally costs somewhere between 50 and 100 million SEK. Although such a terminal is naturally dimensioned for large volumes, the difference also lies in the fact that it has to be dimensioned for lifting both trailers and heavy 40-foot containers. Special demands therefore apply both to the construction of the terminal’s handling areas and the cranes that need to be installed.



Swap-body adapted to Swedish road and rail traffic: Length 10.7 m, width 2.6 m, height 3.3 m. With the maximum weight of 22 tons, it can be loaded using simple industrial forklifts at simple terminals.

Load carriers

The most important load carriers in intermodal traffic are containers, swap-bodies, and trailers. Containers are designed to meet the demands of sea transportation, which means that 6 fully loaded containers can be stacked on top of each other and can be lifted vertically by means of the corner castings.

A swap-body is designed as a truck trailer and can be lifted off or parked on legs. They are not usually stackable but often have forklift pockets. The dimensions of swap-bodies are governed by standards that depend upon the truck dimensions in different countries.

A trailer, also called a semitrailer, normally consists of a frame, a superstructure, and a wheel undercarriage. Semitrailers intended for intermodal traffic are equipped with special lifting fittings.

In road-rail intermodal traffic, the swap-body is the most efficient load carrier because it can best exploit the capacity of both truck and railway wagon and is flexible with regard to different kinds of handling equipment and logistics setups. The swap-bodies in use today are normally between 7.45 and 7.82 metres long and adapted to international traffic with 18-metre trucks carrying loads of up to 27 tons.

In Sweden, trucks can have a maximum length of 25.25 metres and a load length of 21.9 metres and carry loads of up to 40 tons. A transport using two swap-bodies of between 7.45 and 7.82 metres, a combined internal load length of 15.4 metres and able to carry 27 tons, are totally inefficient when compared to loading directly onto a Swedish truck.

A 25.25-metre truck must consist of a least two units to be practicable. One possible solution is to have two identical swap-bodies on a 25.25-metre truck; the swap-bodies can then be 10.7 metres long. They should have forklift pockets and corner castings according to the 20-foot container standard. It should thus be possible to devise a new type of intermodal load carrier, known as swap-body class C+ or super swap-body:

- Exterior length: 10.7m
- Gross weight: 22-24 tons
- Handling: Forklift pockets
- Lifting fixtures for transferring arm

One major advantage of this type of load carrier is that truck and trailer transport load carriers of the same length and that the load carriers, if equipped with legs, can be shifted between truck and trailer easily. Using uniform swap-bodies of the same length that are optimised for Swedish trucks, is not only efficient from the point of view of transportation but also has great advantages in the logistics perspective. Uniform logistics systems can be built up from producer to consumer.

High-speed freight trains: Faster than the truck – cheaper than the airplane

The railways were previously very strong in the mail and express freight market but have increasingly lost their position to air cargo and road haulage. Since the advent of express trains and high-speed trains, the railways in many countries have once again begun to expand in the mail and express freight market. The systems that survived are also in the process of being further developed.

Characteristic of *high-speed* freight traffic, i.e. freight traffic at speeds over 200 km/h, is that the rolling stock consists of modified passenger rolling stock, not further developed freight wagon designs. *Express* freight traffic, on the other hand, uses both rolling stock based on conventional freight wagons, but adapted to higher speeds, and stock based on the high-speed passenger train concept.

The best known high-speed freight train today is France's TGV mail train, that carries mail on the French high-speed lines. The trains have a maximum speed of 270 km/h and their design is based on the TGV passenger train version.

Sweden has special mail trains that operate at 160 km/h and are based on modified freight wagon designs. Added to this is the express freight traffic on passenger trains, which has now been discontinued. Possibilities exist already today for a maximum speed of 200 km/h in Sweden.

The market for express and high-speed freight trains is small with regard to volume, but is an expansive market and offers considerable revenue potential because of the high value of the goods transported. Just like in other markets, competition is stiff and prices are under pressure in this segment too, even if price levels are considerably higher than in other areas of rail transport.

Much of the freight is transported as mail, express, recorded delivery, or single consignment. Much of it goes by road and some also by air. In the case of air cargo, it is mainly intercontinental freight that is transported by air, while most feeder transportation and transportation within Europe is by road. Air cargo is in fact the market segment where the railways have succeeded in making inroads in recent years, and it is primarily truck-hauled and transeuropean transports that have been replaced by rail transport.

The high speed freight trains can interact with both road haulage and air freight and function both as main transport mode and feeder transport mode in a transport chain, as shown in the figure below.

To be able to integrate high-speed freight trains in an intermodal transport chain, it is important that there exist efficient terminals in suitable locations. Though it is true that rail connections have been built at most airports in Europe over the past 10 to 15 years, these are designed for passenger traffic. The integration of the airports with express freight traffic should therefore be looked at very seriously in the future.

The French TGV postaux – with a maximum speed of 270 km/h – are the fastest freight trains in the world today.

Maximum speed plays a more important role in express freight traffic than in conventional freight traffic, where the vehicles' maximum speed is often subordinate to other requirements. The demand for high maximum speed puts special demands on the rolling stock's engineering and technical equipment.

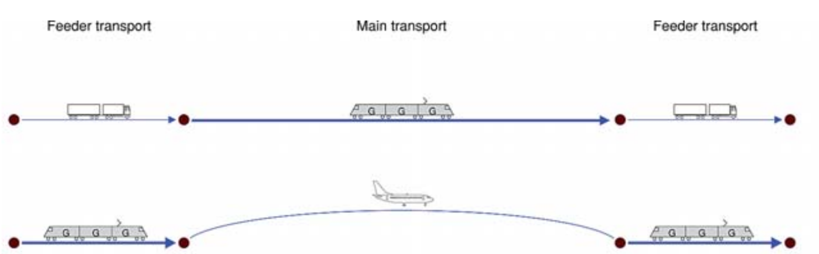
Further developed freight wagon designs are used primarily for speeds up to about 160-200 km/h. The changes that are needed to be able to operate at these speeds are mainly in the braking system and running gear and in certain cases also the load securing equipment.

At speeds over 200 km/h, *passenger train designs* are used exclusively. Examples include the TGV mail trains in France and the use of multiple-unit trains instead of locomotive-hauled trains, in the U.K.

Draft outline of a multiple-unit freight train

A draft outline of a multiple-unit freight train has been produced. The basic principle is to build on an existing multiple-unit train concept and adapt it to express freight traffic. Windows, interior fittings and comfort installations like air-conditioning are not needed; on the other hand, the doors need to be large to permit fast loading and unloading. The walls can be straight between floor and ceiling to increase space utilisation and simplify the design.

If the train is to be used at conventional terminals, as for the mail services today, a design with normal floor height could be used. The load would

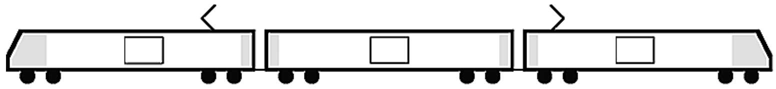


High-speed freight trains interact with both road haulage and air freight. The train can be both the main transport mode and the feeder transport mode in the transport chain.

consist of wheeled bins that are rolled onto the train. In the long term, a fully automated system could be developed. A 4-axle bogie wagon would have a volume capacity of approx. 150 m^3 (about the same as a truck) and be able to load approx. 30 tons, equivalent to two 2-axle mail cars. A three-car train would take the place of a mail train consisting of a locomotive and six 2-axle wagons. For larger volumes, more units can be added.

To improve operating economy, it might also be possible to use the trains during the daytime. The market is limited, but could be expanded through price differentiation. Longer runs down into Europe might make it necessary to run the trains during the day. It is then an advantage to have trains that have the same performance level as passenger trains.

As regards express freight trains, the costs have been calculated for a complete high speed freight train, for example carrying mail, consisting of a locomotive and freight wagons compared with a multiple-unit train, and with full capital costs. The transport cost in SEK/ton is then approx. 30% lower using the multiple-unit train. This is partly because no locomotive is needed and partly because productivity is higher using trains also during the day and at a higher speed.



Length	~ 80 m
Maximum speed	200 - 250 km/h
Payload	~ 80 tonnes
Loading area	~ 200 m^2
Freight volume	~ 480 m^3

Requirement specification for a multiple-unit train for express freight traffic.

More efficient infrastructure

What has been said above about wagons and trains is intimately connected to the development of the infrastructure. Below follows a summary of the most important action that needs to be taken.

Tracks for higher axle loads

Raising axle loads is of crucial importance in order to reduce trade and industry's transport costs and increase the railways' market share for heavy freight. It is generally very expensive and more complicated because the track's superstructure and substructure, bridges and culverts may be dimensioning factors.

On the other hand, better running gear and better checks and measuring methods might allow higher axle loads to be permitted on existing track, though perhaps with certain restrictions.

Wagons with longer wheelbases – e.g. tandem-coupled 2-axle wagons instead of bogie wagons – may be preferable in order to reduce the metre load and lessen the geotechnical stresses.

The fact that it is the dynamic stresses that are the dimensioning factors and that these can be reduced using modern wagons, and that the risks can be made less by means of modern checking and measuring techniques, means that it may be simpler to raise the axle loads in Europe than enlarge the loading gauge. Historically speaking, axle loads have been gradually raised in Europe for freight traffic, as have speeds for passenger trains, as a consequence of better quality rolling stock and track.

Bridges for higher axle loads

Bridges can be a critical link when upgrading to higher axle loads. Old bridges, however, are often found to be over-dimensioned. By making measurements on old bridges and using modern calculation methods, it is possible to work out exactly what loads they can carry. The bridge norms' traffic loads are conservative and more knowledge about the real traffic loads can be used when upgrading bridges.

The results of measurements indicate that overloading of freight wagons does occur. This leads to uncertainty as regards the dimensioning traffic loads, which can be reduced by weighing freight wagons for example.

Larger loading gauge

A larger loading gauge is at least as important as higher axle loads and the greatest effect is obtained by combining the two. In Sweden, a very generous loading profile (C) is already being introduced in most of the network. On many lines, it has proved to be possible to enlarge the loading gauge by relatively simple means. Even if more complicated measures are needed in some cases, for example in tunnels, the total cost is nonetheless not excessive.

Sweden has had a broader loading gauge than Europe from the very start. There are however plans to enlarge loading gauges in Europe, too, for example in Germany. Sometimes there may be physical obstacles to enlarging loading profiles on some lines, but these may in some cases be of a more bureaucratic nature rather than purely physical. Better calculation and measurement methods may be a solution.

Industrial sidings

Access to industrial sidings is a crucial factor if wagonload traffic on the railways is to be a serious alternative for many transport customers. Industrial sidings are rapidly disappearing. Swedish industry is still largely located in places where there is a railway. Industrial sidings should therefore be developed instead of closed down. There are some industrial sidings that are no longer needed as a consequence of restructuring in industry, but new ones are also needed.

The administration and planning of industrial sidings must be simplified and Banverket can play a much greater role with its extended responsibilities. Banverket has been given greater responsibility for financing industrial sidings but sometimes it is difficult to draw the line between who is responsible for what. Fees for investments and maintaining points are also important; these should be standard costs and set according to socio-economic average cost. In the long term it must be both simpler and more cost-efficient to build an industrial siding.

Freight trains in the USA can be 2-3 km long with a gross weight of 10,000–15,000 tonnes. They have automatic couplers and generally more than one locomotive.

Signalling adapted to freight traffic's needs

A signalling system more adapted to freight traffic is needed in order to increase capacity and reduce operating costs. Better advance signalling is an efficient way of obtaining gentler retardation for today's freight trains. Sweden has relatively short braking distances for freight trains, which subjects brakes, wheels, and track to very high stresses. If the train driver is given early information through the signalling system to brake one braking distance earlier, heavier or faster trains can be permitted, or gentler braking obtained with today's trains.

In combination with some form of electro-pneumatic brake, really large gains could be made both in capacity and operating reliability. These measures could probably be implemented faster and more cheaply than introducing the European signalling system ERTMS/ETCS that also offers the same advantages.

Longer trains

The normal length of a train in Sweden is 650 metres, but on certain lines trains 750 metres long can be operated. Banverket is planning to expand the network for 750-metre trains, so most new lines and junctions are planned for this length.

Trains of double that length, 1,500 metres, have been tested in Sweden by joining together two trains and controlling the second locomotive from the first via radio. This system could be used on the lines with the most traffic to radically increase capacity. It does mean, however, that some freight yard tracks and passing lines would need to be lengthened. Such a system is easier to introduce with electronically controlled braking systems, that can also be used to control the locomotives remotely, and automatic coupling.

Electronically controlled braking systems

Conventional pneumatic brakes work by using the train's air line both to pressurise the braking system and control the brakes. During braking, the signal reaches the front portion of the train first, which starts to brake before the rear portion. In long trains, this subjects the train to enormous pressures which may cause damage to the rolling stock. Once the train has stopped, it takes a long time to re-pressurise the brakes.

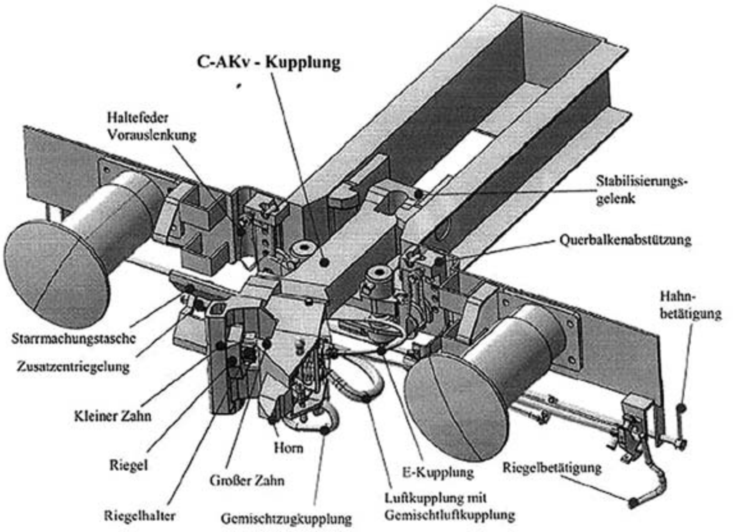
With electronically controlled brakes, the whole of the train's braking system is regulated at the same time, regardless of the length of the train and the air line can also be used to pressurises the brakes the whole time. The brakes are applied more evenly and the braking distance is shorter, or the speed can be increased at the same time as maintenance costs are reduced. This technique is in use in the USA, mainly for long unit trains. In Europe the system is very much needed, not primarily to operate longer trains but to shorten braking distances and reduce maintenance costs.

Intelligent wagons and trains

The computer-controlled braking system is the foundation of the intelligent freight train. The computer and communications systems have a substantial over-capacity that can be used for other control and monitoring tasks on the train.

Intelligent freight wagons have equipment on board for communication and position determination and a computer system for monitoring the wagon and its load. It can for example control the brakes, overheating, wheel damage, running characteristics and freight comfort and automatically send an alarm if abnormalities are detected. Limited systems are in operation in the USA and Europe and they do not require all wagons to be equipped with the system.

An *intelligent freight train* makes use of information from all the wagons and the whole train. In combination with modern IT, it would be possible to create an intelligent train where many monitoring and operation functions that today are performed manually or mechanically could instead be performed electronically. If this can be combined with intelligent train control where the whole traffic situation can



The SAB-WABCO –AKv automatic coupling fitted to a freight wagon. The buffers are only needed during a transition period.

be surveyed, the infrastructure can be used better. In the long term the systems can be satellite-based and integrated with the new safety and traffic control system ERTMS/ECTS.

Remote-controlled locomotives

Remote-controlled locomotives are used in the USA to haul long, heavy unit trains. Locomotives can be placed at the front, in the middle, or at the rear of trains up to 3,000 metres in length. Two modified American systems are in operation in Switzerland and Germany. In Europe, the primary use of radio-controlled locomotives is not to haul extremely long trains, but they can nonetheless contribute to improvements, especially on lines with steep gradients, in cases of wheel-slip on leaves etc.

Automatic coupling

Manual screw-couplings and side-buffers are still used in freight traffic in Europe. The most serious disadvantages are that the coupling requires a good deal of manual effort, which drives costs, is a hazardous task, and also takes time. Manual coupling also limits the trains' weight and makes it impossible to connect power, signalling and air lines automatically.

Automatic couplings have great advantages: simpler, faster coupling, faster shunting, less risk, and heavier, longer trains. A modern automatic coupling must be able to withstand both jolts and jerks, be able to connect both compressed air and electronic equipment automatically, and be able to be remote-controlled. Technically speaking, such couplings are available today, but the difficulties involved in taking a decision to introduce automatic coupling throughout Europe are quite naturally enormous. The railways in the USA, the former Soviet Union, Japan, and many other countries switched to automatic coupling a long time ago.

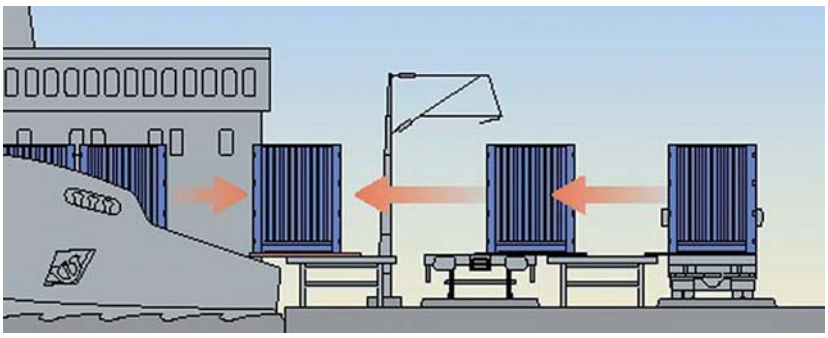
The question of whether or not to introduce automatic coupling should not be postponed. The time to introduce an automatic coupling in Europe is really now when the railways' market share is relatively small with a relatively little need for wagons. A large proportion of the railways' fleet of wagons is obsolete and in need of replacement. Automatic couplings could be tried out first on unit trains that operate in closed systems in order to gain practical experience.

A decision to introduce automatic couplings must naturally be made at a European level. Once the decision has been taken, careful planning and extensive preparation will be needed. If the economic issues can be solved, automatic couplings could be introduced without delay and have a significant positive impact on freight traffic. Studies have indicated a pay-off period of 5–10 years but this needs to be investigated further, also taking market aspects into account.

Automatic transfer of unit loads

In order to make terminal handling even more efficient, an automatic horizontal transfer system is needed. One example of such a system is the Swedish CCT system (CarConTrain), that was tested as a prototype but never reached commercial production. The system consists of a wagon that travels parallel with the track, which is equipped with arms for transferring freight horizontally.

The system can transfer unit loads of any width and length fitted with corner castings. They can thus be 2.5 or 3.6 metres wide or 3 or 1,000 metres long, which means that it would be possible to unload a full trainload of

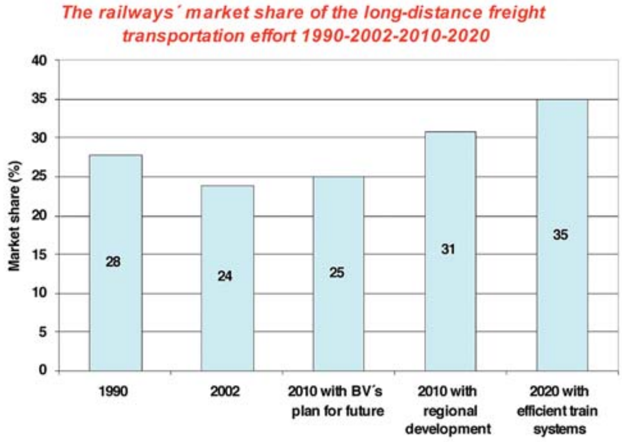


Example of a horizontal transfer system, the Swedish CarConTrain system (CCT). The system can transfer containers and swap-bodies of different widths and lengths between different modes of transport and to and from storage positions. The system can be fully automated.

containers in 90 seconds. Since it can be fully automated, it could be used in unmanned terminals, warehouses, and ports. Here, this system is called Automatic Combi. It provides enormous opportunities to create efficient logistics flows in the future.

Forecasts for efficient train systems

In connection with the recently completed government-commissioned Swedish Railway Study, Railway Group KTH, together with Banverket, drew up forecasts to reflect different organisational models for 2010 and technical development in the direction of efficient train systems by 2020.



Development of rail's market share between 1990 and 2002, and for some alternative forecasts with different changes in supply between 2010 and 2020.

To begin with, it is quite clear that if no changes in supply occur, the railways' market share will slowly shrink from 24% in 2002 to 22% in 2020. This is due to economic development where industries with more highly refined goods are increasing more rapidly than those with less refined goods and the fact that international transportation is increasing faster than domestic transportation.

In the forecast for 2010 with Banverket's plan for the future implemented, it will increase to 25%, mainly due to an increase in axle weight to 25 tons and the introduction of loading gauge C for wagonload trains and unit trains, and slightly higher quality in international traffic as a result of continuing deregulation. In the regional investment alternative for 2010, where organisational measures are taken to stimulate rail transportation as much as possible, but without making conditions difficult for road haulage, the railways' market share increases to 31%, which means that it is higher than in 1990.

This alternative assumes that international traffic is completely deregulated with a good quality level, and that there are regional operators who can offer good service to customers. Axle load is increased to 30 tons and Sweden uses loading gauge C. Industrial sidings have been expanded instead of closed down, and there are as many industrial sidings as in 1990 (though not in the same places since trade and industry have restructured). A Light Combi system has been established.

This structure is also assumed to form the foundation of efficient train systems in 2020. In addition, duo locomotives have been developed, together with freight wagons and terminal technology for intermodal traffic and new transport concepts, and IT for monitoring and control have been introduced. This results in substantial economic improvements for wagonloads, unit trains, and intermodal transport. International transport is assumed to function as well as domestic transport, which is very important because the point of departure is so bad and volumes are increasing.

The result of efficient train systems is that rail's market share will increase to 35%. An increase to 35% may seem a very large one, but it also assumes a paradigm shift. A comparison with road haulage shows an increase from 25% to 35% in just 11 years from 1985 to 1996, as a result of the great changes that have taken place in the form of increased gross weight and better roads and through a deregulation that has benefited customers.

All in all, the forecast for 2020 means that long-distance truck traffic will fall by approx. 10 billion ton-kilometres or 23% compared with if nothing is done. At the same time, industry's transport costs will be reduced as a result of increased efficiency in the railways' transport systems. Achieving this will require a functioning rail market, new products, and the use of new technology, most of which exists today but has not been implemented.

Problems and opportunities in the development of the rail industry

There is no getting away from the fact that the railway is an old system, and one that has also enjoyed a monopoly for many years, and that the system suffers from a considerable degree of conservatism and inertia. Possibly as a consequence of the fact that the railways have tended to close down parts of their operations instead of develop them, customers themselves are often conservative. Firstly, the railway operators' efforts to attract new customers have been marginal in comparison with those of the road haulage companies, and, secondly, the railway is not a real alternative for many customers.

Considerable development has, however, been undertaken by the major operators together with their major customers, not least in Sweden where Banverket has played an active role. This primarily concerns unit train traffic, which is so extensive that customers can have them tailored to their needs and can develop wagons and load carriers and also include operators and infrastructure managers in the process. There are several good examples of this in Sweden, for example Stora-Enso's base-port system.

Radical attempts have also been made to make inroads into international traffic, not least by IKEA Rail. This is an example of a customer that invested substantial resources in getting an international rail traffic concept to work, but ultimately was forced to give up. Obviously, the practical obstacles are still too great. One major problem was crossing the newly built Öresund Bridge. A switch between power and safety systems takes place half-way across the bridge, which requires dual-system locomotives and makes it impossible to just switch locomotives in a freight yard.

The major operators and the major customers are good at developing the large transport systems, but it is difficult to bring about any transport system development for smaller customers, even if they together have some substantial flows of goods. The new, small private operators have a more flexible organisation and production and often work more in their local market. They do not always have lower costs than the larger operators but they are better at meeting the needs of the smaller customers. However, there are not so many small operators and they are not established in all regions. The problems thus primarily concern small customers and generally in international traffic. The fundamental aim of deregulation is to make the railways more efficient and attractive so that rail's market share increases. Opening up the market to more operators gives customers more choices at the same time as it puts pressure on the old operators to improve. International transportation is growing fast in an increasingly integrated Europe. Because volumes are large and distances great, such transportation is ideally suited to rail both technically and economically.

Deregulation of the railways in Europe has thus far not brought about any major improvements in Swedish traffic to the continent. Deregulation of road haulage, on the other hand, has reduced prices across the board, which has meant that the railways have also had difficulty in competing on price. Even if there are positive signs with new transport concepts and operators, most of the intentions of deregulating international traffic remain to be implemented in practice. I*t is thus primarily a question of organisation and policy, not an engineering issue.* Hopes are often put in engineering solutions to solve the railways' problems in international traffic, for example locomotives that can be operated in several countries or a pan-European signalling system. These measures are desirable in the long term and also benefit freight traffic, but in a freight traffic perspective there are other measures that are no less important.

For freight traffic, factors such as loading gauges, axle loads, weight per metre and train lengths are crucial. If we can achieve an interoperable railway network that allows one and the same locomotive to be used for example between Sweden and Spain, this is naturally very good.

For freight traffic, however, it is an even more pressing issue to be able to operate efficient freight wagons with high load capacity all the way. *It is the wagons with the freight that are to be taken to the recipient, not the locomotive.*

Switching locomotives does not need to take more than 10-15 minutes; transferring freight between wagons,

"The Europe-wagon" made by K-industries is a large-volume wagon with a low floor, a substantial loading area, and track-friendly running gear.

Significant potential exists to develop international transportation in Europe if all the organisational and technological difficulties can be resolved.

on the other hand, is impossible – it will be transported by road instead. Continuing to operate freight wagons that because of axle loads, loading gauges, etc only fulfil today's minimum common requirement, is not a tenable solution in the long term. Herein lies an important challenge for the infrastructure manager, to cooperate on a European level to adapt the infrastructure to the future needs of freight traffic.

What is needed is a pan-European high-quality freight traffic network, developed in a European perspective and not a patchwork of different national standards. The pan-European freight network proposed by the EU is a step in the right direction, but must be followed by co-ordinated efforts on the part of the infrastructure managers. Increased investment in high-speed networks for fast passenger traffic can also free up capacity in the conventional freight traffic rail network.

In one way, it is simpler to increase market share for passenger transport by rail. By investing in new infrastructure and operating faster trains, the train's market share will increase automatically at the expense of road and air transport. The short travelling times for fast trains make the train a market leader and there is still great potential.

Speed is not as important in the case of freight traffic, where cost and quality are the crucial factors. Investment in infrastructure does not automatically lead to a higher market share for rail freight traffic, but has more long-term effects by creating better conditions for increased freight traffic with higher capacity and quality at a lower cost. Persuading customers to choose rail for freight transport means that operators must satisfy the customers' needs.

In the short term, the freight traffic market is more dependent upon the operators than on the infrastructure. But operators are having difficulty in making their businesses profitable and thus also in developing traffic. To a certain extent, this is because road haulage is too cheap – competition between haulage companies pushes prices down and it is easier for them to stretch the rules than for a rail operator. Foreign haulage companies can operate throughout Europe, which is not so easy for the railway operators It is difficult to overcome the negative aspects of competition between haulage companies.

Road haulage does not pay its full cost to society at the same time as track access fees in some countries are higher than the financial cost to society . Introducing road tolls and kilometre tax as many countries in the EU are doing can help improve the railways' competitive situation. Freight customers are rational and choose the alternative that can meet their requirements at the lowest total cost. But freight customers also need to be able to trust the railway and there is a greater chance of achieving this if there are more alternatives.

In summary, it can be said that the political principle decisions needed to develop freight transport have already been made – but have not been implemented in practice. It is deregulation of the railways, an economic approach of internalising external effects and investment in the railway infrastructure, and a long-range standardisation effort that need to be pursued more consistently and in all countries in Europe. The rail industry also needs to develop its products and technical systems to be able to live up to the ambitions of the politicians and the requirements of their customers.

Summary and conclusions

Wagonload traffic

- Develop industrial sidings instead of closing them
- Operate "liner trains" adapted to customers' needs
- Trains pick up and drop wagons along the way
- Marshalling as needed at one or a few marshalling yards.
- Wagons can be loaded and unloaded when the train stops along the way

Duo locomotives – combined electric and diesel locomotives

- Uniform traction system: duo locomotives with both electrical and diesel power-replace both standard and terminal locomotives in use today
- Operate electric long-haul trains on main lines and diesel trains on branch lines, shunting on industrial sidings using electric or diesel locomotives
- Approximately the same capacity as today's Rc and T44 locomotives
- Economically viable also for small to medium trains – several locomotives can be used to haul heavy trains
- Manufactured from standardised components: electrical equipment from multiple-unit trains and industrial diesels

More efficient freight wagons

- Development of more efficient concepts with more load per wagon
- Higher axle load and larger loading gauge
- Smoother running gear with little dynamic stress on the track
- Introduction of electronically controlled braking systems
- Introduction of remote-controlled automatic couplings

Infrastructure

- Enlarged loading gauge – to loading gauge C in Sweden
- Increased axle load – 27.5 tons for wagonloads and 30 tons for unit trains in Sweden
- Increased bearing capacity (metre weight)
- Adaptation of signalling to freight traffic, for example extended advance signalling
- Adaptation of freight yards and passing tracks to longer trains
- Prioritised freight networks with higher axle load and larger loading gauge in Europe

Intermodal traffic

- Liner train systems with many small terminals along the way on sidings with both ends connected to the main line
- Loading and unloading of unit loads during short stops
- Super-swap-bodies, 10.7 metres and 24 tons for efficient road and rail transport
- Swap-bodies and light containers in Light Combi systems and heavy containers and trailers concentrated to a small number of large terminals
- Develop automatic loading and unloading of containers using the CCT system

Terminals

- Full service terminals, "Logistics Centres", – strategically located terminals for several different transport modes and warehouse functions
- Exchange points, "Stops" – small, unsophisticated terminals close to customers or along the way to optimise the transport chain
- Use ports as full service terminals if possible
- Locate the next generation of truck terminals close to railway lines
- Terminals open to all operators

Express freight trains

- Use the express train network to expand the market for overnight transport
- Develop multiple-unit trains for parcels, mail and express freight
- Groupage of mail, parcels and express freight may expand the market
- Coordinate rail and air for freight in strategic locations

A wider, square-shaped loading gauge instead of the one with rounded corners currently in use is an important factor in reducing the transportation cost of volume freight. The illustration shows a C loading gauge wagon in comparison with the normal G1 loading gauge.

Research, development, and demonstration

The implementation of change in the railway industry is very slow, both organisationally and technically speaking. Nonetheless some development is being pursued; in addition to investment in infrastructure, freight wagons and running gear have developed fast in recent years. Greatest difficulty is developing new products and traffic concepts both nationally and internationally.
Research, development and demonstration are all important. More development and demonstration is needed in the short term and more research in a longer perspective. Short term here means the coming 3-5 years and long term 5 years or more into the future. The long-term projects are radical and need to be tested more in theory before being tested or implemented in practice.

Measures in the short term

Measures that can be taken in the short term are such measures where fully developed technology is tested in practice and thus prepare the way for later implementation on a larger scale. In connection with these demonstration projects, measurements can also be made, methods refined, and models calibrated. There is thus scope for research also in these projects, even if the emphasis is on development and demonstration. Examples of such measures include:

- No more industrial sidings closed
- Demonstration projects to establish Light Combi systems
- Demonstration projects for 10.7-metre super-swap-bodies for rail and truck
- Upgrading of existing freight wagons for higher speed and axle load – model calculations and trials
- Measurement systems and models for increasing axle loads and speeds on existing track
- Trials of advance signalling in the ATC system
- Trials of radio-controlled brake valves on the last wagon (EOT)

Development can be accelerated with incentives such as lower track access fees for wagons that do not damage the track and that exude little noise, and some form of co-operation bonus for new transport systems.

Measures in the long term

Development steps that require more research and development are those where the technology does not yet exist or where more work is needed to find an optimum solution. IT systems may also need to be adapted to the needs of rail traffic so that they are sufficiently robust. Below are listed some examples of critical development factors that have been identified as appropriate for continued research and development:

- Duo locomotives, continued technical development and construction of a prototype
- Automatic terminal technology for horizontal transfer, development of prototype
- Introduction of automatic coupling, evaluation of effect on costs and market
- Remote-controlled automatic coupling, demonstration project
- Electronically controlled brakes and robust technology for the intelligent freight train
- Development of light materials to reduce noise and vibration and increase payload
- More cost-effective infrastructure, everything from bridges to industrial sidings

As far as duo locomotives are concerned, a research project is under way at the Royal Institute of Technology, where an in-depth study is being made together with TFK. When this is completed, it will be of interest to implement a demonstration project.

The whole field of IT and control systems for freight trains makes up an area of its own that is of especial interest. This area is part of the new "TIMM" competence centre that the Royal Institute of technology (KTH) is setting up together with other researchers.

Research, development, and demonstration projects for freight traffic in the future thus include everything from preserving industrial sidings and finding simplified methods to build new industrial sidings, to sophisticated IT systems and automatic couplings for operating the intelligent freight train throughout Europe.

With a "Light-Combi" system the railway can be competitive for smaller consignments of high-value goods over shorter distances. The picture shows the Swedish experimental train where a fork-lift carried on the train and operated by the driver, unloaded and loaded swap-bodies under the catenary at small terminals along the line.

Efficient train systems for freight transport

is an interdisciplinary study that was conducted by “Railway Group KTH” at the Royal Institute of Technology, and financed by the Swedish National Rail Administration, the Swedish Transport and Communication Board, the Swedish Agency for Innovation Systems, the Swedish State Railways and Green Cargo. The major part of the study was conducted from 2002-2004. The project was run as an interdisciplinary project involving researchers from different departments at the Royal Institute and also a number of outside experts. Participants in the project have also produced the reports listed below.

Principal reports

- Effektiva tågsystem för godstransporter - Sammanfattning på svenska, KTH Järnvägsgrupp 2005 nr 0502
- Efficient train systems for freight transport - Summary in English, KTH Railway Group 2005, no. 0503
- Effektiva tågsystem för godstransporter - En systemstudie (Huvudrapport) av Bo-Lennart Nelldal (red), KTH Järnvägsgrupp 2005 nr 0504
- Efficient train systems for freight transport - A system study (Principal report in English) by Bo-Lennart Nelldal (ed.), KTH Railway Group 2005, no. 0505

Underlying reports

- Fordon och infrastruktur för effektiva godstransporter [Rolling stock and infrastructure for efficient freight transport], KTH Railway Group, no. 0506. Includes A-G:

A. Dual system locomotives for future rail freight operation by Stefan Östlund

B. Löpverk för högre axellast och hastighet [Running gear for higher axle loads and speeds] by Per-Anders Jönsson

C. Ökade laster med hänsyn till spårnedbrytning [Greater loads in the perspective of track wear] by Sebastian Stichel

D. Lätta konstruktioner för högre nyttolast [Lightweight designs for higher payloads] by Per Wennhage

E. Noise and vibration aspects on railway goods transportation by Ulf Carlsson

F. Infrastruktur för effektivare godstransporter på järnväg [Infrastructure for more efficient freight transport by rail] by Gerard James

G. Industrispår – förutsättningar för utveckling [Industrial sidings – prerequisites for development] by Lars Ahlstedt and Bo-Lennart Nelldal

- Automatkoppel [Automatic couplings] by Rune Bergstedt, Railway group KTH 2005, no. 0507
- Bromssystem [Braking systems] by Rune Bergstedt, Railway group KTH 2005, no. 0508
- IT-teknik för effektiva tågsystem för gods [IT for efficient train systems for freight], Railway group KTH 2005, no. 0509. Includes A-B:

A. Intelligenta informationssystem [Intelligent information systems] by Rune Bergstedt
B. Fördelad dragkraft och fjärrstyrda lok [Distributed traction and remote-controlled locomotives] by Rune Bergstedt

- Effektiva tågsystem för vagnslast- och systemtåg [Efficient train systems for wagonload and unit trains] by Peter Bark, Railway group KTH 2005, no. 0510
- Transportmarknadens struktur och järnvägens konkurrenskraft [The structure of the transport market and the railways’ competitiveness] by Jakob Wajsman, Railway group KTH 2005, no. 0511
- High-speed rail freight by Gerhard Troche, Railway group KTH 2005, no. 0512
- Konkurrenskraftiga kombitransportsystem [Competitive intermodal transport systems] by Evert Andersson, Peter Bark, Bo-Lennart Nelldal and Jakob Wajsman, Railway group KTH 2005, no. 0513

THE RAILWAY GROUP KTH

The Railway Group KTH – Centre for Research and Education in Railway Engineering was formed in April 1996 with the purpose of supporting and developing competence in railway engineering at the Royal Institute of Technology, KTH.
The Railway Group consists of eight departments, each representing different railway engineering disciplines.
The greater part of the Railway Group’s financing is regulated though agreements between the Royal Institute of Technology, the Swedish National Rail Administration (Banverket), Bombardier Transportation Sweden AB, Interfleet Technology AB, the Swedish Association of Train Operators, and SL Infrateknik AB.
The Railway Group´s research shall focus on issues that

- are crucial to the railway system´s efficiency and competitiveness
- are aimed at improving the system´s performance, increasing revenues, and/or reducing costs.

The departments that are members of the Railway Group are:

RAILWAY TECHNOLOGY
Professor Mats Berg
Phone +468-790 84 76
e-mail mabe@kth.se

TRANSPORTATION AND LOGISTICS
Associate professor Bo Lennart Nelldal
Phone +468-790 80 09,+4670-762 30 56
e-mail bolle@infra.kth.se

LIGHTWEIGHT STRUCTURES
D.Eng. Per Wennhage
Phone +4670-620 64 34
e-mail wennhage@kth.se

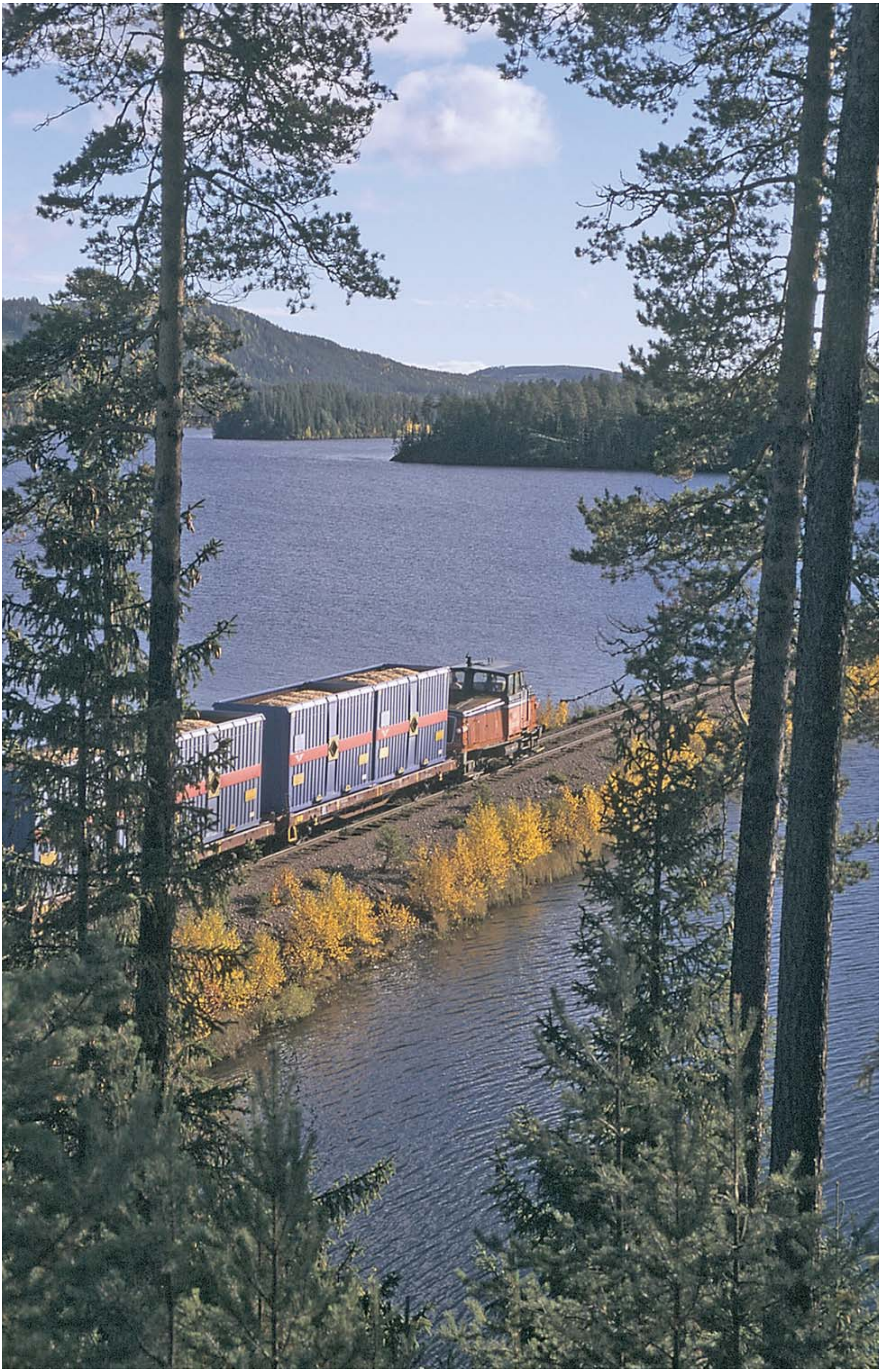
DEPT OF CIVIL AND ARCHITECTURAL ENGINEERING
Professor Håkan Sundquist
Phone +468-790 80 30
e-mail hsund@struct.kth.se

ELEKTRICAL MACHINES AND POWER ELECTRONICS
Professor Stefan Östlund
Phone +468-790 77 45
e-mail stefan@ets.kth.se

MARCUS WALLENBERG LABORATORY FOR SOUND AND VIBRATION RESEARCH
D.Eng. Ulf Carlsson
Phone +468-790 90 11
e-mail ulfc@kth.se

MACHINE ELEMENTS
D.Eng. Ulf Olofsson
Phone +468-790 63 04
e-mail ulfo@damek.kth.se

VEHICLE DYNAMICS
Professor Annika Stensson
Phone +468-790 76 57
e-mail annika@fkt.kth.se



KTH Railway Group
The Railway Group KTH at The Royal Institute of Technology in Stockholm pursues interdisciplinary research and offers education in both railway technology and railway traffic planning. The research programmes aim to develop new methodology and contribute knowledge that can develop the railways as a means of transportation, and make the train more attractive to customers and more profitable for the railway companies. The Railway Group is financed by Banverket (The Swedish National Rail Administration), operators SJ and Green Cargo, and Bombardier Transportation among others.

Several reports have been produced in the research project entitled "Efficient train systems for freight transport". The principal report, compiled and edited by Associate Professor Bo-Lennart Nelldal, is intended to present the project's research findings for researchers, operators, transport customers, train manufacturers, and other interested parties. This summary gives a brief overview of results and conclusions, even to non-experts in the field.